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SUSTAINABLE ENERGY ENGINEERING GRADUATE PROGRAM

BAHIR DAR, ETHIOPIA

Assessment and Modeling of the Ethiopian Energy Sector Management Systems

By

Biniyam Getachew Gessesse

Bahir Dar, Ethiopia

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ASSESSMENT AND MODELING OF THE ETHIOPIAN ENERGY SECTOR MANAGEMENT SYSTEMS

BY

BINIYAM GETACHEW GESSESSE

A THESIS SUBMITTED TO BAHIR DAR INSTITUTE OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS IN SUSTAINABLE ENERGY ENGINEERING.

DECLARATION

I, the undersign, declare that "Assessment and Modeling of the Ethiopian Energy Sector Management Systems" is original work of my own, has not been presented for a degree of any other university, and all the sources that I have used or quoted have been indicated and acknowledged by means of referencing. It is submitted in partial fulfillment of the requirements for the degree of Masters in Sustainable Energy Engineering at Bahir Dar University.

Biniyam Getachew **Date**

____________ ____________

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Ethiopia is a nation rich with abundant sources of renewable energy and has an enormous potential for the generation of sustainable energy including electricity. However, access to clean, efficient and modern energy services is a critical challenge the nation is facing. The aim of this study was to assess and model the Ethiopian energy sector management system. In doing so, both qualitative and quantitative research methods were employed to gather and analyze the necessary data. Unstructured interviews, direct observations, discussions with officials and experts and review and analysis of secondary were used. The findings indicated that the overall energy sector management systems and the national energy policy of the country are incapable of addressing the long term energy challenges. The sector is mainly challenged and characterized by inefficient generation, transmission and utilization of renewable energy sources; poor mixes of energy supply together with highly imbalanced, inadequate, irregular and insecure demand and supply; and visible environmental degradation. To the reverse of this, international and state commitments, the new privatization modality devised for the sector and the demand of electricity shown in the neighboring countries are considered as opportunities of the sector. The models developed in all scenarios revealed that the emissions of CO_2 are non-existent by 2030. As a result the supply of energy in the modeling period would be changed to renewable and the primary energy supply system would get diversified from a system dominated by wooden biomass to the use of renewable and other indigenous resources. Due to this, one can dare to say that all the scenarios would lead the country to achieve the 7th goal of Sustainable Development, SDG 7; sustainable energy for all.

Key words: Assessment, Energy, Ethiopia, Modeling.

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LIST OF ABBREVIATIONS AND ACRONYMS

CSA	Central Statistics Authority
ECRGES	The Ethiopia's Climate-Resilient Green
EEA	Ethiopian Economics Association
EEA	Ethiopian Electric Agency
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
FDRE	Federal Democratic Republic of Ethiopia
GIZ	Gesellschaftfür Internationale Zusammenarbeit
GERD	Grand Ethiopian Renascence Dam
GW	Giga Watt
IEA	International Energy Agency
Kwh/m^2	Killo Watt hour per meter square
MDG	Millennium Development Goal
MoMPN	Ministry of Mine, Petroleum and Natural Gas
MoManI	Model Management Infrastructure interface,
MoWIE	Ministry of Water, Irrigation and Electricity
OSeMOSYS	Open Source Energy Modeling System
SDG	Sustainable Development Goals
TWH	Tetra Watt Hour

Chapter One: Introduction

1.1. Background

Energy deeply and seriously influences the livelihood, standard and quality of life of human beings. It is fundamental to all aspects of human welfare, including access to clean water, health care and education and increasing agricultural productivity. It significantly affects socio-economic development and the overall quality of life. The report by the International Energy Association, IEA, declared that 2.7 billion people globally lacked access to efficient and clean energy for cooking and heating; 1.3 billion lacked accesses to electricity, among which 84% deprived population were living in rural areas of sub-Saharan Africa or Southeast Asia (IEA, 2014).

Ethiopia is a nation rich with abundant sources of energy and has an enormous potential for generation of sustainable energy including electricity. Azeb (2015) has indicated that the terrain of Ethiopia has comparative advantages for hydropower projects that could generate an economically feasible 30,000 MW of energy that is equivalent to an electricity generation of 162 Twh. In contrary to this, the current production is only 3.98 Twh which is equal to an exploitation of only 2.5%. Ethiopia receives a solar radiation of 5000 – 7000 Wh/m² according to region and season and thus has great potential for the use of solar energy. The average solar radiation is more or less uniform, around5.2 kWh/m^2/day. Though there are no grid-connected biomass power plants exist, several sugar factories have been using sugar cane bagasse for station supply since the 1950s. A total of 30 MW of capacity surplus could be fed in the grid by sugar factories. No estimation of municipal waste power production potential is available at the time (except the ongoing Koshe Waste-to-Energy Project with a capacity of 50MW). Even though, the wind Energy potential of Ethiopia is estimated to be 10,000 MW with a wind speed varying between 7 and 9 m/s, no commercial wind energy power plant exists to date. The geothermal resources of the country are estimated to be 5 GW of which 700 MW are suitable for electricity. However, only 7.3 MW geothermal power plant has been commissioned so far.

Table 1.1: Energy Situations of Ethiopia

Resource	Unit	Exploitable reserve/Potential	Exploited	
			Amount	Percent
Hydro Power	MW	45,000	2360	<5%
Solar	Kwh/m^2	4-6		<1%
Wind- power Speed	MW m/s	1350 MW > 7	171 (under Construction)	<1%
Wood	Million tons	1120	560	50%
Agricultural waste	Million tons	15-20	6	30%
Natural gas	Billion m3	113	-	0%
Coal	Million tons	>300	-	0%
Oil Shale	Million tons	253	-	0%

Source: Electric Power, October 2015, London, UK, By AzebAsnake, CEO of EEP.

In contrary to the above facts, the country is one of the lowest energy consumers in the world for various reasons. GIZ (2015) has reported that about 23 per cent of the total population of 95 million has access to electricity. The report further explains that out of the 67 million population living in rural areas, only 5 per cent has access to energy. This seriously limits the country's potential for economic growth and social development. Assessing the root causes for this least exploitation should be answered through studies. A study conducted on the Energy Sector of Ethiopia has shown that the electricity loss in Ethiopia is about 20%, which is much higher than the international average, 12-13%, that have been brought from lack of effective Energy Management (Embassy of Japan, 2008). The reason why for those contradictions and the measures planned to be taken and achieved require further study.

An article authored by Dawit (2012) has indicated that the national energy balance of Ethiopia has been so far predominated by two sort energy resources (20% Hydro and 80% biomass). The article has also stated that, due to that, the country has been suffering from massive depletion of indigenous biomass resources. The study, further, has in-sighted that, despite insisting the need to ameliorate the negative consequences of biomass fuel consumption on the livelihood of the poor in Ethiopia, energy proponents have seldom developed comprehensive strategies for its efficient utilization. The strategy devised by the Federal Democratic Republic of Ethiopia (FDRE) has stated that to achieve an annual economic growth rate of more than 10% that the government aspires to, it is necessary to expand electric power supply at a rate of more than 14%, which call for greater commitments of the government (ECRGES, 2011).

In addition to those facts, EEA (2009) has reported that the development of the energy sector and energy consumption in Ethiopia is at a low level even by African standards. However, the growing energy demand triggered by the economic growth is putting the sector under pressure. The report further has stated that the low level of energy sector development in Ethiopia, the financial burden of import of petroleum fuels, the degradation of forest resources due to the consumption of a huge proportion of biomass energy and its implications for environmental sustainability justify why the issue of energy sector development become the critical national development agenda. While the country has a large and diverse sources of energy, to-date the development of these resources is insignificant as compared with the national demand.

Having these facts in mind, it is high time to devise proper energy management strategies for the development of sustainable energy management systems through provision and exploitation renewable energy. The current study aims at assessing the current situation of the energy sector and develop appropriate model to change the current situations.

1.2. Statement of the problem

The low level of energy and power sector development in Ethiopia is the major reason for the energy sector to become a critical development agenda. The Ethiopian energy sector is challenged by different factors like rapid population growth 2.6% annually (CSA, 2007), an aim to export electric energy, the goal to become middle income country in 2025 (ECRGS, 2011) and a surging energy demand for 10 to 12% per annum (GIZ, 2015).

Even though the country is also known to have large and diversified potential sources of renewable energy, to date the development of these resources is insignificant owing to several factors. The share of renewable energy other than biomass in gross inland energy consumption is too much lower or non-existent which was 1.32% in 2010 of domestic energy supply (IEA, 2014). Moreover, GIZ (2015) has indicated that about 23 percent of the total population and only 5% of the rural residents has access to electricity. In recent years, the country undeniably has made significant progresses in expanding energy access, however, its experience accentuates many of the challenges it is facing in providing sustainable energy for all.

Even though there is no any study carried out to discuss quantitatively, electric power outage which is directly resulted from poor energy management system is knocking out everyone's door & has recently become an issue of good governance of the nation's citizens. Therefore, sustainable energy planning, by considering various scenarios, is fundamental to maintain the sustainable development of the country.

The data stated above has shown us that there is a greater gap between the potential and exploitation of sources of energy and a significant imbalance between demand and supply of energy which lacked sustainable and long-range energy management system. Therefore, assessing the country's energy sector management systems by identifying the major and basic challenges and prospects and modeling a system through development of long-term energy management system to introduce comprehensive framework for energy system analysis is fundamental for the betterment of the situations stated above.

1.3. Objectives of the study

1.3.1. General objective

The broad objective of this study is to assess and model the country's energy sector management systems.

1.3.2. Specific objectives

This research is specifically aimed to:-

a) Assess the current position & situation of the energy sector of Ethiopia;
b) Identify the major nationwide challenges of the energy sector;
c) Investigate the global and national opportunities to manage the potential resources, generation, transmission and utilization of energy;
d) Develop energy sector management system model specifically for the electric sector;

e) Discuss and recommend some points on how to improve and make changes on the current situations of the energy sector of the country.

1.4. Research questions

To achieve the objectives of the study, the following research questions would seriously be answered;

1) How the current situation of the energy sector of Ethiopia looks like?
2) What are the major nationwide managerial challenges the Ethiopian energy sector is facing?
3) What are the global and national prospects and opportunities fundamental for the betterment and change of the situations of Energy in Ethiopia?
4) Which energy modeling approach is suitable to address the Ethiopian Energy Sector?

1.5. Scope of the study

The study basically focuses on assessing and modeling the Ethiopian Energy Sector Management Systems which includes identifying the major nationwide energy sector challenges specifically the renewable one and identifying the national as well as the global prospects and opportunities in order to 1) get the major challenges of the sector identified 2) know and make use of the advantages that would be resulted from identifying the global and national opportunities and prospects of the sector and 3) develop appropriate model for the electricity sector.

The scope of the thesis is thus limited to assessing the current situation of the sector, identifying the management challenges and prospects of the country's energy sources and developing an energy model for the electricity sector. Identifying the operational challenges of the energy sector of the country and developing energy model other than the electric sector is out of the scope of this research.

1.6. Limitations of the study

The main limitations the researcher has been facing while undertaking this research was obtaining relevant, recent and accurate data. Most of the secondary data obtained were not as recent as expected, clashing with each other, and not in line with the topic under study. The other limitation that should be mentioned here is that the issue under discussion in the research is not yet researched well in Ethiopia. As a result the researcher has faced difficulty to compare the methods followed, the results and findings obtained, and the remarks concluded.

1.7. Significance of the Study

Up on its successful completion, this research is expected to have valuable contributions especially for those who are responsible for managing and owing the energy sector and academics. The following are the main significances this research would worth;

a) The research and its findings would help governmental and non-governmental organizations in the energy sector to know how the situation of energy sector currently looks like in the country;

b) It will support the continuous energy management improvement initiatives by devising strategies based on the current situations;

c) The research and its findings will be used as a reference for scholars, experts and students in the field of energy management and engineering;

d) It would add considerable value to the body of knowledge on energy sector management systems.

1.8. Research Process

Like other studies the research process of this study begins from conceptualizing and stating the research problem and ended up by forwarding conclusions and recommendations. The researcher, after stating the problem correctly, has clearly defined, the objectives, scope, research questions, significances, and expected results. Secondly, relevant literatures were reviewed both intensively and extensively. Next, the design of the research was prepared by identifying the research's type, focus, methods, and instruments. Finally, using the techniques for data analysis and interpretations, the data gathered were refined, analyzed, organized, interpreted and summarized as per the objectives and research questions set initially. Based on this conclusions are made and some points are recommended in line with the findings of the study. While doing so, greater care was taken regarding issues of data measurement's reliability, replicability, objectivity and representativeness. The figure shown below indicates how the research flowed and made.

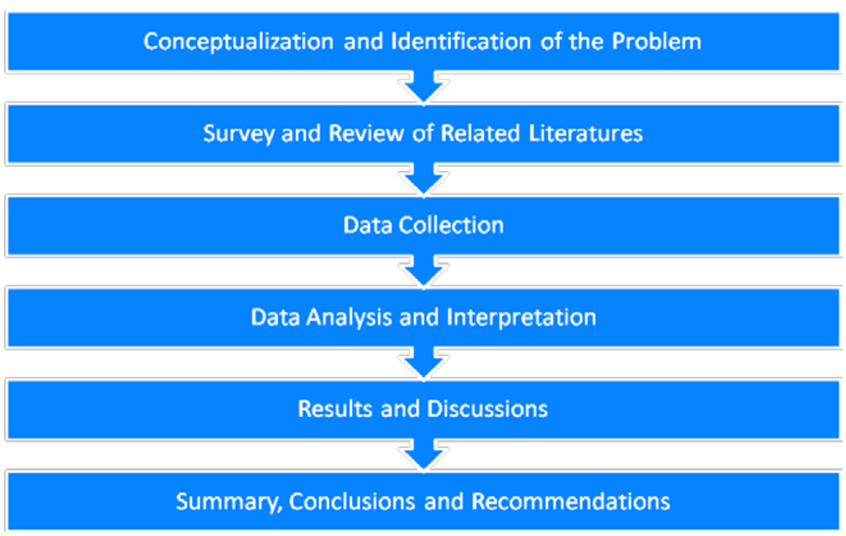

Figure 1.1: Research Process

1.9. Organization of the Research

This study basically consists of five chapters and is organized in the following manner. The first chapter gave an overview to the national as well as global existing situation of the energy sector. It also highlighted the confusions that existed in the literature related to the potential and exploitation of the energy resources of Ethiopia. Thus, this chapter presents statement of the problem and other related rationales that initiated the researcher to undertake this study. The second chapter discusses on related literatures on the significance, the situation, demand and supply, energy modeling systems, the bottlenecks and related issues of the energy sector of Ethiopia. The third chapter presents the methods, materials and processes followed and used to achieve the objectives of the study. The data and information gathered are presented and analyzed. More importantly, the findings of the research are briefly discussed in this chapter. Eventually, the last but not the least part, chapter five, winds up the research through concluding statements, recommendations, and future research directions.

Chapter Two: Literature Review

2.1. Introduction

Energy is taken as one of the invaluable inputs for socio-economic development of Nations. It significantly plays a critical role in underpinning efforts to achieve the local as well as global development goals and improving the lives of poor people across the world. According to Karekezi (2002a) lack of access to clean, affordable, reliable, adequate, safe and environmentally-friendly energy is a severe constraint on the growth and development of nations. These facts together with the strong links between the energy sector and the millennium development goals (MDGs) make it even critically important to address the challenges and prospects for the sector in sub-Saharan Africa (Karekezi and Majoro, 2002). With no doubt the provision of energy services is a necessary but not sufficient condition for sub-Saharan Africa countries in addressing poverty (IEA, 2014).

According to EEA (2009), the development and status of the energy sector is very much related and dependent on a country's level of socio-economic development. Energy development, which can be defined as the increased provision and use of energy services, is an integral part of enhanced economic development. The report further declared that, the linkages among energy, other inputs, and economic activity clearly change significantly as an economy moves through different stages of development.

Azeb (2015) has indicated that Ethiopia is still at a low level of development of the energy infrastructure and access to energy. The status of the country is highly far less away from the average even from the sub-Saharan countries both on capacity installed per person and per capita consumption for electricity. Given the fact that 85% of the population of Ethiopia lives in rural areas however electricity supply from the grid is almost entirely concentrated in urban areas and about 1% of the rural population has access to electricity until the rural Electrification program was launched (MoWIE, 2014). According to GIZ (2015), however, this situation was increased to 5%. It is a well-known fact that access to sustainable energy is a key factor for promoting social progress and economic growth; both of which are closely linked to sustainable poverty reduction (EEA, 2009).

Bio-mass is the largest source of household energy in Ethiopia. According to MoWIE (2014), excessive dependence on this biomass energy sources has important implications for human health, soil and land management, agricultural land productivity, and environmental effects. The Ethiopian energy sector is facing several challenges. These include, but not limited to, shortage of electricity generation capacity as evidenced by rampant power shedding through the years, the huge investment finance required for energy generation and transmission projects, lack of substitutes supplements for biomass fuels used in households in the face of decreasing availability of fuel wood, low level of efficiency of use of energy in all sectors, low level of renewable energy development outside large scale hydropower development, lack of a comprehensive energy policy and strategy tuned to the current and impending challenges and opportunities (EEA, 2009).

2.2. The Concept of sustainable energy management

According to Journal of Economic Development (2012) Energy management is defined as the process of planning, directing, implementing and controlling the process of generation, transmission and energy consumption. It further states that energy management as a kind of synthesis of phenomena and concepts of modern energy management, or the use of modern settings of management in the energy sector.

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Furthermore, when outlining the basic settings for power management, modern management is based on the assumptions of sustainability and conservation of energy stability for present and future generations. Therefore, modern energy management can be seen as a kind of synthesis of three actuarial sciences: energy, sustainable development and management, which are interconnected and conditioned, as shown in Figure 2.1.

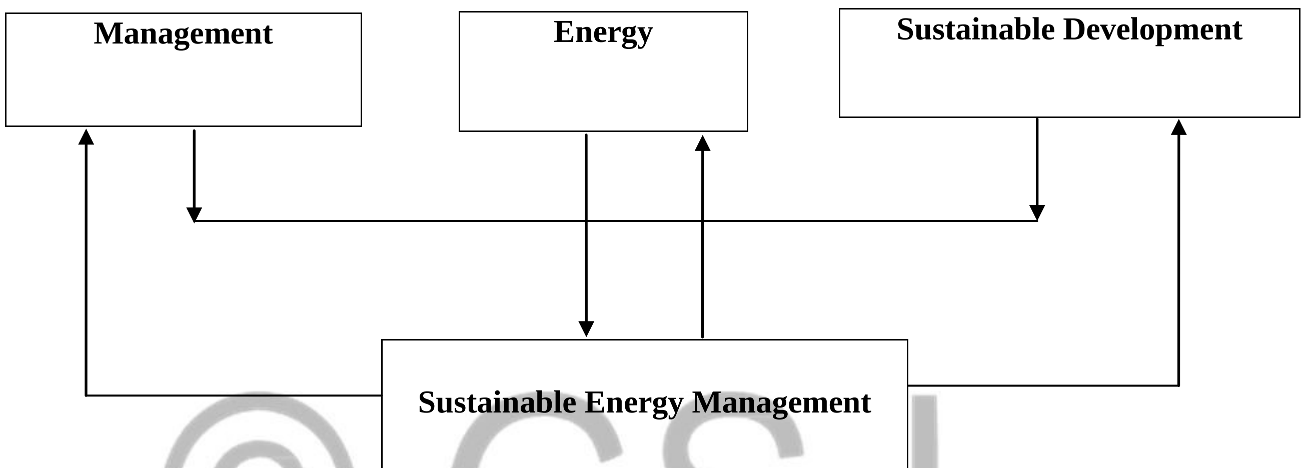

Fig. 2.1: The basic concept of sustainable energy management

Sustainable Energy Management is a unique new concept, idea and approach that require many changes in the traditional way of understanding and interpretation of energy management at all levels. Sustainable management of energy integrates many features of the environment. Sustainable energy management concept cannot therefore be construed as an adopted and defined the concept, but must be constantly modified and adjusted in accordance with changes in the three areas that define it, and in accordance with the specific country or region where applicable. Basically, the concept of sustainable energy defines the following parameters in the environment:

- Management and interpretation accepted theory, the existing experience, state regulations, navigation companies, the requirements of all stakeholders, level of education, awareness and commitment, and general orientation toward social responsibility;

- Energy. first of all legislation, existing energy resources, new energy resources, energy efficiency level, the level of technology development, production and consumption levels, system stability, connectivity with other systems, the degree of self-sufficiency:
- Sustainable development and acceptance of the concept at the state level, the ratification of the international agreement, the parameters of national sustainable development strategy, the list of priorities.

Accordingly, sustainable energy management can be defined as the process of energy management that is based on fundamental principles of sustainable development. Sustainable energy management must therefore be regarded as a concept that greatly deviates from the traditional management mode, which has largely ignored the need of preserving, restoring and saving energy resources.

2.3. Description of the energy sector

The sub-Saharan Africa region compares poorly with others in the developing world in terms of the proportion of the population relying on traditional biomass for cooking. At the national level, many countries like Liberia, Burkina Faso and Tanzania have more than 95% of their population relying on traditional biomass for cooking and heating. Access to modern energy systems for cooking is therefore very low in most sub- Saharan countries. In the east Africa region, for instance, less than 30% households use LPG or improved cook stoves (Bazilian et al., 2012). In West Africa, Senegal has more than 20% of its population using light petroleum gas (LPG), while Ghana has less than 10%. Many other land-locked countries like Mali and Niger are worse off (Mainali et al., 2014).

The numbers of people relying on traditional biomass for cooking are projected to increase in sub-Saharan Africa over the next 25 years or so. The increasing numbers of people relying on traditional biomass for cooking is linked directly to the per-capita incomes, which are not expected to increase high enough for people to switch away from traditional biomass use.

Modern forms of energy play an enabling role in sustainable development and are closely linked with poverty reduction, climate change mitigation, education, food security, and public health (Karekezi et al., 2012). An article published by Dawit (2012) has indicated that more than 3 billion people (nearly half of the world population) are globally deprived of access to modern energy alternatives. All of these people live in poor countries and depend on traditional biomass resources to meet their basic energy need which in turn has caused worsening health and environmental consequences. The article further has stated that the national energy balance of Ethiopia has been so far predominated by two sort energy resources (Hydro 20% and biomass 80%) and energy poverty of Ethiopia is manifested in its indigenous biomass resource resilience.

Ethiopia is among the few countries with a broad diversity of abundant renewable energy resources though the resources are poorly exploited. According to Dereje (2013) Ethiopia has the potential to obtain sustainable energy from renewable sources; 45,000 MW of hydro power energy, an 4-6 Kw/m^2 of solar energy, 1350 MW from wind energy, 1120 from geothermal sources and so on. Paradoxically, the country suffers acute deficits in terms of access to clean energy. In combination with the steady, substantial drop in the costs of other renewable energy technologies like wind turbines and solar panels, renewable energy sources offer many opportunities. Ironically only a minor fraction of these resources has been exploited so far.

The National statistics as stated by Dawit (2014) has indicated that the potential of biomass energy is actually being exploited, representing approximately 50% of the woody biomass potential and 30% of agricultural residues, but only 5% of hydroelectric potential and less than 1% of combined wind, solar, and geothermal potential is currently exploited. The country has also experienced unprecedented growth in demand for electricity. The severe energy crisis in the country is reflected in the low level of access to clean energy in remote rural villages, where over 85% of the country's impoverished population resides. Alleviating the energy crisis by harnessing these renewable resource opportunities offers long-term societal and economic development benefits. His study also concluded that Supplying clean energy to remote areas through the expansion of existing grid systems is not cost effective in Ethiopia, and furthermore would be technically difficult and impractical. The study results suggest that government intervention in rural energy and attention to decentralized approaches are necessary to close the energy supply and demand gaps. In rural areas, the government could help build effective institutions, legal frameworks, and regulatory structures that support decentralized energy use and forest conservation to help overcome the technical, economic, institutional, and financial barriers to renewable energy development.

Except examining the imbalance between the demand and supply of energy, assessing the existing situations of the development of the energy sector, and investigating the limitations for the development of individual renewable sources of energy, no study have been undertaken to assess and identify the major nationwide management challenges and prospects of energy. Therefore, thinking to embark a research on energy management and development, would significantly play considerable roles in changing the current situations, developing an efficient energy management system to face the challenges bottlenecking the sector and make use of the considerable prospects we have on hand.

Ethiopia has considerable energy resources that need to be exploited to accelerate its socio-economic development. The energy resources include hydropower, geothermal, wind, solar, woody biomass, natural gas and coal. Resource exploitation, however, has been largely limited to biomass and hydropower. The proven fossil fuel resources in the country are limited to natural gas and coal and these have yet to be developed. Despite the presence of a variety of energy resources, the bulk of the national energy consumption is met from biomass energy sources. Biomass energy (fuel wood, charcoal, wood, waste wood, crop residues and animal dung, including biogas) accounted for 89 percent of total national energy consumption in 2006 (Mekonnen, 2009). Domestic energy requirements are mostly met from wood, animal dung and agricultural residues. Electricity consumption among the sectors was 33% by households, 40% by industries and 26% by service sector.

2.4. Energy resources of Ethiopia

Ethiopia is endowed with various energy resources including hydro, geothermal, natural gas, coal, biomass, solar and wind energy. The gross hydro-energy potential of the country is estimated at 650,000 GWh per year (CESEN, 1986; WAPCOS, 1990), of which 25 percent (160,000 GWh per year) could be economically exploited for power. The gross hydropower potential of 650,000 GWh/year is second only to that of the Democratic Republic of Congo (DRC) (estimated at about 770, 000 GWh/year) in Africa. The "economic" hydroelectric potential of 160,000 GWh per year (or 30,000 MW in installed capacity terms) can support electricity development at a scale fifty times the capacity of hydropower plants currently in operation in Ethiopia. This hydropower potential is distributed in 12 major river basins in the country, including the Abbay, Omo Gibe and Baro basins. Hydropower sites of various capacities abound, with over 20 sites believed to provide over 200 MW each. Although the gross hydro potential of 650,000 GWh/year has not been contested since the CESEN and WAPCOS studies, the fraction of the potential that could be economically exploited has been raised to 40% in some reports. Accordingly, the economic hydroelectric potential is at times stated as 260,000 GWh/year and 45,000 MW. With respect to geothermal resources, CESEN (1986) reported that put the potential at about 700 MW in terms of electricity production. The resource is distributed along the rift valley running from Dallol in the north to the Kenyan border in the south. The main concentration of the geothermal resource is at the Dankil depression (170 MW), Tendaho Graben (380 MW) and Aluto area near Lake Langano (170 MW). Aquifer temperatures of around 200o c have been cited in these sites. The Ethiopian Institute of Geological Studies has since carried out detailed investigation of the geothermal resources in the rift valley. Based on its findings, the institute has revised the resource potential to about 5,000 MW. Based on the geographic distribution of sedimentary basins, oil and gas exploration and geological studies have been undertaken in the Ogaden, Bale, South Omo, Gambella, Abbay basin and Mekelle areas.

Biomass energy resources in Ethiopia have been studied in some depth by CESEN (1986) in the late 1970s, and the Woody Biomass Inventory and Strategic Planning Project (WBISPP) at the turn of the century. Both studies indicated that the biomass stock at the national level could sustain the domestic demand, but that the mismatch between the resource and demand locations created fuel wood shortages in several localities. The more recent WBISPP study of woody biomass resources in Ethiopia was also an extensive undertaking to determine the size and geographic distribution of biomass resources of Ethiopia. The WBISPP estimate for the standing stock and annual yield of biomass was 1,149 million tons and 50 million tons, respectively, for year 2000 (WBISPP, 2004). This translates into a per capita yield of about 0.79 tons of woody biomass for the year 2000 population of 63.5 million in Ethiopia. This value of per capita yield too is above the per capita demand, and as such does not represent any immediate threat for the energy sector. On the other hand, the contrast between the CESEN (1986) study estimates and those of WBISPP (2004) for the standing stock and annual yield for woody biomass resources is alarmingly huge. Ignoring methodological differences in the two studies, the standing stock values would represent an annual decline of 5.2% in the period 1977 -2000. The annual yield figures discussed in the foregoing paragraphs do not include non-woody biomass such as agro-residues and dry dung, which would gain importance in the energy scene as woody biomass resources dwindle. Also, neither study appears to have captured scattered wood stands and lone trees as are found on farm peripheries, compounds, river banks, etc. These resources would, nevertheless, continue to provide lifeline energy to rural households. It should be noted here that the dwindling of woody biomass resources is not attributable to energy consumption alone. In fact energy consumption plays a relatively small role in deforestation. The main factors behind deforestation are believed to be clearing of woodlands for agriculture and settlement, logging of wood for industrial use and cutting wood for use as construction material (Mengistu, 1991). Expansion of urban centers is also becoming a significant factor. Coal resources in Ethiopia are widely distributed over the country, including the western and south western parts of Ethiopia, northern Shewa and Gondar. The resource is estimated to be about 300 million tons (MME, 2009). The coal reserves in most areas are of low calorific value, high ash and sulfur content lignite. However, the reserves in the western and south western parts of Ethiopia, especially in Yayu, and Delbi Moye areas have attracted much attention due to their quality and size. Studies have so far been carried out to use the coal resource for power generation, industrial steam raising and production of coal based fertilizer. Coal briquettes based on refining and compacting low - grade coal can also be used as a household fuel. The areas of rich coal reserves in the western and south western Ethiopia are also associated with oil shale reserves. In all, about 250 million tons of oil shale is believed to exist in Ethiopia (Welela, 2006). Oil shale are rocks containing bituminous material/oil trapped within pores in their structures. The trapped oil can be extracted by crashing and heating the rock in retorts. It is then processed further and finally refined to yield petroleum products. There are also technologies being developed to extract the oil in situ, using radio waves directed at the oil shale strata. These new technologies are expected to cut down oil extraction costs, as well as reducing environmental disruptions. With respect to solar energy, the national average radiation received at ground level is estimated at 5.20 kWh/m2 per day. Obviously, there are seasonal variations (with a minimum of 4.55 kWh/m2 in July, to a maximum of 5.55 kWh/m2 in February and March), and also variations with physical locations (ranging from 4.25 kWh/m2 for Itang in the south west to 6.25 kWh/m2 for Adigrat in the north). The national average radiation value may be compared to that of neighboring Kenya, a tropical/equatorial country with an average radiation of 6.98

kWh/m^2 per day. Solar radiation can be converted to electrical energy in PV systems at average conversion efficiency of about 14% (EREDPC, 2007). Such PV systems can provide electricity for rural homes, schools, clinics, telecommunication stations, etc. In Ethiopia, the Ethiopian Telecommunications Corporation remains the only significant user of PV systems. Solar thermal systems can provide hot water to industrial and commercial enterprises, offices, homes, schools, hospitals, etc., thereby contributing to reduction in electricity demand. However, this application of solar energy too is a rarity in Ethiopia at present. Wind energy abounds in varying degrees in all parts of the country. The central highlands give rise to essentially two distinct wind regimes: the eastern and southern parts of the country falling on the windward side and consequently exhibiting higher wind potential, and the western and north western parts lying on the lee side with lower wind potential. Wind energy is based on wind speed and, as in the case of the solar radiation, wind speeds are subject to variations with specific location of the site, height at which wind speeds are recorded, time of day and month of the year, among others. CESEN (1986) reports indicate annual mean wind speeds of 3.5 m/s - 5.5 m/s, measured at 10 meters from ground, for the eastern and southern parts of the country. This potential is, however, being revised upwards based on better measuring techniques for wind speeds. In fact, recent studies by the SWERA project point to several localities in the country with annual average speeds exceeding 7 m/s. The electricity generation potential of the wind resource in these localities (total area about 20,000 km^2) is estimated at about 100,000 MW (890,000 GWh/year). The use of wind energy in Ethiopia was limited to water lifting in the rift valley communities. Currently, EEPCO is undertaking wind-based electricity generation projects for a total capacity of 120 MW.

Wind-based electricity generation would be important for Ethiopia in complementing the hydro-based generation system which is susceptible to reservoir water shortages in times of drought. On the global scene, wind-based electricity generation is proving a fast growing and effective means to meet energy demand and combat climate change. In the European Union member countries, for example, wind -based generation capacity increased from 2,500 MW in 1995 to just over 40,000 MW in 2005, representing an annual growth rate of 32%. Concomitantly, wind turbine technology has become more sophisticated, with unit generating capacity increasing and generation costs falling. There are now turbines with unit generating capacity of 5 MW. The lower and upper cut-off wind speeds for the turbines are about 2.5 m/s and 25 m/s, respectively. This is a favorable trend for wind energy to play an increasing role in Ethiopia's power supply system.

2.5. The link between energy and development:

Some review and conceptualization of Energy development, interpreted broadly to mean increased provision and use of energy services, is an integral part of enhanced economic development (Toman and Jemelkova, 2002). The development and status of the energy sector is very much related and dependent on a country’s level of socio-economic development. Toman and Jemelkova (2002) further elaborated on the Conceptual Linkages of Energy and Development. The linkages among energy, other inputs, and economic activity clearly change significantly as an economy moves through different stages of development. At the lowest level of income and social development, energy tends to come from harvested or scavenged biological sources (wood, dung, sunshine for drying) and human effort (also biologically powered). More processed bio-fuels (charcoal), animal power, and some commercial fossil energy become more prominent in the intermediate stages. Commercial fossil fuels and ultimately electricity become predominant in the most advanced stages of industrialization and. Again, energy resources of different levels of development may be used concurrently at any given stage of economic development: electric lighting may be used concurrently with biomass cooking fires. Changes in relative opportunity costs as well as incomes can move households and other energy users up and down the ladder for different energy-related services. A study report by USAID (undated) stated that energy advances economic growth and trade activities via: (i) industrialization, (ii) e-commerce, (iii) agricultural markets and trade, (iv)increased productivity, (v) small, medium, and micro-enterprises (SMEs), and (vi) Job creation and income generation.

Energy use increases as more economic sectors develop and more channels for flow are opened. Economic diversity, as measured by the number of economic sectors using energy and the equitability of flows between them, generally, increases. As diversity increases the efficiency of generating outputs with a given amount of energy also increases (Paul, 1998). The same author also noted that there are two distinct development strategies regarding energy use - one which promotes energy use and one which emphasizes diversity and the sustainability of energy. While most countries are said to have employed a strategy of mixing the two, developing countries generally rely more on increasing energy use to increase output while developed countries tend to become more diverse as a means of increasing outputs. Sustainability is enhanced by strategies which promote diversity and resource use efficiency in economic systems. There is a strong connection between the energy sector and a national economy. On the one hand, energy demand, supply and pricing have significant impact on socio-economic development and the overall quality of life of the population. On the other hand, the nature of economic structure and the changes in that structure, the prevailing macro-economic conditions are key factors of energy demand and supply. In addition, energy affects environmental quality through deforestation associated with unsustainable biomass energy dependence and greenhouse gas emission from fossil fuel.

2.6. The role of the energy sector to the national economy

The energy sector is an important sector in Ethiopia in terms of input to the economic activities, revenue generation and its role in investment. Data provided by MoFED (2006) has shown that the value-added of Electricity and Water (at constant market prices) was 2.02 billion Birr. The value has been increasing over time. However, the share of the sector, compared to agriculture, industry and services, is still minimal due to the low development of the sector.

Power is also an important input for addition of other sectors of the economy. The Report further revealed that in the year 2005/06, the government's capital expenditure in the Energy related sector was 264 million Birr (3% of the capital expenditure for economic development). Both the traditional and modern energy sources play a major role in production and livelihood activities in Ethiopia. Energy, specially electricity and power play a great role in automation and boosting productivity by significantly reducing the time it takes in production of goods and services and by increasing the rate of output. The report in the PASDEP document (MoFED, 2005), Ethiopia is still at low level of development of energy infrastructure and access to energy. It is noted that while developing countries' average figure for Electric Power (kW installed capacity per 1000 persons) is 272, Ethiopia achieved only 8 kW. Also in terms of Electricity Consumption (kWh per capita in the year 2001) Ethiopia averaged at 24 kWh while the developing countries' average was 938 kWh. About 94% of the country's electric power generation relies on water resources.

A study by Ethio Resource Group with Partners (2007) shows that with only 6% of households connected and 15% of the population having access to electricity from Ethiopian Electric Power (EEP), access to electricity in Ethiopia is one of the lowest by any standards. Despite the fact that about 85% of the population of Ethiopia lives in rural areas, electricity supply from the grid is almost entirely concentrated in urban areas. Among other things, dispersed demand and very low consumption level of electricity among rural consumers, limited grid electricity penetration and coverage of less than 1% of the rural population have been the situation that explains how the service was at low level of development until very recent times. Time series data compiled (for world countries) by the Energy Information Administration in USA show that the per capita primary energy consumption for Kenya is five to six-fold that of Ethiopia implying the low level of development of the energy sector services in the latter. Data obtained from the Energy Information Administration for a period that covers 1980 to 2006 show that while primary energy production has steadily rose over the reference period, per capita total primary energy consumption has not improved. The change in terms of index (1993=100) shows that primary energy production increased more than double while per capita energy consumption until the year 2002 was equal to the level of 1980s. Similarly, there has not been any meaningful improvement in energy intensity or efficiency i.e. the amount of energy consumed per economic value generated. There is no doubt that better access to power and energy contributes to improved productivity through enabling more production per unit of inputs and higher labor productivity and enhanced quality of production. Power and energy is also a means for poverty reduction and better quality life through development and better access to quality social services like education, health, infrastructure and communication.

The UN Report on Energy, UNIDO (2008) has underlined that energy today is at the heart of economic, environmental and developmental issues. It is also noted in the report that the world needs clean, efficient and reliable energy services to meet its long-term needs for economic growth and development. Developing countries need to expand access to reliable and modern energy services to alleviate poverty and increase productivity, to enhance competitiveness and economic growth. In this respect, a study report by Roger M. Gaillard (2008) underlines that access to sustainable energy is a key factor for promoting social progress and economic growth both of which are closely linked to sustainable poverty reduction. Energy plays a critical role in underpinning efforts to achieve the Development Goals and improving the lives of poor people across the world. Lack of access to adequate, affordable, reliable, safe and environmentally-friendly energy is a severe constraint on development. The author has noted that research works and history show that there is a close correlation between the use of energy (electricity) and the quality of life. The study refers to evidences from different data and survey sources that there exist two critical thresholds for developing countries to achieve sustainable socio-economic growth when measured with the yardstick of energy consumption. Below 1000 kWh of annual per capita consumption of electricity (which constitutes 60% of the world population) indicators like literacy rate and access to potable water remains, respectively, below 50 and 40 %. When the per capita consumption reaches 2000 kWh, the same indicators rise to 85 and 90%. It was further indicated that the same correlation has been established also for human development indicators like infant mortality or life expectancy. Compared to other countries, rural electrification in Ethiopia is much overdue. The low development of the energy sector, remoteness (inaccessibility) of much of the country's rural side, and the lack of policies and strategies that address the rural electrification and energy needs contributed to this. Against this big backlog and shortcomings in the past, the universal electric access program recently launched for rural villages and towns by the government is the right intervention. The existing pattern of rural settlement, adequate follow-up of the implementation and continuity of the program (given the huge resource requirements) are the major concerns in this respect. Estimates show that Ethiopia's hydroelectric power generation potential is in the range of 15,000 to 30,000 Megawatts (MW). What has been developed so far amounts only to 663 MW3 or only 2 to 4% of the total potential. Among the modern energy sources, hydroelectric power energy is the main source of energy in the country. Although the country has an immense potential for hydroelectric power and energy development, to-date little share of this potential is utilized. These facts and figures show the daunting tasks and challenges ahead in terms of the development and expansion of energy services in the country. A recent report by the Ministry of Mines and Energy (2009) acknowledges that in Ethiopia, currently the energy consumption per capita is at low level, and unsustainable due to over-dependence on bio-mass (fuel-wood). Energy consumption in Ethiopia is low in per capita terms, and its structure is underdeveloped. The current energy supply is made up of less than 1% electricity, about 5.4% hydrocarbon fuels, while the balance is from traditional biomass fuels. Most of the petroleum products are consumed in the transport sector, whereas household energy comprises primarily of biomass fuels. The available evidences also show that about 40 million tons of fuel wood and 8 million tons of agri-residue are consumed annually. In Ethiopia bio-mass is the largest source of household energy. Official survey data that provide the percentage distribution of households by type of fuel used for cooking show that, in the year 2004, in rural areas 81% of the households used collected firewood, while still a large share (49%) of households in urban areas used purchased firewood. On the other hand, Kerosene/Butane Gas, and Electricity were used by only 0.4% of the rural and 19% of the urban households for the same purpose. This excessive dependence on biomass energy sources (mainly fuel wood, animal dung, crop residues) has important implications for soil and land management, agricultural land productivity, environmental and health effects via channels like clearance of the vegetative cover of land, deforestation, soil erosion and other complex consequences for climate change. The steps taken by the Ethiopian government in the past few years through the current development programs that give higher attention to the energy sector is encouraging. The current development is appreciated not only for expanded and big investment commitments for energy development, but also for envisaged energy access to the rural villages. As stated in the current development plan under implementation (2005 -2010 i.e. PASDEP period), power supply will be increased by three-fold, with the construction of 5 major new dams, and addition of 668 MW of generating capacity. It is also indicated that a major rural electrification program is being undertaken, so that at the end of the plan period 50% of the population will have access to electricity, compared to about 17% today. A study by Ethio Resource Group with Partners (2007), reports that the Long range Energy Alternative Planning model (LEAP) is used to analyze and project energy demand and supply. Scenario analysis is made to determine possible development for energy supplies, i.e. conventional source dominated scenario vs. solar and wind energy friendly scenario. It is shown that the energy demand forecast carried out with the model indicates that demand can be expected to grow from 700 PJ (194 TWh) in 2000 to just over 1900 PJ (527 TWh) in 2030, a growth rate of 3.5% per year. Sectoral energy shares change where energy demand from the household sector drops from 91% in 2000 to 78% in 2030 with corresponding increases in the other sectors. Fuel shares in the energy balance also change with share of biomass from total demand declining from 93% in 2000 to 82% in 2030. The study also reports that in terms of supply the reference scenario shows that the nearly exclusive dependence of the electric grid continues into the future and hydropower plants will contribute 96% to total generation on the grid in 2030. In electrified rural areas supplies are currently mostly from off-grid systems but in the future the contribution of grid electricity will increase and by 2030 grid power will account for 66% of total rural electricity demand. Supply shortfalls appear for electricity in 2017 for the grid and immediately for off-grid systems. In the Reference scenario, shortfalls are met with the same supply mix as the base case whereas for the Alternative scenarios the shortfalls are met with solar and wind energy. The detailed analysis by the same study5 shows that solar and wind energy may supply the shortfall of 1TWh of grid electricity in 2017 and 12.8TWh in 2030; for off-grid electricity, shortfalls appear the year after the base year and it was estimated that solar and wind energy could provide 7.3GWh in 2001 and 300 GWh in 2030; for home systems the potential for solar and wind energy would be in 28MWh in 2001 and 13GWh in 2030; and for solar water heaters the potential would be 31GWh in 2001 and 2TWh in 2030.

2.7. The bottlenecks of the energy sector in Ethiopia

Global consumption of commercial forms of energy has increased steadily over the last four decades, recently marked by especially dramatic growth rates in many developing countries. Between 1970 and 1988, developing countries' share of global primary energy consumption increased from approximately 13 percent to about 30 percent. In 2005, the non-OECD countries accounted for just over half (52 percent) of global primary energy consumption. This increase in energy consumption has not, however, resulted in more equitable access to energy services on a per capita basis. In 2005, average per capita energy consumption in the OECD countries was more than four times average per capita energy consumption across all non-OECD countries, and nearly seven times the average per capita energy consumption in Africa (IEA, 2007). In this context, the most immediate energy priority for many developing countries is to expand access. In fact, providing safe, clean, reliable and affordable energy to those who currently have no access is widely viewed as critical for advancing other development objectives. If access is the priority, the immediate obstacle for many poor households and governments in developing countries is a lack of financial resources. Moreover, where access to energy is lacking, other urgent human and societal needs are often unmet too, meaning that energy needs must compete with other priorities. It is possible, in other words, to greatly improve the quality of life for many poor households at a level of energy consumption far below that of the average citizen in an industrialized country. To pay for even basic services, however, households need income-generating opportunities, which also require energy. An estimated 1.6 billion people worldwide lack access to electricity. Providing basic electricity services to these people at an average annual consumption level of 50 kWh per person would imply an increase in global end-use electricity demand of roughly 80 billion kWh per year. This figure represents less than one-half of 1 percent of global annual electricity production (estimated at 18,235 billion kWh in 2004) and less than one-fifth of the expected year-to-year increase in global electricity production projected for the next two decades, according to the IEA's 2007 reference case forecast for 2004–2030. Besides expanding access, many developing countries face at least two other immediate energy-related challenges. The first and most pressing issue for many oil-importing countries is economic: a rapid rise in world oil prices has led to a steep and, for some countries, increasingly unmanageable escalation in their import bill for energy commodities. For example, India's oil import bill increased more than 20 percent in a single year, from $33 billion in 2006 to an estimated $40 billion in 2007. For many smaller and poorer countries, the combination of rapidly rising energy prices and a recent, similarly precipitous escalation of world food prices are generating concerns about internal economic and political stability. For these countries, diversifying their domestic energy resource base and reducing their demand for imported fuels would carry a host of benefits, not only by freeing scarce resources for domestic investment but also by reducing their long-term exposure to the financial and humanitarian crises that now loom in many parts of the world.

The second, important energy-related challenge is environmental (EEA, 2009). As noted in a previous section, energy use is a significant and immediate cause of high levels of air pollution and other forms of environmental degradation in many developing countries. Energy-related emissions from power plants, automobiles, heavy equipment and industrial facilities are largely responsible for levels of ambient air pollution especially in major cities that routinely exceed, sometimes by an order of magnitude, the health thresholds set by the World Health Organization. And in urban and rural areas alike, indoor air pollution attributable to the use of traditional fuels for cooking and space heating exposes billions of people, especially women and children, to significant cardiovascular and respiratory health risks on a daily basis. In many cases, adverse environmental impacts begin well upstream of the point of energy end-use: the extraction of commercial fuels like coal and oil is often highly damaging to local ecosystems and an immediate cause of land and water pollution. Meanwhile, reliance on traditional fuels such as wood can produce its own adverse impacts. Given that developing countries are expected to account for a large and growing share of overall greenhouse gas emissions in the future, active participation in efforts to de-carbonize the world's energy systems is essential as a matter of self-interest and in the interests of averting a global environmental catastrophe. First, however, it is useful to review some of the technology options available to developing countries in seeking to meet their growing energy needs in a global context marked by increasingly intractable environmental and resource constraints.

2.8. Review of the National Energy Policy of Ethiopia

The energy policy document of Ethiopia, drafted in 1994, has encouraged the use of indigenous and renewable energy sources. As per the document, the Ministry of Water, Irrigation and Electricity is responsible for the development of energy resources, implementation strategies, policies and sector laws. Developing and utilizing the existing energy potentials, promoting the development of renewable energy, reducing unnecessary losses of energy, supporting the development of other economic sectors, and developing the efficiency and capacity of the energy sector are the rationale for devising the energy policy document.

The general objectives of the energy policy aimed at are:

a) To ensure a reliable supply of energy at the right time and at affordable prices

b) To ensure and encourage a gradual shift from traditional energy sources use to modern energy sources.

c) To stream-line and remove bottlenecks encountered in the development and utilization of energy resources.

d) To set general guidelines and strategies for the development and supply of energy resources;

e) To increase energy utilization efficiency and reduce energy wastage; and, to ensure that the development and utilization of energy is benign to the environment.

The development of Hydro power due to its availability, encouraging energy mix for supply diversification, developing the energy sector in environmental friendly manner, providing the private sector with the necessary support, developing human resources and establishing competent energy institutions and setting standards and publicizing codes to use energy efficiently are the highest priorities of the policy.

2.9. Energy management system modeling and development

Proper planning is crucial in the energy sector for supporting decision and policy makers with respect to national and regional development. Energy system modeling describes the relationship between economic development, energy use and emissions of CO_2 and project the future energy demand and supply of the country (Van Beek, 1999). Energy models further outline the primary energy consumption, conversion and final consumption of energy.

Impacts of future energy demand and supply can often be analyzed by different types of energy models. Models can stimulate the market penetration and related cost changes of new energy technology or policy with certain degree of technical detail. Models are also used to stimulate policy and technology choices that may influence future energy supply and demand investments in energy systems (Mueller et al, 2012).

A large number of modeling approaches are developed depending on their intended use (data analysis, forecasting, optimization, stimulation, estimation of parameters), target groups (research communities, policy makers, utility companies), the information available (useful energy, energy demand, data on final energy, sector wise energy demand), regional (national, regional, multinational) and conceptual framework. The figure shown below indicates the criterion to classify energy modeling tools.

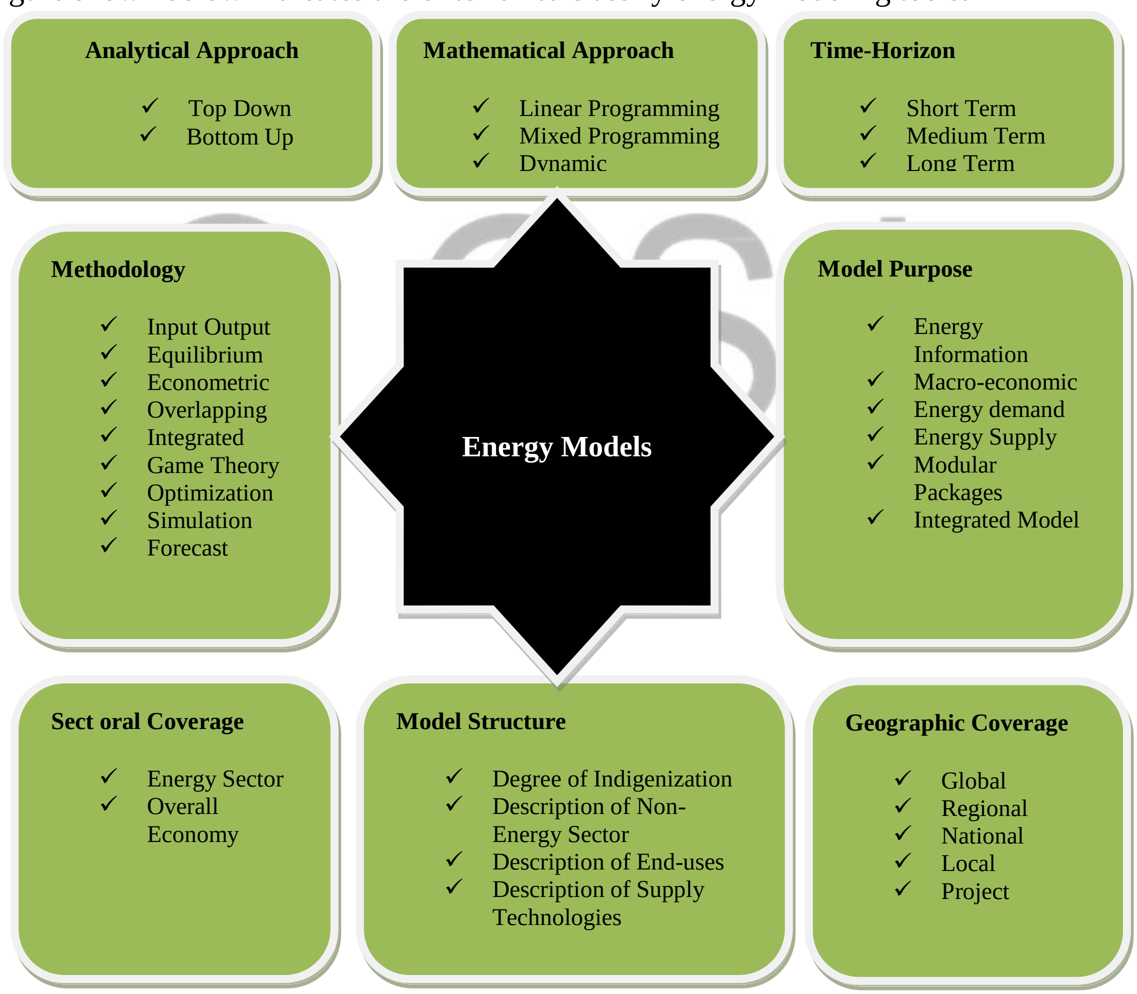

Figure 2.2: Energy Modeling Classification Criterion

2.10. Overview of Energy Modeling Approaches (State-of-the-Art)

Energy models are used to project the future energy demand and supply of a country or a region. They are mostly used in an exploratory manner assuming certain developments of boundary conditions such as the development of economic activities, demographic development, or energy prices on world markets. They are also used to simulate policy and technology choices that may influence future energy demand and supply, and hence investments in energy systems, including energy efficiency policies. However, policy and technology choices induce a dilemma in the choice of energy model (Bohringer, 1998). Every modeling approach abstracts to a certain degree from reality using stylized facts, statistical average figures, past trends as well as other assumptions. Consequently, energy models represent a more or less simplified picture of the real energy system and the real economy; at best they provide a good approximation of today's reality. Nevertheless, it would be impossible to answer very specific questions on energy technologies or economic implications without making some cut backs and approximations, with an uncertain reliability on quantitative figures used by those models. A large diversity of modeling approaches has been developed over time depending on their target group (policy makers, scientific and research communities, large energy supply companies), intended use (data analysis, ex post evaluation, forecasting, simulation, optimization, estimation of parameters, etc.), regional coverage (regional, national, multinational), conceptual framework (top-down: underlying economic theory, bottom-up: technological focus/explicitness) and the information available (data on final energy, useful energy, energy demand by branches in the service, transport, or industrial sector).

Obviously, both types of energy models, top-down and bottom-up, have specific advantages and limitations, of which modelers, users of the results, and policymakers are, however, often not sufficiently aware. Bottom-up models are generally constructed and used by engineers, natural scientists, and energy supply companies, whereas top-down models tend to be developed and used by economists and public administrations. The understanding of the two approaches has increased substantially over the last decade (Hourcade et al., 2006); There have been first few attempts to combine both approaches in one hybrid energy model system, probably so late during the past decade due to the lack of interdisciplinary research teams of necessary larger funds for their operation (Catenazzi, 2009).Recent or current projections and studies of energy demand and supply using energy models (IEA, 2010 and Prognos,2011) are not just made for routine decisions by decision makers in administrations or large energy companies; they also increasingly serve as a scientifically derived information basis for societal debate among governments, energy companies, trade associations, and NGOs.

2.11. Modeling approaches and processes in the energy sector

Policy making in energy sector is strongly influenced by models designed to forecast effects of policies on energy demand, energy related pollution and economic output. Energy models represent a more or less simplified version of the real economy. At best they provide a good approximation of today's reality. According to Mueller et al (2011), Most of the energy models comprise the following main features:

a) Principle: simulation and optimization,

b) Approach: sectoral (top down) or technology oriented (bottom up)

c) Structure: point model (reduced to the consideration of production and demand without power restrictions) or extended model (including grid considerations)

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

The purpose of using energy models in scenario analysis is the most commonly used parameters for model choice and relates to different factors to organize large amounts of data to provide framework for hypothesis testing and reflect understanding form of complex systems (Heemskerk et al, 2003)

2.10.1. Scenario development

The general approach to scenario development mostly considers the description of the alternative options around different assumptions and the explanation of the characterizing parameters and criterion of scenarios development. Subsequently, the modeled scenarios are quantitatively examined and their impacts for the future long term energy path ways of a country are analyzed. The scenarios outline alternative future development paths that a common option space windows of opportunity shows. In scenario development, argumentative considerations are employed. Since simulations with numerical models can only represent some aspects of the scenarios, others especially social and institutional aspects remain excluded. In addition to the quantitative modeling of the scenarios, there is a high verbal description of the many correlations between influencing factors. Thus each scenario is developed, as a basis and interpretation background and quantitative modeling together.

2.12. Modeling tools, software and applications

There are a lot of modeling tools, software and applications for long range energy sector development planning. However, those which are used for the issue under study are raised and discussed.

A) **OSeMOSYS**, an Open Source Energy Modeling System, as defined by many authors is considered as a system designed for long run integrated assessment and energy planning (M. Howells et al, 2011; M. Welsch et al, 2012). It is used as a tool to inform the development of local, national and multi-regional energy strategies and plans and the system covers all or individual energy sectors, including heat, electricity and transport (A. Gupta et al, 2013). Moreover, OSeMOSYS is taken as a deterministic linear optimization model which minimizes the total discounted costs.

The system model is generally driven by exogenously defined demands for energy services that can be extracted from local, national, regional, and global plans, strategies and policies (Welsch et al, 2012). These can be met through a range of technologies which draw on a set of resources, defined by their potentials and costs (A. Gupta et al, 2013). On top of this, policy scenarios may impose certain technical constraints, economic realities or environmental targets (M. Welsch et al, 2012). Like in most long-term optimization models, OSeMOSYS in its standard configuration that assumes perfect foresight and perfect competition on energy markets (A. Gupta et al, 2013).

OSeMOSYS is basically characterized by a wide and flexible technology definition. A technology comprises any fuel use and conversion, from resource extraction and processing to generation, transmission and distribution, and appliances (M. Howells et al, 2011). It could therefore refer to, for example, an oil refinery, a hydropower plant or a heating system. A technology can be defined to consume and produce any combination of fuels. Each technology is characterized by numerous economic, technical and environmental parameters, for example, investment and operating costs, efficiencies, availabilities, and emission profiles (M. Welsch et al, 2012).

B) **Model Management Infrastructure Interface, MoManI,** is a browser-based open source interface for energy systems modeling (A. Gupta et al, 2013). As far as it is able to help energy planners to construct models, manipulate data and modify, add or delete equations, operate OSeMOSYS, design and analyze scenarios and helps to visualize results, this study had employed as a tool for the modeling process (M. Howells et al, 2011).

C) **Open Source Spatial Electrification Tool, OnSSET,** is an optimization energy modelling tool that estimates the most cost-efficient electrification option. Unlike other energy modelling tools, OnSSET considers geographical data related to energy, such as population density, the consumer's distance to the grid and road networks, and night-time light. The results can thereby show where the grid should be extended and where it's better to have mini-grid (i.e. a local grid detached from the national on) or stand-alone systems. With input data regarding costs for grid extensions and different technologies it quantifies the needed investments for increasing electrification in the given area. The off-grid renewable solutions include solar photovoltaic, wind turbines as well as mini and small hydropower plants. The electrification rate in the base year assumes no off-grid solutions (Mentis et al., 2016). The modelled period in OnSSET stretches from 2015-2030, but the results are only shown for the end year, 2030.

Chapter Three: Materials and Methods

In order to address the key research objectives initially stated, this study has gone through with both qualitative and quantitative methods. The qualitative method is employed to assess the situation of the energy sector and the quantitative method is used to develop the model the energy system of the country. The methods used to gather data and information include interviews and discussions with concerned bodies that are responsible for managing the energy sector and institutions, review of secondary but key and reliable documents from different sources, and analysis of cases that are directly related with the energy sector of the country and application of a software for modeling the management system of the sector.

3.1. Research Design

As research design is a systematic plan which can be used to study a scientific problem, this study was designed in accordance with the objectives set initially. As it was indicated in section 1.3 of this study, the broad objective of this study is to assess and model the nationwide management system of the energy sector. As a result, this study is designed in terms of the research's strategy, type, main focus, environment under which the research is conducted, and methods or instruments used for data collection and analysis.

3.2. Data Collection and Treatment

To address the key research questions and based on the logical approaches of data collection in a scientific research, this study has employed a combination of both primary and secondary data sources. Primary data were collected through unstructured interviews, discussions with officials and experts of different institutions and physical observations. In doing so, an unstructured interviews were made with different officials and experts of different institutions responsible for the energy sector, and extensive consultation and discussions had being held with the concerned bodies of the same organizations i.e., experts and management staffs that are directly and indirectly responsible for the energy sector. These institutions are Ministry of Water, Irrigation and Electric (MoWIE), Ministry of Mining, Natural gas and Petroleum (MoMNP), Ethiopian Electric Power (EEP),Ethiopian Electric Utility (EEU), Ethiopian Energy Authority (EEA), Ministry of Finance and Economic Cooperation (MoFEC), the FDRE Plan Commission, and Ministry of Agriculture and Natural Resource (MoANR).

Whereas, secondary data and information were obtained from the different organizations responsible for the energy sector; reports from various studies, including those obtained from different websites, project documents, and other relevant sources.

3.3. Sampling techniques

The data necessary for this study were collected through interviews, observations, discussions and review of secondary data. While undertaking the interviews, the sampling technique used to select the interviewees was non probability which was made based on the responsibility, professional experience and accountability of each expert and official for the sector. The same logic as selecting the interviewees was applied in fixing the number of officials and experts in different sectors. Moreover, the discussion section was made with the senior experts and officials of energy study and development follow up directorate of MoWIE as the department is basically responsible for undertaking and following up energy related studies and development. Based on this 7 people from MoWIE, 2 from MoMNP, 5 from EEA, 5 from EEP, 3 from EEU and 2 from MoFEC were interviewed. The type of interviewed held was un-structured in which the interviewees were allowed to forward their real attitudes they thought right without any limitation.

3.4. Data analysis

After the data were collected, they were analyzed and treated in accordance with the objectives of the study. In doing so, both qualitative and quantitative data analysis approaches were employed to conceptualize theoretical relationship of the variables. Co-relational data analysis approach had also been used to justify the strength of the logical relationship among the variables in line with the research questions.

3.5. Modeling tools, methods and process

As an engineering study, the energy sector management system models planned to be developed could describe the types of technologies employed, use disaggregated data for exploration, identify efficient technologies, reflect technical potential and assess costs of technological options. Due to the above facts together with the target of the study to focus on system cost optimization, the type of model considered to be developed is bottom-up modeling using a software application called Open Source Energy Modeling System (OSeMOSYS). The modeling tool is described briefly as follows.

a) Open Source Energy Modeling System tool, OSeMOSYS

Naturally an Open Source Energy Modeling System tool, OSeMOSYS, is a system for long run integrated assessment and energy planning. It is designed as a tool to inform the development of local, national and multi-regional energy strategies and plans. It does cover all or individual energy sectors, including heat, electricity and transport. It is considered as a deterministic optimization model that could seriously minimize the total discounted costs of supply of energy. The model is driven by exogenously defined demands for energy services which can be met through a range of technologies which draw on a set of resources, defined by their potentials and costs. Given the chosen constraints (natural, technical and/or political), OSeMOSYS could find out the most cost-efficient energy mix to meet the growing demand. OSeMOSYS uses a linear programming method to optimize the system. In order to run the OSeMOSYS code, different interfaces can be used, in the case of this study, a software called MoManI is used.

b) Model Management Infrastructure interface, MoManI

Model Management Infrastructure Interface, MoManI, is a browser-based open source interface for energy systems modeling. As far as it is able to help energy planners to construct models, manipulate data and modify, add or delete equations, operate OSeMOSYS, design and analyze scenarios and helps to visualize results, this study had employed as a tool for the modeling process.

The modeling process was initially set-up in the following way.

The total energy demand was divided into three different sectors; I, U and R. I represent the initial demand in the year where the modeling process bases. In this case the study considered the demand that is already established. U and R represent the accessibility of electricity in the modeled years by their areas; U covered the urban areas while R considered the rural areas.

c) Open Source Energy Modeling System-Open Source Spatial Electrification Toolkit (OSeMOSYS-OnSSET) integration

To facilitate the use of OSeMOSYS and open for detail discussion an integration of OSeMOSYS with OnSSET is considered in this research. In doing so, a harmonization of data which includes an addition of mini grid and stand-alone technologies in OSeMOSYS for example was initially performed. This helps both models consider the same technologies data. In addition to the harmonization of data of the demand is also needed to be adjusted accordingly. Subsequently, an estimation of the Grid Cost with primary results from OSeMOSYS is performed. The Grid Cost is then used as an input in OnSSET. The output from OnSSET is, on the other hand, information regarding the off-grid technology split and is used as an input in OSeMOSYS. Iterations are performed until no significant changes are observed.

d) The Electricity Model Base for Africa, TEMBA

With data from the World Bank the electricity supply in each African country is modeled and connected to each other by trade links in a model called TEMBA. It is built in OSeMOSYS to facilitate national energy planning and is the world's first model of African electricity supply (Taliotis et al., 2016). The development was sponsored by the World Bank and SIDA, and is constantly under modification (KTH-DESA). The business as usual (BAU) scenario created in this study is based on data from TEMBA.

The TEMBA data assumes that the electrification rate will be 100 % by 2030 and that each household corresponds to 5 people. The energy intensity for both rural and urban population in Ethiopia is set to be 696 kWh/household in 2030 (KTH-DESA).

3.6. Scenario construction procedures

In developing the models for managing the energy sector, the scenarios were built through three steps;

Step 1: identifying important key variables from the policy, strategy and planning view point of the nation.

To have and develop an integrated energy management system for the country including policy, strategies, energy demand and supply, and protecting the environment, the following key questions should properly be answered.

a) What options, in terms of energy resources, would be available for Ethiopia to meet its long term electrical energy requirements?

b) How can the diversity of the electric energy mix be improved and clean technology utilization be increased?

c) What options would be appropriate to reduce energy import dependency?

d) How could advanced technologies affect the development of country's energy system?

e) What options would be useful to reduce the negative impacts of energy activities on the environment?

f) How would these options affect the country's economy?

Step 2: Scenario Construction

In this step alternative scenarios are constructed by critically and logically identifying a consistent and coherent set of assumptions as a means of constrains. Having the above concept in mind, the following assumptions are taken as major assumptions for the modeling process; Population is assumed to be increased by 1.5% during the modeling period 2010-2050 in all scenarios and the population is expected to reach 150 Million by 2050. Technologically the electricity sector relies mainly on hydropower, due to time and data constraints together with other reasons, the electricity sector which would be generated from the renewable energy sources and expected to grow and planned to become the leading source of energy in the future, the researcher has modeled only for this sector. Thus, throughout the modeling part of the thesis, when energy is mentioned no other forms of energy than electricity is taken into account. The reason for this constraint is limited time and lack of data.

Step 3: Descriptions of Scenarios under Considerations

Going through the above basic steps, the final step of the modeling process is describing the alternative energy scenarios which were provided for the modeling purpose.

Below is a brief description of the scenarios constructed for the electricity sector based on the available data, the key variables together with target parameters and the respective reasons as to why they were preferred.

a) Scenario A

This scenario is the business as usual, BAU-scenario and was created based on data from The Electricity Model Base for Africa (TEMBA). Modifications regarding the distribution and transmission parameters were made since the modeling tool, MoManI, assume that there is no distribution or transmission system prior to the base year of the modeling. As a result the model creates those parameters by itself as the production of the energy starts. This is not the actual case as there is already a quite extensive distribution and transmission established in the country. The alterations to the standard data were conducted by taking the output value for Accumulated New Capacity in 2010 (after running the model once) for both the distribution and the transmission technology, entering it as an input for the Residual Capacity for each technology and running again.

b) Scenario B

This scenario aims at improving the distribution and transmission system, which according to data and information from different sources specifically from the National Planning Commission, reveal lacking and a big contributor to the many power outages in the country. The scenario assumed and believed that those who are connected to the grid should be able to rely on the national supply and get access to electricity throughout the day with no need of using of a generator. An unswerving connection is also fundamental to different businesses including factories and industries, and attracts investors from the outside too. Investing more capital in distribution and connection is considered as one of the best ways to implement the scenario. Entering a diminishing residual capacity for the distribution and transmission systems would help to realize this scenario. A decreasing value will force the model to do investments in the current systems, which, by assumption, lead to improvements.

c) Scenario C

More or less many of the plans the government of Ethiopia, which basically is related to the development of the energy sector, is highly ambitious. The main objective to construct this scenario, therefore, was to see the result of the current plans and strategies. A residual capacity was entered for the technologies which already exist based on their capacity and the model was forced to invest in different technologies other than the existing according to the plans in GTP II and the Master Plan.

d) Scenario D

In constructing this scenario the same logic was applied as scenario C together with a greater demand than in the stated scenario i.e., scenario C. Other than the drastic increment of the demand for energy, the plan of the government to export electricity to neighboring countries for various reasons has drastically increased the demand for electricity. As far as the country is blessed with abundant sources of renewable energy, Ethiopia has a strong potential to export low carbon energy to the neighboring countries.

The government strategy to export electricity would lead to an increased economic growth which in turn could lead to improved living standards followed by an increased energy demand. The demand in this scenario is therefore based on a forecast to 2030 that was presented in the CRGE.

e) Scenario E

This scenario is constructed by considering goal 7 of the sustainable development goals. If Ethiopia shall reach the SDG 7 by 2030, it is interesting to know where the grid should be extended and where it is more cost efficient to supply people with electricity by mini grid or a stand-alone system.

In this scenario integration between OSeMOSYS and OnSSET was performed so as to obtain these results. As far as the integration was chosen to be done with a clone of scenario C since this scenario represents the national goals and a demand without big exports.

Chapter Four: Results and Discussions

This chapter of the thesis presents the results obtained regarding the situation and position of the energy sector of the country, the stand and readiness of different institutions responsible for managing the sector, the challenges and bottlenecks that restricts the development of the sector, and the perspective national as well as global prospects and opportunities for the development of sector. In doing so, primary data and information were collected through interviews, observations and thorough discussions with the respective officials and experts of different institutions responsible for planning, coordinating, directing, organizing and leading the energy sector. Added to that, secondary data and information were gathered from different literatures, articles, reports and other relevant sources were explicitly gathered and used so as to accomplish the objectives set in the thesis. The results obtained from both sources are presented and analyzed in the following way.

4.1. Results and Findings

4.1.1. Situations of the energy sector in Ethiopia

Assessing and outlining the current situation of the energy sector of the country was one of the specific objectives this study was seeking to accomplish. In doing so, primary data through interview, observation and discussion and secondary data from relevant documents was gathered. Based on that, the following parts of the study tried to brief the situation of the energy sector.

4.1.1.1. Potential and exploitation of energy resources

All of the interviewees attending the interview section of this research believed that Ethiopia undoubtedly is rich both in conventional and non-conventional energy sources.

However, extreme idea differences happen when a question is raised about the exploitation of these resources. Taking the Grand Ethiopia Renascence Dam together with other energy generation related projects and motives of the Government of Ethiopia as examples, part of the participants of the interview said that the country is seriously exploiting these resources. To the opposite of this, part of them believed that only very few amount of the resources the country possesses is being exploited. Appreciating the political commitment and motives of the government (especially regarding GERD) to make changes in the current situation of the energy sector, they all finally agreed that the exploitation of these resources is inadequate as compared with the growing demand of energy as well as the potential of the country. Added to that, they all thought that hydro power should be the major source of electrical energy of the country; as the country's number one potential is water plus the past lessons the country had taken while constructing hydro power projects and generating energy from them. This generally indicates there is a greater gap in observing the same sector differently.

However, secondary data collected from different sources indicated that the country is naturally abundant in energy sources especially the renewable; in which below 5% of all the renewable sources of energy are tapped; of which 99% is obtained from the hydro powers sources. Except showing up the gross megawatts of energy and power that could be generated from those abundant sources of energy, the data obtained from secondary sources didn't point out the specific capacity each source would generate. Moreover, there is not a clear cut feasibility study, project proposal and strategic plan as to when and how to develop each source.

Although the country is endowed with abundant renewable energy resources and has a potential to generate over 60,000megawatts (MW) of electric power from hydroelectric, wind, solar and geothermal sources, currently it only has approximately 2,300 MW of installed generation capacity. The figure shown below indicates the electric power potentials of the renewable energy sources and their respective installed capacity.

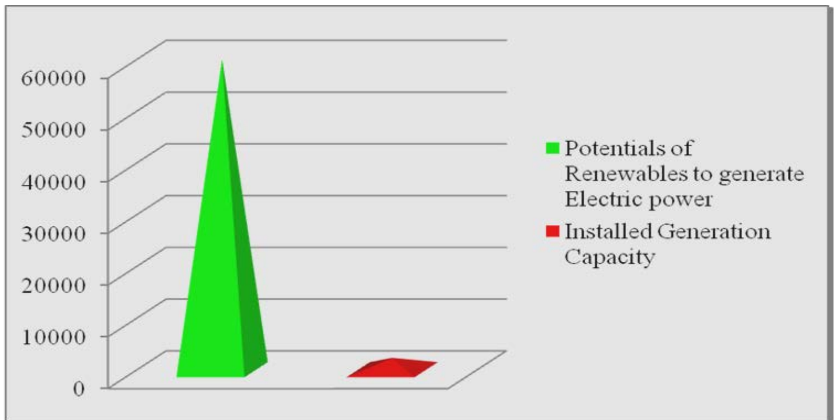

Figure 4.1: Renewable Energy Sources Potential and Exploitation

Despite the presence of a variety of energy resources, including the renewable sources, as sources of clean energy, the interviewees together with secondary data strengthen that traditional biomass fuels are major sources of energy in Ethiopia. In other way round it means that, the bulk of the national energy consumption is met from biomass energy sources (fuel wood, charcoal, wood, waste wood, crop residues and animal dung, including biogas) accounted up to 89% of total national energy consumption which has severe consequences on the environment (through environmental pollution and degradation) and the health and economy of both the nation and the people. Petroleum fuels and electricity also taken as the second sources of energy next to wooden biomass met merely about 7.6% and 1.1% of the national energy consumption respectively. Secondary data gathered reveal that Access to modern energy services is limited to the urban population which more or less ignored the 85% of population living in the Ethiopian rural.

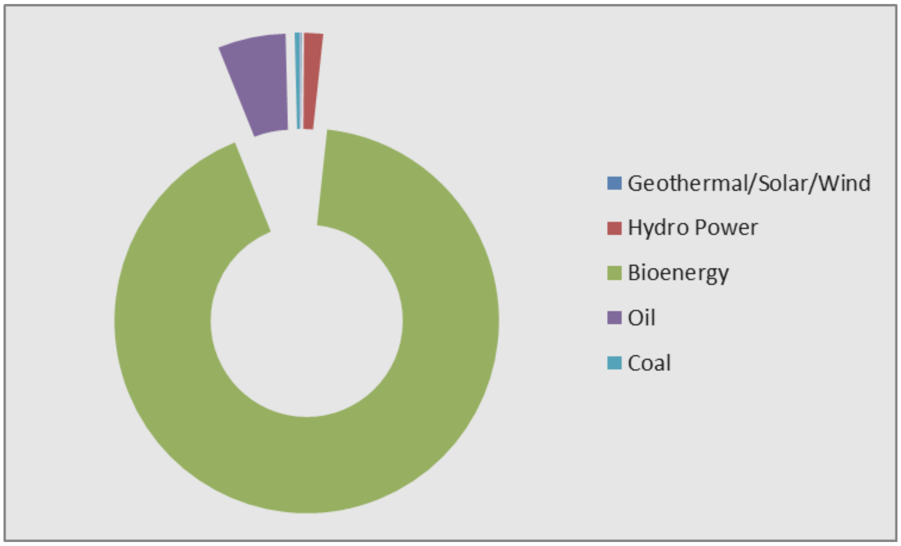

Fig. 4.2: Energy Consumption Pattern by Resource Type

While undertaking the interview part of this research work, a question was raised about which sector is dominating the energy consumption in the country; in answering this question, they have equally been divided in to three groups. Some of them believed that the household sector is the major consumer of energy; some said that the industrial sector is pre-dominating the energy consumption and the remaining agreed that the transport sector is the leading sector. However, secondary data insights that the energy sector in Ethiopia is characterized by the predominance of the household sector, accounting for 93% of the total energy consumed in Ethiopia. The main energy requirements in the residential sector are for cooking and baking with bio-energy. The residential sector also consumes 37% of the total electricity supplied in Ethiopia. The following figure indicates the energy consumption pattern of each sector.

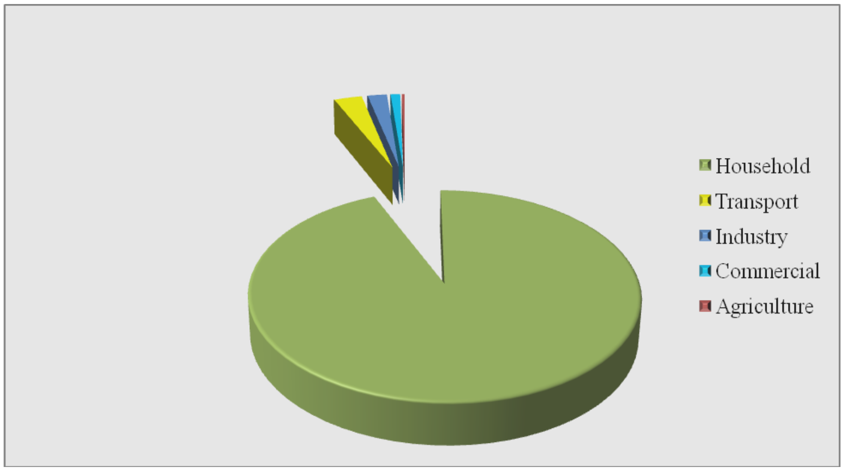

Fig. 4.3: Energy Consumption Pattern by Sector

4.1.1.2. Demand and supply of Energy

Almost all of the interviewees of this research whispered that the demand for energy in Ethiopia is highly increasing from time to time; the growth of population, the double digit economic growth of the nation for the last consecutive years, the high raising buildings being under construction in big cities of the country, the country's development policies, plans, and strategies (like Housing Development Programs, Industrial Parking Development plans, etc.), are listed by the interviewees as the main causes for the growing of the nation's demand for energy. To meet this demand, the interviewees also believed that, the government has taken several measures; including launching of mega energy generating projects like GERD, working with foreign private companies to develop the untapped energy sources like the geothermal projects, and devising and implementing energy efficiency and auditing strategies in energy consuming industries etc. However, they all believed that, there is still a shocking imbalance between the demand and supply of energy which would either take long period of time to match them or need urgent, strategic and wise decisions so as to narrow the visible imbalance.

Secondary data obtained from EEP indicates that the demand for electricity is forecasted to be grown with an average annual compound growth rate of 13.5% in the coming 10years. The following graph shows the trend of the growing demand of energy of the country for the following ten years. The red line in the following figure indicates the geometrically increased demand for energy and the blue one indicates the sluggish supply.

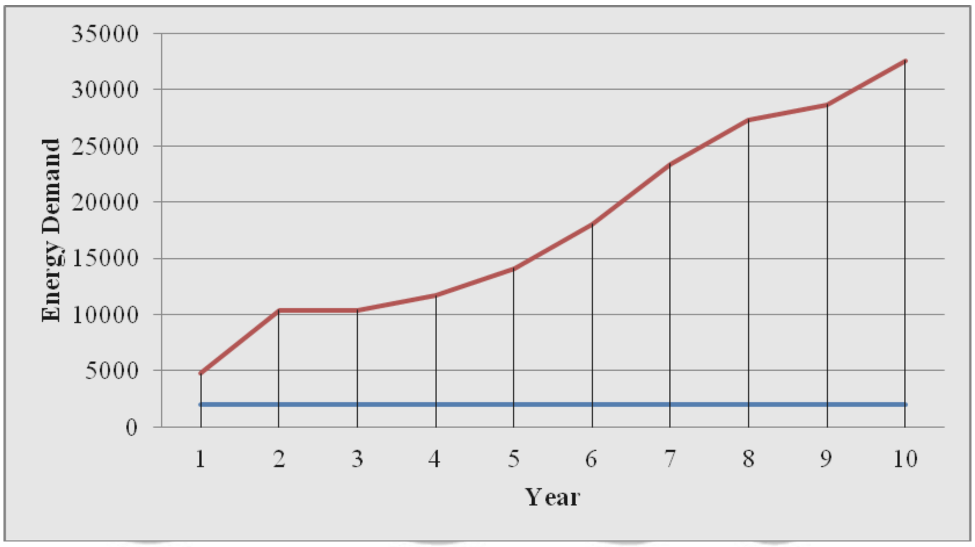

Figure 4.4: Forecasted Energy Demand of the Country

The figure above has shown us that the demand for energy in the coming ten years as usual would increase dynamically from 4290 in the base year to 33,000 at the end. The government has to seriously given sufficient attention to match the expected gap that would happen between the demand and supply.

Planning to meet such a growing demand, the government of Ethiopia has developed and devised energy generating projects to generate above 14,000 MW of Energy from mixes of renewable energy sources until 2025 as shown and summarized in table 4.1.

Table 4.1: Energy Generation Plan until 2025 (Energy Supply)

S.No	Type of Resource	Energy planned to be generated		Indicative Cost in Millions of USD
		Installed Capacity (in MW)	Energy (GWH)	
1	Hydropower	11,105	50,308	20,123
2	Solar	300	525	540
3	Wind	1,520	4,955	3,140
4	Geothermal	1,270	9,224	5,008
5	Bio-energy	420	2940	525
Total		14,615	67,952	29,336

When we see the cost of generation per MW and GWH of energy from the data in the above table, producing energy from bio-energy sources is relatively less costly than others. As long as, the consumption of energy in the Ethiopian sector is dominated by the residential sector at the same time the energy consumption pattern for this sector is dominated by bio-energy sources, it would give the country greater opportunity to reconcile such important attachments. Since the second less costly source of energy to generate is hydropower, which is more abundant source than others, the decision to obtain about 75% of the energy from hydro power is a wise decision. More importantly, the mixes of renewable energy sources in which the government has planned to develop in the coming 10 years seems essential in removing uncertainties for being dependent on one resource. However, the plan still would not solve the shocking imbalance between demand and supply of energy.

4.1.2. The Significance of Energy in the Socio-Economic Development of Ethiopia

As most of the interviewees of this research were from those institutions responsible for managing, directing, controlling and leading the energy sector, they all-in one voice witnessed that the development of the sector is the most significant as compared with other sectors. Except few (3 in number), most of them agreed that, the sector could be categorized among the factors of production (it is impossible to continue the production process, if there is not energy). Moreover, the price of energy is a major determinant of variable costs in production. They believed that the development of the energy sector adds value for the betterment of the growth and development of the other sectors; most importantly for the agricultural transformation, transportation system, urban development and industrial revolution of the country.

Trying to explaining the strong connection between the energy sector and a national economy, one of the interviewees in which others have been agreed on stated that; on one hand, energy demand, supply and pricing have significant impact on socio-economic development and the overall quality of life of the population. On the other hand, the nature of economic structure and the changes in that structure, the prevailing macro-economic conditions are key factors of energy demand and supply. Documents taken as sources of this research divulged that the pace of economic growth is greatly linked to the rate of energy consumption; as shown in the bar graph below to achieve an annual economic growth rate of more than 10% that the government aspires to, it is necessary to expand electric power supply at a rate of more than 14%, which is taken as the right idea accepted by those experts and officials involved in the interview and discussions. In addition, energy considerably affects environmental quality through deforestation associated with unsustainable exploitation of resources.

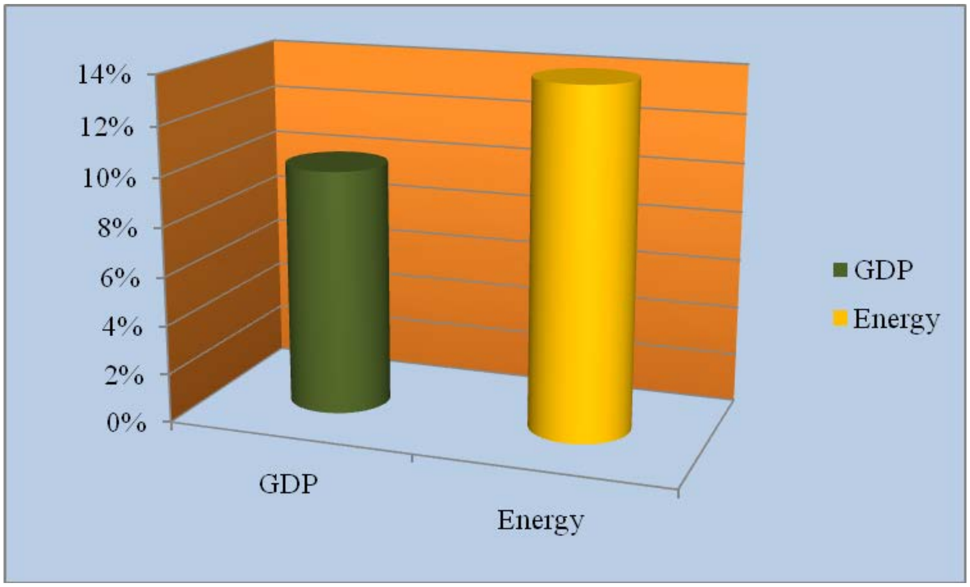

Figure 4.5: Significance of Energy

4.1.3. Problems, challenges and prospects of the energy sector

While undertaking this study, the researcher had given the interviewees and participants of the discussions of the research to identify the major challenges for the least development of adequate, clean, affordable, reliable, safe and environmentally-friendly energy as well as the respective local and global prospects that would contribute to make visible changes for the growth and development of the energy sector. Therefore, the following parts of the research outlined the challenges as well as the prospects of the energy sector.

4.1.4. Challenges and constraints of the development of the energy sector of Ethiopia

This part of the study tries to outline the major challenges that hinder the development of the energy sector of Ethiopia.

4.1.4.1. Planning, Financial and investment constraints

As it has been discussed in the earlier parts of the study, both the interviewees as well as secondary documents used in this research revealed that Ethiopia is a nation blessed with renewable sources of energy. However, together with other problems lack of a comprehensive development program for the sector is the most critical challenge that should be focused on. Due to this the bulk of the national energy consumption is met from biomass energy sources which have greater impact in polluting and degrading the environment and only very less amount of those resources are exploited and used. The question that comes in everyone's mind here is that instead of exploiting, developing and using the renewable sources as major sources of energy which are environmentally friendly, how and why the wooden biomass has become the dominant sources of energy? The answer that was given by the interviewees for this question was that lack of capital investment due the huge amount of financial resources required for energy generating projects. While explaining their answer they stated that it is enough to take the ongoing as well as the previous hydropower projects like the GERD how energy generation and transmission is capital intensive (billions of dollars is required for a single energy generating project). Even though there is an encouraging improvement of taking the energy sector as one of the key for growth and development from time to time, the attention given by the government for the sector in financing and developing the abundant sources of energy was somehow not sufficient. However, they seriously assumed that the government should still have a lot of assignments to be worked out so as to bring visible changes in the sector. Few of them also believed that except identifying and recognizing the potential that could be generated from the renewable resources in different parts of this research work, there is not a clear cut feasibility study, project proposal and strategic plan as to when and how to develop each source i.e., planning constraints. Added to that, they also strongly believed that no energy generating project has been completed with the initial budget and defined period as per the contractual agreement. This basically is due to limited capacity both in financing and planning of Energy generating projects.

Taking the above points as the basic challenges, secondary data also state that as far as the most immediate priority of the energy sector of the country is expanding access to safe, clean, reliable and affordable energy is widely viewed as critical for advancing other development objectives. As far as access is the priority, the immediate constraint for the government of Ethiopia is lack of financial resources. Moreover, the documents further explain that where access to energy is lacking, other urgent human and societal needs are often unmet too i.e., energy needs must compete with other priorities as it is taken as the driving force for the development of other sectors. Added to that, the documents indicated that the steps taken by the Ethiopian government in the past few years through the current development programs that give higher attention to the energy sector is encouraging. The current development is appreciated not only for expanded and big investment commitments for energy development, but also for envisaged energy access to the rural villages. However, more is left to go through.

4.1.4.2. Institutional limitations

The secondary data as well as the interviews held while undertaking this research work shown that the organizational setup of different institutes which are responsible for managing and owing the energy sector is not sufficient and compatible with sustainable energy management principles. The power and authority to lead, direct, control and manage the energy sector is divided and given for more than one institute. The organizational structure shown below followed by a brief explanation illustrates the current institutional setup of the energy sector in Ethiopia Ministries and main agencies and departments that deal with energy issues.

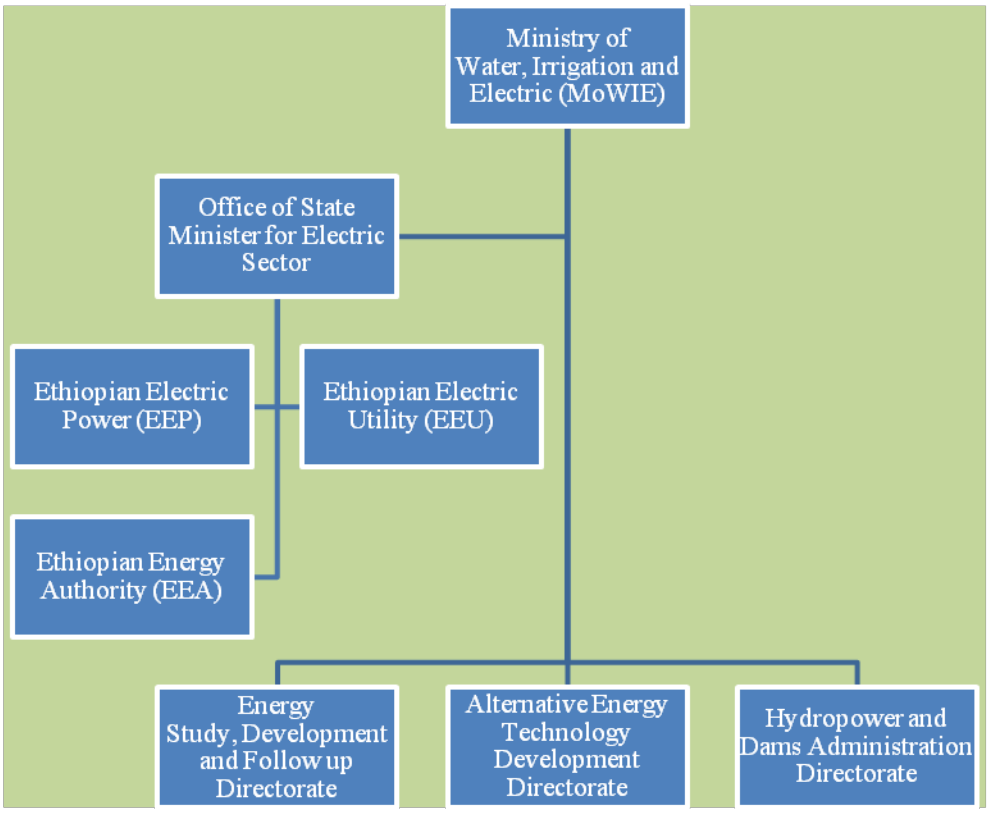

Figure 4.6: Existing Institutional Setup for Managing the Energy Sector

The Ministry of Water, Irrigation and Electricity (MoWIE) is the overall overseer of the power sector including policies, strategies and plans for the power sector. The ministry is responsible to oversee and supervise four electricity sector quasi-agencies:

a) The Ethiopian Electric Power (EEP) is responsible and accountable for the construction and operations of the generating plants supplying the national interconnected system, of the transmission network, including the exports to neighboring countries, and for overall planning and system management.

b) The Ethiopian Electric Utility (EEU) which is mandated for the construction and management of the distribution system and commercial management of electricity. The above two companies were previously forming the Ethiopian Electric Power Corporation (EEPCO) which are divided in to two in December 2013.

c) The Ethiopian Energy Authority (EEA) which previously was known as Ethiopian Electric Agency and re-organized with new powers and duties announced in December 2013 which is responsible and accountable to serve as the power sector regulator with functions including licensing, permitting, Power Purchase Agreements and tariffs. The Authority is also responsible for energy efficiency and energy conservation in particular to set-up standards, carry-out testing and labeling of appliances, industrial and commercial audits.

At a regional level, energy activities are mainly supported by regional energy bureaus, which are part of regional states, and by regional energy institutions, such as the Amhara National Regional State Water and Energy Bureau. However, the involvement of the private firms in the energy sector is negligible.

Even though, the Ministry of Water, Irrigation and Electricity (MoWIE) is the main institutional setup established for developing, steering and managing the overall activities of the energy sector, parts of its duties especially management of conventional sources of energy like petroleum and natural gas and Bio-fuel is given for Ministry of Mining, Natural gas and Petroleum (MoMNP). Starting from the name given for MoWIE (Ministry of Water, Irrigation and Electricity), the institutional set up for managing and developing the energy sector is taken by the interviewees of the study as insufficient and partial which could be taken as one of the challenges for the less development of the sector. When we see the professional mix of the employees of both the ministry as well as the quasi institutes, secondary data indicate that most of the employees in MoWIE are graduates of natural and social sciences and engineers and technologists working in the ministry are very few. Due to this, the gross technical skills to manage and develop the energy sector are not compatible with the principles of sustainable energy management. However, the technical skills of the quasi institutes could be taken better, since there are enough engineers and technologists found in the sector.

4.1.4.3. Challenges related to technology and efficiency

The limitations to identify and implement advanced energy technology and the inefficiency appeared during transmission together with the very less efficiency that is discovered in home appliances are among the respective challenges that are being identified both by the interviewees and secondary data during the research process. The secondary data also indicated that the electricity loss in Ethiopia is about 20%, which is much higher than the international average, 12-13% as shown in the figure below, that have been brought from lack of effective Energy Management which would help in resolving energy efficiency related problems.

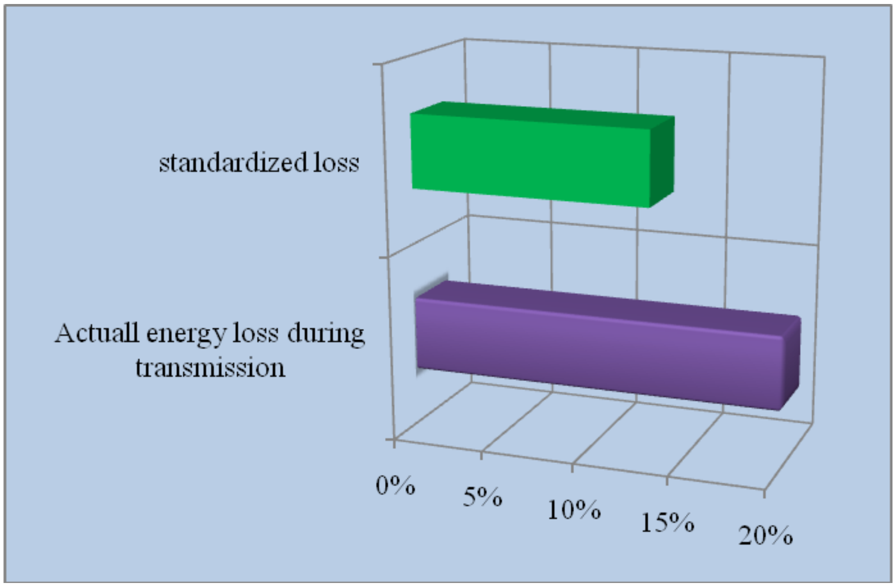

Figure 4.7: Actual Energy Loss during Electric Transmission

Even though there are some efforts applied by very few private firms, secondary data together with other studies revealed that the development of solar and wind energy resources is not encouraging. Many of the products of those new technologies on the market are unaffordable to the majority of society and are not properly promoted to attract the customers even for those who could afford to buy them. Lack of information on potential demand centers is also one of the major constraints to the development of these resources and technologies. Researches undertaken to improve the efficiency of the most common home appliance (mitad) that is used in most Ethiopian together with the project that is underway to generate energy from waste (Reppi Waste to Energy Generating Project) could be taken as good start for the country. However, the country seriously lacked developing and advancing solar, wind, bio energy, geothermal and mini and micro hydro power sources and technologies.

4.1.4.4. Environmental Constraints and risks

As it has been said in the previous parts of this research work Ethiopia generally lacks access to adequate, affordable, reliable, safe and environmentally-friendly energy as traditional biomass fuels are major sources of energy which is a severe constraint on development. The interviewee together with the secondary data revealed that energy related emissions from power plants, automobiles, heavy equipment and industrial facilities are largely responsible for air pollution especially. And in urban and rural areas alike, indoor air pollution attributable to the use of traditional fuels for cooking and space heating exposes millions of people, especially women and children, to significant cardiovascular and respiratory health risks. In many cases, adverse environmental impacts begin well upstream of the point of energy end-use: the extraction of commercial fuels like coal and oil is often highly damaging to local ecosystems and an immediate cause of land and water pollution. Meanwhile, reliance on traditional fuels such as wood can produce its own adverse impacts. The forest cover, due the reliance of traditional fuels from wooden biomass sources, has dwindled to about 3% which has plummeted from a mere 40% at the turn of the last century. This in turn has become the reason for the migration of wild lives living in the forest areas which considerably resulted in a decrease in the revenue of the country that the tourism sector has to generate. Longer-term, climate change caused by energy-related emissions of greenhouse gases can be expected to pose many risks. Due to this one of the constraints of the energy sector the country is environmental challenges through environmental degradation and pollution.

Except the environmental problems rose from biomass fuels and the transport sector, the government of Ethiopia is striving in devising carbon free (zero carbon emission) development endeavors like the Addis Ababa Light Railway Transport (AALRT) which uses electricity as fuel.

In short, as they have been identified and stated in the previous parts of this study, the main bottlenecks the Ethiopia Energy Sector is facing can briefly stated as follows:

1. The huge investment finance required for energy generation and transmission projects/programs and heavy foreign currency burden resulting from import of petroleum fuels
2. Lack of a comprehensive and integrated long-range energy development programs, plans and strategies that could answer as to when and how to develop the rich abundant sources of energy to match the dramatic imbalance of the supply and demand of energy
3. Poor institutional set up to manage the development of the sector in integrated manner and in line with the principles of sustainable energy management
4. Low level of renewable energy development outside large scale hydropower development
5. Lack of substitutes / supplements for biomass fuels used in households, in the face of decreasing availability of fuel wood
6. Low level of efficiency of use of energy in all sectors

4.1.5. Prospects and opportunities of the energy sector of Ethiopia

In order to outline the respective prospects and opportunities, the researcher has seriously discussed with the interviewees as well as exploits secondary data as much as possible. The following parts of the thesis briefly explained the global as well as national opportunities and prospects for the development of the energy sector of the country.

4.1.5.1. Global prospects and opportunities of the energy sector

The interviewees together with secondary data used for the purpose of this research revealed that most of developed and developing countries have reached to consensus to focus on developing and using clean, reliable and renewable energy sources, decrease release of greenhouse gases which are generated from utilization of nonconventional sources of energy that causes global warming, allocate trillions of dollars for developing nations to build green economy and so on. The government of Ethiopia through its leaders seriously played its part while those agreements were made. Both the interviewees and the statements in the secondary data agreed that this would bring greater opportunity for the country to meet the national development plans of the energy sector. As we have stated in the previous parts of this research the major constraint that hinders the development of this sector is the huge investment requirements while planning to develop the renewable energy sources. As far as the stated agreements indicated that trillions of dollars would be allocated for developing renewable energy sources, this would give the country greater opportunity for the better exploitation of the renewable energy sources and would help to improve its prospects of the situation of the sector. As long as the country's development plan is seeking to build green economy, those opportunities would enhance the growth and development of the country.

The other opportunity that is identified is the opportunity that development of renewable energy would bring. Together with other parameters and variables (like political requirements), development of renewable energy sources is in line with the strategies, programs and development endeavors of global and bilateral financing institutions like World Bank (WB), International Monetary Fund (IMF), United Nations (UN), etc. as a result this the interviewees believed that it would give the country the opportunity to improve the future prospects and make visible changes by developing Renewable Energy Sources.

The other global opportunity that most of the interviewees agreed on is transfer of technology, skills and knowledge. As discussed in the earlier parts of this research, the technical capacity to develop and manage the renewable sources of energy is very limited. The opportunities stated above would help the country to develop the untapped sources of renewable energy through multi-billion energy generating and transmission projects. This would help the local professionals to take important lessons on planning, managing and developing renewable energy sources. Most importantly, advanced knowledge owned by those companies which would be here to execute the projects would be obtained by the local professional and utilization of advanced energy technology would be transferred.

4.1.5.2. National prospects and opportunities of the energy sector

The other parts of the prospects and opportunities of the energy sector identified both in the secondary documents and by the interviewees were the national opportunities and prospects of the country. As they said the first national opportunity the country owned is being rich of energy sources especially renewable sources. Explaining their reason why they took this as an opportunity, renewable sources offer multiple benefits and opportunities in the Ethiopian context. Firstly, they are domestically available. Through deployment of renewable sources net importing bills can be reduced and revenue can be increased by exporting energy for neighboring countries, as a result, this would improve current account balances. Secondly, renewable sources are cost-competitive. Added to that, renewable can be deployed much faster than fossil-fuel based power plants and would help to trigger additional economic benefits, such as job creation and socioeconomic development, in particular in rural areas. Most importantly, renewable sources are core components for any low carbon strategy and offer important environmental co-benefits, such as improved local air quality and water security. Regarding the supply of energy to meet its growing demand as stated in the development endeavors of the country much is expected more from renewable energy sources, such as wind, solar, geothermal, biomass (municipal landfills, organic waste) as well as hydropower, are highly desired in Ethiopia.

Energy development basically renewable energy had become a cross cutting issue by the government of Ethiopia. Both in the GTP 1 and GTP 2, the government is showing its commitments in different ways. IGTP 1 the government had gone through to execute the construction of GERD to generate 6000 MW without compromising with any external force and has currently completed 60% which would be ready to generate some megawatts of electricity soon. In GTP 2 the government of Ethiopia has shown its commitment by allocating 20 billions of dollars for the energy sector. In addition to that, the government is exporting 160 MW of electricity for its two neighbor countries (100 MW for Sudan and 60 MW for Djibouti) and has concluded to export some more megawatts of electricity to Kenya, South Sudan, and Tanzania. This demand in the export market, that would give a sense as it becomes part of the source of the foreign currency, would give the country the opportunity to develop its renewable energy sources.

As it has been observed and recognized by the government of Ethiopia, it impossible to develop all the sources of energy with a single entity to meet the growing demand of energy and power. Due to this, the state has opened the energy sector for private firms (Which is known as Independent Power Producers (IPP) for power generation) to involve in the generation and provision of energy at their own investment and finally selling the generated energy to EEU with credit payments. Explaining with the aid of example, the new energy law enacted recently allows private developers to generate and sell power to the EEU. So far, Reykjavic Geothermal, the Icelandic company, signed a memorandum of understanding with the Ethiopian Government to generate 1000 MW from geothermal reserve. Reykjavik which plans to invest USD 4 billion on the geothermal project has negotiated to sign the first power purchasing agreement in the history of the country. The state has opened its door to follow suite to change the energy picture of the nation once and for all. This competitive environment is taken as an opportunity as it will create many more advantages to the nation's energy industry. Moreover, it would also give the country the opportunity to relief from the financial burden which limits the government for thorough development of renewable sources and would help to make visible changes in the future prospects and situations of the sector.

4.1.6. Outputs of the modeling process

With the aid the software used for the modeling process (OSeMOSYS and OnSSET), the results obtained are presented as follows. Significantly, the most important changes are presented in figures which can be understood easily and a discussion is followed in the next section.

a) Outputs related with annual emissions

Having the scenarios under considerations, this part of the thesis presents how the results regarding the annual emissions for each case look like.

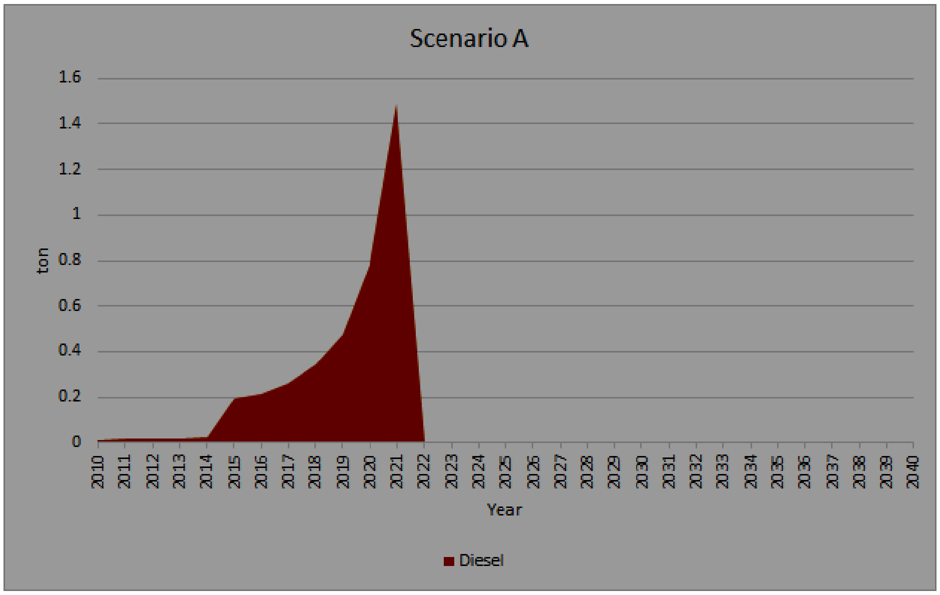

Figure 4.8: Annual emissions, scenario A

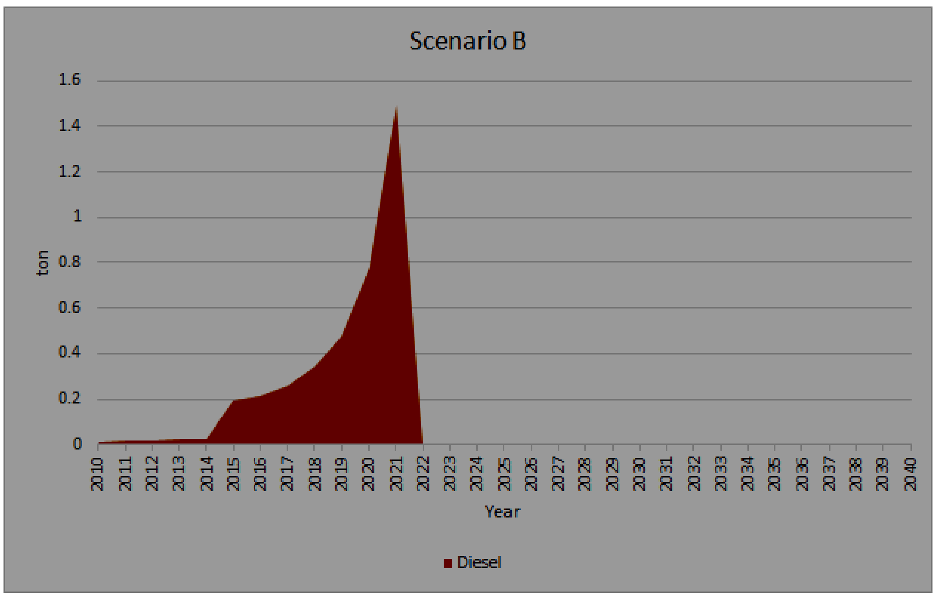

Figure 4.9: Annual emissions, scenario B

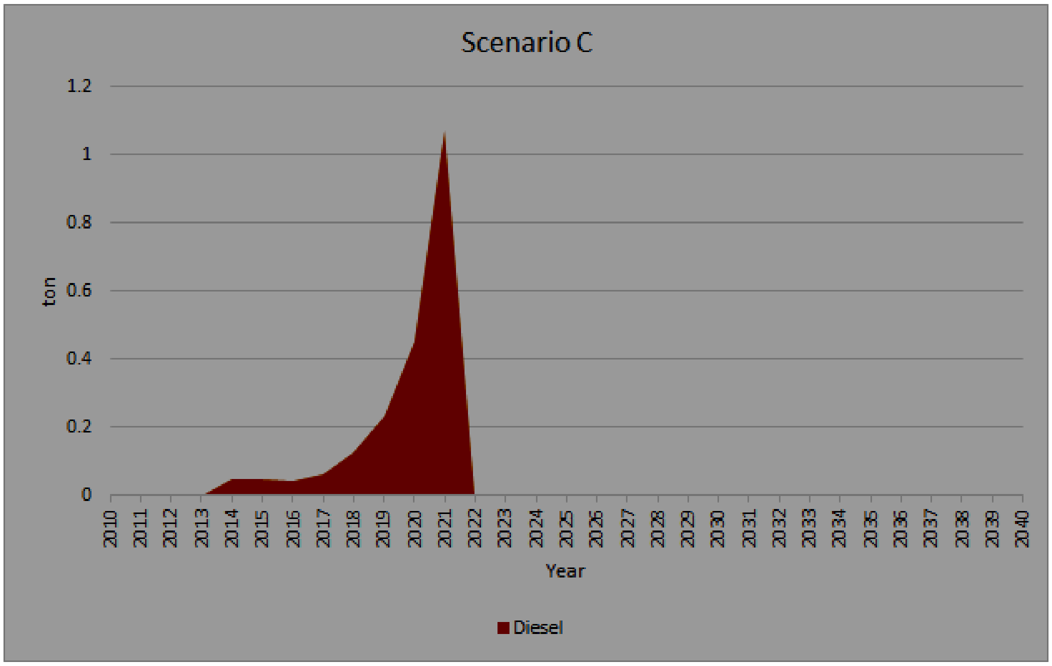

Figure 4.10: Annual emissions, scenario C

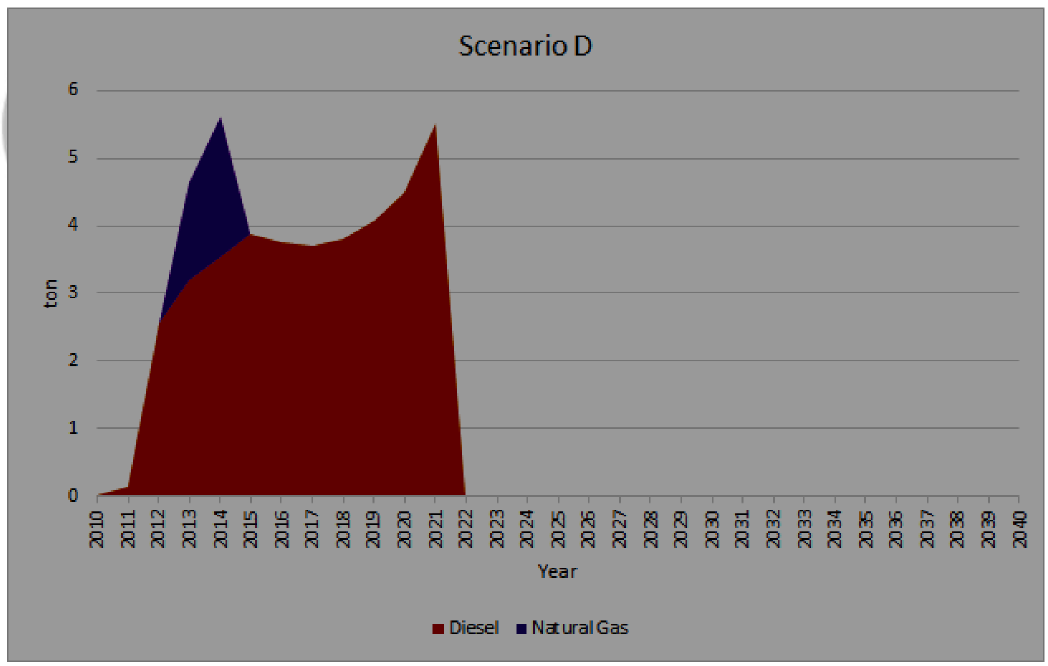

Figure 4.11: Annual emissions, scenario D

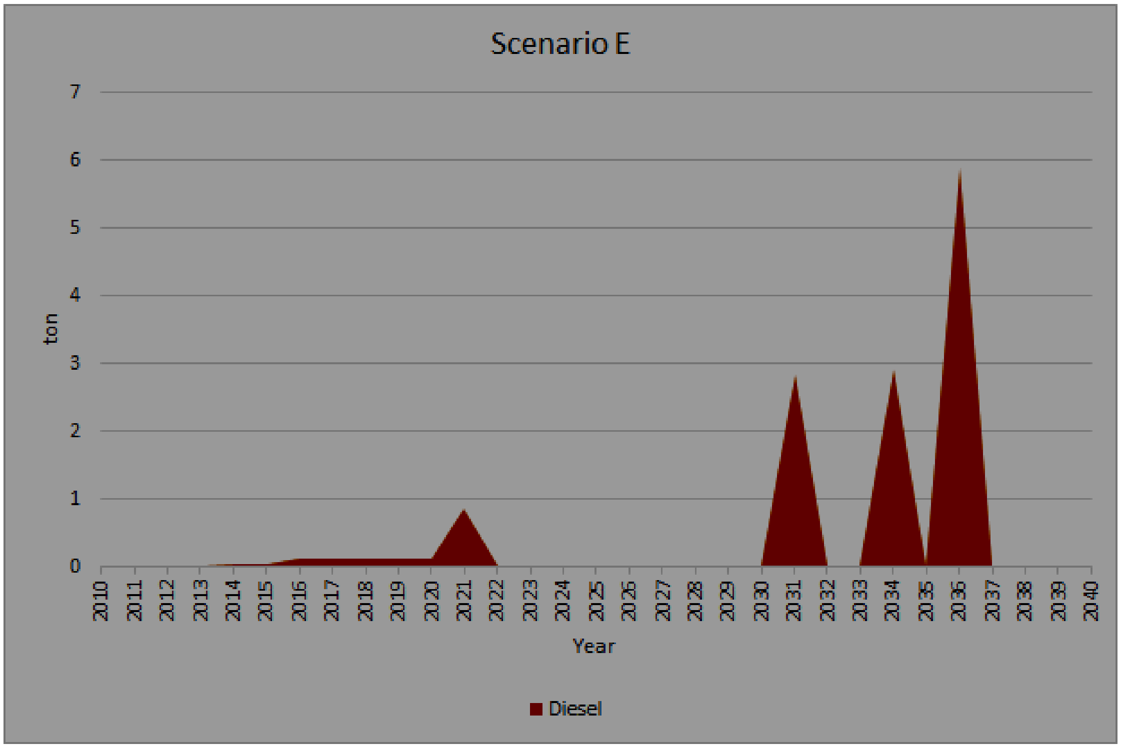

Figure 4.12: Annual emissions, scenario E

b) Outputs regarding capital investments

This part presents the total capital investments required in each modeled.

Table 4.2: Capital Investment, 2010-2040

Scenario	A	B	C	D	E
Capital investment in distribution and transmission (Millions of Dollars)	27 141,41	27 712,03	27 141,41	34 113,63	18 181,26
Total capital investment (Millions of Dollars)	147 438,1	141 534	173 839,52	230 423,10	243 825,78

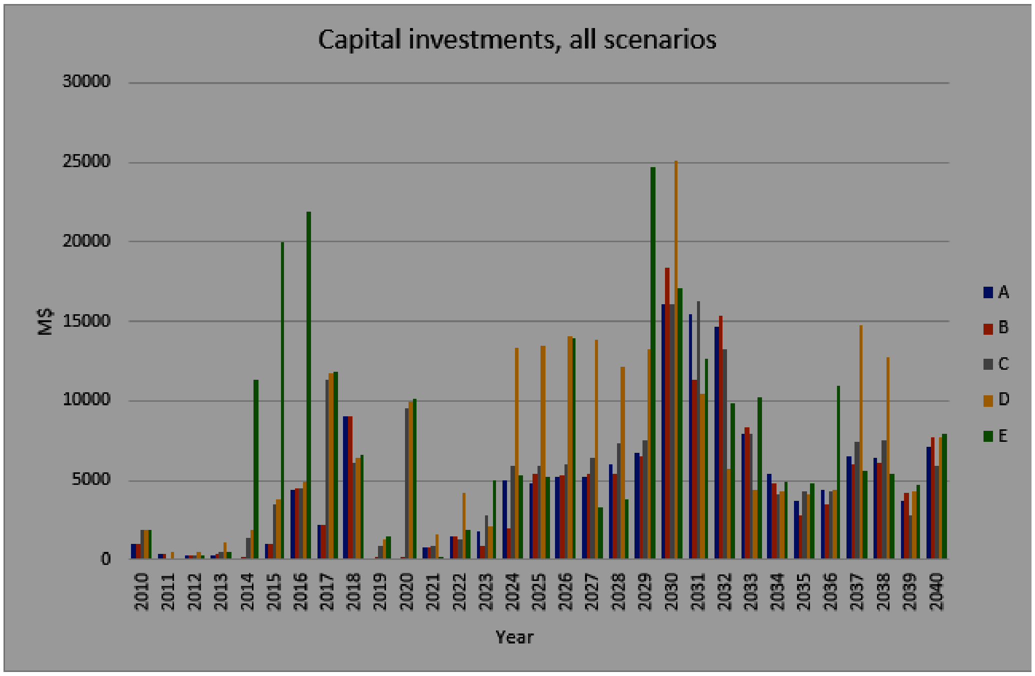

Figure 4.13: Capital Investment by year for each scenario

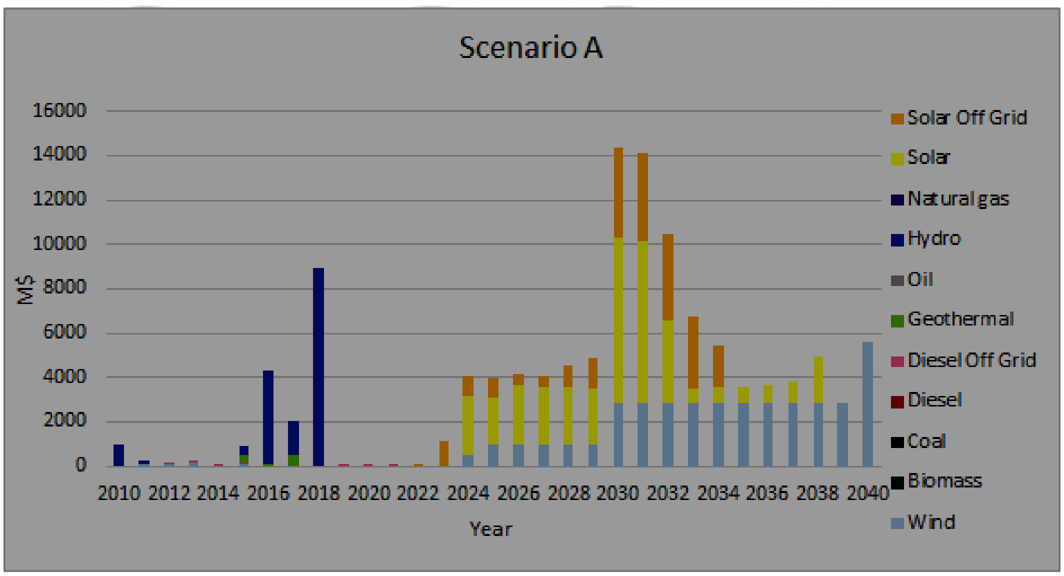

Figure 4.14: Capital Investment by year for scenario A

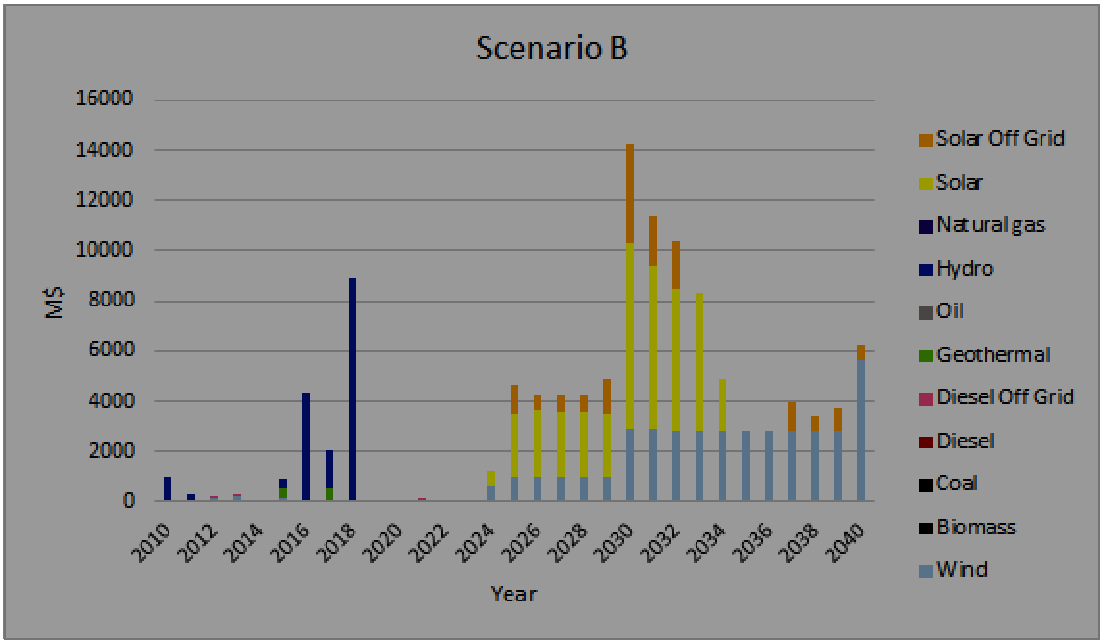

Figure 4.15: Capital Investment by year for scenario B

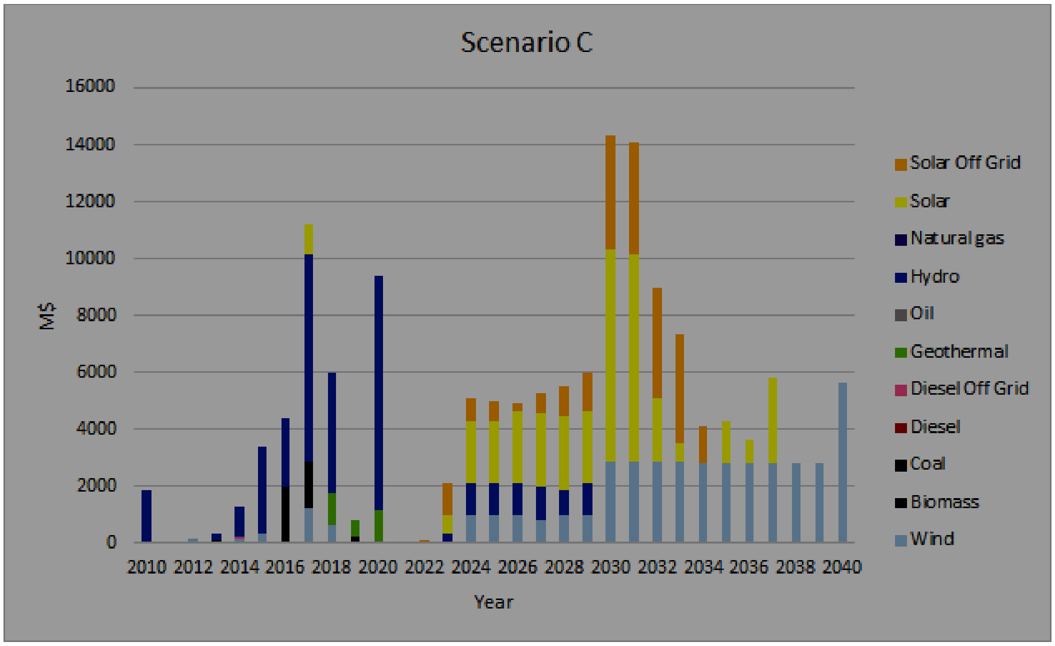

Figure 4.16: Capital Investment by year for scenario C

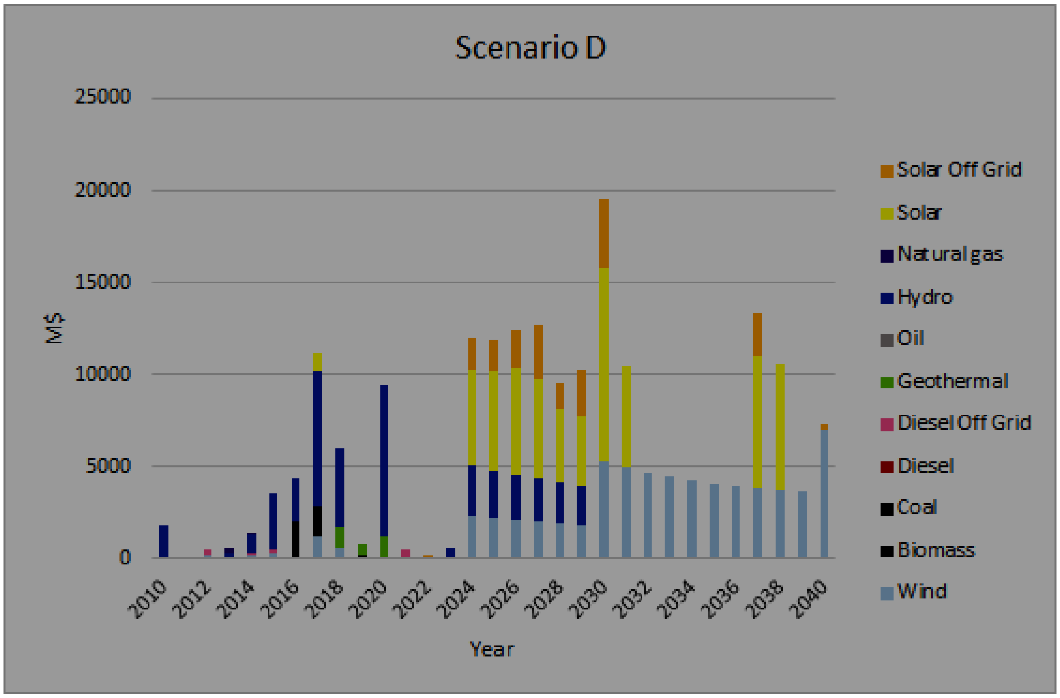

Figure 4.17: Capital Investment by year for scenario D

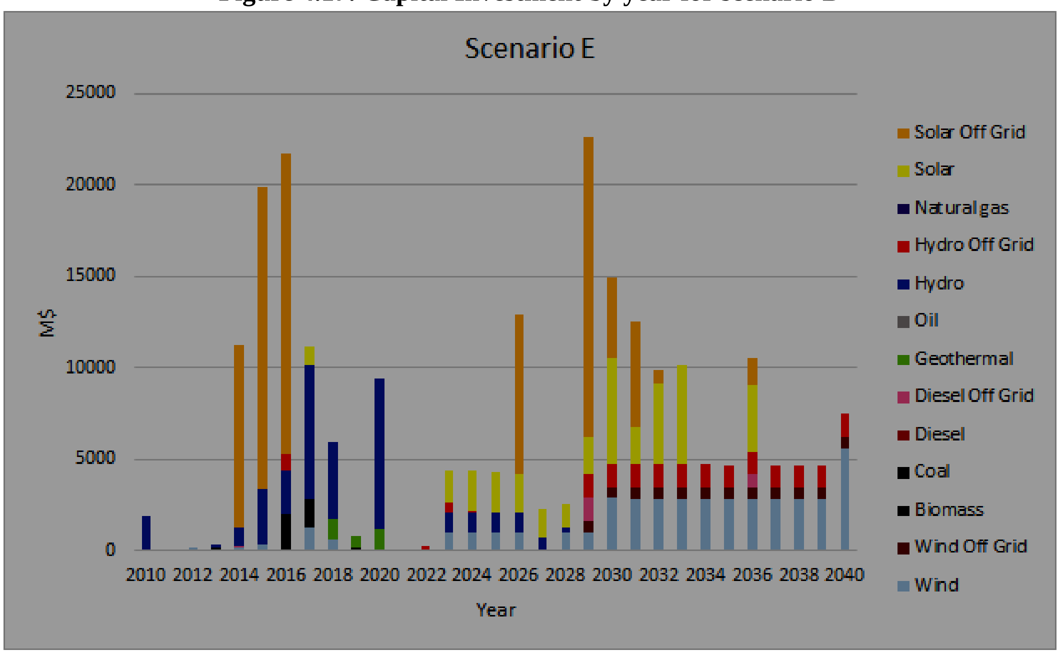

Figure 4.18: Capital Investment by year for scenario E

c) Outputs on Annual Production of Energy by Technology

The Figures presented below show the annual production of energy by technology for each scenario followed by a table that compares each scenario.

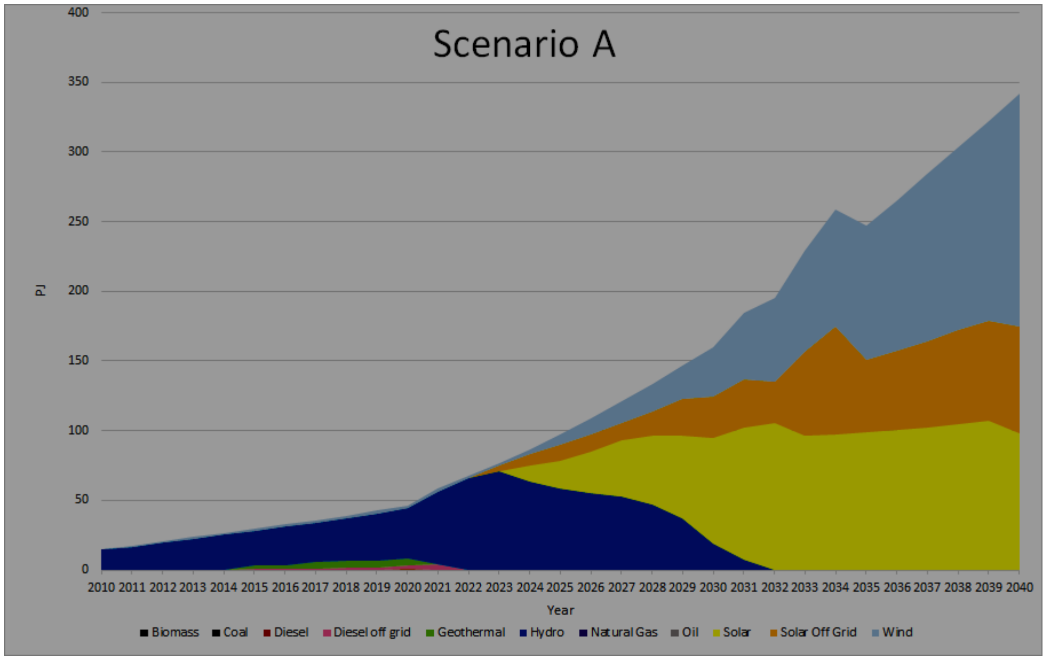

Figure 4.19: Total production by technology per year, scenario A

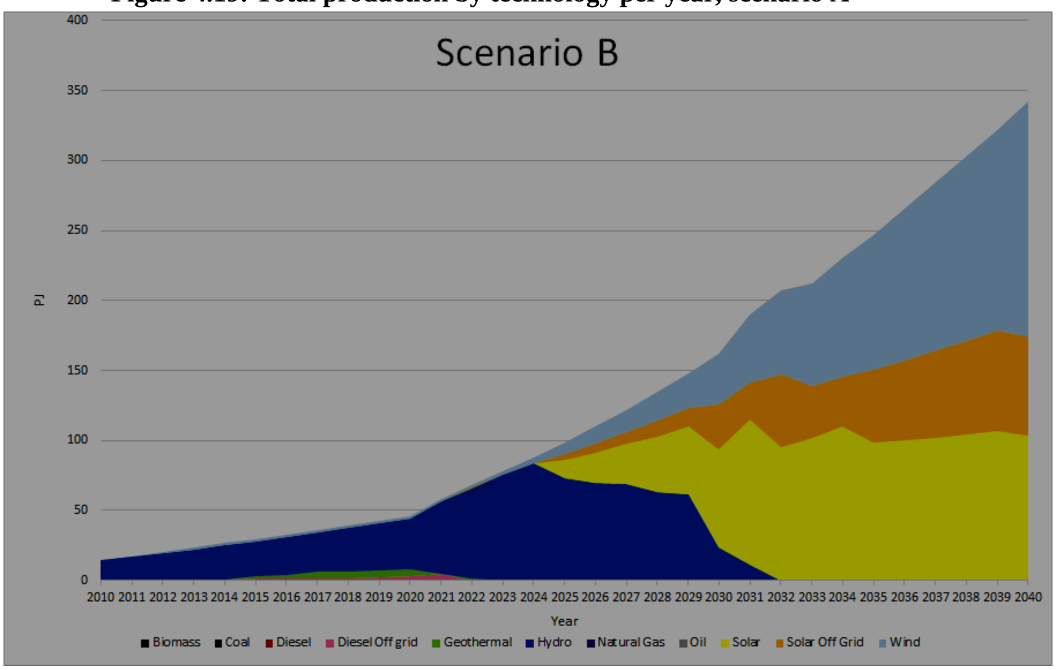

Figure 4.20: Total Annual Energy Production by Technology, scenario B

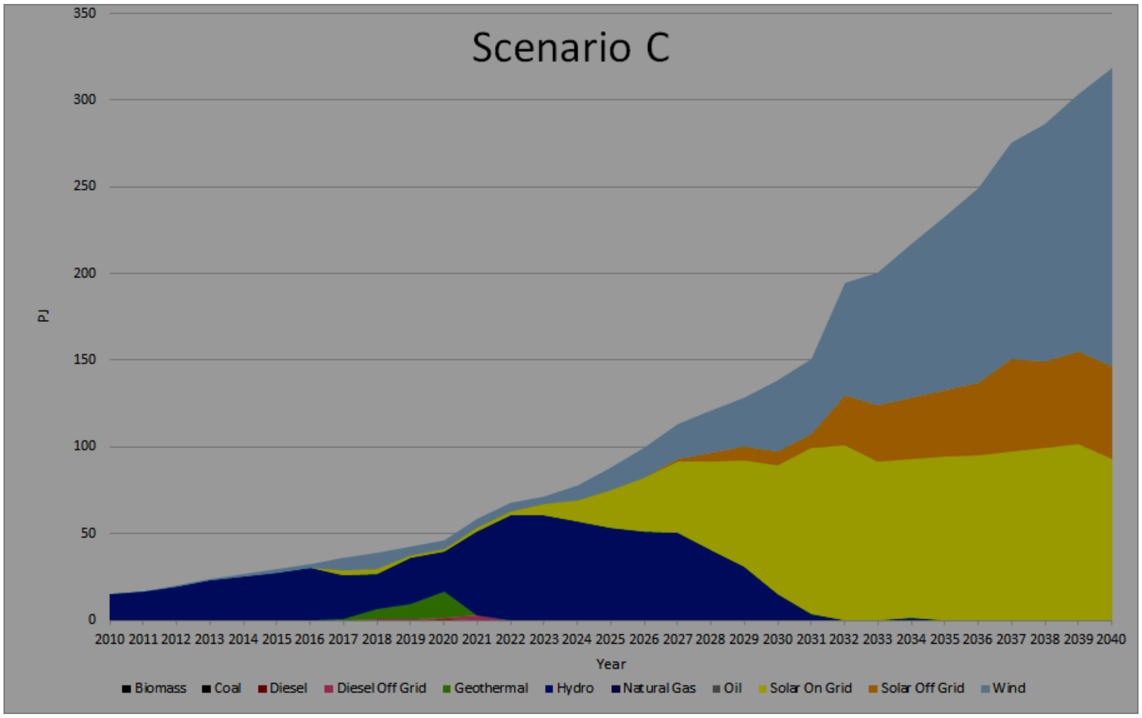

Figure 4.21: Total Annual Energy Production by Technology, scenario C

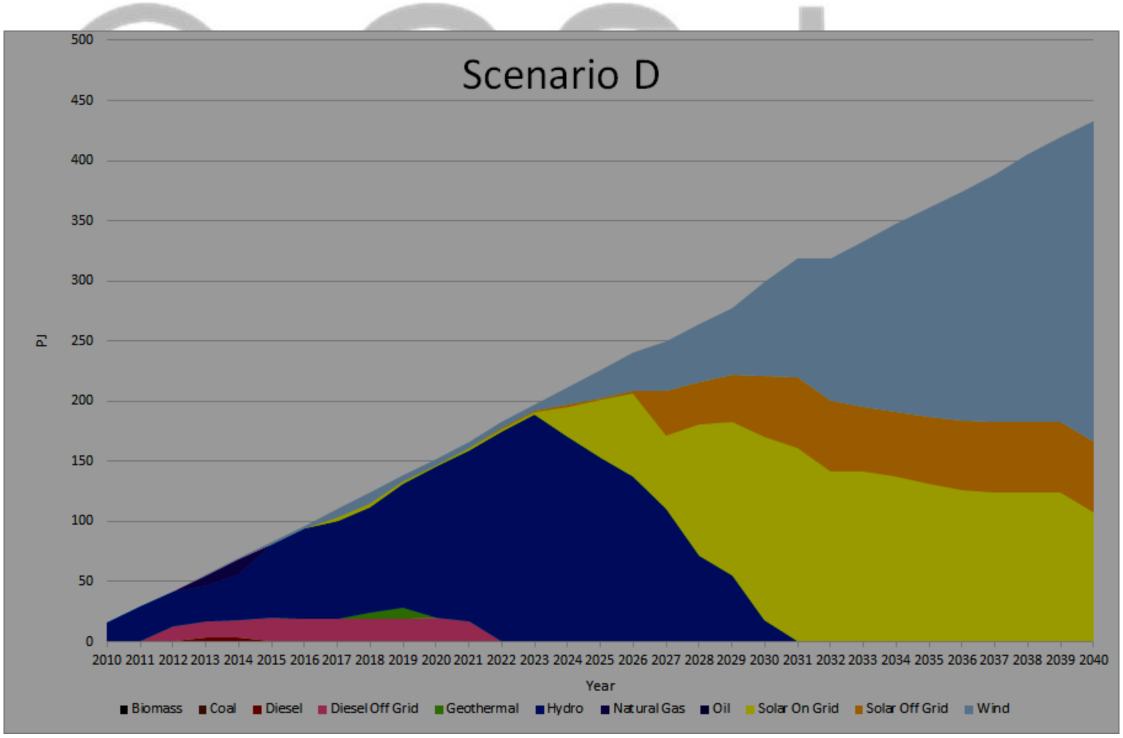

Figure 4.22: Total Annual Energy Production by Technology, scenario D

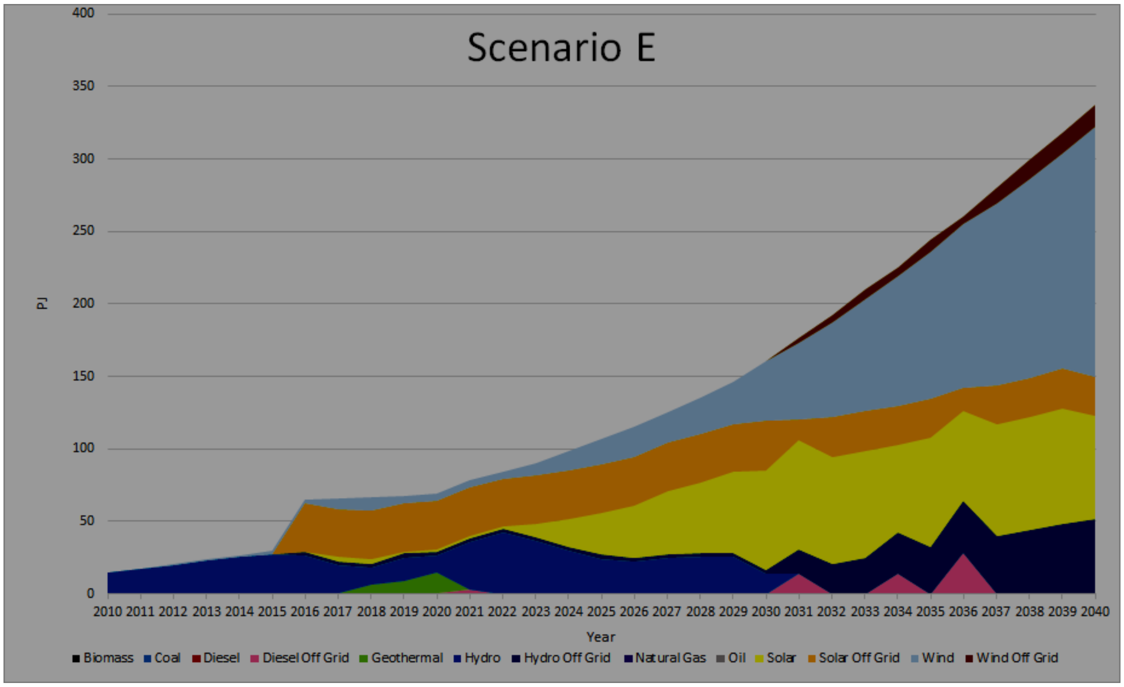

Figure 4.23: Total Annual Energy Production by Technology, scenario E

Table 4.3: Total Energy Production by Technology, 2030

	Production in 2030 (PJ)				
	Scenario				
Technology	**A**	**B**	**C**	**D**	**E**
Biomass	0	0	0	0	0
Coal	0	0	0	0	0
Diesel	0	0	0	0	0
Diesel Off Grid	0	0	0	0	0
Geothermal	0	0	0	0	0
Oil	0	0	0	0	0
Hydro	19	23,39	15,56	17,76	14,02
Hydro Off Grid	0	0	0	0	2,70
Natural gas	0	0	0	0	0
Solar	75,43	70	74,13	155,03	68,48
Solar Off Grid	29,95	32,09	29,95	50,34	34,30
Wind	35,80	36,52	40,55	78,30	41,11
Wind Off Grid	0	0	0	0	0,02
Total	160,19	162	160,19	299,44	160,63

4.2. Discussions and Interpretations

Having gone through the overall procedures stipulated in the study so as to achieve the objectives set initially, the researcher had identified the following issues as key points of the energy sector which needs brief discussions. Therefore, the following parts of the study tries to briefly discuss the key issues identified based on the findings of the research.

4.2.1. Limitations of the national energy policy

The national energy policy of Ethiopia was introduced in 1994 by the Transitional Government of Ethiopia. As a road map for managing the energy sector, the national energy policy was reviewed and the following are identified as major limitations. The policy does not exhaustively assess the country's energy potential and available technologies. This means that the figures and mixes that are stated in the policy document and the actual found out from recent studies are totally different. Even though the policy has tried to touch solar, wind and other technologies, it more or less reflects hydro power as major potential and energy technology of the country. The other drawback the policy lacked is timely updating; the policy has counted about twenty four years without any update. In addition to this the overall structure of the document indicated that the policy is short term. As a result the policy is still dependent on the data, information and situations which were in 1994. The other limitation of the policy is fragmentation which did not ensure and identify the role and responsibility of different partners for its implementation. The policy is generally inconsistent with international experiences.

4.2.2. The challenges of the energy sector

As seen and presented in the previous parts, there are many challenges that critically hinder the development of the nation's energy sector. As long as the sector is very essential and sometimes taken as one of the factors of production for the development of other sectors, it is vital to understand the root causes of those challenges together with developing and devising proper approaches and strategies to address them.

With no doubt secondary data and the interviewees witnessed that Ethiopia is a nation blessed with abundant sources of renewable energy with very little exploitation and seriously exposed to energy poverty. The basic question that should be raised here which constraint challenges for this little exploitation. To do so, the researcher has identified many challenges of the sector among which planning and financial investment challenges together with poor institutional setups contributes much for this little exploitation. This means that as far as the capital investment required by both energy generating and transmission projects is very huge currency which is considerably significant for the country, the development and exploitation of such resources took very long time.

The plan prepared by the Ethiopia government for the next 10 years as indicated in the following table show that averagely a hydro power project requires 1,812,066.64 USD/MW, a solar power project needs 1,800,000 USD/MW, a wind power project requires 2,065,789.47 USD/MW, a geothermal power needs 3,943,307.09 USD/MW, and bio-energy requires 1,250,000 USD/MW which is very expensive.

Table 4.4: Energy Generation Unit Cost

S.No	Type of Resource	Energy planned to be generated (in MW)	Cost in Millions of USD	Unit Cost/MW
1	Hydropower	11,105	20,123	1,812,067
2	Solar	300	540	1,800,000
3	Wind	1,520	3,140	2,065,789
4	Geothermal	1,270	5,008	3,943,307
5	Bio-energy	420	525	1,250,000
	Total	14,615	29,336	2,174,232.64

If we take the average unit cost of energy generation of the five renewable energy sources which is equal to 2,174,232.64 USD/MW to calculate the overall renewable energy potential of the country which is estimated to be 60,000 MW minus the exploited one which is equal to 4290 MW, we would have got

Total capital required = 2,174,232.64 USD/MW*(60,000MW-4290MW)

=above 121 Billions of USD

This would probably equal to the sum of 3 to 5 fiscal year's budget of the nation. As far as the cost of generation does not include the transmission cost, the cost is expected to increase when we add those costs.

As we have seen in the previous parts of this study, the government of Ethiopia in its history has allocated 20 Billion US Dollars for the energy sector in GTP II period (2016-2020). With such trends some 30 more years are required to exploit the resources abundantly available.

The time required to develop such resources and make use of the advantages brought from them would be doubled when the planning capacity and the institutional set up had become poor. As it has been analyzed earlier, the institutional set up of the energy sector, the professional mix found in those institutions and the planning capacity of those institutions to meet the dynamically growing demand of clean and affordable energy is very challenging.

To address the planning challenges and bring visible changes in those situations the government should undertake re-engineering and establishment of strong and dynamic institutional setup and investing a lot in building the capacity of the human asset. Added to that, the government should seriously establish strong partnership with local as well as foreign investors to share its capital investment challenges so as to develop and exploit the renewable energy sources.

4.2.3. Household energy consumptions

As it has been presented and stated in the previous parts of this study, the residential sector of Ethiopia is the most dominant energy consuming sector which takes the lion's share (about 90%) of the total energy consumed. More importantly, about 93% of the energy source for this sector comes from biomass, especially wooden biomass sources which causes for the degradation and depletion of the environment. However, comparing with other sources of renewable energy, bio-energy sources of energy are relatively less costly than others to develop (1,250,000 USD/MW and 178,571.43 USD/GWH as shown in table 4.5). In addition to that above 60% of the electricity generated is consumed and used by this sector. Above all, the energy efficiency of the appliances used in this sector is very less which ranges between 12 and 15% which results in wastage of the less available produced energy. Generally, we can dare to say that the residential sector in its energy consumption is high energy and electricity consumer, less efficient and woody biomass energy dominated sector. That is the reason it has come here as a key issue.

All the data and information shown above indicates that this sector has to get sufficient attention, as

a) it is the most dominant energy and electricity consumer,

b) it is the major reason for environmental pollution and degradation

c) it is the least energy efficient sector

To address those problems technologically as well as administratively, it is mandatory for the government to go through scientific researches. Basically, the government should establish a research and technology innovation center for household appliances (especially for cooking appliances). Moreover, it should devise strategies to encourage energy efficient devices. More importantly, it should see from different directions to develop and generate energy from bio-energy resources in renewable manner as the generation process is less costly as compared with other resources.

4.2.4. Energy efficiency and consumption pattern

As stated earlier in different parts of this research, the efficiency of the energy sector of Ethiopia is less as compared with other countries and the international standards. The electricity loss in Ethiopia which occurs during transmission is about 20%, which is much higher than the international average, 12-13%, and the efficiency recognized in the home appliances of the household sector ranges between 12-15%.This means that about 858 MW of the electricity out of the current approximated 4,290 MW of electricity generated is lost due to transmission related reasons. As it is seen earlier, the energy consumption pattern of the country is predominated by wooden biomass (above 90%) though the country is rich in abundant sources of renewable energy.

Therefore, the other critical issue the government of Ethiopia has to gone through in this sector is devising and implementing plans, programs and strategies that would promote energy efficiency remove biomass dependent energy sources and enhance the energy resource mixes. Above all the government should put energy auditing as mandatory task for energy consuming heavy industries. The government should also think to develop how to subsidize highly energy efficient industries and sectors.

4.2.5. Discussions and Interpretations on the modeling part

Having the outputs presented above, this part of the thesis point out the brief and precise interpretation of the results obtained regarding the modeling process.

4.2.5.1. Data Related Uncertainties

The major sources of data for this research work, specifically for the modeling parts are taken from the future energy sector plans and forecasts of the country. Therefore, it is very interesting to discuss how the difference between a theoretical model and the reality looks like. It is also important to discuss the probability of either reaching the pre-set goals or not. One factor contributing to uncertainties is the fact that it was hard to find historical data about the actual production taking place while it was relatively easy to find forecasts and future goals. It is quite common that arrangements do not turn out to be as planned and initiatives take longer time than intended. The Grand Ethiopian Renaissance Dam and The Reppie waste-to-Energy facility projects could be taken as examples. As stated in GTP I and GTP II those projects were planned to be completed 2-3 years before though only 60% of the GERD and 90% of REPPIE are completed for various reasons. From previous energy generating projects experience implemented in the country, it is even still impossible to judge when those facilities will be producing as planned.

Various documents of the country in the energy sector indicate that the national energy goals are very ambitious. Clearly the country has a great potential to achieve an energy system 100% from renewable energy sources. The major challenge is how to address the challenges in relation with time and finance.

Obviously, Power interruptions and outages are a big hindrance in Ethiopia's development as they influence the whole society and its prosperity. As a backbone for most development endeavors, interruption of power affects both private individuals as well as large businesses in different ways. If we took a company producing perishable items as an example and if its fridges got shut down due to power outages, it loses loads of products which may lead to significant economic loses. If we consider students, they often require a computer to search for information required for an assignment. If there are problems with the stability of electricity, they will most likely also have trouble with charging of the computer or with accessing internet. This will in consequence slow down and make the whole studying process inefficient. If a health institution loses power, risks associated with damaging the functionality of medical equipment which may have direct consequences as severe as loss of human life would be born. Power outages are also very discouraging for foreign investors which in its turn make it harder for Ethiopia to establish itself on the international arena.

To make solutions for the above challenges, most businesses are forced to rely on diesel generators when the power supply from the national grid fails. In addition to the economical problems it brings in different ways, the energy generated from this source is not sustainable as it emits carbon dioxide and can be pretty expensive in the long run. It is thus also a question of independency, economy and environment. If the country is seeking to reach the 7th goal of sustainable development (SDG 7), it should directly start finding a solution to this problem and decrease the numbers of diesel generators around the country.

4.2.5.2. Annual Emissions

In this regard, when we are looking at the figures that show the carbon emissions of the different scenarios under consideration i.e., (from figure 4.8 to figure 4.12), one can notice that scenarios A and B are more or less identical, and scenario C follows a similar pattern though there is a difference in amount. The first three scenarios reach the maximum emissions of carbon dioxide in 2021 with a total emission amount of 1.5 ton in scenarios A and B, and lower i.e., 1.1 ton in scenario C. Scenario D has the largest amount of emissions in 2014 and 2021. Furthermore, one can observe an addition of a fuel - natural gas, for scenario D, in figure 4.11. This can be explained by the increased demand which may require a bigger production by current, established technologies in order to get satisfied.

Scenario E has a slightly different curve (see figure 4.12) and emits a lot of carbon dioxide from 2030 onwards. During the modeling period (2010-2030), the largest emissions occur in 2021 and correspond to a value of 0.85 ton. This indicates that scenario E is the most environmentally friendly scenario, for the period under considerations. The scenario also presents how the emission looks like during this time. In this regard, one can conclude that by 2030 none of the presented scenarios emit any carbon dioxide emissions, thereby all electricity is derived from renewable sources. The emissions in scenario A, B and C all sharply end in 2022. This is because from this year onwards the model starts to produce electricity solely from those sources (see figure 4.19-figure 4.22).

The result from all scenarios indicates that the time span in which the emission of carbon dioxide has relatively become higher is the nearest future. The phenomenon can be explained by the fact that it is impossible for the nation to tolerate this high amount of emissions as far as the problem would become a big environmental challenge. It also indicates that the transformation to renewable energy has become immediate which didn’t consider the existing financial condition as well as the time challenge of the country. Generally, it is well known that the nation does require some longer time in order to establish renewable energy sources and reach sustainable satisfaction of the demand. The demand is high but the renewable sources cannot produce enough so that conventional sources of energy should be used.

To have a carbon free energy generation and utilization is becoming a common desire that pertains to today's society living in every corner of the world so as to decrease the negative impacts green house gases like carbon dioxide emissions have on the environment. The main aim here is to sustain the planet one is dependent on. However, social development and environmental protection are often in conflict as it is generally difficult to achieve one without disrupting the other. Developing countries like Ethiopia are trying to face such challenges by providing clean energy which is environmentally friendly through the exclusive usage of renewable energy sources which is basic for sustainable development. During the time where choices are mandatory to be made and one has to prioritize which might be worthy, some emissions should be allowed which means that more people would get access to electricity and therefore improve their life standard. One can further discuss the moral perspective by considering the fact that, in the past, the majority of global environmental destruction has been caused by the so called western developed economies. These economies achieved high living standards relatively early and led a lifestyle that required a lot of carbon dioxide emitting energy for many years, which resulted in great environmental damage, with noticeable traces still left today. One can ask themselves whether these actors should consequently take greater responsibility when it comes to environment protection, possibly supporting those who have not achieved an equally extensive development, and have thus not caused as much pollution, etc.

4.2.5.3. Capital Investments

While someone is fascinated to compare scenario B with scenario A, capital investment has become a particular interest. The difference in these scenarios lies in the residual capacity for distribution and transmission which was degraded in the first one that presumably made the model to invest more. The increased total capital investment for scenario B was thus expected. In table 4.2 it is shown that the investments in the distribution and transmission system are the same for scenario A and C as far as scenario C was created from A and no changes were made regarding the distribution and transmission which also was expected.

The assumption, when making scenario B, was that the additional investments would lead to improvements in transmission and distribution. As mentioned during development of scenarios, Scenario B, flaws in distribution and transmission together with other things were contributors for frequent outages of power. One can get rid of power outages and obtain a more sustainable energy system by improving the distribution and transmission system in the situation where the utilization of diesel generators is reduced.

Furthermore, regarding the total capital investments as presented in table 4.2 and figure 4.13, one can clearly observe that scenarios D and E absorb the largest and un-affordable amount of investments. This is due to the significantly increased demand that was applied for these scenarios. It is worth to mention that the increased demand also rises due to an increased demand to export which would be turned into a valuable income for the country.

The figure and table moreover indicate that scenario B is the cheapest and would be sufficient to meet the respective demand. It is, however, important to stress the fact that the scenarios are not comparable with each other as they vary greatly in their input. It is also possible for someone to argue that the most expensive case, scenario E, is the most complex and realistic one as it includes the geospatial perspective. It takes into account the geographical conditions when determining whether a certain area should have its electricity supplied by the grid or other technologies.

In order to enable the production of a new technology, investments need to be made for that technology. Therefore, figures 4.14 to 4.18, showing the investments per year for each scenario, represent the same kind of information as the production by technology, presented in the sections below.

4.2.5.4. Annual Production by Technology

For this specific area of study the information used to create the scenarios are the national policies, plans, programs and strategies. The Growth and Transformation Plan II (GTP II) and the Master Plan of the country seeks to achieve an electrification rate of 90% by 2020 and 100% by 2037. From this plan one can assume that 100% of the population will have access to electricity by 2030 and thus the 7th goal of sustainable development (SDG 7) will be achieved. In addition to this the demand from TEMBA is based on a forecast from IEA and includes a growing demand from a growing population which most probably can be seen as representing the demand from the whole population by 2030. Scenario E was created to see how the population would meet their electricity demand and the respective costs needed to be invested to extend the existing grid or create mini grids. The demand was set with the assumption that every citizen would be able to access electricity by 2030 with an average electricity consumption of 695 KWH/year. From those assumptions, one can thus argue that all scenarios will ensure electricity for all inhabitants by 2030.

In table 4.2 one can see that by 2030 all the scenarios have the same ranking between the existing technologies, with solar on grid being the most prominent one, followed by wind, solar off-grid and lastly hydro. Results from OnSSET present a similar trend, showing that among technologies not connected to the grid, solar is by far the most used energy source (see figures 4.19 to 4.23). Scenario E has a larger mix of different technologies and has the ranking as mentioned, followed by hydro- and wind off grid. The results presented in figures 4.19 to figure 4.22 show that all scenarios except scenario E have an increased penetration of solar power starting from 2022. Due to this hydropower would start to decrease as far as more cost-efficient alternatives are available. A production of electricity from solar off grid sources has already been observed in scenario E from 2015 onwards. However, this scenario also follows the same pattern like other scenarios with a large penetration of solar on grid from 2022 and onwards (see figure 4.23). One can also see an increasing amount of wind power during these years. This higher penetration of renewable sources might be explained by the fact that these technologies would be developed in efficient and less expensive manner over the years under consideration.

The results for 2030 in all scenarios show that the production of electricity would become dependent on three different energy sources; hydropower, solar energy and wind energy (see table 4.2). From this one can find it interesting to discuss whether this energy mix is sufficiently diversified and constitutes a resilient electricity system. It is important to have many energy sources as that reduces the risk of paralysis of the society that can occur when a country relies on one resource and that resource fails. As sustainable sources of energy, one can judge that there are not more renewable sources of energy left to implement other than hydro, solar and wind. Of course, there might be better options available for storage and therefore the reliability of the covered renewable sources might go up.

As discussed earlier hydro power is the most dominant sources of electricity in the nation (up to 95%), as a result dependency from this source is considered as seriously risky. Therefore, the energy mix obtained from those scenarios is taken as positive as far as the government of Ethiopia has planned to initiate and build green economy as well as the scenarios allow exploiting the untapped sources (solar and wind) of energy and developing alternative sources of energy.

Having reviewed the national policies and reports such as GTP II, one can assume that the officials are not worried about the above-mentioned issue, as the statistics included in those documents state that only 5% of the total potential for hydro power is being used.

Another fact contributing to the uncertainty on hydropower is that the water flowing through Ethiopia (like Blue Nile) also is considered as a major source of life for some countries like Sudan and Egypt. As it is a shared resource Ethiopia's utilization of it might affect Egypt negatively which in turn might create tension between the countries. Hydropower is therefore not only a question of energy, but also health, economy and politics.

4.3. Summary of results

The overall review of the energy sector shows that Ethiopia, potentially, is blessed with abundant but untapped sources of renewable energy. The results further more revealed that below 5% all of the renewable sources of energy are tapped of which 99% is obtained from the hydro powers sources. Added to that, the bulk of the national energy consumption is met from biomass energy sources (fuel wood, charcoal, wood, waste wood, crop residues and animal dung, including biogas) accounted up to 89% of total national energy consumption. Huge amount of investment required for energy generation and transmission projects/programs, heavy foreign currency burden resulting from import of petroleum fuels, lack of a comprehensive and integrated long-range energy development programs, poor institutional set up to manage the development of the sector in line with the principles of sustainable energy management, environmental pollution and degradation basically arisen from the household and transport sector, poor technical and technological advancements of renewable energy technology, low level of renewable energy development outside large scale hydropower development, low level of efficiency of use of energy in all sectors and lack of substitutes/supplements for biomass fuels used in households are still the major challenges and constraints contributing for the least development of the energy sector. To the reverse of this, commitments and agreements made by both developing and developed countries together with global financing institutions to concentrate and finance the development of renewable energy so as to build green economy, has become the global prospects and opportunities of the country through provision of financial resources to develop the renewable sources of energy. In addition to this, availability of renewable energy sources, the commitment the government is showing to develop the sector, the new modality the government has developed to increase the involvement of the private sector in energy generation processes are identified as the national prospects and opportunities of the country.

It is critical to find potential energy pathways for Ethiopia which can meet the country's energy demand in a balanced and sustainable manner in the coming decades. For this purpose different energy scenarios are representing possible futures of energy systems which might unfold if the development is considering the goals of sustainable development.

From the above discussions it can be observed that all the scenarios would result in output that are characterized by meeting the energy sector goal of the country i.e., demand and supply mix goal, environmental goal. In summary, the scenarios summaries' energy path ways and their impacts on the energy system in terms of primary energy supply mix energy intensities and energy related CO_2 emissions are examined.

These results are useful for energy planning purposes and assisting in formulating energy policies for the country. In order to formulate effective energy policies, a comprehensive analysis is needed that will take in to account the wider impacts of various energy options (such as economic-wide impacts). This task would be carried out by the next researcher which can use this study as a first input source.

Chapter Five: Conclusions and Recommendations

5.1. Introduction

Having collected and analyzed the data and identified the key findings, the following parts of the thesis outlines the major conclusions drawn and lists out a set of recommendations. Added to that, the future research works which are to be carried out related to the topic of this research are finally proposed.

5.2. Conclusions

This study was aimed at assessing and modeling the Ethiopian energy sector management system. The overall energy sector management systems together with the national energy policy are incapable of addressing the long term energy challenges the country is facing. The Ethiopian energy sector is mainly challenged and characterized by inefficient energy generation, transmission and utilization of renewable sources, poor mixes of energy supply, highly imbalanced demand and supply of supply of energy and environmental degradation for various reasons. The current status and position of the sector generally found out that the existing energy policy settings are short term perspectives, fragmented and internationally inconsistent.

With the constraints given and assumed to run the modeling tools, the findings presented in all scenarios are cost efficient which would be able to benefit the economy. Even though the environmental and climate aspect was significantly simplified by delimiting greenhouse gases emissions to carbon dioxide, the issue of environment was a bit more complex. As a result, all the scenarios revealed that the supply of energy in the modeling period would drastically be changed to renewable and the emissions of CO_2 are non-existent by 2030. This would benefit the society in a sense that a population gets an improved quality and standard of life due to an increased access to clean and modern electricity.

Despite the different constraints the scenarios all have been given to compare, solar and wind sources of energy, in the near future, would become, the most dominantly used technologies and all carbon dioxide emissions cease to exist by 2030 i.e., the primary energy supply system would get diversified from a system dominated by wooden biomass in the later period to the use of renewable sources and other indigenous resources. Due to this, one can conclude that all the scenarios would lead the country to achieve the 7th goal of Sustainable Development, SDG 7; sustainable energy for all.

5.3. Recommendations

The findings of this study indicates that the least development of the energy sector especially the renewable sources together with the in efficient utilization of energy in all sectors had become critical to make crucial decisions in order to make tangible changes in this sector. It is established that the development of renewable energy and energy efficiency are two components that should go together to achieve sustainable development of the nation’s energy sector. Therefore, it is recommended that the country should do the following so as to bring visible improvements in the current situation;

- Participating all the disciplines responsible for the energy sector, the government of Ethiopia, with no doubt, should review the national energy policy to make it long term, continuous and internationally consistent. Moreover, a comprehensive and coherent energy policy is essential in guiding the citizens towards an efficient usage of its energy resources.

- The government should establish an institute responsible for research, development and promotion of energy efficient products. The institute should basically focus its research on home appliances as far as the residential sector is identified as the most energy consuming sector with very little efficiency. Moreover, the government should think and make study to re-engineer and re-establish the existing institutions responsible for the sector.
- The government together with the private firms who are involved in the energy sector should promote energy-efficient products and appropriate practices at the side of the end users and energy generation. The government should strategically subsidize such technologies using different modalities.
- The government should strengthen its cooperation with the private sector, bilateral and international monetary organizations to take advantage of global partnerships and as a result get reliefs from the financial headaches required for energy generating projects.
- The government should also seriously strive to carry out a resource survey and assessment to determine the total renewable energy potential in the country as well as identify the local conditions and local priorities in various ecological zones. This would help the government to prepare genuine strategic, structural and master plan of the energy sector.
- The government should plan either to outsource or privatize the responsibilities of those institutions leading the sector partially or fully so as to increase their efficiency.
- The government should also plan to build the skills and capacity of the human resources found in the energy sector.

5.3.1. Recommended Energy Sector Management System Model

The model recommended here as shown in fig 5.1 is mainly aimed at matching the demand and supply gap of the sector by putting solution to address the challenges and make use of the opportunities arisen from the sector for changing the current situation.

First and foremost, managing the sector in an integrated manner is very crucial. This means that each and every development activity of the sector should be led inclusively and centrally with greater political commitments.

a) There should be a comprehensive policy & plan of the sector that paves the way and decides the future growth and development of the country as energy is pivotal for any development endeavor. As far as the role of the private sector, donors and the public is very essential, it is mandatory to involve them in the policy review and planning phase. The plan should be devised based on the actual resources available and should be classified as short term, long term and middle term plans.

b) Re-engineering of the institutions and agencies owing and responsible for the energy sector including privatizing parts of their responsibilities should be done so that it would help to establish and provide one stop energy development and management service.

c) Finally, staffing the energy sector with technically, conceptually and managerially skilled human resource is vital to make visible changes in the sector. A continuous effort to build the capacity of the staffs of the sector in line with sustainable energy engineering, development and management is mandatory.

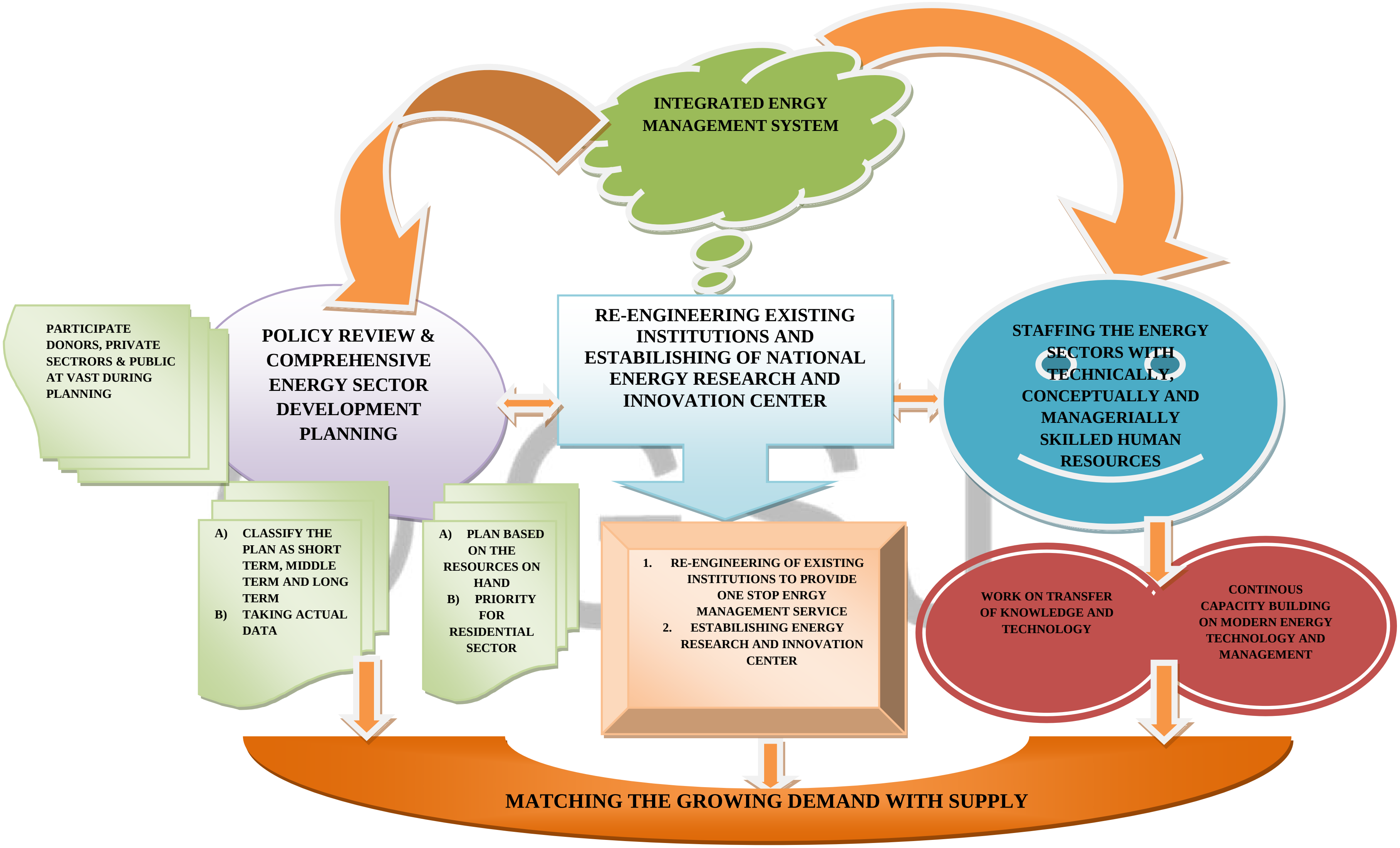

Figure 5.1: Recommended Energy Sector Management System

5.4. Future research areas

Even though there are a lot of reports and documents prepared by both governmental and non-governmental institutions (which sometimes clash each other) talking about the potential, the situation, and the status of the development of the energy sector of Ethiopia. The main limitations of this study was the absence of previous research work in the area, and obtaining structured data to analyze, compare and contrast the development of the energy sector from different perspectives. As a result, those reports and documents were thoroughly used for this study. The other challenge that was noticed while undertaking this research was that there is no any institution that develop energy management system model so as to evaluate, compare and propose efficient energy management system models so that the author of this research has obliged to ignore this part. Therefore, further specific studies can be done to develop energy management system model in different agencies and institutions responsible for energy management of the country, feasibility study on the different potentials of renewable energy, to assess and evaluate the energy policy and regulations of the country with respect to renewable energy and energy efficiency, to establish and develop renewable energy fund, etc

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APPENDIX: INTERVIEW GUIDE

My name is Biniyam Getachew, I am a post graduate student at Bahir Dar Institute of Technology, Bahir Dar University. I am working with a graduate student research in title 'Assessment and Modeling of the Ethiopian Energy Sector Management System' as partial fulfillment for the degree of award of Masters of Science in Sustainable Energy Engineering. The study is to be conducted with the objective of assessing and modeling the Ethiopian energy sector management system.

Thinking to have relevant, accurate and quality data and information in the energy sector, you are one of the officials/experts who have been selected deliberately to participate in this interview. Therefore, you are kindly requested to participate in this study and provide the information whatever you thought relevant. I would like to ask for you a few questions about the management system of the energy sector.

The nature of the interview is unstructured which is open to reflect your ideas, suggestions and comments with no limits. However, you can refuse to answer any question I would raise. You may end the interview at any time. You can also refuse to participate in the study entirely. Your refusal will not restrict you from any of your rights. The interview will last approximately take one hour. I, therefore, request your time in responding to a set of questions towards this objective.

Your responses will be kept confidential and there will be no way of linking your individual perspectives to the final results of the study findings. I would like to inform you that the responses that you provide to the questions are very essential, not only for the successful accomplishment of the study, but also used to suggest appropriate model and management system for the energy sector.

If you have any suggestion, you can contact me with these addresses

Biniyam Getachew (Mob No 0930071202/0939818989) (Email: bingetguess@yahoo.com)

Given all the above information, may I Proceed with the questions?

Yes; ----proceed with the interview No; ---- give thank and Stop.

1. General information
   a) Would you tell me about your professional back ground?
   b) Would you tell me your general and specific experiences in the energy sector?
2. What do you think about the potential/energy generation capacity of the country?
3. Do you think Ethiopia has exploited the existing energy generation capacity adequately?
4. What is/are your justification/s for question number 3?
5. What are the major sources of energy pre-dominating the energy system of the country?
6. Which sector do you think is the most energy consuming sector?
7. What do you think about the demand and supply of energy in the country?
8. How can you describe the significance of the energy sector for the growth and development of other sectors?
9. What do you think the challenges and constraints contributing for the least development of the energy sector?

10. Do you think the institutional set up and establishment to manage the energy sector is sufficient?
11. What is your attitude towards efficiency of energy in generation, transmission and utilization in the country?
12. How do you evaluate/measure the knowledge towards the energy policy of the country in your office?
13. How do you evaluate the adequacy of the energy sector management system, strategies and plans both your office and the country?
14. What opportunities do you think the energy sector had?
15. What comments, suggestions and recommendations do you have to make changes in the energy sector?
16. Finally, do you have anything to say as concluding remarks?

Thank you so much once again!