Modeling and Analysis of Long-Term Energy Scenarios for Sustainable Strategies of Ethiopia

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To my parents

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ABSTRACT

Despite robust economic growth, Ethiopia is one of the countries with poor energy accesses. Contributing factors are poor availability of energy, unreliable and insufficient quality of energy, and insufficient policy. Recognizing that energy access and security are indispensable to economic transformation, Ethiopia needs to cope with key challenges related to energy security, climate change mitigation and also diversification of energy supply. In order to achieve these targets and strive towards sustainable energy for all, Ethiopia's energy system requires a major transformation. The main achievement of this research has been the development of alternative energy options under different conditions for Ethiopia up to 2050.

To identify an energy pathway that would meet Ethiopia's energy needs in a sustainable manner, three scenarios are considered: the business-as usual (BAU), moderate shift (Scenario1) and the advanced shift scenario (Scenario 2). The scenarios were developed, quantified and analyzed using a bottom-up model for Long Term Alternative Energy Planning (LEAP). These scenarios represent a range of energy policy measures that Ethiopia could adopt to achieve its sustainable development goals. The BAU scenario reflects a continuation of the current policy trend and considers on economic growth rate of 7 %, while Scenario 1 and Scenario 2 represent moderate and advanced levels of commitment in economic growth, energy diversity and reduction of energy import dependency and CO_2 emissions limits, respectively.

The scenario analysis shows that the primary energy requirements for Ethiopia's socio-economic development will increase sharply over the period (2010-2050) in all three scenarios. BAU, Scenario 1 and Scenario 2 show an expected to growth at annual rates of 4.1, 4.9 and 5.7 % respectively. If the current policy trends (as represented by BAU) continue, the total energy demand in Ethiopia is expected to reach 6,553 Petajoule (PJ) by 2050 from 1,313 PJ in 2010. Nevertheless, the energy intensity is expected to decrease gradually across the three scenarios, from 65MJ/$ in base year (2010) to 22, 20 and 13 MJ/$ in 2050 for BAU, Scenario 1 and Scenario 2 respectively. Importantly, under Scenario 2, the energy intensity will decrease with an average annual rate of 3.9 %. Certainly, Scenario 2 has the largest capability of energy savings. The per capita primary energy consumption in Scenario 2 is the highest (at annual rate of 4.1 %) and followed by Scenario 1 (3.3 %) over the period. With respect to energy intensity, energy diversity and per capita consumption, BAU scenario shows is the least preferred option with highest risks related to security and diversity of supply.

In Scenario 2, the proportion of oil consumption will decrease to 7.4 %, i.e., lower than the values of 17.72 % and 11.5 % for the BAU and Scenario 1, respectively. The demand for non-conventional renewables is expected to increase significantly in all three scenarios from around 1 % in 2010, to 11 % 23 % and 36.6 % for the BAU scenario, Scenario 1 and Scenario 2 respectively over the period of 2010-2050. Overall, under Scenario 2, the degree of diversification in the total energy requirement would increase and gradually will become environmentally friendly in Ethiopia, with rapid growth in the use of alternative clean energy.

The absolute CO_2 emissions under the three scenarios from 2010 to 2050 will slightly increase due to the stronger economic development, which still stay within the limits of an ambitious climate change mitigation policy. Nevertheless, Scenario 2 has the lowest CO_2 emission intensity, followed by the Scenario 1 and BAU scenarios. By 2050 the CO_2 emissions intensities of BAU, Scenario 1 and Scenario 2 will reach 0.1, 0.08 and 0.05 kg CO_2 per US$ of GDP, respectively.

Overall, the results of analysis demonstrate that the alternative scenarios (Scenario 1 and Scenario 2) would result in a sustainable energy transitions that would shape the future sustainable development of the Ethiopia's energy system and show how the country can move forward in the next 40 years.

Further, this research highlights the set of policy perspectives that could contribute to the transformation of the energy system towards a more sustainable development.

Keyword: Energy security; Sustainable development; scenario analysis; LEAP model; Ethiopia's energy system

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LIST OF ACRONYMS

AAGR	Average Annual Growth Rate
AfDB	African Development Bank
AETPDD	Alternative Energy Technologies Promotion and Dissemination Directorate
BAU	Business as usual scenario
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
CRGE	Climate-Resilient Green Economy
CSA	Central Statistics Agency (Ethiopia)
DSM	Demand Side Management
EAEDPC	Ethiopian Alternative Energy Development and Promotion Center
EEA	Ethiopian Electricity Agency
EEPCo.	Ethiopian Electric Power Corporation
EPA	Environmental Protection Authority of Ethiopia
EPSE	Ethiopian Petroleum Suppliers Enterprise
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ETB	Ethiopian Birr
GERD	Grand Ethiopian Renaissance Dam
GHG	Greenhouse Gas
GTP	Growth and Transformation Plan
GWh	Gigawatt-hour

ICS	Interconnected System
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long-range Energy Alternatives Planning
MDGs	Millennium Development Goals
MoA	Ministry of Agriculture of Ethiopia
MoFED	Ministry of Finance and Economic Development of Ethiopia
MoI	Ministry of Industry of Ethiopia
MoME	Ministry of Mines and Energy of Ethiopia
MoWE	Ministry of Water and Energy of Ethiopia
Mt	Metric ton
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
SCS	Self-Contained System
SNNP	Southern Nations, Nationalities and People, Ethiopia
TWh	Terawatt-hour
UEAP	Universal Electricity Access Program
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change

LIST OF UNITS

Energy	Derived energy units	Power
Energy unit: joule (J) J = Nm (newton x meter) 1 MJ (megajoule) = 1.000.000 J	1 kWh (kilowatt hour) = 1 kW (power) during 1 hour (time)	Power: energy per time unit Power unit = watt (W)
1 GJ (gigajoule) = 10^9 J	1 kWh = 3,6 MJ	W = J/sec
1 PJ (petajoule) = 10^12 J	1 MWh = 3.6 GJ	1 MW (megawatt) = 1.000.000 W
	1 TWh = 3.6 PJ	1 GW (gigawatt) = 10^9 W
		1 PW (petawatt) = 10^12 W
	1 Mtoe (mega tonne oil equivalent) = 41,87 PJ	
	1 toe = 7,33 boe	

Source: Devogelaer et al., 2013, p. 117

1 INTRODUCTION

The energy system and its development prospects are fundamental to every economic activity. Thus, a sufficient energy supply is a precondition for economic development. At the same time, the use of fossil energy sources is the largest single contributor to man-made global climate change. The use of nuclear energy has been proven to incur risks of nuclear accidents, as well as nuclear proliferation (IPCC, 2007). Even the use of biomass has been the cause of major deforestation in some developing parts of the world. As a consequence of economic growth and population growth, the global energy demand is increasing (EIA, 2007; OECD/IEA, 2011, p. 1). At present around 80 % of the global energy demand is met by fossil fuels, consisting mainly of oil, coal and gas (IEA, 2013, p. 4)[1]. If this development continues, the increase of CO_2 emissions could substantially increase the global average temperature, and this would have critical impacts on the environment (IPCC, 2007).

Therefore, every country trying to secure a sufficient supply of energy for its future development needs to strive for sustainable production and use of the energy required. Such a sustainable system could ensure energy to boost the socio-economic development in a country or region for an optimal balance of production and consumption (Wang, J. J. Jing, et al. 2009, p. 12). Sustainable energy planning is therefore fundamental to maintain the sustainable development of a country. With the help of sustainable energy planning, developing countries like Ethiopia can secure a sustainable energy supply to meet the sustainability and millennium development goals.

Ethiopia is also concerned about the security of sustainable energy supply and green economy development. This research intends to address long-term sustainable energy scenario options which can meet the challenges of both energy security and climate change mitigation in Ethiopia.

Based on the energy situation in 2010, the time horizon of this study extends to 2050 and includes the socio-economic and the updated technical requirements. New energy demand and energy supply scenarios for Ethiopia were developed. The “business as usual” and two additional scenarios, which are taking into account possible more ambitious economic development through a more sustainable energy supply, are considered.

[1] *International Energy Agency (IEA, 2013),*
http://www.worldenergyoutlook.org/pressmedia/recentpresentations/LondonNovember12.pdf ,
Accessed February 2014

Renewable energy sources such as wind, solar, hydro and biomass play a crucial role in sustainable energy supply. In order to reduce on the one hand the dependence on imported fossil fuels and on the other to support the reduction of greenhouse gases. Ethiopia can make an important contribution with the implementation of a sustainable energy policy. The current share of renewable energy other than biomass in gross inland energy consumption is low or non-existent, and in 2010 was at 1.32 % (IEA, 2013) of domestic energy supply. However, the use of fossil fuels continues to increase substantially. Due to low domestic supplies of fossil fuels, the import dependency of the Ethiopian energy supplies amounts to almost 5.47 % of the total energy supply share in 2010 (Ibid). The growing dependency on imported fossil fuels and the substantial increase of oil prices could bolster the chances of clean renewable energy sources to becoming an important part of Ethiopia’s energy supply. To achieve this breakthrough, appropriate conditions and policies need to be created. While the conditions in some areas still appear insufficient, there are encouraging signs that an increased use of renewable energy is already underway. As an example, Ethiopia’s climate resilient green economy strategy can be seen in the ambitious targets for reducing greenhouse gas emissions and instituting renewable energy by 2025 (CRGE, 2011). This study characterizes the impact of increasing the use of various renewables (e.g. solid biomass, biogas, wind, solar thermal and photovoltaic) to make a positive contribution to the environment, economy and society, the expected impact is estimated. This PhD thesis analyzes the possible contribution of an extensive use of clean renewable energy sources to the reduction of climate and environmental impacts of the future energy use of Ethiopia. Which could enable a strong sustainable development of the country with substantially higher economic growth, lower import dependency and accelerated social development of the country. To analyze these possibilities three different scenarios for a development until 2050 are analyzed: A business as usual scenario, which extends the present official energy policies out to 2050, a moderate sustainable scenario, including a moderately higher economic growth and a higher share of renewable energy supply and an advanced sustainable scenario, including an even higher economic growth and the highest share of renewable energy sources. The three scenarios are analyzed with the help of the modeling framework LEAP (Long-range Energy Alternative Planning System). The analysis focuses on the possibilities of a sustainable energy supply based mainly on renewable energy sources. It looks explicitly at the development of the energy demand of the different sectors of the economy (households, transport, industry and the commercial sector).

1.1 Background and problem statement

Ethiopia is one of Africa's oldest independent states and a major inland country of East Africa, with an estimated population of 90 million. It has a gross area of 1,104,000 km^2 and shares borders with Djibouti, Eritrea, Sudan, Republic of South Sudan, Kenya and Somali (see Fig 1-1: The map of federal democratic republic of Ethiopia). Meanwhile, Addis Ababa, the capital of Ethiopia, is also the seat of the headquarters of the African Union, "the political capital of Africa", and also hosts the headquarters of the United Nations Economic Commissions for Africa[2].

The economy of Ethiopia is one of the fastest growing in the continent. From 2008 to 2011, the average growth rate was reported at 10.4 %, and estimated growth was 8.6 % in 2012 (ECA/SRO-EA/ICE/2013/08, p 6). Improvements in the agricultural, service and construction sectors, growth in export and improved investment flows are the main reasons for the growth of the country. Ethiopia also recently announced major plans that massively increase energy sector development as a driver of future growth. A number of big projects are already in the pipeline, expected to be introduced into the energy system in the mid to later part of this decade (ECA/SRO-EA/ICE/2013/08, p. 106).

[2] *United Nations , http://www.un.org/en/ecosoc/newfunct/pdf13/dcf_ethiopia_logistics.pdf , Accessed September 2013*

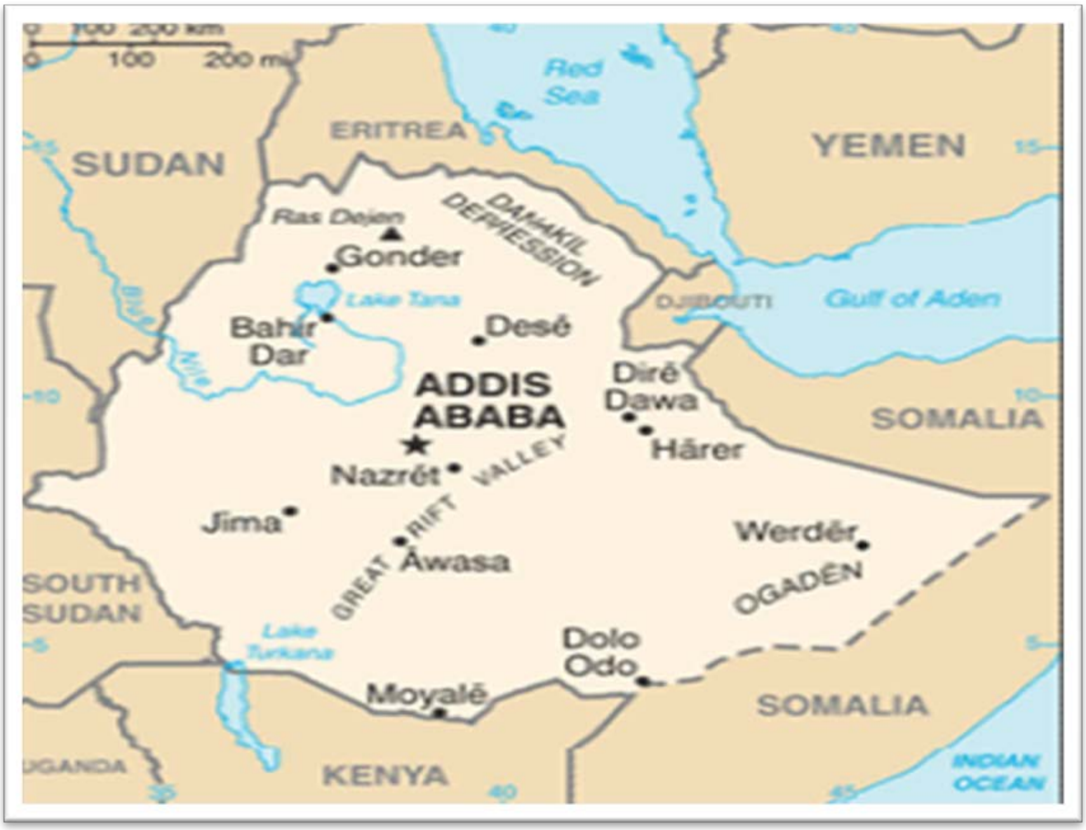


Figure 1-1: The map of the federal democratic republic of Ethiopia
Source: Central Intelligence Agency (CIA), "The world fact book"[3]

Ethiopia's Background

- *Lies between latitudes 3 degrees and 15 minutes and 18 degrees north of the equator, and between 33 degrees and 48 degrees to the east*
- *Size; Total: 1,127,127 km^2 (land: 1,119,683 km^2, water: 7,444 km^2)*
- *Lowest point: Denakil Depression: - 125 m*
- *Highest point: Ras Dashen 4,620 m*
- *Population about 84.7 Million (in 2011)*
- *Coastline : 0 km (landlocked)*

• Rural population: 84%; Urban population: 15.13%; Density: 59.4/sq. Km; Population growth 2.6% per year (according to 2007 Population and housing census of Ethiopia)

Source: Moges (2009); World Energy Council, p. 4; CIA (Ibid); CSA, 2007

[3] *CIA, The world Fact Book, https://www.cia.gov/library/publications/the-world-factbook/geos/et.html , Accessed 29/11/2012*

Ethiopia's economy has maintained a positive growth rate, and it is expected that this trend will continue in the coming years. The growth of the country's economy is steadily increasing the demand for energy, and this will continue to play a vital role. Nevertheless, this role can be hindered by several challenges including: security of energy supply, energy import dependency, protection of the environment, and inadequacy of the existing energy system.

Ethiopia's potential for hydropower is considerable. But it is necessary to have a broad mix of renewable energy sources, especially in times of climate change when precipitation can be diminished. Today, the energy household of Ethiopia is characterized by extremely low primary energy consumption, low level of electrification, a general dependence on firewood and increase dependence on imports of fossil fuels, sole dependence on hydropower resources for electricity and low standards of energy efficiency. Overall Ethiopia's energy sector is challenged due to the following factors:

- the economy and population growth /2.6 %/, annually[4];
- the goal of becoming a middle-income country by year 2025 (CRGE, 2011);
- surging demand for energy of 10-12 % per annum, due to rapid economic growth;
- only ~14 % of the population having access to electricity (USAID, 2013, p. 8);
- almost all of the country's modern fuel need is met by importation of petroleum products, steadily increasing energy prices, especially petroleum (uncertainty about future energy prices);
- the goal of becoming a net exporter of electricity in the region.

In order to deal with the above challenges, it is important that a long-term perspective should be taken when examining various energy options and policy frameworks to guide the development towards a sustainable energy system. The existing energy strategies and policies are not adequate to address the above challenges. Therefore, to deal with such uncertainties in the long-term, identification of alternative energy pathways and assessment of the consequences of these pathways would be useful for Ethiopia's future energy planning and to manage the use of energy more efficiently. Besides helping Ethiopia to develop sustainably, such planning can help to avoid future energy crises for the country. A sustainable energy supply for Ethiopia requires the use of renewable energy sources and increased energy

[4] *This is based on the Ethiopia's Population and Housing Census result of 2007* http://www.csa.gov.et/newcsaweb/images/documents/pdf_files/regional/Oromya1.pdf , [Accessed June 2010]

efficiency in the main economic sectors to avoid a vast increase of GHG emissions and an even greater import dependence.

This research is devoted to the development of long-term energy planning for Ethiopia to develop a comprehensive framework for energy policy analysis. This framework can help decision makers and most importantly energy policymakers to formulate long-term sustainable energy policies based on the available potential of different energy sources in the country. To facilitate identification of long-term energy pathways and an assessment of the pathways, a scenario-based analysis approach is taken. The scenario approach helps to examine the interactions between different and diverse forces that would shape the future development of the energy system of Ethiopia. To examine the long-term impacts of various scenarios of the energy sector, there is a need for a modeling approach which is able to address the energy sector in detail. Among the energy models, a bottom-up approach is employed for this research work, since the input-output model would be the most suitable model for the purpose of analyzing wide impacts in detail. The energy consumption in the base year will be analyzed by using the end-use model LEAP (Long-range Energy Alternative Planning system) developed by Tellus Institute, Boston. LEAP belongs to the group of accounting models, used to simulate and manage scenarios of future energy developments of a country. LEAP allows a high level of disaggregation of both the supply and the demand of energy[5]. In many countries energy modeling has had a significant impact in shaping national energy policies. The research developed a comprehensive potential impact assessment of the proposed sustainable energy scenarios on economic development, as well as on greenhouse gas emissions, in order to ensure viable and sustainable long-term energy pathways for Ethiopia. The research explores the feasibility of using energy models and planning tools for the development of a sustainable national energy policy for Ethiopia and analyzes future energy scenarios for the country in the context of energy security and sustainable development.

[5] *Heaps, C.G., 2012. Long-range Energy Alternatives Planning (LEAP) system. Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org,*

Research Questions

In short, there is a need for Ethiopia to develop a comprehensive framework for energy policy analysis. This framework would help energy policymakers to formulate long-term sustainable energy policies by examining the following specific questions:

A: Current energy system in Ethiopia

- What are the current and anticipated energy supplies and demands; current and planned energy legislation, regulation and policies; and the current and planned infrastructure for delivery, generation and distribution of energy in the region?
- How do the economic strengths of the country relate to these energy systems – i.e. which policies are considered to be the strongest and weakest for a sustainable energy system?

B: Planning sustainable energy systems

- What is the future energy demand of the country and how can this be satisfied with the least cost in the mid to long term?
- What methodologies have been used by the country for :
    - i. Energy planning, and
    - ii. Sustainable energy policy planning?
- Has any attention been given to sustainable and or renewable energy in the planning process?
- What energy policy planning methodologies and, more specifically sustainable energy policy planning methodologies, (if any) are commonly used by the government?
- Which sustainable energy policy options are recommended for Ethiopia? And how can the viable sustainable energy policies planning methods be improved upon in a manner specifically tailored to Ethiopia?

C: Anticipated Impacts of sustainable energy policy planning on Ethiopia's current energy policies

- What impacts are expected on energy security, the environment impacts and social development as a result of implementing the suggested sustainable energy policies?

- What national policies have been successful in wide scale implementation of new technology within Ethiopia in the current context?
- Are there international sources to support the early and most expensive stages of sustainable energy development?

1.2 Research Objectives

The main objective of this research is to identify a long-term energy pathway that would meet Ethiopia's energy needs in a sustainable manner while drawing on the potential of indigenous energy resource. In pursuing this broad objective, the research identifies a Long Term Alternative Energy Planning (LEAP) adaptable to Ethiopia's specific energy conditions.

There are also some specific objectives that can be addressed concurrently with the main objective. These are:

- To review energy development, resources potential and associated policy responses in Ethiopia.
- To develop long-term energy scenarios for Ethiopia by considering key factors that have the potential to influence Ethiopia's energy policies in the future
- To develop an energy model of the Ethiopian energy system and to examine the long-term energy impacts of various scenarios in terms of energy supply mix, energy needs generation mix technology mix and CO_2 emissions.
- To assess policies significance of the developed scenarios in terms of sustainable energy system in Ethiopia.

Hypothesis

The major premise of this research is that Ethiopia has had a poor record of performance for sustainable energy supply and use, and that this poor performance has been caused by poor domestic policy decisions. Better decisions could have been made that were more in line with Ethiopia's economic structure, demography, geography and trade profile. The essential objective of this thesis is to test the following hypothesis:

1. It is possible to develop an energy modeling framework, and use this framework, to examine the long-term energy impacts of various scenarios for energy needs, fuel mix, technology mix, generation mix and CO_2 emissions.

2. It is possible to identify a long-term energy pathway that would meet the country's energy needs in a sustainable manner.

1.3 Scope of research

This research focuses on the question of whether it is possible to change the current energy trends towards sustainability while achieving current energy and climate policy objectives in Ethiopia. This question is addressed with the help of the energy planning model LEAP.

The development of the model pursued the goal of developing an adequate simulation for Ethiopia capable of incorporating a sustainable energy supply and policy and measuring the consequences at the national level. The integrated environment, energy and economy model LEAP, an accounting model allows users *"to track how energy is consumed, converted and produced under a range of assumptions, with a high level of detail for supply and end-use sectors"* (ERI, 2003, p. 4). The framework of the energy model is based on the anticipated needs of the scenario analysis. The model makes it possible to simulate different policies and their expected effects for different sectors over a period of 2010 to 2050.

The study is thus focused on the modeling and analysis of the energy sector of Ethiopia. The scenarios are assessed in terms of their long term sustainable energy strategies and their impacts on a possible energy policy framework. The study addresses primary energy mix, electricity generation mix by fuel and type of technology and greenhouse gas (GHG) emissions reductions. In this research the discussion on GHG emissions focuses mainly on CO_2 emissions from energy generation. For the purpose of modeling, demand is categorized into household, industry, transport and commercial sectors. The model forms the basis for calculating the impact of utilizing renewable energy resources in Ethiopia. Energy policy measures are assessed according to environmental aspects and impact on social and economic policy. The objective of the scenario development and modeling is to determine the effects of different combinations of various energy technologies, identify possible conflicts with other social and economic policy priorities and assess the ability of the technologies to achieve a higher proportion of renewable energy. Scenarios development and modeling was a participatory process designed to include stakeholders and experts in the field of energy policy and energy supply who are actively involved in scientific work. The time frame for the analysis of this research is for 40 years from 2010 to 2050. A forty-year time horizon accounts for energy the long life span of energy technologies and the long term implications of climate change.

1.4 Research framework

This research mainly focuses on modeling and analyzing Ethiopia's future energy system. It is multidisciplinary in nature and requires the application of several methodologies and diverse information. Thus, the main research of this study will be implemented in a four step approach. Fig 1-2 provides a broad overview of the methodological framework applied in this research.

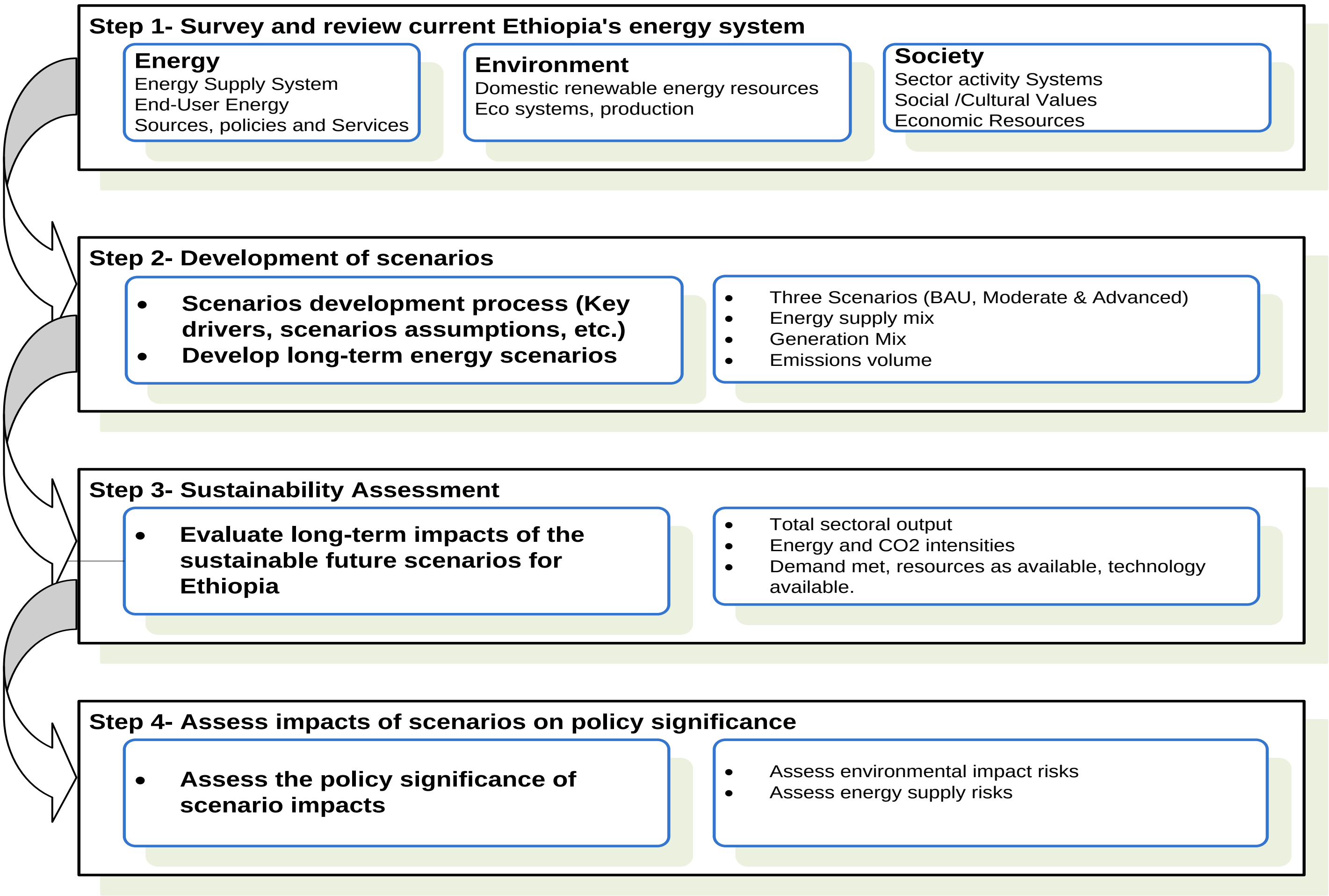


Figure 1-2: The overview of the methodological framework
Source: Adapted from Susan Krumdieck & Andreas Hamm 2009, p. 5

Step 1: Surveys and review Ethiopia's current energy system

The first step is the assessment of the energy supply system, energy auditing of the end-user energy service needs, and a survey of the geography, environment and renewable energy resources, existing energy polices and cultural values. This survey and review work is used to characterize the current energy system. The data is the basis for modeling to be carried out in the next step.

A. Energy supply system

The energy supply and distribution system data was obtained by interviewing different stakeholders, energy experts and dispatching questionnaires to government agencies and from power production and supply companies.

B. Energy demand and end-user activities

Energy audits are a well-known method of understanding the end user's physical system and behavior patterns. Data accessed from the local energy audits and assessments include activity patterns, energy use, energy technologies used and energy costs. The range of sectors' quality preference for energy services and energy supply characteristics are assessed.

C. Environmental assessment

The resources used and the environmental impacts of the activities of the system are also assessed. In some regions much of this information may be available from government agencies or researchers.

D. Social values and shared cultural vision

A method is developed for surveying the social values about the energy supply and environmental impacts, and the shared cultural vision about the activity system.

Step 2: Development of Scenarios

To assess the future energy demand, the long-term energy service levels are modeled to produce reference sector energy demand profiles for Ethiopia. The scenario approach is used by considering key factors related to energy access and security in Ethiopia. These factors include energy supply security, energy diversity, use of advanced technologies, socio-economic development and CO_2 limits. In the context of this research, three scenarios are formulated by considering the influence of these factors, namely: Business as usual (BAU) scenario, and two further scenarios, Scenario 1 (Moderate shift) and Scenario 2 (Advanced shift). Scenario 1 and Scenario 2 are characterized by different rates of growth of the gross domestic product (GDP) and more different levels of renewable energy use. These scenarios are explained in depth in Chapter 5.

The scenarios are developed using the LEAP tool with the built-in environment, energy and economy model, whereby a quantitative description and evaluation takes place. LEAP is selected because it is one of the bottom-up models capable of analyzing the energy system at a disaggregated level and with detailed representation of technologies. The energy supply options chosen for the future analyzing are determined by the available energy resources, and the sustainability intentions and values determined in the surveys in Step 1. Commercially proven technologies are considered in the methodology. The type of power supply system is determined by undertaking a basic engineering concept overview using known performance of each technology and the information about available resources collected in Step 1.

Step 3: Sustainability assessment

The results of the scenarios' impacts on energy sustainability are obtained from the energy model, and the energy oriented input-output model of Ethiopia is assessed. Environmental risk is estimated according to the likelihood and impact of environmental damage. The risks to essential activities posed by fossil fuel availability can be assessed by analyzing the impact of fossil fuels on the activities in question.

Step 4: Assess Impacts of scenarios on policy significance

An integrated modeling tool of LEAP is suitable framework for analysis, since it takes into account the complex and diverse interactions between the various sectors of the economy explicitly and consistently. The implications for energy policy for Ethiopia are determined by comparing the impacts of the three scenarios (BAU, Scenario 1, and Scenario 2) and by considering limitations and constraints that may arise in pursuing various policies. Thus the effects of the scenarios on energy consumption and the environment are mapped in detail. The development of scenarios made it possible to identify different energy technologies, possible policy measures and political strategies which form a balanced approach to sustainable development, in terms of social, environmental and economic objectives. The deliverables for each step are outlined in Table 1-1.

Table 1-1: The deliverable for each step

Step	Activity	Questions Answered	Deliverable
1	Data collection	What are the existing demands and supplies for available potential resources?	Database development and review of current energy status.
2	Energy scenario modeling	What could be various development patterns and how could energy demand be met?	Identification of various growth scenarios and potential energy resources.
3	Sustainable energy options	What could be long term sustainable energy paths amongst the identified scenarios?	Ranked sustainable energy scenarios.
4	Energy policy	What short term and long term policy action plan should be adopted?	Guideline on policy formulation.

1.5 Significance of the study

This research has a number of important benefits:

- ✓ A significant benefit of this research is that the developed scenarios are driven by factors pertaining to energy related issues in Ethiopia and also various options available to support an increased energy demand, while reducing CO_2 emissions through use of renewable energy.

- ✓ Another major benefit is the development of a valuable research framework which enables examination of the energy and economic sectors at a high level of detail. The energy sector model, which is strong in technology representation, can capture details of an energy system both on the demand and supply sides. In this way, the research is able to analyze both the energy and economic impacts in greater detail.

- ✓ The assessed sustainable energy options and the suggested policy measures for their implementation can have a number of positive socio-economic effects for Ethiopia. Examples include improved cost-effectiveness of energy supply, increased security of supply, improved efficiency of energy use, positive effects on local industry, technology development, employment and positive impacts on environmental protection.

- ✓ The pathways derived from the analysis, which detail how the energy sector in Ethiopia may develop over a long-term time horizon, provide additional information that helps energy policy makers define guidelines and strategies for policies to shape the country's energy sector.

The result of this research could be useful the following ways: 1) Based on research findings the policy makers will be able to make more informed decisions by knowing the nature of the relationship between energy, environment and economy. 2) The energy policy researchers could also apply this knowledge to shape further future energy policy. 3) Stakeholders of the energy sector may find it an important strategic tool to which extent and ways to involve in the energy project development.

1.6 Structure of the thesis

This thesis is organized by seven chapters each with detailed explanation and brief discussion. The study is structured as follows:

Chapter 2 presents an overview of Ethiopia's energy balance, energy system status, review of existing energy policies and the country's institutional dimension in the energy sector. The current electricity sector is also described in this chapter, with information related to electricity generation by type of fuel and technology.

Chapter 3 assesses the available indigenous energy resource potential (conventional and renewable energy).

Chapter 4 introduces energy modeling to define the technique and selection of models, explains the model LEAP briefly.

The main part of the report is represented in Chapter 5. The chapter describes the scenario development process in detail, develops three energy scenarios, and provides a brief discussion of the modeling framework. The scenarios are examined in terms of their impacts on energy requirements, technology mix and CO_2 emissions. The modeling results as well as the investigated scenarios are described in their forms and framework assumptions.

In Chapter 6 an overview of “sustainability” aspects of energy system is presented, the scenarios using selected sustainability indicators are described as well as the scenarios’ policy significance is assessed.

Finally, the findings and the conclusions from this research are given in Chapter 7 along with a number recommendations and suggestions for future work.

2 STATUS QUO OF ETHIOPIA'S ENERGY SYSTEM

Ethiopia is a transforming country featuring favorable GDP growth rates for the last decade and increasing pace in recent years. Between 2008 and 2011, the average growth was reported at 10.4 % (ECA/SRO-EA/ICE/2013/08, p. 106). The Ethiopian government has released the "Plan for Accelerated and Sustained Development to End Poverty" (PASDEP), a strategic agenda for the five-year period 2005/06-2009/10. The main objective of this strategic agenda is to eradicate poverty. Here it is mentioned that one factor that can contribute to poverty reduction is an improvement in energy access. There is a plan to develop the energy sector in the strategic agenda. (PASDEP, 2006, p. 12). A rural electrification program was launched under PASDEP called Universal Electrification Access Program (UEAP). The goal was to increase the number of electrified population up to 50 % in 2010, from an initial 16 % at the end of 2005, by increasing the power capacity from 791 MW to about 2,218 MW by 2009/10, expanding of the grid to 13,054 km and the energy loss was planned to be reduced from the current level of 19.5 % to the international average of 13.5 %, during the same period of time (World Energy Council, 2009, p. 10).

However, besides the country's economic growth and the strategic plan, access to energy in Ethiopia is relatively low, no more than 41 %[6] of the population has access to electricity and the rest of the energy consumed is taken from traditional resources, such as wood fuel and dung (SREP investment plan, 2012, p. 1). The total installed capacity of electric generation for the country is about 2,060 MW, (88 % of which is from hydropower, 11 % diesel and 1 % thermal) which covers only 10 % of national energy demand (Meder, K., 2011, p. 5). As in most Sub-Saharan African countries, the gap between urban access and rural access is huge. Urban electricity access is estimated at 85 % while only 11 % of rural households (85 % of 85 million people) enjoy grid electricity (IEA WEO, 2012). Further enhancement of the energy sector is a must in order to maintain the economic growth and become a middle-income country by 2025 according to the Ethiopian government plan.

Therefore, sustainable energy options for Ethiopia must be identified, requiring a comprehensive analysis of the current energy situation. This chapter presents an overview of the Socio-Economic aspects, the pattern of energy supply and demand in Ethiopia. The discussion also covers an explanation of electricity generation and consumption patterns.

[6] *Gro Ventures, http://www.gro-ventures.com/wp-content/uploads/2013/10/Gro-Energy-Electricity-in-the-EAC-and-Ethiopia1.pdf , Accessed September 2013*

Lastly, an overview of existing energy policies and the country's institutional dimension in the energy sector is given.

2.1 Socio-Economic and environmental situation

2.1.1 Socio-Economic dimension

Ethiopia is ranked as the second most populous country in Africa. Ethiopia's population is over 90 million, growing about 2.7 % annually over the period of 2000-2012. The population density grew at 2.79 % per annum (66 people/km^2 in 2000 and 89.4/km^2 in 2011). The urban percentage of the population was 14.9 % in 2000 and has reached to 17 % in 2011 and will continue with an annual urbanization rate of 3.57 % over the period of 2010-2015 (World Development Indicators, 2013, p. 21).

Ethiopia has been experiencing a remarkable economic development which has made Ethiopia one of Africa's, and the world's best performing economies. According to the International Monetary Fund (IMF, 2013, p. 159), the real growth was 8.4 % per annum over the period of 2001-2010, with an average figure of 10.8 % per annum for the period from 2005/06 to 2009/10. The economy is dominated by the agricultural sector with high increases in the growth rates of the services and industry sectors. Ethiopia's GDP was around US$ 30 billion in 2011 which was slightly smaller than that of Ghana (US$ 31 billion with a population of only 24 million) (Economist intelligence unit, April 2010). As well, the country's growth rate averaged at 10.4 % over the years 2008 to 2011, driven primarily by a commercialization of agriculture (accounts for 44 % of GDP, about 80 % of total employment and 70 % export earnings), construction and service sectors are source of growth (AfDB and Ethiopia, 2013, p. 3). However in terms of GDP per capita, Ethiopia still lies at low-income level. In 2011 World Bank reported Ethiopia achieved per capita income of US$ 410, being positioned 211 in the world[7]. The economic growth of the country has resulted in a dramatic drop in the national poverty rate, from 60.5 % in 2005 to 30.7 % in 2011 (IMF, 2013, p. 4). Figure 2-1 shows Ethiopia's real GDP per capita over the years 1993 to 2012.

[7] *World Bank, Economic overview, http://www.worldbank.org/en/country/ethiopia/overview , Accessed February 2014*

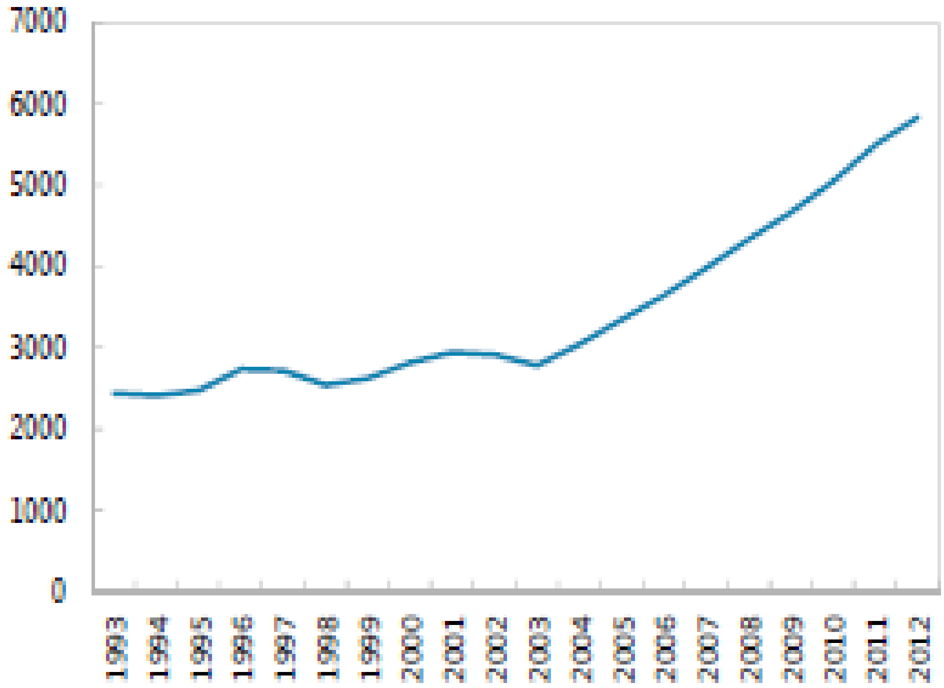


Figure 2-1: Ethiopia: Real GDP Capita (Birr) (1993-2012)
Source: IMF 2013, p. 4

Note: Exchange rate of the Birr against the dollar is 18.1597Birr per US$ as of December, 2012 (data from National Bank of Ethiopia).

Ethiopia's economy continues to grow through the performance of the reforms to the state-led Growth and Transformation Plan (GTP), implementing several plans of socio-economic development. In 2005, the government started to implement the "Agriculture-piloted Industrialized Development Strategy", increasing agricultural input, powerfully developing emerging industries, exporting industrial goods to earn foreign currency, promoting tourism and aviation and attracting foreign investors to participate in Ethiopian energy and mineral resource development. As a result, the national economy kept the rapid growth at 9 % and above. GTP is a five year development plan launched in 2010 for poverty eradication, sustained growth, and to lay the foundation for structural transformation (MoFED, 2010). The five year economic plan has achieved high single-digit growth rates. GTP will need to consolidate the results achieved to achieve the Millennium Developments Goals (MDGs) while focusing on growth and transformation. According to the African development bank report 2010, Ethiopia's GDP in comparison to Africa's economy in general was almost double over the period of 2003-2009 (see Figure 2-2).

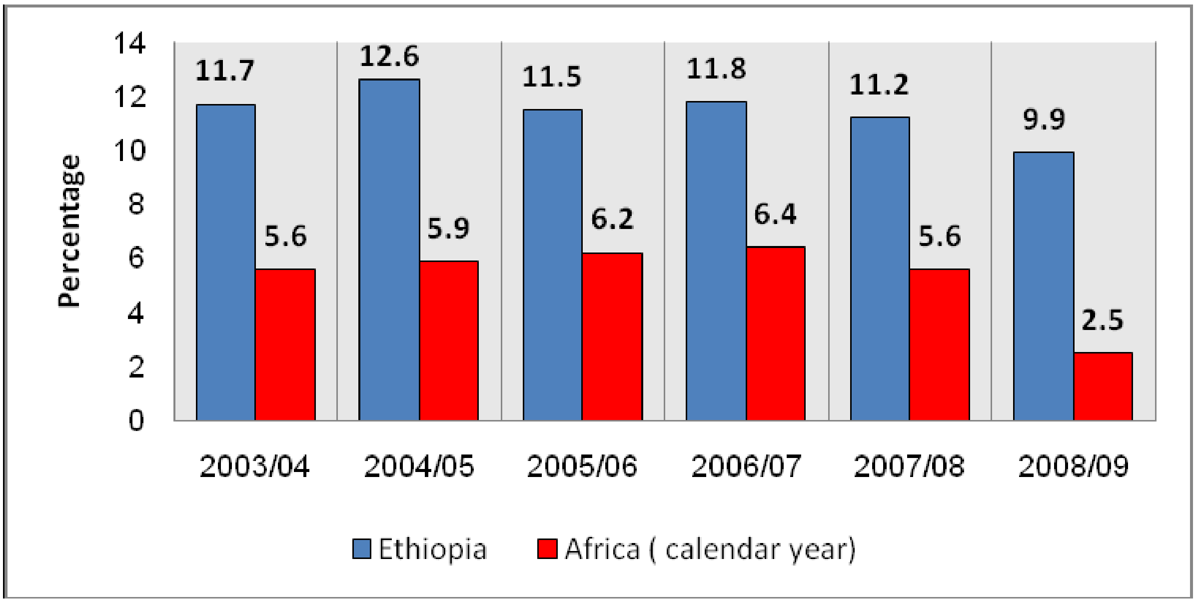


Figure 2-2: Ethiopia's GDP in comparison of Africa
Source: AfDB, 2010, p. 1

The agricultural sector plays a key role in the country's economy which accounts for 44 % of GDP in 2012. Since 2007, the fraction of the country's GDP accounted for by the agricultural sector has continuously grown slower in comparison to the other sectors (service and industry) and grew by 5 % in 2012 while the industrial sector grew by 13.6 % in the same period. This indicates Ethiopia's economy has gradually moved forward to industrialization. The service sector was estimated to have grown by 11 % in 2012, driven mainly by the rapid growth of international standard hotels, real estate, financial intermediation, public administration and retail businesses (AfDB, 2013, p. 3). The industrial sector grew by 13.6 % in the same year; this is mainly due to, a construction boom and an expansion in mining and manufacturing.

The pace of agriculture sector growth declined over the 2003-2009 period, while the average annual growth of the service sector greatly increased its share of country's GDP during the period of 2003 to 2009, and was followed by the industry sector (see Figure 2-3).

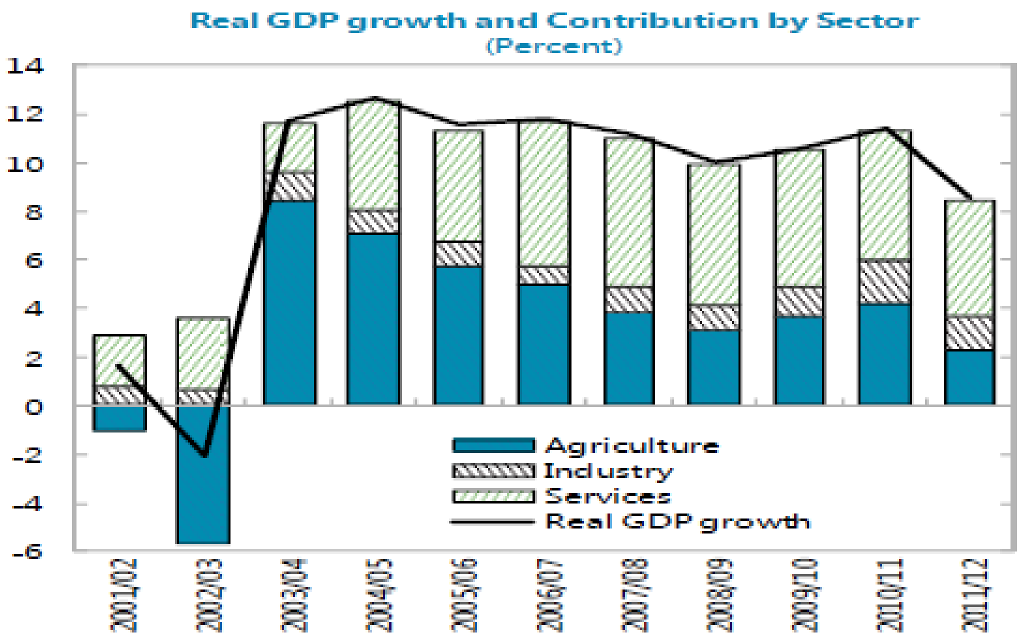


Figure 2-3: Sectoral growth over 2001-2012
Source: IMF 2013, p. 5

Agricultural production relies on petty farmer cultivation and planting, adopts traditional cropping pattern and basically crops and harvest by weather, moreover, the irrigated area accounts for only 0.77 % of cultivable area, thus the natural disaster resistance is low (FAO, 2005, p. 49). Main agricultural products include teff, corn, wheat, sorghum, barley, millet, oat and others were main economic crops include coffee, chat, flowers, vegetables, oil crops, etc. Ethiopia ranks 5th in the world and 1st place in Africa for its coffee yield, but its coffee processing technologies are out of date, and most of its exported coffee is roughly processed or unprocessed (ICO, 2012, p. 8). In recent years, Ethiopian flower plant exports have greatly increased, and Ethiopia has ascended to 4th place in the world and the 2nd place in Africa next to Kenya. Moreover, Ethiopian flowers are popular in the international market for their large size, long blooming period and scope[8].

Animal husbandry is huge in scale, and Ethiopia ranks 1st in Africa for its livestock quantity up to 52 million heads, inclusive of cattle, sheep and goat[9]. Animal husbandry weighs 25 % in the gross value of agricultural output (Behnke R., 2010). However, traditional pasturing makes the unit output of animal husbandry very small; basically small scale household

[8] *Allafrica, http://allafrica.com/stories/201305210024.html , February 2014*
[9] *Indiafrica, Investment Opportunities in Ethiopia, http://www.indiafrica.in/FCountryProfilesInvestmentOpportunitiesinEthiopia.html , February 2014*

pasturing is dominant and herdsmen live dispersedly, mainly distributed in low-lying areas of East and South Ethiopia. Animal husbandry is significantly affected by climate and plague and develops slowly.

Industrial basis is weak, industrial sectors are incomplete, industrial structure is unreasonable, and industrial products mainly include textile, leather, food & beverage, metal, furniture, tyres, building materials, etc.[10].

2.1.2 Environmental dimension

Ethiopia's emission rate compared to any developing countries shows low level. In comparison to Sub-Saharan Africa countries, Ethiopia's energy related CO_2 emission per person is still very low whereas they have grown over the period of 2000 and 2010, to the transport sector growth which leads to an increase of imports of petroleum products. Ethiopia's CO_2 emission per capita was 0.06 tons in 2010 and 0.27 Kg of CO_2 per US dollar using 2005 prices (GDP using market exchange rates) (IEA statistics, 2012,p 94). However, conventional economic development would project environmental impact. The country's emissions are expected to grow rapidly since more carbon intensive fuels are being applied in the growing economic sectors.

Energy related CO_2 emissions have grown between 2000 and 2010 and the specific CO_2 emissions per capita actually increased from 0.05 metric tons per capita to 0.06 metric tons per capita of the same period. Based on the peak in 2009, an increase of 4.55 % was recorded (IEA statistics, 2012, p. 100).

Figure 2-4 presents Ethiopia's energy related CO_2 emissions (metric tons per capita) in the year 2009, in comparison to World, OECD countries and sub-Saharan Africa countries.

[10] *Ethiopian Government Portal, http://www.ethiopia.gov.et/de/economy, February 2014*

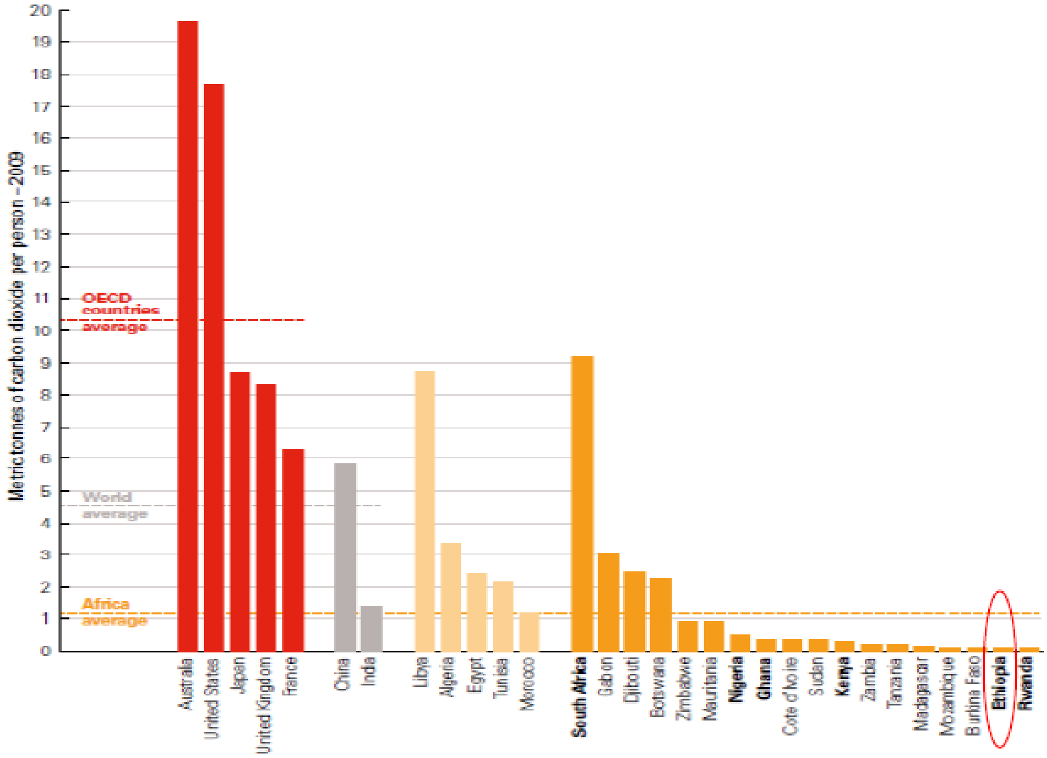


Figure 2-4: African major sources of GHG emissions, per capita CO_2 Emission
Source: United Nations Environnent Programme (UNEP), 2011, p. 11

2.2 Ethiopia's energy balance: General overview

The energy balance of Ethiopia, according to the International Energy Agency (IEA), shows Ethiopia's energy consumption is estimated at about 31,370 kilotons of oil equivalent (ktoe) in 2010 with a per capita energy consumption of 0.4 toe (IEA 2012, II.133). The structure of energy consumption in Ethiopia reveals that the energy use of Ethiopia, like many of the countries in Sub-Saharan Africa, is characterized by a heavy reliance on traditional biomass (wood fuels, crop residues and cattle dung). There are four types of primary energy supply in Ethiopia, namely; imported fossil fuel, hydro, geothermal and combustible renewables and waste. Combustible renewables are used mainly in rural areas for cooking and lighting purposes when about more than 80 % of the country's population lives in rural area (Figure 2-5).

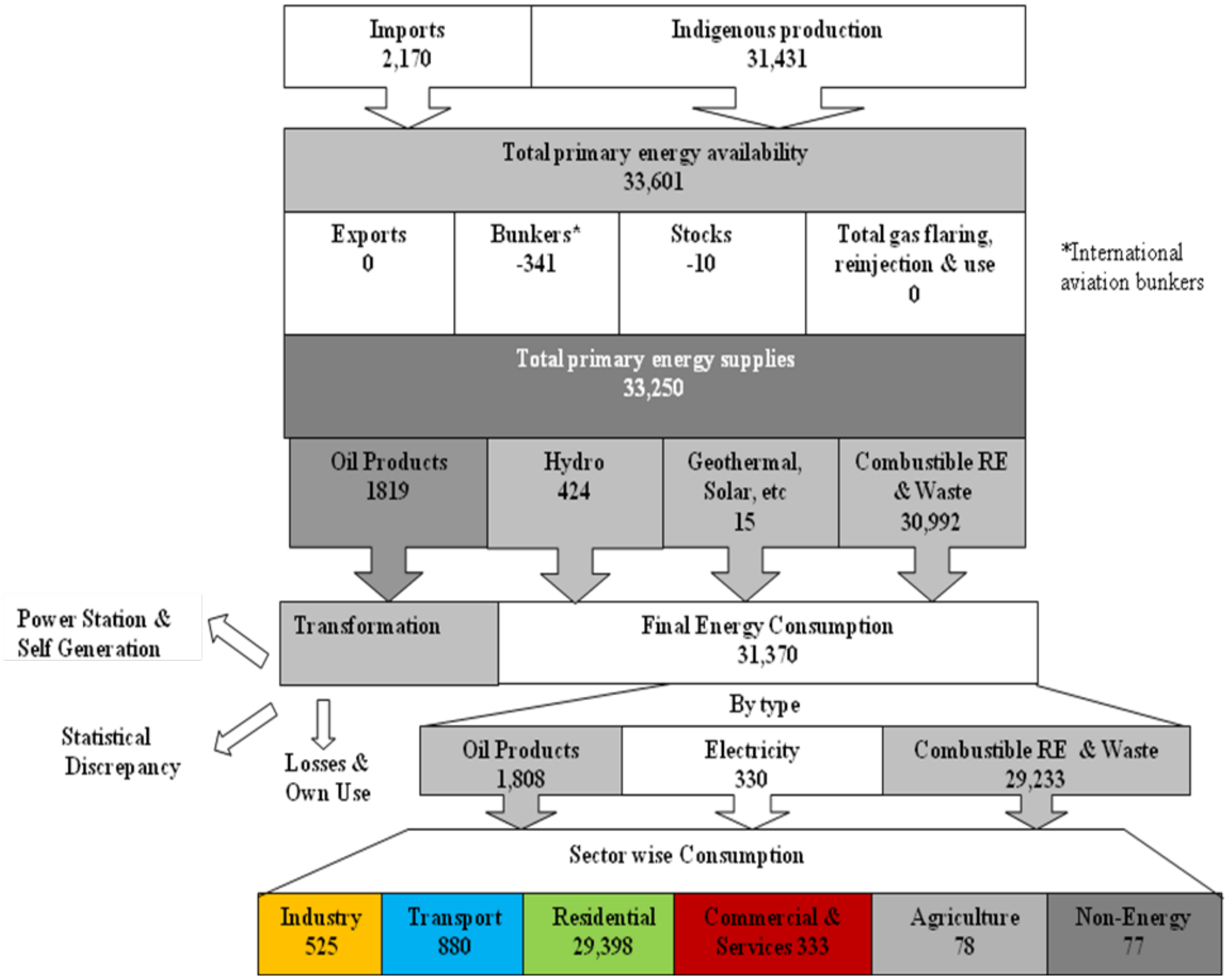


Figure 2-5: Energy flow in national Energy system in 2010 (ktoe)
Source: compiled based on IEA 2012

2.2.1 Primary energy supply

Ethiopia's energy supply is primarily based on traditional biomass with a share of 93.2 % of the final energy consumption, with 78 % being derived from woody biomass, 7 % from crop residues and 8 % from dung (ERG, 2009, p. 4-12). The oil sector use accounted for 5.47 % and hydropower 1.27 % of the final consumption in 2010 (see Figure 2-6)[11]. The share of combustible renewables in the national energy balance is declining gradually. This is mainly

[11] *IEA - International Energy Agency, http://www.iea.org/stats/WebGraphs/ETHIOPIA4.pdf , Accessed July25, 2013*

due to the increased penetration of energy efficient household stoves (SREP investment plan, 2012, p. 1).

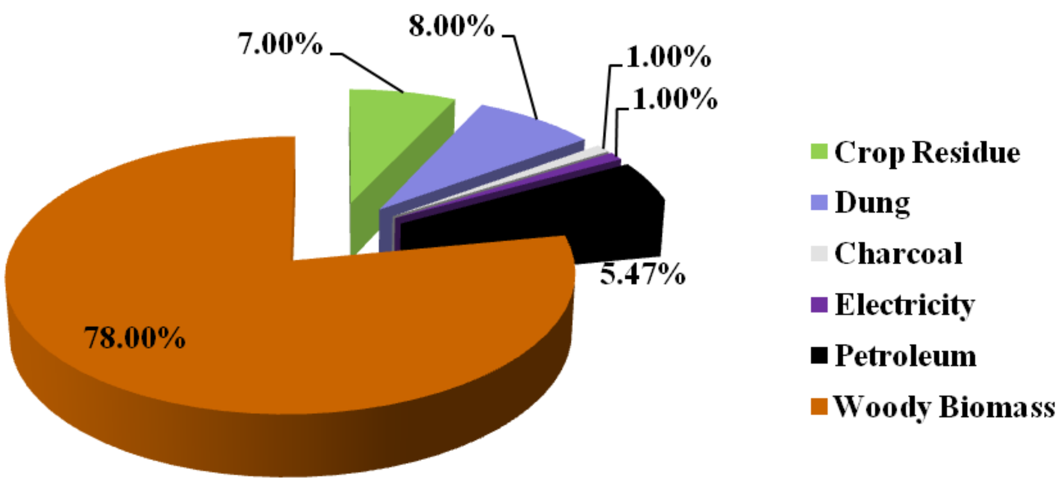


Figure 2-6: Share of total primary energy supply of Ethiopia in 2010
Source: Ethio Resource Group (ERG), 2009, p. 4-12 & IEA, 2013

- Bioenergy meeting more than 90% of total energy consumption
- Gross annual yield for bioenergy is estimated to be about 96 million tons
- Bioenergy is predominantly used for domestic and commercial cooking
- The volume of bioenergy consumed is growing steadily (at an estimated rate of at least 3%/year)
- Hydropower is the main source of electric power

Source: Ethio Resource Group (ERG), August 2009, p. 4-12, & complied from different sources

Although Ethiopia is endowed with a high hydro potential, this contributes only about 1 % of the total energy supply, which accounts for 88 % of the electric generation, followed by 11 % from diesel and, 1 % geothermal energy (EEPCo. 2011). The energy supply mix will change considerably due to changes in the power sector. In the transport sector new transport fuels (electricity and liquid biofuels) may have considerable shares and new industrial fuels such as coal and pet coke now being introduced in cement and other industries will make larger contributions for industrial energy[12]. In the residential sector liquid biofuels may become important cooking fuels (COMMEND, 2006).

The total primary energy supply increased from 25,242 ktoe in 2000 to 33,250 ktoe in 2010, achieving an annual growth rate of 2.78 % (IEA, 2011). However if combustible renewables are excluded from the energy mix, the growth was 6.3 % per annum. In comparison of supply shares for 2000 and 2010 the energy mix shows considerable changes: significant increases for hydropower, petroleum and solid fossil fuels (see Figure 2-7).

In the last 10 years' time (2000-2010), the growth of combustible renewables was the highest (29.1 %). Meanwhile the growth of primary energy supply (excluding combustible renewable) is still predicted to be high (IEA, 2011). These changes will have important implications for the environment: improved sustainability of forest resources, reduction of indoor air pollution; potential increase of greenhouse gas emissions due to increased use of petroleum and solid fossil fuels.

[12] *Allafrica, http://allafrica.com/stories/201106281065.html , Accessed December 2013*

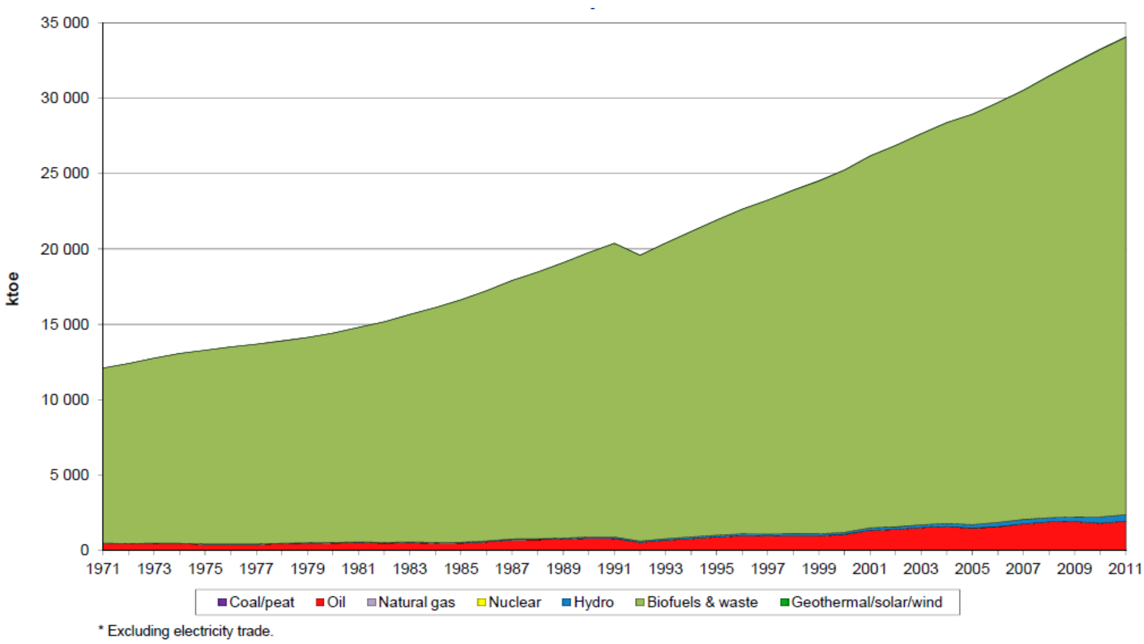
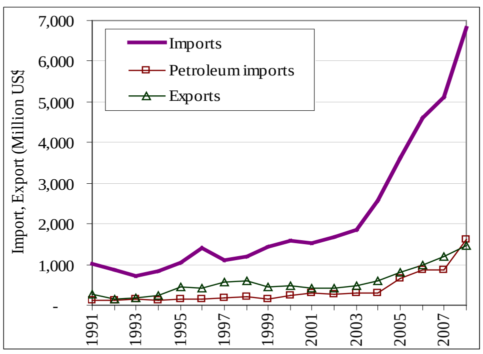


Figure 2-7: Total Primary Energy supply of Ethiopia (1971-2011)[13]

Petroleum fuels constitute about 5.47 % of the total energy, where the transport sector consumes the highest share (IEA, 2011). The country has been spending huge amount of foreign currency to import petroleum products. Looking at the amount and structure of imports for petroleum in 2008 (Figure 2-8), Ethiopia's import of petroleum fuels covers the 77 % of the total export earnings at the expense of more than 768 million USD per annum (Assefa, 2012, p. 7).



Item	2004	2005	2006	2007	2008
All imports	2,587	3,633	4,593	5,126	6,811
Petroleum imports	310	667	860	875	1,621
All exports	600	818	1,000	1,185	1,466

Figure 2-8: Petroleum imports of Ethiopia
Source: National Bank of Ethiopia, Annual Statistics 2009, p. 23

[13] *IEA, 2011, http://www.iea.org/stats/WebGraphs/ETHIOPIA5.pdF , Accessed September, 2013*

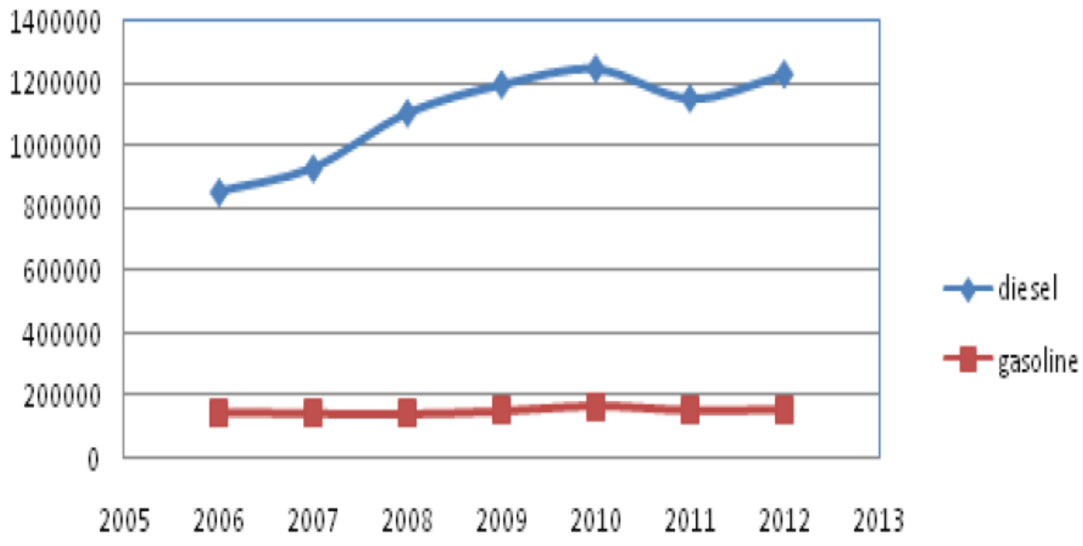


Figure 2-9: Trend in the consumption of gasoline and diesel (in Mt)
Source: Assefa, 2012, p. 7

Transportation’s consumption of oil products was about 60 % distantly followed by the industrial, residential, and commercial sectors each taking 25 %, 14 % and 1 % respectively of 2010 imports (IEA, 2012). Petroleum consumption has shown an increase of about 75% from 1.03 million tons in 2000 to 1.9 million tons in 2010 (Ibid) (Figure 2-9). Transport fuels, i.e. diesel, gasoline and jet fuel, account for about 70 % of total petroleum consumption. The comparison of current balance for Ethiopia and oil import values (Figure 2-10) presents the importance of energy security, and post 2008 oil price increase led to a drift of current account balance.

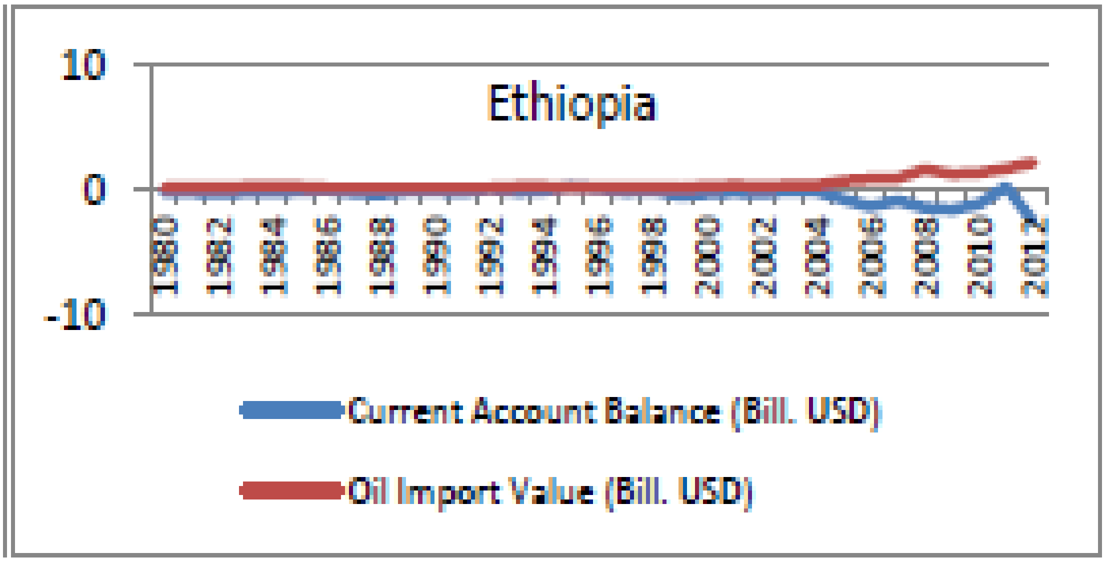


Figure 2-10: Oil import values and current account balance in Ethiopia (1980-2011)
Source: Economic Commission for Africa Sub-Regional office for Eastern Africa ECA/SRO-EA/ICE/2013/92013, p. 17

2.2.2 Final energy use

Energy use in Ethiopia has been growing in recent years. Especially, growth in transport energy use and in industrial energy use has been quicker than that of the residential sector, while those of the agriculture and commercial sectors have not much changed. The household sector is by far the largest energy consuming sector by more than 90 % (using mainly biomass for cooking), followed by the transportation sector (using almost exclusively imported petroleum, except for recent efforts to integrate biofuels into the energy mix) (IEA 2012) (see Figure 2-11).

The total final energy consumption in Ethiopia increased from 23,876 ktoe in 2000 to around 31,370 ktoe in 2010. In the last 10 years (2000-2010), the final energy growth was 2.77 % on average annually (IEA, 2012). Structurally, the share of the industry sectors in 2010 of the total final energy consumption was 2.05 %. The transport sector energy consumption was 4.23 % of final energy consumption, and the commercial sector around 1 % of final energy consumption. Looking at the developments in the various sectors of consumption, the field of industrial final energy consumption increased from 2000 to 2010 by 5.83 % annually. It increased from 298 ktoe in 2000 to 525 ktoe in 2010 (Ibid). The transport sector as well has seen an increase of final energy consumption between 2000 and 2010 by 5.57 % annually. In households energy consumption between 2000 and 2010 has annually risen by 2.61 % (Ibid). The declining share of the residential sector's energy use was probably caused by the rapid development of the infrastructure in the transport sector and industrialization in line with the escalation of economic activity during the last decade.

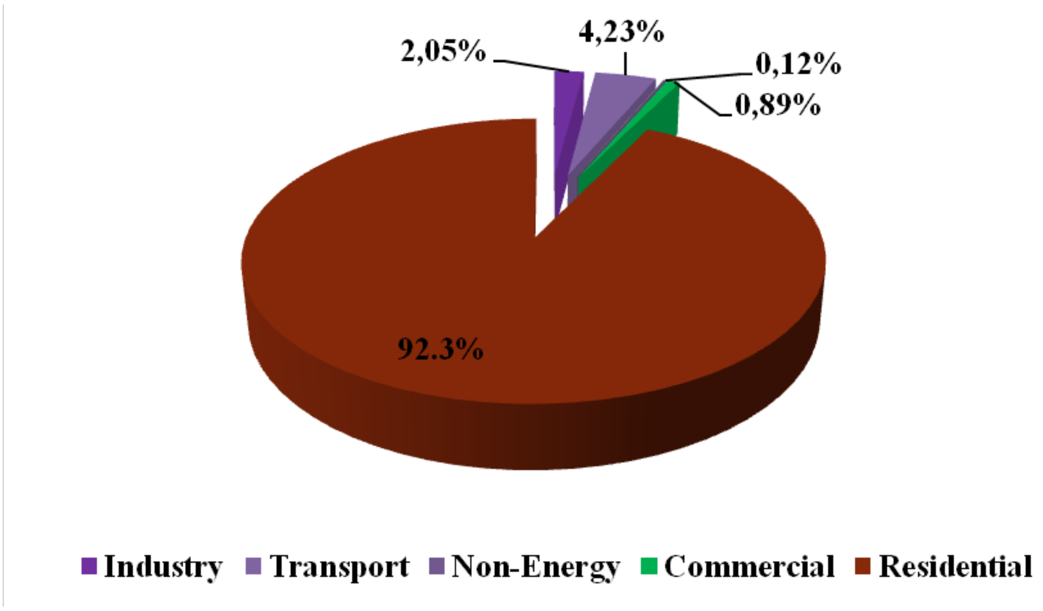


Figure 2-11: Energy use by sector in 2010
Source: IEA, 2012

Note: Non energy use covers those fuels used as raw materials in the different sectors[14]

Therefore, from an energy security perspective it needs to be followed closely what happens to sustainable management of the biomass in the country, the trend in imported fuel dependence and progress in the electricity sector. Findings suggest that rapid decline in forest bio-stock and growth in demand in Ethiopia[15], coupled with the largely unsustainable harvest are sources of serious concern for biomass-dependent household energy security in terms of continuity of sufficient supply and affordability of wood and charcoal, particularly in urban areas. The pace of transition to alternative indigenous green energy sources (such as electricity), integration of improved and efficient cook stoves as a mitigation technology,

[14] *International Energy Agency (IEA), Balance definition.* *http://www.iea.org/statistics/resources/balancedefinitions/ , Accessed September 2013*
[15] *Conservation International,* *http://www.nestle.com/asset-library/documents/creating%20shared%20value/responsible-sourcing/deforestation-guide-ethiopia.pdf , Accessed February 2014*

sustainable forest harvest and overall energy portfolio transition are going to remain structural challenges for Ethiopia.

The supply shares starting 2010 using some of the major targets for the energy sector show considerable changes: significant increases for hydropower, petroleum and solid fossil fuels; and introduction of biofuels and wind energy. These changes will have important implications for the environment: improved sustainability of forest resources, reduction of indoor air pollution; potential increase of greenhouse gas emissions due to increased use of petroleum and solid fossil fuels.

The share of energy use by sector and the types of energy used within sectors will also change when the Growth and Transformation Plan (GTP) is realized. Some of the main changes will include reduced energy intensities for biomass fuels for the household sector, increased use of electricity and liquid biofuels, significant increases in the use of fossil fuels in industry, and introduction of electricity and biofuels in the transport sector. The more significant changes are explained briefly:

2.2.2.1 Residential

The household sector is still the main energy consuming sector in Ethiopia. This sector is the largest consumer of combustible renewables and waste, which is used for cooking and baking by most rural households and a considerable proportion of urban households. A considerable proportion of households in rural areas, particularly in lowland pastoralist areas, also use biomass energy for lighting. In 2010 of the total biomass energy consumption 98.6 % was used by the residential sector whereas from the total oil products energy consumption 13.57 % was used (IEA, 2012) (see Table 2-1). The high percentage of combustible renewable used in this sector is due to the fact that about 80 % of the population live in rural and remote areas and most of them rely on waste and combustible renewables for cooking purposes(Johnson and Mengist 2013, p. 1).

2.2.2.2 Transport

The Energy demand of Ethiopia in the transport sector is increasing rapidly. The transport sector accounted for 60.42 % of the total oil products energy consumption in 2010 (IEA, 2012). In the transport sector biomass energy is used as well as ethanol fuel blended with gasoline. A 5 % blend to gasoline (E5) fuel came into effect in Addis Ababa in September 2008 and this level has been raised to 10 % (E10) since 2011 (ERG, FFE, 2009, p. 15). However, the energy from bioethanol in the transport sector is very small compared to the oil products and considered as insignificant. The total energy demand of the transport sector has significantly increased, by 5.57 % on average per annum, over the period of (2000- 2010) (IEA, 2012).

Table 2-1: Sector wise energy demand of the total primary energy supply in 2010
Source: (IEA 2012, ERG for FFE 2009, EEPCo; Ethiopia Petroleum Enterprise)

Source			
Sector	**Biomass (%)**	**Petroleum (%)**	**Electricity (%)**[16]
Residential	98.60	13.57	13.57
Industry	0.10	24.9	38.01
Commercial & Services	0.73	1.3	23.63
Transport	-	60.42	-

2.2.2.3 Industry

In the industrial sector energy consumption has grown very rapidly, although its share in the total energy consumption is still small (see Figure 2-11). In the energy balance of Ethiopia according to IEA, industries used 38.01 % of the total electricity consumption in the year 2010. From the total oil products consumption, 25 % was used by the industry sector in 2010 (IEA, 2012). Biomass energy is also used to produce heat and power but very little: in the tea industry wood is used for the drying of tea and in the sugar industry sugar cane bagasse is used to generate power for internal use (ERG, FFE, 2009, p. 15). The growth of electricity demand in this sector was also very rapid in the last decade.

[16] *The 23 % electricity losses are attributable to the poor design of the distribution network and to inadequate maintenance (USAID, 2013, p.23)and the rest accounts for own use (EEPCo.2011)*

The industry sectors' total final energy consumption in 2010 was 2.05 % (IEA, 2012). The low absolute energy consumption of the industry sector can be explained due to the agricultural based economic policy of the country.

2.2.2.4 Commercial and service sector

The service sector is composed of the commercial and social services sub-sectors. Over the period of 2000-2010, the growth of total commercial and service energy demand was 3.91 % per annum (IEA, 2012). However, if combustible renewables and waste were excluded the average growth of energy demand in the sector was 9.89 % per annum in the same period. Combustible renewable and waste energy is used in the commercial and service sectors for cooking and baking in institutions such as restaurants, bakeries, local drink houses, schools and universities, hospitals, and others (Mengistu A., 2013, p. 25). The growth of oil products in this sector increased rapidly over the period (2000-2010), reaching 7.18 % growth per annum (IEA, 2012). Oil products have gradually been replacing combustible renewables. There are two possible explanations for this shift of consumption. The growth of urbanization and the higher income per capita have accelerated the shift from the traditional combustible fuels to oil products and electricity.

Electricity as well grew very rapidly in this sector by 10.8 % per annum during the period (2000-2010) (IEA, 2012). This was caused by the rural electrification program (Universal Electricity Access Program - UEAP) carried out by the government in the last decade (EEPCo, 2011, p. ii).

2.2.3 Overview of the power sector

Ethiopia is a country with a positive trend in electricity supply and growth of about 7.72 % per year during 2004 - 2010 (EEPCo. Facts in Brief 2010-11, p. 4). The power sector is dominated by large hydropower plants. According to the Ethiopian Electric and Power Corporation (EEPCo.), Ethiopia's total electricity generation in 2010 was 3,981 GWh. Yet the per capita use of about 50 kWh per year is low compared to 510 kWh for sub-Saharan Africa (SREP investment plan, 2012, p. 2) Figure 2-12 shows the per capita electricity consumption of Ethiopia from 2003-2010. The highest growth rate of electric consumption has been recorded in the residential sector with about 10.9 % followed by commercial and service sectors with growth rate of 10.8 % per annum during (2000-2010) (IEA, 2013) (see Figure 2-13).

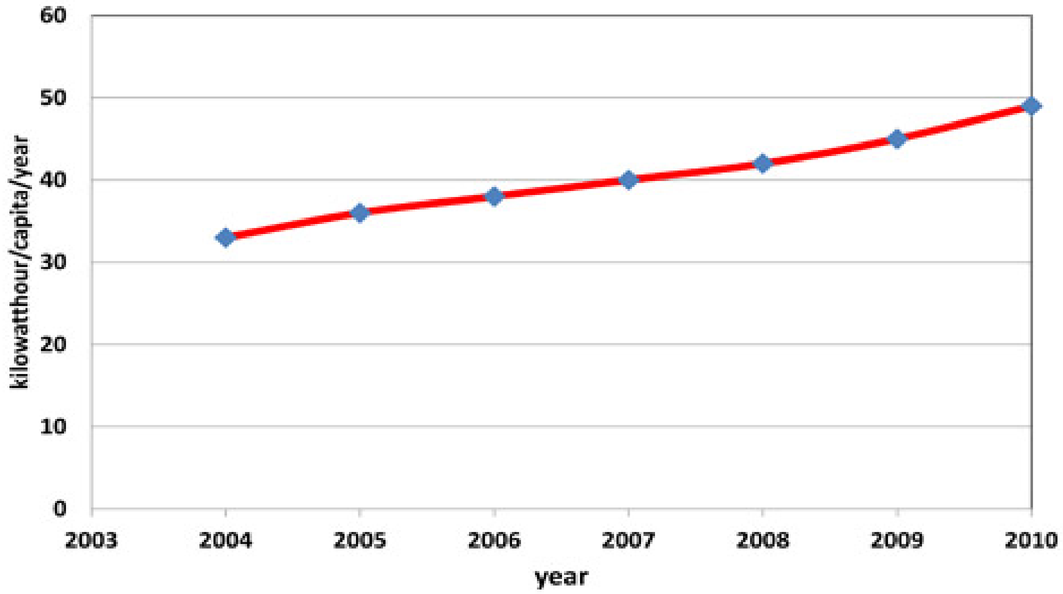


Figure 2-12: Electricity use per capita trend in Ethiopia (2003-2010)[17]

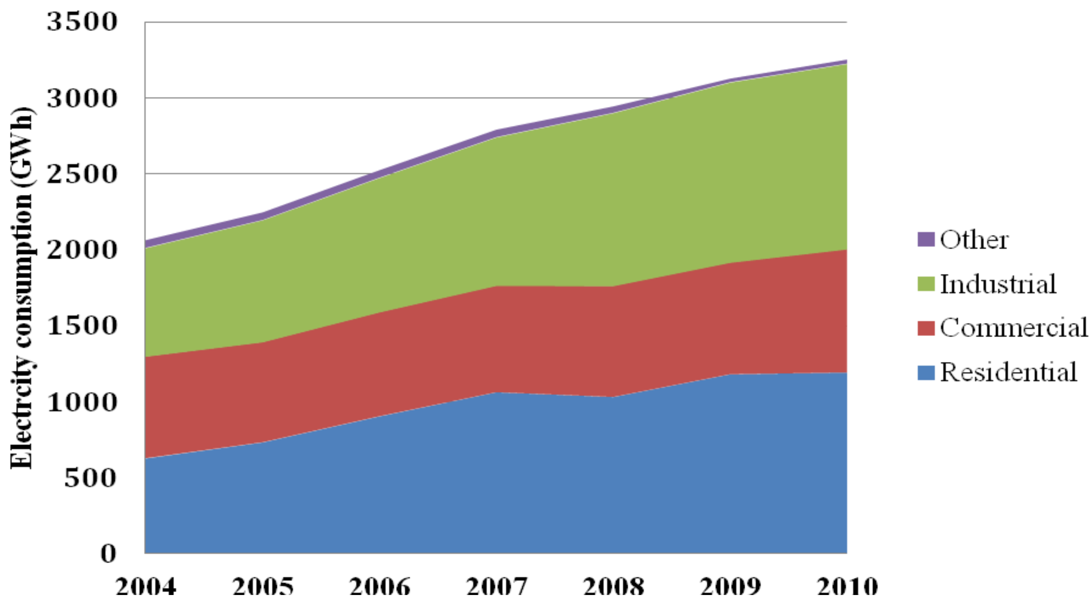


Figure 2-13: Electricity consumption by sectors (GWh)
Source: EEPCo. Facts in Brief 2010-11, p. 4

[17] *Klimstra Jacob, 2012, p.5. http://www.wartsila.com/en/africa-yearns-for-electricity, Accessed September 2013*

Electricity was used mainly in three sectors, the commercial, residential and the industrial sectors. In 2010 the highest electricity consumption in industry sector (Low Voltage -LV and High Voltage -HV based industries) was 37.5 % of the total consumption of electricity followed by residential sector used 36.5 %, and 25 % by the commercial sector (EEPCo., Facts in Brief 2010-11, p. 4). Only an insignificant amount was used in the others (street lighting and own consumption). Figure 2-14 presents percentage of electricity consumption by different sectors in 2010.

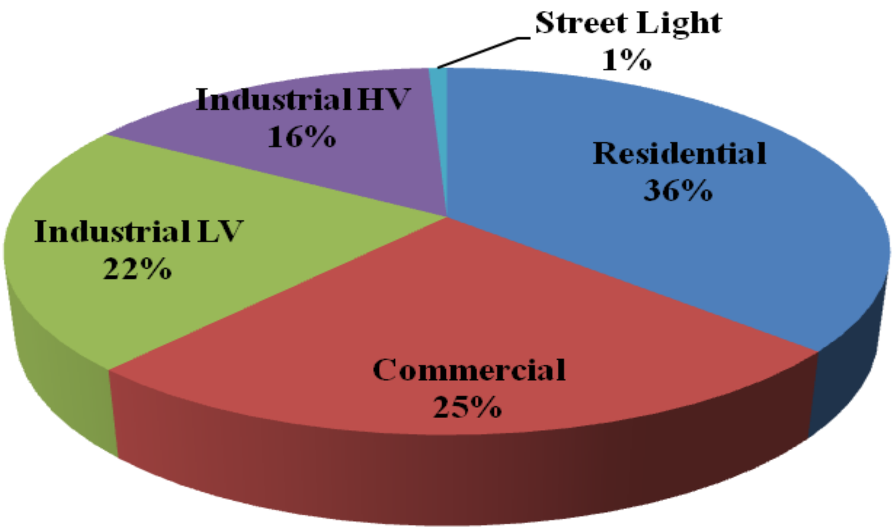


Figure 2-14: Sector wise electricity consumption in 2010
Source: EEPCo. Facts in Brief 2010-11, p. 4

Ethiopia is endowed with hydro potential. For that reason, Ethiopia's electricity supply is dominated by hydropower (see Figure 2-15). Ethiopia had an installed power capacity of 2,060 MW in 2010, out of which hydropower plants made the biggest contribution of about 86 %, around 13 % was contributed from thermal (diesel) and the remaining 1 % was from geothermal sources. The use of other renewable energy technologies (wind and solar) was insignificant (see Figure 2-16).

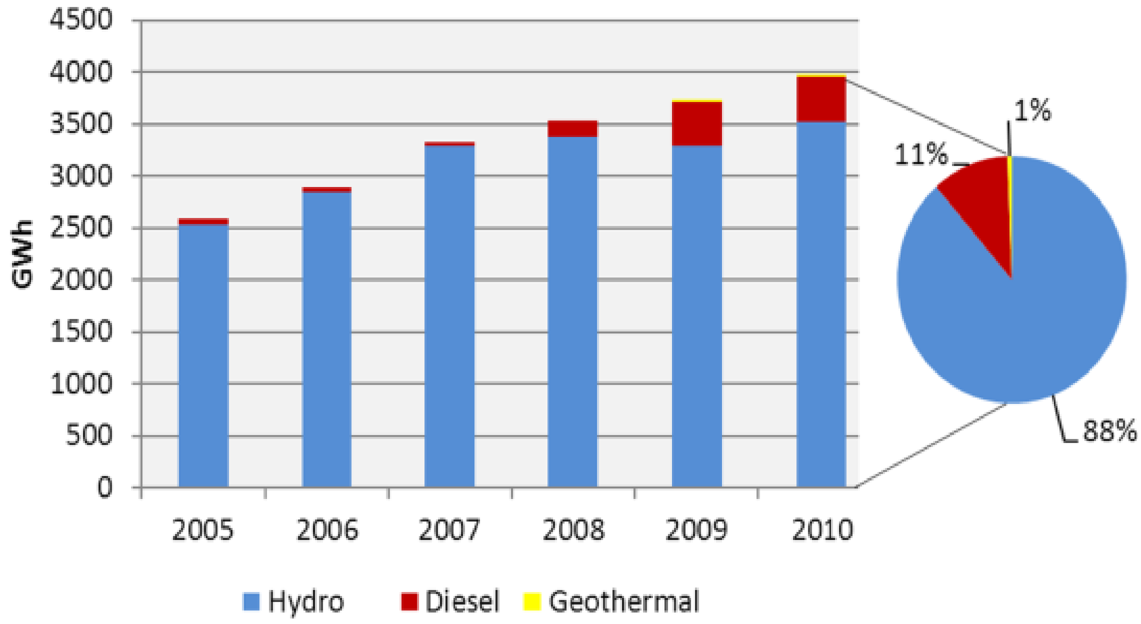


Figure 2-15: Development of Electricity Generation of EEPCo.-2005-2010 (GWh)
Source: Meder, K., 2011, p. 5

According to SREP (Scaling-Up Renewable Energy Program Ethiopia Investment Plan) (SREP investment plan, 2012, p. 1), Ethiopia has one of the lowest rates of access to modern energy services, its energy supply primarily based on traditional biomass usage, such as wood fuel and dung with the rest of the energy consumed taken from petroleum and electric power. The official access rate of the Ethiopian population to electricity in 2007 was about 20 %. However, this figure has increased and was 23 % by the year 2010; this figure is based on the population living in the electrified areas (41 % of its 85 million people).

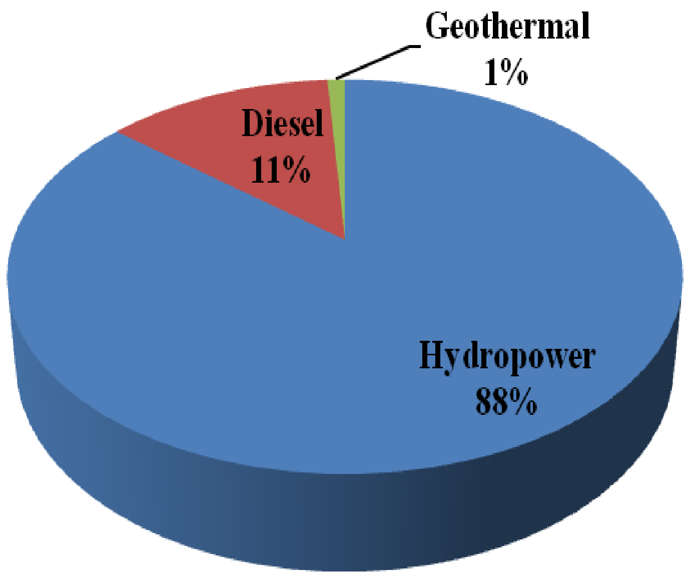


Figure 2-16: Percentage of electrcity generation by source in 2010
Source: Ministry of Water and Energy, Energy Balance and Statistics, 2011

Hydroelectricity generation has been growing substantially. Electricity generation from hydropower increased by 11.6 % per annum over the period of 2000-2010 (IEA, 2012). Petroleum based electricity generation had shown an increasing trend from 2000-2008 then decreased from 2008 to 2010 due to a rise in price (petroleum subsidy removed in 2008)[18] and after 2010 increased due the economy growth (Mengistu A., 2013, p. 20). However, the share from geothermal sank from 2000 to 2002 and from 2002 to 2007 there was no generation at all due to a technical failure of the plant (GSE, 2013, p. 11). The electricity production overview for Ethiopia in 2010 is present in Table 2-2. The Inter-Connected system (ICS) of Ethiopian Electric and Power Corporation (EEPCo.) currently operates 1,843 MW of hydropower, 7.3 MW of geothermal and 172MW of diesel grid-connected power plants. The Self-Contained systems (SCS) are from 6.15 MW hydropower and 31.34 MW diesel off-grid power plants (EEPCo. 2010, Facts in brief 2010/2011, p. 3)

[18] *International Monetary Fund (IMF), 2013, p. 45: https://www.imf.org/external/pubs/ft/dp/2013/afr1302.pdf , Accessed February 2014*

Table 2-2: Electricity Generation capacity of Ethiopia in 2010
Source: EEPCo. 2010, Facts in brief 2010/2011, p. 3 [19]

Sources	Installed Capacity (MW)			Production (GWh)
	ICS	**SCS**	**Total**	
Hydro	1,842.75	6.15	1,848.9	3,524
Diesel	172.3	31.34	203.64	433.56
Geothermal	7.3	-	7.3	23.61
Total	2,022	37.5	2,060	3,981

The Ethiopian Electric Power Corporation (EEPCo.) is the national electricity utility engaged in the generation, transmission, distribution and sale of electricity in Ethiopia. The generation system consists of the Inter-Connected System (ICS) accounting for 98 % of the installed capacity mainly from a set of large hydro systems with thermal back up, and the Self-Contained System (SCS) which contributes 2 % (EEPCo. 2010, Facts in brief 2010/2011, p. 3). Mostly, SCS is used for electrifying rural areas isolated from the national grid. The use of thermal fuel in electricity generation increased in both the ICS and SCS (see Figure 2-17).

[19] *EEPCo. , http://www.eepco.gov.et/eepco.php, Accessed January 2012*

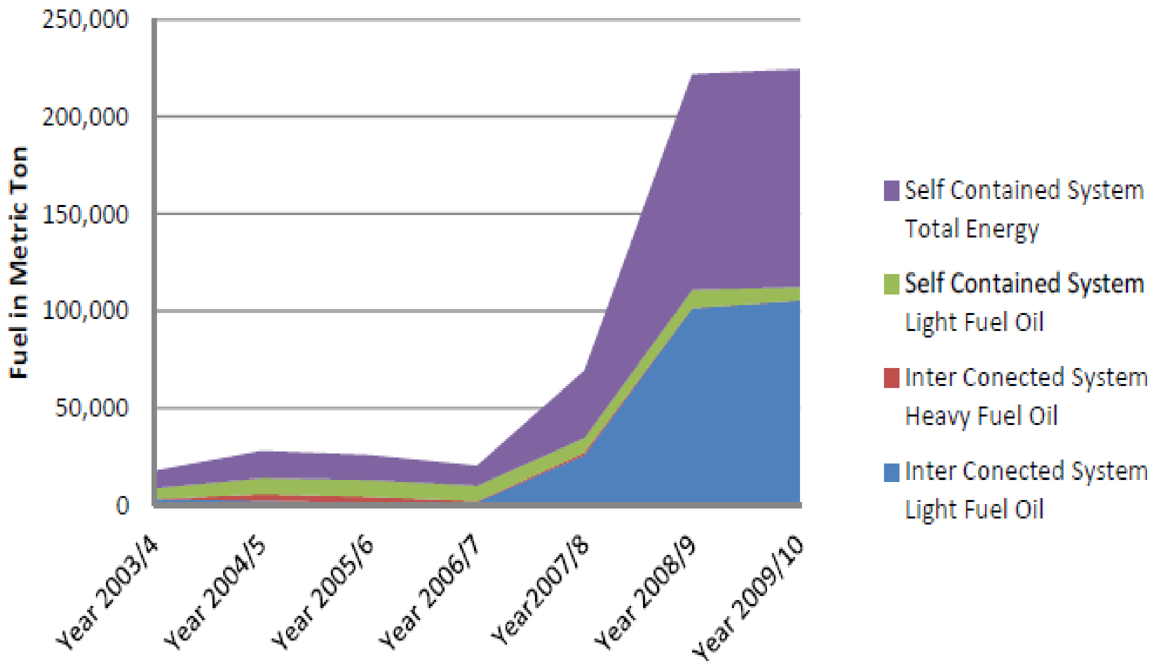


Figure 2-17: Fuel consumption for diesel power plants
Source: Ministry of Water and Energy, Energy balance statistics, 2011, p. 5

Significant expansion in power capacity of Ethiopia is expected to lead to:

- enhanced electricity access in the country. There had been a significant expansion in electrified villages from 2004 to 2010.
- increased electricity export to regional market, the Djibouti-Ethiopia interconnection has already been implemented (export started with 32MW) and the Ethiopia-Sudan interconnection has already been finalized (export started with 100MW)[20]. The Ethiopia-Kenya interconnection is currently under construction and will be in full service by 2016[21].

In the electricity sector, according to the Growth and Transformation Plan (GTP), efforts of the government are to rapidly expand generation from 2,000 MW to 10,000 MW by 2015, expand energy access to towns and villages and to export infrastructure development and power delivery (MoFED, 2010, p. 36).

[20] *Ministry of Foreign Affairs (2012), http://www.mfa.gov.et/news/more.php?newsid=1035 , Accessed December 2013*

[21] *EEPCo., Ethio-Kenya Electricity Highway Project Launches. http://www.eepco.gov.et/newsandevents.php?rm=18, Accessed December 2013*

For domestic connected consumers, the reliability, affordability and availability of power is of prime energy security importance. Energy shortages in the last few years and repeated interruptions due to aging distribution infrastructure undermine the quality of electricity supply. But affordability is a key strength of between the Ethiopian electricity sector, and to electricity consumers. Figure 2-18 and Table 2-3, presents the existing and planned power system scheme program by EEPCo until 2015.

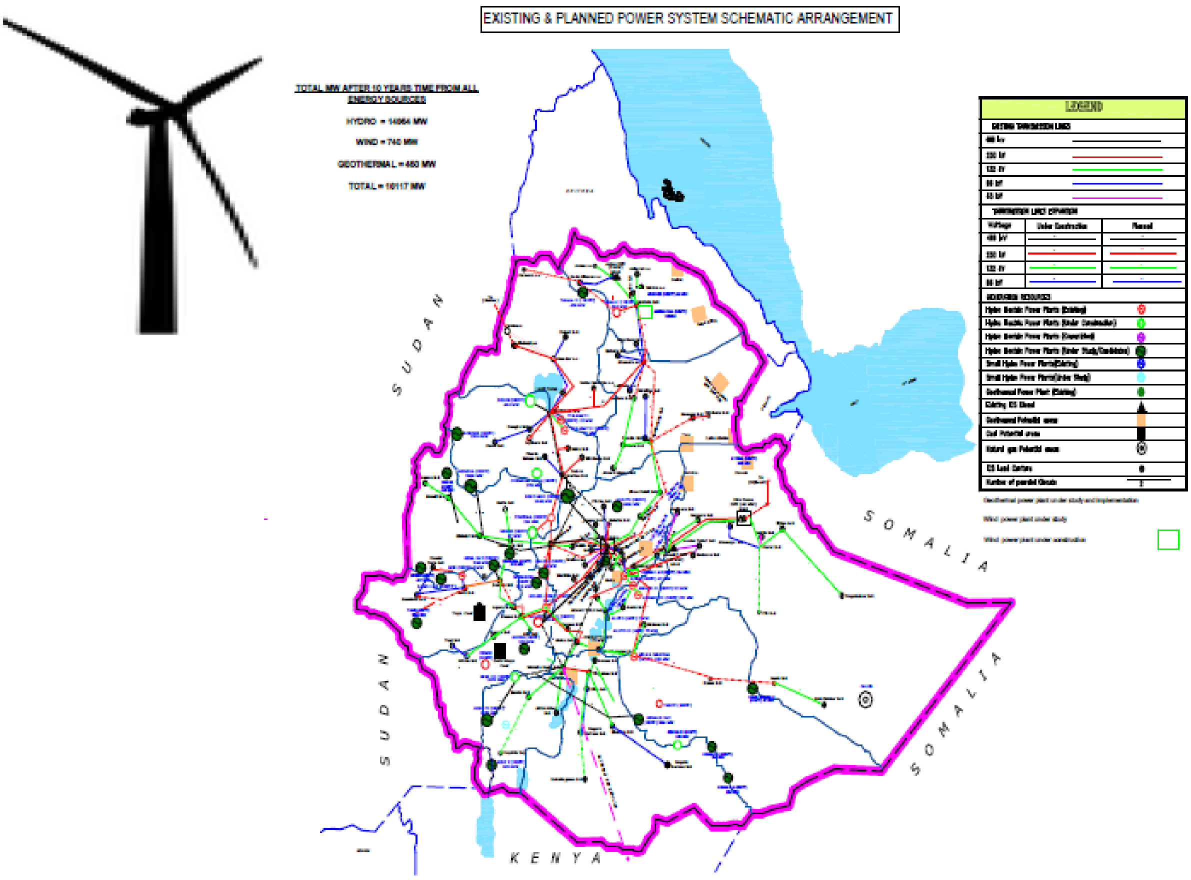


Figure 2-18: Existing and planned power system schematic arrangement
Source: EEPCo, 2009

It is clear that (Table 2-3) with the planned power projects hydro electricity generation will remain the dominant power resource in Ethiopia and nearly all power plants will be state owned and operated. Geothermal is likely to become a significant energy resource in the future. Wind is a recent development on a smaller scale and solar projects have been slow to take off in power generation for Ethiopia. The table below shows all of the current large-scale power projects in Ethiopia.

Table 2-3: Existing and Planned power system capacity
Source: USAID, 2013, p. 10

No.	Project	Resource	MW	Cost US$ m	Ownership	Status	Donors
1	Grand Ethiopian Renaissance	Hydro	6,000	4,800	State	Under Construction	None
2	Gilgel Gibe III	Hydro	1,870	1,800	State	Under Construction	None
3	Genale Dawa III	Hydro	254	400	State	Under Construction	Chinese EximBank
4	Small, Mini & Micro Hydro	Hydro	Various	Various	State/Private	In Discussion	TBD
5	Corbetti	Geothermal	100-300	400-1,200	Private	Under Negotiation	GRMF, TBD
6	Aluto-Langano	Geothermal	35-75	140-300	State	Under Construction	World Bank
7	Tendaho	Geothermal	100-300	400-1,200	State	Under Construction	GRMF, TBD
8	Dofan	Geothermal	100	400	State	Under Construction	GRMF, TBD
9	Corbeti	Geothermal	100	-	Reykjavik PLC	Under Negotiation	TBD
9	Small Geothermal	Geothermal	Various	Various	Private	In Discussion	TBD
10	Adama I	Wind	52	117	State	Completed	China EximBank
11	Adama II	Wind	153	340	State	Under Construction	TBD
12	Ashegoda	Wind	120	285	State	Completed	AFD
13	Debre Birhan	Wind	400	900	State	To start 2014	TBD
14	Aysha	Wind	300	615	State	Under Negotiation	TBD
15	Orchid & Regenerco	Solar	150	300	Private	Under Negotiation	TBD
16	MetEC Solar PV	Solar	20	5	Private	completed	None
17	Solar Energy Foundation Solar PV	Solar	20	5	Private	Under Construction	SEF/ NGO
18	Cambridge Industries	Biomass	50	120	State	Under Construction	None

Since the previous expansion plan, new generation plants have been commissioned and yet others have been identified, studied or otherwise planned for immediate implementation. According to EEPCo the transmission studies are also on a continual process of being reviewed and updated accordingly. While generation and transmission planning proceed as parallel activities, their implementation requires careful coordination to ensure that properly to achieve the desired performance of the future supply system as a whole (EEPCo Replanning Process, 2011, p. 3, 7 and 9).

Similarly, new proposal for interconnections between and among neighboring countries which are now becoming significant as a result of increasing cooperation and inter-dependence had to be taken into account critically. Moreover, the unprecedented, escalating demand for electric power arising from recent social and economic developments that is unfolding since the previous power system expansion plan is accommodated in the new update (EEPCo, Ethiopian Power System Expansion Master Plan Update (2006), p. 6).

The expansion of the Ethiopian power system to focus on development of the renewable indigenous energy resources; primarily on the massive hydro resource which the nation is particularly endowed with, as this will be the best alternative to serve the regional demands for electricity in the coming future (Ethio Resource Group, 2009, p. 1-2). The long-term generation expansion plan of Ethiopia should tailored in line with such perspective, as it helps to reduce the neighboring countries reliance on hydrocarbon fuels and thermal based mode of generation, which is quite expensive when the international oil price strikes peak. This is also in line with the clean development view of the Kyoto protocol. Under the Kyoto agreement such interconnection projects, in which generation of electricity based on fossil fuels is replaced with renewable hydro energy could be eligible for Clean Development Mechanism (CDM) subsidies ((UNFCCC, 2006)[22].

Based on such opportunities and considerable hydro resource potential (about 30,000-40,000 MW) (ECA/SRO-EA/ICE/2013/08, p. 110), Ethiopia envisages to practice cross border power trade by developing the hydro resources and having contractual agreements on export of power between its neighboring countries. The Ethiopian power system, when expanded as planned, will have energy available that is surplus to Ethiopia's domestic needs (USAID, 2013, p. 53). The surplus energy will vary through time, from higher values immediately after

[22] *UNFCCC, Available at* *http://cdm.unfccc.int/filestorage/C/D/M/CDMWF_AM_2GHDC30TPDJK04LS07SY07X9MFZRG5/AMS_I.D._ver09.pdf?t=Vk98bjF5dXAxfDBSVH60AjT9kNFyinIvl-UF , Accessed June 2011*

addition of new generation. The surplus energy could provide an opportunity for export sales to the neighboring states of Sudan, Djibouti, Kenya, and Tanzania could provide such markets if conducive environment in the economic integration and cross-border trading with Ethiopia develops, in particular.

Regional infrastructure development co-operations are in conformity with the interest of the financing institutions like the World Bank (WB), African Development Bank (AfDB), Ethiopian Investment Bank (EIB), and others who are strategically supporting development activities in the world. It is also in conformity with the objective of the New Partnership for Africa's Development (NEPAD) strategy[23]. The development of regional infrastructure projects especially in the field of electric energy (interconnection projects) is important for African countries.

There is a need for African countries to pool their resources and enhance regional co-operation and integration in order to improve international competitiveness by making energy services available at competitive prices (UNECA, 2005, p. 2).

Therefore, Ethiopia should devise a strategy for accelerating cross-border electricity trading with neighboring countries and other nearby countries to spur the economic growth through developments of the untapped hydro resources for electricity generation. Among the key components of the growth strategy is the provision of reliable and least-cost electric power to the Ethiopian people. Having such a low cost electricity supply is the most critical component to Ethiopia's competitiveness as an investment destination within the region.

The Djibouti-Ethiopia interconnection has already been implemented with a capacity of 32 MW and the Ethiopia-Sudan interconnection has already been implemented with a capacity of 100MW. The Ethiopia-Kenya interconnection currently under construction will be in full service by 2016[24]. The plan targets the Egyptian market by 2018 with an export potential of 3,400 MW (ECA/SRO-EA/ICE/2013/08, 2013, p. 114). Ethiopia as well under negotiation to sell 100MW to Yemen and also interest has shown from South Sudan and Somali land. The power transmission to Yemen will be through a power cable laid on the floor of Red sea via Djibouti. This agreement will be supported by finance of the banks of the countries (Ethiopian Embassy in London, 2014, p. 5). The interconnection prospects with Tanzania, which is as third party country, are also underway. Tanzania seems interested in pursuing a

[23] *NEPAD, http://www.nepad.org/crosscuttingissues/news/1584/nepad-capacity-cornerstones Accessed February, 2014*

[24] *EEPCo. http://www.eepco.gov.et/newsandevents.php?rm=18, Accessed September 2013*

power import option in the medium term at least. The existing and planned regional interconnection of Ethiopia shown on Figure: 2-19.

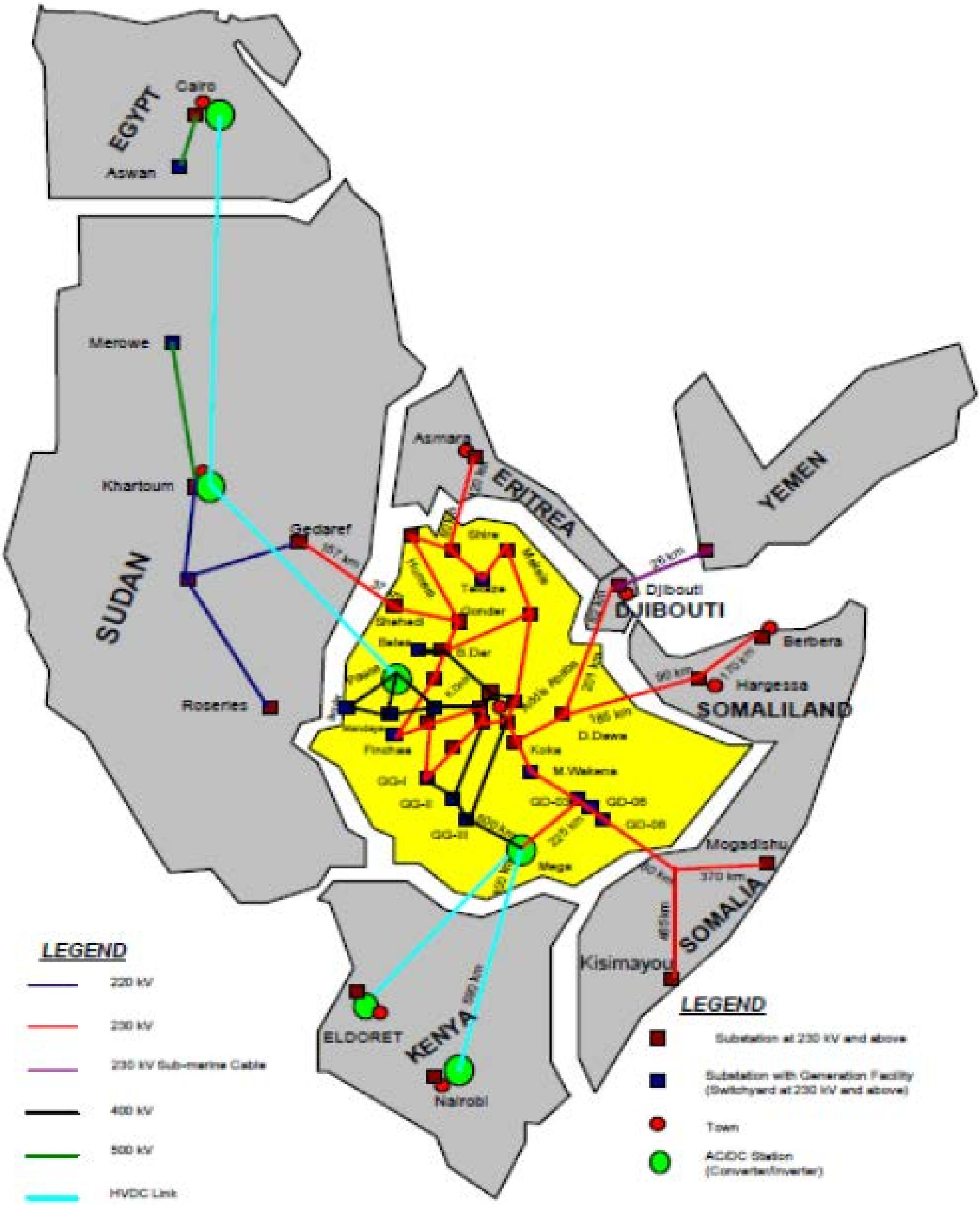


Figure 2-19: The possible interconnection of Ethiopia's electricity market
Source: EEPCo, 2009

2.3 Review of existing energy polices for Ethiopia

Enhancing energy access is a policy objective being embraced as a policy priority. To trace energy access goals to the degree to which they are pursued and implemented, a proper measurement and monitoring mechanism is needed. That in itself depends on what is meant by energy access. In May 1994 the Transitional Government of Ethiopia (TGE) introduced energy policy, the first of its kind[25].

"*This policy is intended to enhance and foster "Agricultural Development Led Industrialization (ADLI)" strategy and is consistent with other sector polices. In addition to this it provides the necessary support and incentives the participation of the private sector and community, particularly women in the development of energy.*" (MoWE, Energy Policy 1994, p. 2)

This is still in action as the policy of the Government of Ethiopia (GoE). It aims to address household energy problems by promoting agroforestry, increasing the efficiency with which biomass energy is utilized and facilitating the greater use of modern fuels. The policy recognizes the global awareness of the impact of energy crisis in development and economic growth and the import dependence on imported energy technology (Ministry of Water and Energy, 2011)[26].

The policy paper states that the country will rely mainly on hydropower to increase its electricity supply but also take advantage of geothermal, solar, wind and other renewable energy resources where appropriate. In addition, it aims to further explore and develop oil and gas reserves (MoWE,Energy Policy 1994, p. 4). It also refers to the need to encourage energy conservation in industry, transport and other major energy consuming sectors, to ensure that energy development is environmentally sustainable and to provide appropriate incentives to the private sector.

"*In achieving a shift from traditional energy fuels to modern fuels, still giving due and close attention to ecological and environmental issues.*" (MoWE, Energy Policy 1994, p. 3)

The following key direction states the energy policy: (1)expansion of hydro based generation; (2)expansion of agroforestry and reforestation; (3)exploration of oil encouragement and

[25] *(MoWE), (1994): Available at http://www.mowr.gov.et/EEA/LEGAL/The%20national%20Energy%20Policy.pdf , Accessed October 2013*

[26] *MoWE, 2011. "Brief Note on the Ethiopian Energy Sector." Addis Ababa, Ethiopia.*

natural gas development; (4)enhancing energy efficiency; (5)sustainable energy development; (6)ensuring energy development and supply; (7)encouraging private sector participation in energy and environment development; (8)effort to develop alternative energy; (9)rural energy development; (10)enhancing the role of women in energy supply and use (11)establishing an energy policy coordinating and implementing institution, and (12)promoting energy science and technology. (MoWE, Energy Policy 1994, p. 4)

Reference is given also to the need "to replace, at least in part, transportation fuel with other energy sources produced within the country" (Ibid). However, key energy security strategies and management frameworks are not specified. Revision of the energy policy is currently underway, which is believed to bring forth key developments, including issues of energy security, cleaner energy, access and the energy export strategy of the country.

Government's household energy policy:

"To have an achievement for a balance of supply and demand household fuels. Government will seek to stabilize their prices by increasing the supply of alternative fuels and relieving the pressure on wood resources (Ibid, p. 5).

The transport energy supply policy:

- *Formulate policy measures and give emphasis to the introduction of improved and appropriate transport technologies in the rural areas;*
- *Adopt conservation measures to reduce the use of petroleum products in the transport sector;*
- *Balance the petroleum products in the transport sector by substituting, wherever possible, to new non-petroleum fuels"* (MoWE, Energy Policy 1994, p. 5-6).

Government's industrial sector energy policy:

- *To ensure that industrial energy supply will be compatible with the industrial development of the country;*
- *To ensure that industrial energy use and supply will be based on economic and efficiency criteria.*

Government's agriculture sector energy supply policy:

To increase the supply of modern energy sources to the agriculture sector: (Ibid)

- The Current National Energy strategy and Biomass Energy

The current national energy policy has as its major objectives to ensure a reliable supply to support the agricultural development led industrialization strategy and to ensure and encourage a gradual shift from traditional energy sources to modern energy sources.

Of relevance to biomass (traditional) energy resources the policy proposes the following:

- ✓ greatly expand and strengthen agro-forestry programme
- ✓ provide alternative energy sources for the household and other sectors
- ✓ introduce energy conservation and energy saving measures in all sectors
- ✓ ensure community participation, especially women in all aspects of energy development and encourage the participation of the private sector

(Source: MoWE, Energy Policy 1994)

With respect to traditional fuels, the energy policy proposed a national afforestation program to increase the supply of wood fuel and to develop efficient ways of using agricultural residues as energy sources.

- The Energy strategy both liquid fuel and electricity

Until recently there was no attempt to reduce the pressure on wood fuel. Unsustainable utilization of the forest and woody plants resulted in ecological imbalances, like drought, loss of soil fertility, desertification etc. Today Ethiopia's forest is over exploited to the extent that it cannot be recovered by sustainable utilization[27]. The primary consumer is the household sector in the rural areas.

To sustain the country's economic development and maintain national security, the government of Ethiopia has drawn key strategic issues with regard to the liquid fuel sector. The first is to increase efficiency on utilization of liquid fuel and the second is substituting imported fuels with locally produced fuels. One component of the strategy related to ensure security of energy supply is biofuel development and use. Its main aim is developing, utilizing and exporting biofuels that could substitute imported fossil fuels and sustain the

[27] *Only 3.56% of Ethiopia's natural forest cover still exists, the depletion rate is estimated at 150.000 to 200.000 ha per annum, http://www.cbd.int/countries/profile/default.shtml?country=et#status , Accessed October 2013*

development of the economy and support for better trade balance. (MME, Biofuel Strategy of Ethiopia, 2007, p. 9-10)

The other strategy which has been implemented by Alternative Energy Development and Promotion Center (AEDPC) is improving end use efficiency. The strategy focuses on the improvements in the energy consumption trend of the rural and urban population (SREP investment plan, 2012, p. 19).

The Federal Government of Ethiopia has taken several measures to address the power sector. The enactment of the investment Proclamation Number 37/ 1997 particularly allows the participation of private investors in the generation and supply of electricity (Hailu Girma, (2000, p. 20).Council of Ministers Regulations Number 7/1996 and as amended in Number 36/1998 extends attractive package of encouragement in the form of duty and profit tax exemptions (Federal Negarit Gazeta, 1998).

The energy supply mix will change considerably due to changes in the power, transport, industry, and residential sectors. In the power sector, the near exclusive dependence on hydropower plants may change due to the introduction of considerable wind capacity. In the transport sector new transport fuels (electricity and liquid biofuels) will have considerable shares. New industrial fuels, such as coal and pet coke, now being introduced in cement and other industries will have larger contributions for industrial energy. In the residential sector liquid biofuels may become important cooking fuels.

In 2010 the government introduced a five year (2011-2015) plan called the *Growth and Transformation Plan (GTP)*. With regard to increased access to electricity, the plan stipulates the following targets: To increase electricity coverage from 41 % to 100 % (Universal access by 2015); reducing the distribution losses from 11.5 % to 5.6 %; to reach generation capacity of 8,000 MW from 2000 MW; increasing connection to 4 million from 2 million; rehabilitation of power transmission lines from 450km to 8,130km; increasing transmission lines from 126,038 km to 258,038 km (Ministry of Finance and Economic Development, GTP, 2010, p 14-15 , 36 & 71-75). In comparison of supply shares for 2010 and 2015 using some of the major targets for the energy sector show considerable changes: significant reduction of biomass; significant increases for hydropower, petroleum and solid fossil fuels; and introduction of biofuels and wind energy. These changes will have important implications for the environment: improved sustainability of forest resources, reduction of indoor air pollution; potential increase of greenhouse gas emissions due to increased use of petroleum and solid fossil fuels[28] (see Figure 2-20 and Figure 2-21).

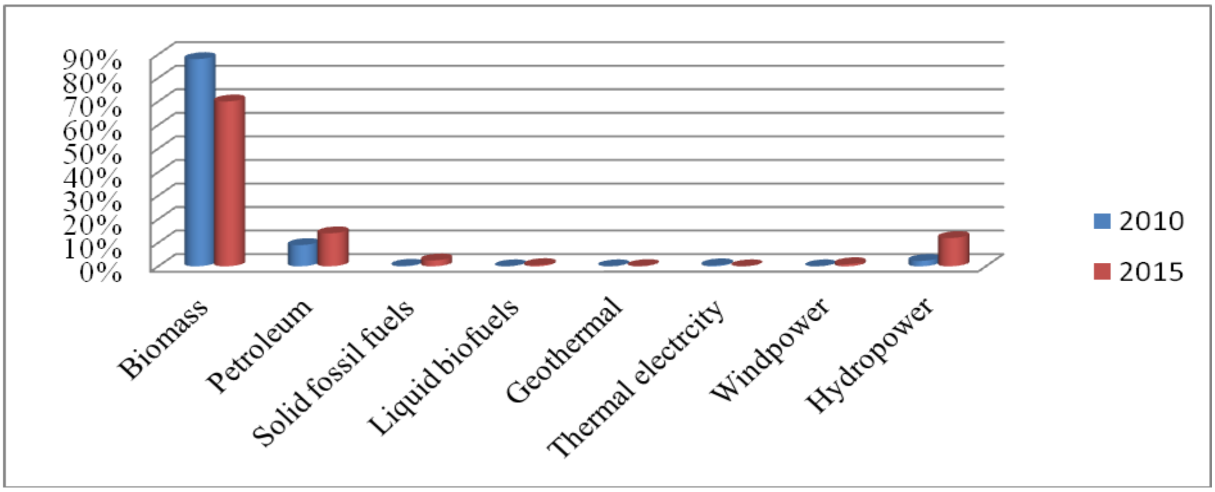


Figure 2-20: Primary energy supply by source 2010 and 2015
Source: Based on GTP, 2010

The estimates for 2015 are based on 10 GW of hydro, 866 MW of wind, 195 million liters of ethanol, 3 million tons of petroleum, 0.42 million tons of solid fossil fuels, and 9 million efficient biomass stoves (reducing per-capita energy use by half).

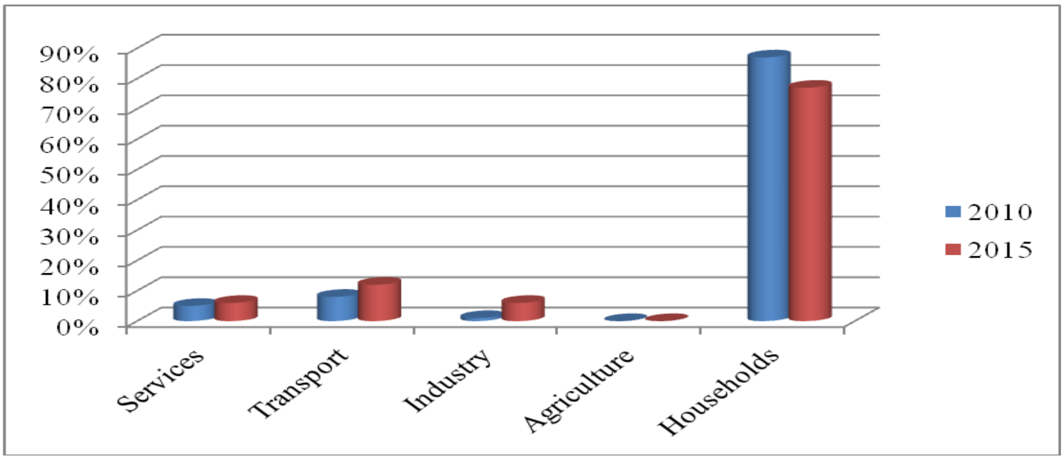


Figure 2-21: GTP estimate of energy use by sector
Source: Based on GTP, 2010

[28] This disregards reduction in non-renewable biomass use.

The share of energy use by sector and the types of energy used within sectors will also change when the proposed actions are realized. Some of the main changes will include reduced energy intensities for biomass fuels for the household sector, increased use of electricity and liquid biofuels, significant increases in the use of fossil fuels in industry, and introduction of electricity and biofuels in the transport sector. The more significant changes are explained briefly:

a. *Reduction of biomass energy use in both per-capita and aggregate terms*. Dissemination of nine million household stoves, with 40 % savings over traditional stoves, will reduce aggregate biomass energy consumption considerably (this is despite the 13 % increase of the population) (MoWE, 2013, p. 9). This will provide substantial headway to establishing sustainability for forest resources in Ethiopia.
   - Rapid dissemination of energy efficiency, especially in rural areas, must therefore be among the top priorities in the plan
   - Biofuels could be an important household fuel at the end of the period (mainly ethanol)
   - Access to modern energy services, per-capita commercial energy availability, and others

b. *Rapid rise of demand for solid fossil fuels in industry*. Rapidly rising demand for solid fossil fuels, particularly for cement and metal industries, can be expected in the coming five years.
   - Increased use of fossil fuels in industry will increase greenhouse gas emissions from the sector; air pollution impacts will also rise.

c. *A more diverse range of transport fuels*. At the end of the GTP period the transport sector will use a more diverse range of energy including petroleum, biofuels and electricity. These changes can be expected only after 2015 since the construction of the rail infrastructure and supply of substantial amounts of biofuels will take some years to complete.

d. *Increased use of petroleum in the agriculture sector*. Energy requirement (mainly for diesel) for irrigation, cultivation and other farm activities will rise due to expansion of large commercial farms. However, the aggregate amount consumed will not be significant compared to other sectors.

Source: SREP investment plan, 2012, p. v-vi & Ethio Resource Group, 2011, p. 5-6

Changes in the long term

Some of the main implications for the long term include:

a. Requirements for commercial energy may grow by tenfold in the next fifteen years. This has important implications in economic and sustainability terms. Indigenous resources must be developed at an accelerated rate and the balance must be met by imports. Resources available to meet requirements for development of indigenous energy sources and imports will be considerable. The rapid rise in per-capita energy consumption will increase environmental and social impacts.
b. A growing economy requires growing energy services; this means that end-use energy services must necessarily grow rapidly but not necessarily final energy. Energy services can be increased without proportional increase in final energy demands. Efficiency is the key in energy systems, in socio-economic systems (e.g. transport modes, settlement patterns). The potential for Demand Side Management (DSM) and Energy Efficiency (EE) are substantial in Ethiopia, particularly for the power sector and in transport.
c. Meeting one of the strategic goals for the energy sector, energy security, requires that Ethiopia accelerates its indigenous resource development to meet energy demands. The current development in the power sector is an example of this. The energy security goal will also be addressed by shifts towards indigenous resources; an example of this is the shift to electric railway for freight transport.
d. The rate of biomass energy consumption can be expected to grow as fast as population (2.6 % per year).[29] This will increase the pressure on natural resources. Energy efficiency and substitution actions for the biomass energy sector must be accelerated and implemented extensively. Such actions should be part of larger natural resource rehabilitation and conservation projects to maximize their benefit.
e. The size and diversity of energy resource development and their use is increasing rapidly. A large proportion of the plan, design, manufacture and supply, and service of the modern energy area is undertaken by foreign companies. Local capacity to design, develop and operate increasingly complex energy systems must be developed.

Source: Ethio Resource Group, 2011, p. 10-13

[29] *This assumes constant per-capita consumption; growing energy efficiency may be counter balanced with growing per-capita consumption due to growing incomes.*

2.4 Institutional dimension

The institutional framework of the Ethiopian energy sector is based on a number of key institutions presented below:

Ministry of Water, Irrigation and Energy (MoWIE): MoWIE which replaced the former Ministry of Water and Energy (MWE) is the leading government institution in the energy sector whose primary role is developing, planning and management of energy resources as well as creation of strategies, policies and regulation of different institutions of energy sectors. After 2010 national election, the ministry renamed as Ministry of Water, Irrigation and Energy (MoWIE). The mandates and responsibilities include development, planning and management of energy resources, policies development, strategies and programs, development and implementation of laws and regulations, managing petroleum operations and oversee rural electrification, promote development of alternative energy, set standards for petroleum storage and distribution, determine volume of petroleum reserves and provide technical support to regional energy bureaus and offices. MoWIE is the energy policy making organ of the government. Based on studies and recommendations of one of its departments, energy policy implementation follow-up and supervision, the MoWIE formulates various energy sector policies and supervises their implementation when approved (Ministry of Water and Energy, 2011) [30].

- ***The Ethiopian Energy Authority (EEA)***: EEA which replaced the former Ethiopian Electric Agency will regulate all energy activities in Ethiopia, including energy sector investment in the country (licensing, safety and quality standard) and also set the prices for the private sector and sate owned power distributors (FfE, 2010, p. 89).

- ***The Ethiopian Electric Power Corporation (EEPCo.)***: The Ethiopian Electric Power Corporation was one of state owned giant public utilities, until recently, engaged on energy generation, transmission, distribution and sale (FfE, 2010, p. 88). Late 2013, the corporation split and renamed in to two corporate entities, the Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). EEP is responsible for the power supply and tasked to undertake and oversee the country's power project including the mega hydro dams and the transmission lines, while EEU is responsible for delivering

[30] *Ministry of Water and Energy, (2011): "Brief Note on the Ethiopian Energy Sector." Addis Ababa, Ethiopia*

electricity services, operations distribution and sales. The split came due to the vast expansion of the power sector and the need for modernizing the service delivery of the company which EEPCo could not carry[31]. The more detailed engagement of the corporation is outlined at the end of this chapter (FfE, 2010, p. 93).

- ***The National Reserve Oil Deposits Administration (NRODA)***: NRODA was established in 1997 to operate and maintain the national petroleum reserve of the country and to ensure security of supply (Ibid, p. 89). The administration merged with Ethiopian Petroleum Enterprise (EPE) and formed Ethiopian Petroleum Supply Enterprise (EPSE).

The instutational framework of key government agencies in Ethiopia's energy sector is presented in Figure 2-22. The Ethiopian electric power office (EEPO), the Ethiopian Energy Authorighty and the National Reserve Oil Deposits Administration (NORDA) are part of the Minstry's instutational capacity to implement the energy policy.

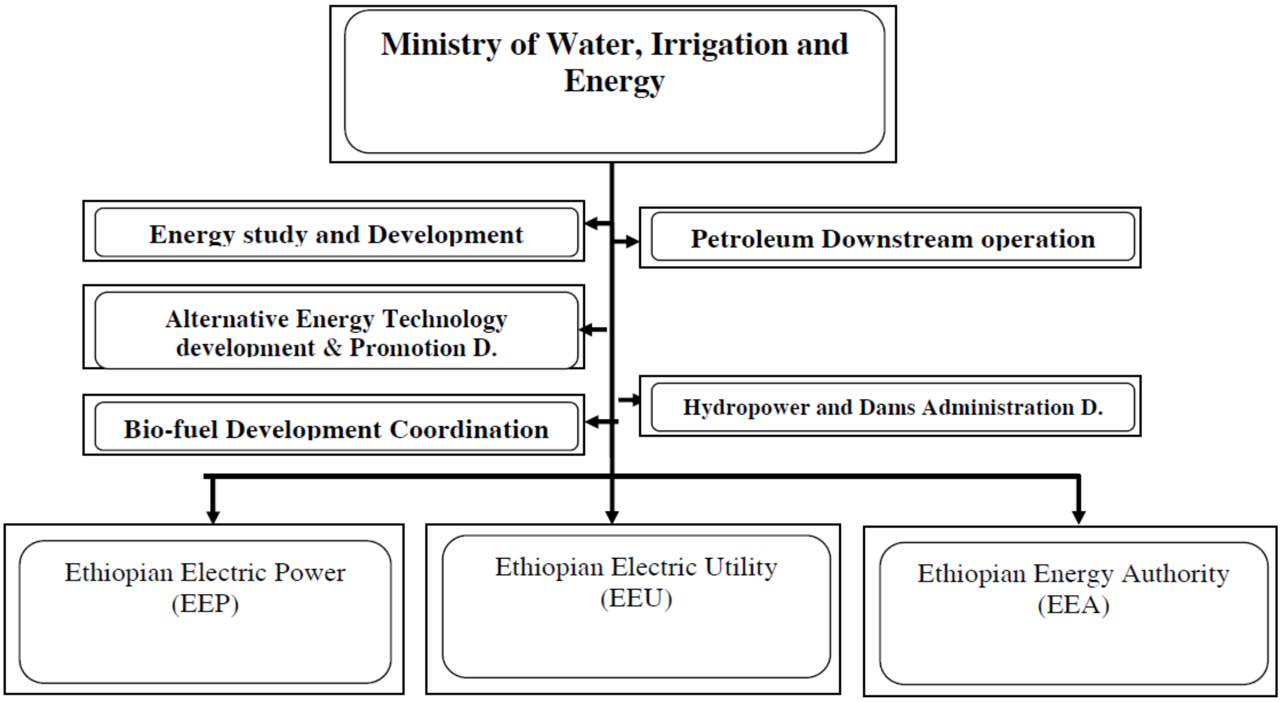


Figure 2-22: Institutional framework of the energy sector in Ethiopia
Source: MoWIE, 2013

[31] *Ethiopian Electric Power Corporation (EEPCo.) , http://www.eepco.gov.et/ Accessed December 2013*

The energy sector also has a key institution with the Ministry of Water and Energy vital for the promotion of energy access and security. Beyond these institutions there are further programs and organizations with relevance of the energy sector. These include:

- ***Regional Energy agencies*** are government bureaus responsible for promoting and facilitating modern energy technology programs.

- ***Alternative Energy Technologies Program*** conducts research in technology development and promotion of rural energy technologies such as improved stoves, PV solar, and biogas.

- ***Ethiopian Petroleum Enterprise (EPE):*** EPE is an operational wing of government entrusted with the responsibility of implementing fuel procurement and storage.

- ***Universal Electricity Access Program*** oversees universal electricity access activities, with responsibility of supporting and promoting off-grid rural electrification projects by cooperatives and private sector operators operating outside the national grid.

- **Ministry of Trade** plays the role for setting retail prices and regulates the distribution of petroleum products by oil distribution companies.

- ***Ministry of Finance and Economic Development*** oversees public finance for projects

- ***Ministry of Mines*** takes the responsibility of Geothermal and hydrocarbon resources exploration.

- ***Environmental Protection Agency*** regulates environmental aspects of energy development.

Source: Girma, 2000, p. 21-32 & USAID 2013, p. 15-17

The Ethiopian Electric and Power Corporation (EEPCo.):

The Ethiopian Electric and Power Corporation (EEPCo.) is a state owned monopoly power utility supplier. It also recognizes the importance of the diversification of energy resources to ensure stable energy supply and is trying to develop various kinds of power plants[32]. There are few small private power generators with combined capacity of less than 1 % of the total generating capacity. EEPCo restructured in 1997 by the regulation no.118/97 of the Council of Ministers after serving in the name of Ethiopian Electric Light and Power Authority (EELPA) which was established in 1956 (EEPCo. 2010, Facts in brief 2010/2011, p. 3). The corporation engaged in the business of energy generation, transmission and distribution.

A summary of statistical highlights for EEPCo Include the following:

- Sales of Electricity of 3,845 GWh in 2011
- Customers of 1.9 million by the year 2011
- Transmission lines of 10,900km at different kv levels
- Distribution lines of 138,000 km
- Annual average electricity growth rate of more than 10 %
- Per customer average electricity consumption of 168kWh per month
- Total electricity generation for 4,976.5 GWh with peak demand of 913MW, in 2011
- End user average tariff of around US$0.03/KWh
- Total system losses of 23 %
- More than 12,000 employees

Source: USAID, 2013, p. 22-23

i. Generation Resources and Generation Planning

Hydro based power generation is the main source of electricity on which the country relies to cover present and future electric needs at large. For the generation of the power, the EEPCo runs around 14 major dams scattered across the country; namely Koka, Awash II, Awash III, Finchaa, Finchaa Amerti Neshe, Melka wakana, Tis Abay I, Tis Abay II, Gilgel Gibe I, Dire Dawa, Awash 7 Kilo, Tekeze,Gilgel Gibe II, Beles and a Geothermal power plant named Aluto Langano (EEPCo).

The Inter-Connected System (ICS) mainly consists of cascade plants on the Awash River known as Koka, Awash II and Awash III plus additional plants at Finchaa on the Fincha

[32] Ethiopian Electric Power and Corporation (EEPCO.), http://www.eepco.gov.et/corporationprofile.php , Accessed February 2014

River, Malka Wakana on the Wabi River & Gilgel Gibe I on the Great Gibe River. Also connected to the ICS is the small Tis Abbay I plant and adjacent to it is the Tis Abbay II power station both of which are on the Nile River.

EEPCo. is currently building additional big hydropower plants which are expected to increase the installed capacity of the company 4 to 5 fold. The Grand Ethiopian Renaissance Dam (GERD) with a generation capacity of 6,000 MW is one of the mega hydro power projects under construction and will be the largest hydroelectric power project in Africa (EEPCo)[33].

In addition to Macro and Mega projects being constructed, numerous small scale generations have already been studied and a few have been developed. These stations range from about 300 kW run-off-the- river plants to a 6500-10,000 kW storage plant (EEPCo, 2013, p. 3).

ii. The Power Sector Consumers

The Inter-Connected System

EEPCo operates an Inter-Connected System (ICS) consisting of 12 hydro, 11 diesel standby plants, one geothermal plant and two wind farm power plants with installed capacity of 1,939.6 MW, 112.3 MW, 7.3MW and 81 MW, respectively (EEPCo. 2013, Facts in brief 2012/2013, p. 1). In 2010, EEPCo commissioned three large hydro power plants (Tekeze (300MW), Gibe II (420MW), and Beles (460mw), which increased its power generation capacity to over 2,000 MW (USAID, 2013, p. 23). The thermal stations are stand-by diesel stations at different places including emergency diesel units at Kaliti (14MW), Awash Town (35MW) and Dire Dawa (40MW), which are required to mitigate the power shortage during seasonal influence on the hydro reservoirs (Ibid). Total Inter-Connected System (ICS) growth between 2010 and 2013 has averaged 2.9 % (EEPCo. 2013, Facts in brief 2012/2013, p. 2).

Patterns of consumption on the ICS have shown consistently higher growth in the residential, commercial and industrial sectors. Based on EEPCo's data, in 2013, 39 % of the total ICS consumption was in the industrial sectors while about 36.6 % and 23 % of total consumption were accounted for residential and commercial sectors respectively. In between the years 2009 and 2013 the commercial sector increased the consumption by 12 % annually and

[33] *EEPCo., About Grand Ethiopian Renaissance Dam,* *http://www.eepco.gov.et/abouttheproject.php?pid=1&pcatid=2, Accessed February 2014*

similar percentage the residential sector. Industrial sectors consumption have shown an average growth rate of 13 % from 2009 to 2013 (EEPCo, 2013, Facts in brief 2012/2013, p. 4).

Self-Contained System

Those towns which are out of the ICS and connected to either small hydro or diesels are collectively referred to as the Self-Contained system (SCS) (EEPCo, 2011).

In 2013, the SCS consists of three small hydro and several diesel power plants. Generation in this system is mainly by diesel power plants having an aggregate capacity of 26.80 MW. The contribution from the small hydropower plants was only 6.15 MW from this Dembi small hydro power plant with 0.8 MW was out of operation since 2010 (EEPCo. 2013, Facts in brief 2012/2013, p. 1).

SCS sales in 2013 was 87.46 GWh, making consumption about 1.8 % of that on the ICS. In SCS, the largest demand was originated from the residential sector (54 %), followed by the commercial sector (32 %) and the remaining demand were in the industrial sector, street light and own consumption (Ibid, p. 4).

Off-Grid Electrification

The government of Ethiopia has been undertaking several measures to meet the requirements of the growing energy need of the economy. With regard to this, electrification of small towns that can help as market places for the farmers has thoroughly undertaken by the Alternative Energy Technologies Promotion and Dissemination Directorate (AETPDD) under ministry of water and energy (MoWE)[34]. A rural electrification package aims at expanding rural electrification as it could significantly contribute to reducing poverty. The strategy relies on two pillars: (FfE, 2010, p. 89)

i. The implementation and operation of electricity supply systems in rural areas by the private sector or community-based organizations

ii. An ambitious grid extension program to be implemented by EEPCo.

[34] *The Federal Democratic Republic Ethiopia Ministry of Water and Energy , http://www.mowr.gov.et/attachmentfiles/Downloads/Cooking.pdf , Accessed January 2014*

3 INDIGENOUS ENERGY RESOURCES OF ETHIOPIA

Ethiopia has a land area of around 1.104 million square kilo meters (12th in the world)[35], varying terrains and very ample natural resources. Mineral resources with proven reserves include gold, platinum, nickel, copper, iron, coal, tantalum, silicon, sylvite, phosphate, marble, limestone, oil and natural gas, but a large part of Ethiopia's land has yet to be prospected, so the actual resource reserves will be confirmed by future prospecting (The Economist, 2013, p. 3-4).

Ethiopia has embarked on an ambitious energy sector development strategy, largely focused on export markets in the sub-region. The Government has reported that in the 2005-2010 development plan and implementation period, the number of cities with access to electricity increased from 648 to 3,367, and the population with service coverage increased from 16 % to 41 % (MoFED, 2010, p. 3). Following the 2010 period, and the end of the preceding of 5 year development plan, the Government introduced another plan for the 2011-2015 period, which it called the *Growth and Transformation Plan (GTP).* With regard to electricity access, the plan stipulates the following targets: electricity population coverage to increase from 41 % to 75 % (universal access by 2015) (MoFED-GTP, 2010, p. 37); increasing electricity generation capacity from 2,000 MW to 8,000 MW; reducing electricity distribution losses from 11.5 % to 5.6 % (close to international standard); increasing connections from 2 million to 4 million; increasing transmission lines from 126,038 km to 258,038 km; and re-building distribution lines from 450 km to 8,130 km. The plan does not fall short on ambition (Ibid, p. 36-37).

The strategy is motivated by the energy resource potential of Ethiopia, which is quite significant and enables an export oriented development strategy. The hydropower potential of Ethiopia is estimated between 30,000 to 45,000 MW (though some estimates show the economically affordable power estimate at 40 % (CESEN, 1986), currently exploited at barely 3 %.

It is believed that Ethiopia has a reserve of 113 billion m^3 of natural gas, 300 million tons of coal and 253 million tons of oil shale currently under exploration (Ministry of Water and Energy, 2013, p. 4), It has, however, made efforts to integrate solar (with potential of 4-6

[35] *CIA, The world Fact book, https://www.cia.gov/library/publications/the-world-factbook/rankorder/2147rank.html?countryname=Ethiopia&countrycode=et&regionCode=afr&rank=27#et , Accessed June 2013*

kWh/m^2, particularly in northern Ethiopia) and wind energy (100,000 MW potential capacities) (Ibid). Wind capacity is highest in the Mekelle region (northern Ethiopia) in Ashegoda, Harena and Aysha where wind speeds reach 8 m/s, Adama and Gondar reaching 6.64 m/s and 6.07 m/s, and Harar, Debre Berhan and Sululta with 4m/s potential (GTZ-TERNA, 2005, p. 27). An estimated 5,000 MW geothermal capacity along the East African Rift Valley of Ethiopia offers additional resource capacity, currently barely exploited (ECA 2013, p. 108-109). In this chapter, the potential of indigenous resources is discussed. Quantitative resource data are crucial for the developing the model (Chapter 5) and evaluating the future policy alternatives (Chapter 6) in the model.

3.1 Conventional energy resources

3.1.1 Oil

Ethiopia is one of the fastest growing non-oil based economies in Africa. Almost all of the country's modern fuel need is met by importation of petroleum products. In 2007/08 the volume of importation had grown by 39 % compared to 2006/07 (Ministry of Water and Energy, 2011). Compared to the east Africa region, the petroleum consumption change of Ethiopia over the period of 2000-2011 was high, with an increase of 93.6 % (Figure 3-1). Oil products are the most important provider of energy to the transport and industry sectors.

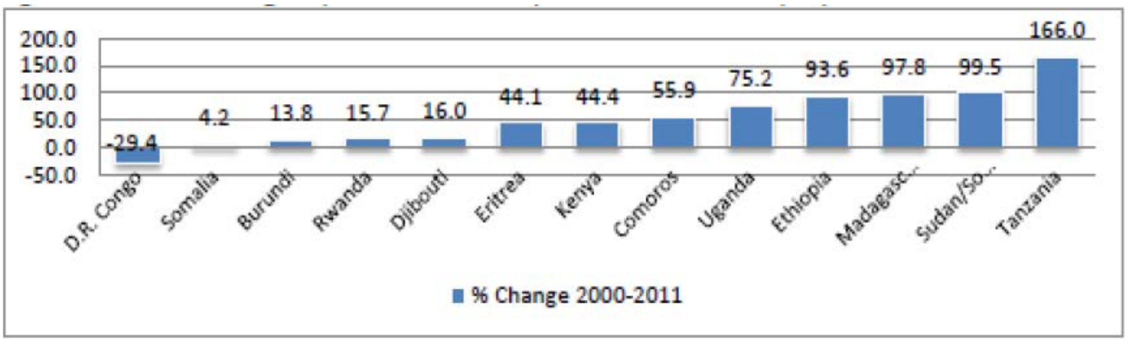


Figure 3-1: Percent change in Petroleum consumption in thousands bbl/day: 2000-2011
Source: Based on data from US EIA[36]

[36] *US EIA, International Energy Statistics, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=alltypes&aid=2&cid=ET,&syid=2008&eyid=2012&unit=TBPD, Accessed November 2013*

Oil, natural gas, and coal account for the largest proportion to the final energy consumption share of the world (IEA, 2013, p. 4). In perspective, in Ethiopia, coal and natural gas have zero value.

The country has not yet started exploitation of the potentially available coal and natural gas reserve. Petroleum products are the sole modern fuels consumed in the country. Almost all of the country's modern fuel need is met by importation of petroleum products.

As Ethiopia is net importer of oil products, the increase of oil price in the international market has contributed to a widening trade deficit and inflation by way of a pass-through effect. The major types of petroleum products that are required in the national market are Regular Gasoline (MGR); Jet Fuel; Kerosene; ADO (Automotive diesel oil); LFO (light fuel oil); and HFO (heavy fuel oil).

Table 3-1 and Table 3-2 show the increase in the volume and value of petroleum products imported from 2004/05 to 2011/12.

Table 3-1: Volume of petroleum products imported (2004/05-2011/12)

Source: Ethiopian Petroleum Enterprise (EPE) as reported in National Bank of Ethiopia Annual Report[37], 2012

	Petroleum Products (in Metric Tons)				
Year	Regular Gasoline (MGR)	Jet Fuel (A-1)	Fuel Oil	Automotive Diesel Oil (ADO)	Total
2004/05	133,193	332,978	161,254	746,899	1,374,325.0
2005/06	122,503	355,650	158,227	757,644	1,394,024.8
2006/07	143,663.6	401,492.4	158,842.8	904,378.2	1,608,377.0
2007/08	144,505	492,084	180,993	1,093,805	1,911,387
2008/09	142,983	505,701	152,704	1,170,531	1,971,919
2009/2010	194.066	610,846	123,621	1,568,443	2,303,104.07
2010/2011	143,878.8	559,522.5	150,968.0	1,047,862.0	1,902,232.0
2011/2012	150,619.1	544,519.6	144,501.3	1,302,451.2	2,142,091.2
AAGR (2004/05-2011/2012) (%)	1.8	7.3	-1.6	8.3	6.5

[37] *National Bank of Ethiopia Annual Reports, http://www.nbe.gov.et/publications/annualreport.html, Accessed September 2013*

Table 3-2: Value of petroleum products imported in '000' Birr, 2004/05-2011/12
Source: Ibid

Value of petroleum imports (in '000' Birr)					
Year	Regular Gasoline (MGR)	Jet Fuel (A-1)	Fuel Oil	Automotive Diesel Oil (ADO)	Total
2004/05	519,684	1,363,931	297,854	2,784,699	4,966,168.0
2005/06	837,674	1,914,852	395,449	3,520,364	6,668,339.8
2006/07	740,426.2	2,168,104.6	461,230.4	4,503,816.2	7,873,577.5
2007/08	1,118,494.9	4,189,310.1	847,556.7	8,855,755.4	15,011,117.2
2008/09	890,747	3,671,264	671,463	7,548,767	12,782,241
2009/2010	1,375,397	4,451,842	744,190	10,254,924	16,826,353
2010/2011	1,743,315	9,738,630	1,171,276.2	14,096,853	26,750,074
2011/2012	2,604,584.2	9,795,246.5	1,805,728.2	22,531,329	36,736,887.6

Note: Exchange rate of the Birr against the dollar was 9.0071 to 17.705 Birr per US$ in 2004/5-2011/2012[38]

Major petroleum fuel consumers

According to data from EPE reported by National Bank of Ethiopia 2011/2012 annual report, the country has imported a total of 2,142.1 million metric tons of petroleum products, worth Birr 36,736.9 million (about USD 650,426.8 million). The value was 37.3 % higher than that of the preceding fiscal year on account of the rise in the international oil price and increased fuel demand owing to the growing domestic economy. Component wise, the import values of

[38] *ExxUN, Exchange Rate , http://www.exxun.com/afd_hy/Ethiopia/ec_exchange_rates.html , Accessed October 2013*

jet fuel and fuel oil declined, while that of regular gasoline and automotive diesel oil increased (National Bank of Ethiopia annual report 2011/2012, p. 31).

The largest consumers of petroleum products are the transport, industry and household sectors respectively. According to data IEA, the transportation sector is the largest consumer of petroleum products (60.4% of the total oil consumption) (IEA, 2012). The transportation sector mainly consumes Automotive Diesel Oil (ADO), which as of 2011/2012 has a share of 61 % of the total petroleum products imported (see Table 3-3). It is a clear indication that basic intervention to alleviate problems related to petroleum importation should primarily focus on the transportation sector. It is has to be clear that road transport takes almost all the share of oil consumption. Since, currently, rail transport has been terminated for maintenance and reinstallation. However, the aviation sector, which consumes Jet Fuel A, has also shown growth in account of the current appreciated activities of Ethiopian Airlines.

The household sector meet important sector of petroleum fuel consumption, mainly kerosene is consumed for cooking purpose in the urban areas and lighting in non-electrified rural regions. Moreover, commercial sectors are also significant consumers of kerosene for cooking purpose.

Table 3-3: Sectoral oil consumption in 2010 (Ktoe)
Source: IEA, 2012[39]

Sectors	Type					
	Gasoline	Jet Fuel	Kerosene	Gas/diesel	Residual fuel oil	Liquefied Petroleum Gases(LPG)
Industry	0	0	0	270	131	0
Transport	152	320	0	694	0	0
Residential	0	0	239	0	0	8
Total final consumption	152	320	239	1144	131	8

[39] *IEA, Ethiopia: Oil for 2010, http://www.iea.org/statistics/statisticssearch/report/?country=ETHIOPIA&product=oil&year=2010, Accessed December 2012*

It is clear that the supply for petroleum oil is going to grow in the near and mid futures, which means that the country will have to import more petroleum oil from year to year. According to importation forecast made by EPE the total volume of import will grow by 9 % each year (see Table 3-4).

Table 3-4: Importation of petroleum products projected data, quantity in MT
Source: EPE, 2013

	Petroleum products					
Fiscal year	**Regular Gasoline**	**Jet fuel (A-1)**	**Kerosene**	**Fuel oil**	**Gas oil (ADO)**	**Total**
2012/13	198,817	303,688	351,131	197,722	1,657,847	2,709,205
2013/14	216,710	331,020	382,733	215,516	1,807,054	2,953,033
2014/2015	236,214	360,812	417,179	234,913	1,969,689	3,218,806

Oil resources and reserves

Ethiopia is an oil importing country with small reserves of oil, natural gas and other fossil energy resources. As of 2013, domestic crude oil reserves and natural gas reserves had been 68,000 m^3 and about 25 billion m^3 respectively, failing to meet domestic energy demand. In addition, Ethiopia lacks oil refining capacity. Hence domestic fuel oil demand is mainly met by import. It is believed that Ethiopia has 253 million tons of oil shale which is currently under exploration (Ministry of Water and Energy, 2013).

Of the total import of fuel in 2012, 61 % was diesel, 26.7 % jet fuel, 7.1% regular gasoline, and 4.9 % fuel oil and others (National Bank of Ethiopia, 2012). , The government of Ethiopia currently mandate in displacing of 5 % of blending with ethanol (ERG, FFE, 2009, p. 15). As such, the impact of the current program on energy security mitigation is minimal. However, large-scale nationwide expansion of the program has the potential to deliver fuel displacement effects. The ministry of Water and Energy claims that as a result of ethanol blending, in the years 2009-2011 saved about 10 million US$ were saved (Forum for Environment, 2011, p. 5). By such measure, the benefits of a scaled-up integration of biofuels would be sizeable.

3.1.2 Coal

The coal resource of Ethiopia (bituminous & lignite) is estimated at about 300 million tons, mainly located in 9 sites mostly in the northern, central and south-western parts of the country (Ahmed, 2008, p. 1; see Figure 3-2). The better quality coal deposits are located in the south-western high forest areas.

3.1.3 Natural Gas & Oil Shale

Ethiopia is currently not a producer of natural gas or oil shale. It is believed that it has 113 billion m^3 of natural gas deposits in the eastern part of the country (EIGS, 2008) and 253 million tons of oil shale (Ministry of Water and Energy, 2011) currently under exploration.

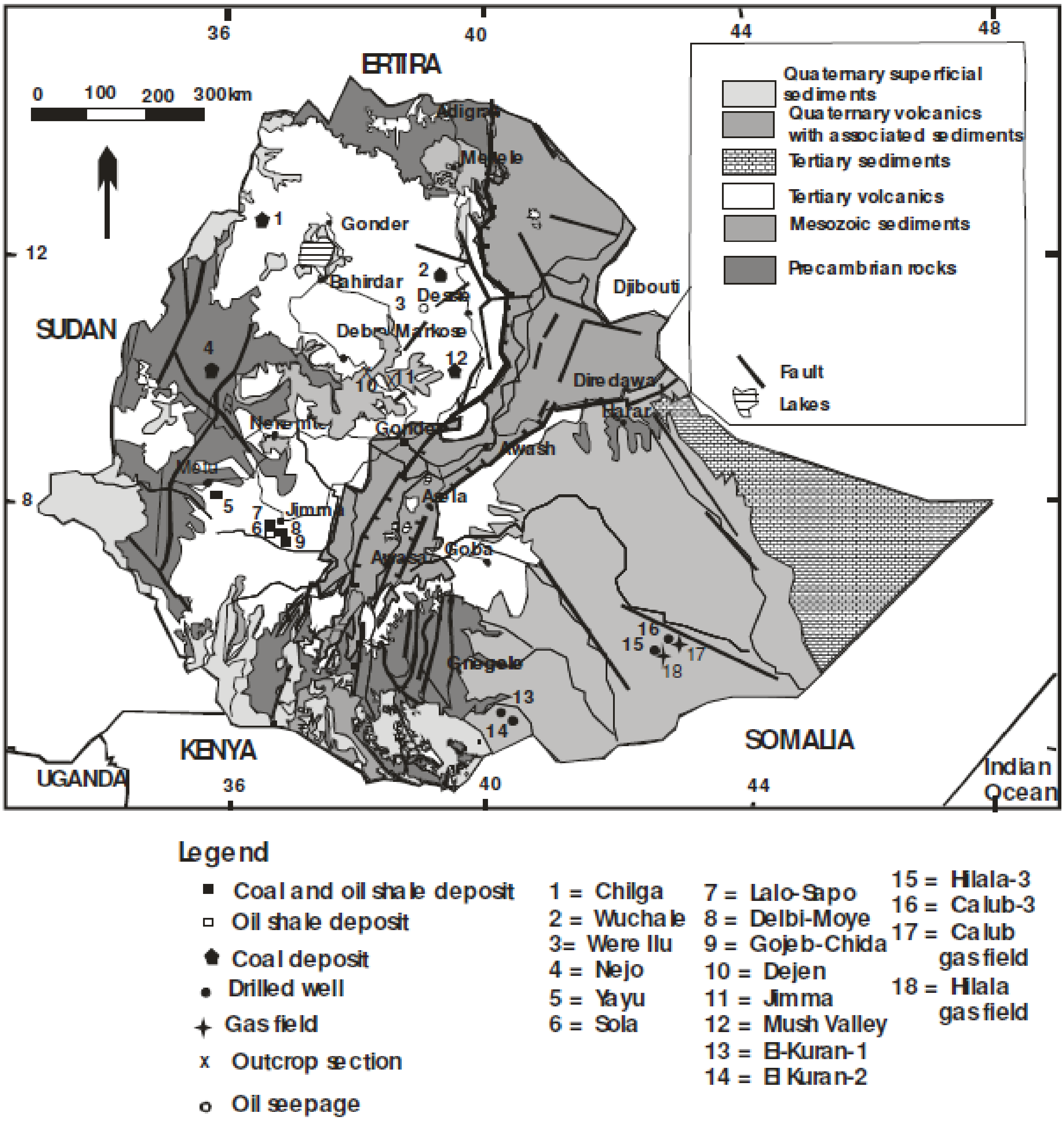


Figure 3-2: Potential basins for hydrocarbon in Ethiopia
Source: Ahmed, 2008, p. 68

3.1.4 Nuclear

There is no nuclear energy in Ethiopia's current energy mix and nuclear energy technology is not very well developed in Africa. South Africa is the only African country with nuclear energy in operation. However, according to Ethiopia's draft energy policy document recommends Ethiopia start harnessing nuclear energy as an alternative energy source and target generating up to 1,200 MW of electricity to help meet total power demand by 2037[40]. The document is due to make it to the Council of Ministers shortly (the document does not propose when) and for the first time tabled a recommendation to consider nuclear energy as a viable alternative energy source in addition to the alternative energy sources like wind, solar, geothermal and bio-waste. However, the document does not indicate the launch date of a nuclear program. This recommendation was proposed mainly due to the recent discovery of potential Uranium in Ethiopia. Uranium is the main ingredient in nuclear energy development; the deposit is the first of its kind in Ethiopia, having been detected in the Borena and Bale zones of the Oromia regional state (South of Ethiopia). However the amount of the deposit is not yet known[41].

3.1.5 Biomass energy

Ethiopia as many of the developing countries is characterized by heavy reliance on traditional biomass (93%) (ERG, 2009, p. 4-12). More than 83 % of Ethiopia's 84.7 million people live in rural areas (World Development Indicators, 2013, p. 21). The vast majority of these people are dependent on traditional fuels (Wood, charcoal, crop-residues, and livestock dung). Traditional bioenergy resources which are primarily used for cooking by households and services sectors. For many, this combination of fuels barely allows for the fulfillment of basic human needs such as proper nutrition, warmth and light. As it is presented in Table 3-5, the household consumed almost all biomass fuels.

[40] *Africa Review, http://www.africareview.com//Business---Finance/Ethiopia-mulls-1200MW-from-nuclear-energy/-/979184/2089920/-/28a2gjz/-/index.html?relative=true , Accessed November 2013*

[41] *The Ethiopian Reporter, http://www.thereporterethiopia.com/index.php/news-headlines/item/820-ethiopia-to-go-for-nuclear-energy , Accessed November 2013*

Table 3-5: Average share of biomass fuels consumption by sectors (1990/00-2009/10)
Source: Ministry of Water and Energy, 2013

Sector	Biomass fuels (%)
Rural households	86.42
Urban households	8.18
Commercial and public utilities	0.46
Others	4.93

Household biomass energy consumption patterns

Biomass, or more precise -- traditional biomass, is essential in meeting the local energy demand of many regions of developing countries, since it is an easily available and affordable energy for cooking and space heating. As presented in Table 3-5 above, the rural households in Ethiopia consumed over 86 % of biomass fuel on average in the last decade followed by urban household (8.2 %) and other sectors (about 5 %) (Ministry of Water and Energy, 2013).

In Ethiopia dependency on biomass is still nearly 90 %. Half of the biomass is used for baking “Injera” (EREDPC, 2006). In many parts of the country, fire wood already has become a scarce (and expensive) commodity, forcing the fuel wood carriers, mostly women and children, to travel longer distances.

The shortage of biomass in the country is mainly related to poor combustion technologies. Almost all the entire rural population uses three stone open fired stoves used for cooking and baking with low thermal efficiency of between 5 % and 10 % (Jargstrof B., 2004). This has resulted in the need for big volumes of fuel per activity. In addition, Ethiopia also sees its biofuel potential, particularly to displace imported fossil fuels. Since 2009, the country started a fuel blending mandate as an experimental program in the city of Addis Ababa. The blending of E10 (10 % ethanol-blended gasoline) has been effective in the country since March 2011 (Forum for Environment (FfE), 2011, p. 12).

Currently, the Ethiopian Rural Energy Development and Promotion Center (EREDPC) has developed new and higher efficiency stoves, Gonze and Mirt Midija. These stoves use efficiency improvement to reduce the intensity of energy consumption, to primarily reduce the increasing pressure on forests and secondly mitigate health problems resulting from indoor air pollution. Besides, starting from Ethiopian Millennium (2007 G.C) the government has been promoting plantation of new seedlings in the devastated areas in order to alleviate problems related to weather condition and reduce drought and desertification. Figure 3-3, presented below, shows the biomass consumption of countries in the East African region. In comparison, Ethiopia's biomass consumption is higher than the average in the region.

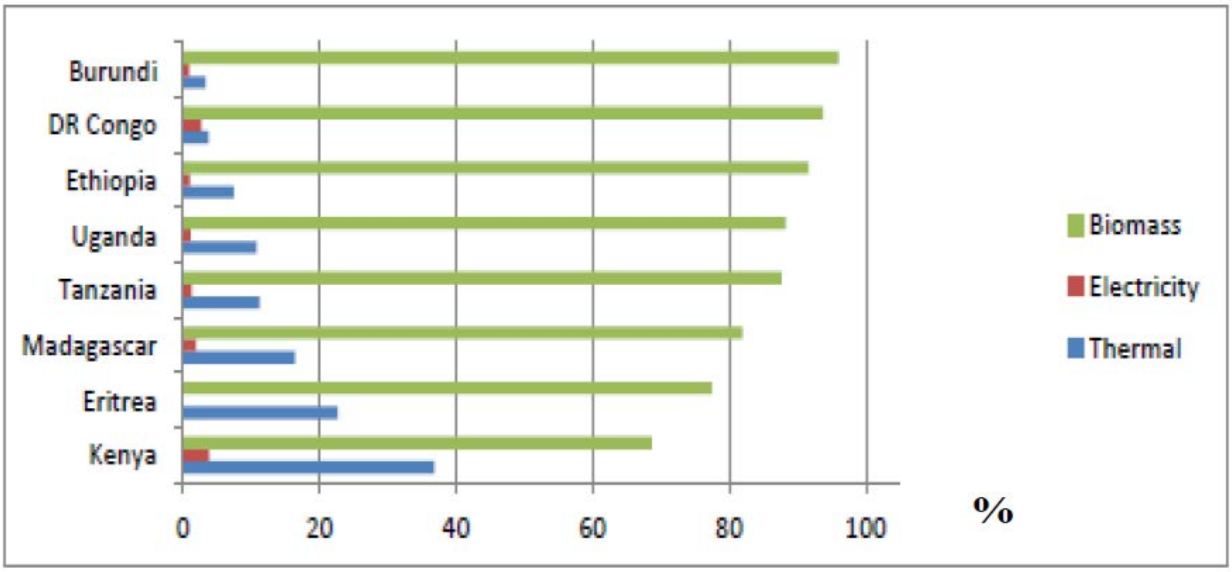


Figure 3-3: Sources of energy consumption in the region
Source: ECA/SRO-EA/ICE/2013/92013, p. 8

Ethiopia has diverse biomass resources and an overview of the Ethiopian biomass energy source includes the following:

- Woody biomass: parts of branches and trunks either whole or split
- BLT (Braches, Leaves and Twigs): fallen litter of small dead branches, twigs and leaves, or small branches with leaves taken from trees cut for poles
- Crop residues: stalks and leaves of cereal, pulse and oil crops
- Dung: dried (normally cattle dung), often mixed with soil and grass to form "dung cakes"
- Bagasse: residues from sugar cane stalks after juice has been extracted. Almost solely used by sugar mills
- Briquettes: generally of coffee husks, but also made of cotton stalks

- Oil Cake: residues from oil seeds after oil has been expressed
- Charcoal: Pyrolysis product of wood. Conversion rates from wood between 12-15 % for small inexperienced producers, to 25 % for large experienced producers.

(Source: Lulie M. and Tesfaye G. 2012, p. 39; Guta D. 2012, p. 134)

Biomass, which includes wood, charcoal, animal waste and agricultural residue, is the most widely used form of energy in Ethiopia (Lulie M. and Tesfaye G. 2012, p. 2). Nearly 90 % of Ethiopia's current total energy demand is met using biomass fuels. Within the household sector, the contribution of biomass fuels is close to 97 % (Ministry of Water and Energy, 2013).

Among the key issues that characterize the Ethiopian biomass energy sector, the following are some that stand out[42]:

i. the fact that the sector relies heavily on biomass energy resources,

ii. the fact that the household sector is the major consumer of energy (which comes almost entirely from biomass) and,

iii. the fact that biomass energy supplies are coming mainly from unsustainable resource bases (which has catastrophic environmental implications)

According to estimates by Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2004), national woody biomass stock is estimated 1,150 million tons with annual yield of 50 million tons in the year 2010 (Lulie M. and Tesfaye G. 2012, p. 12). The figures are excluding other biomass fuels such as Branches/Leaves/Twigs (BLT), dead wood and homestead tree yields. The highest yields are found in the Southwest and Western Lowlands and in the Southwest highland forest areas. The northern highlands and eastern lowlands of Ethiopia have lower woody biomass cover. The spatial distribution of the "deficit" indicated that areas with severe woody biomass deficit are located in eastern Tigray, East and West Hareghe, East Shewa and East Wellega Zones of Oromiya and the Jigjiga Zone of the Somali Region (Minstry of Agriculture (MWE), 2004, p. 1). Figure 3-4 presents the trends and share of biomass fuel consumption of Ethiopia in last decade (1999/2000-2009/2010). The firewood was the major biomass source consumed in the last decade.

[42] *Energypedia https://energypedia.info/wiki/Ethiopia_Energy_Situation#Biomass , Accessed November 2013*

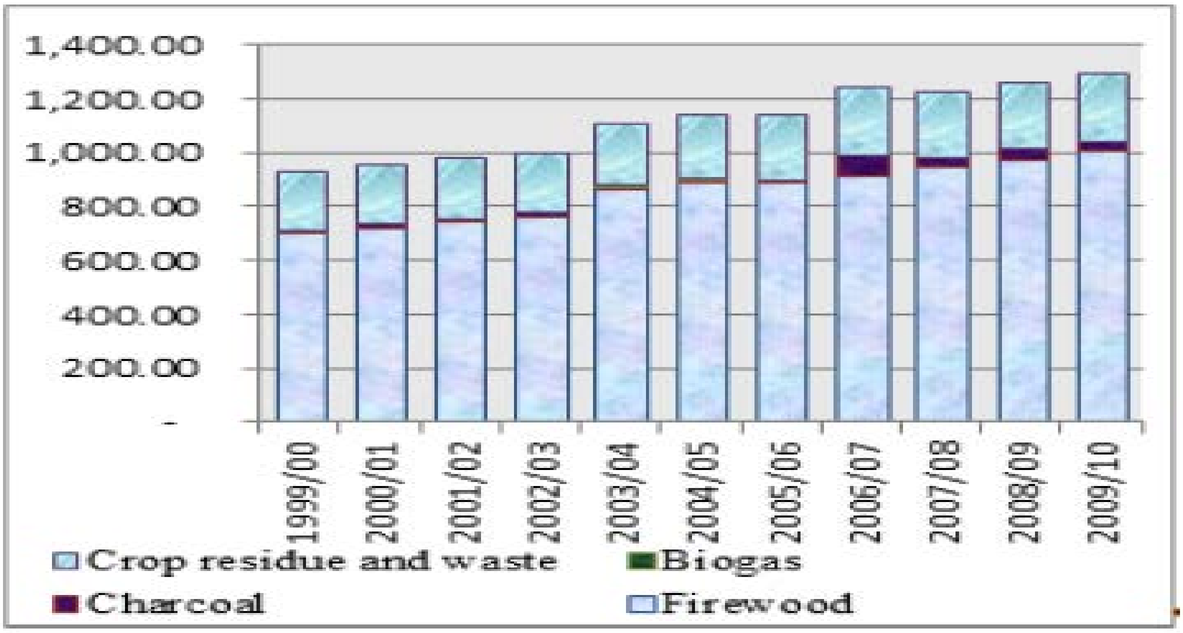


Figure 3-4: Trends and patterns of biomass consumption in Tera Joules (TJ)
Source: Guta D. 2012, p. 135

Ethiopia's energy situation is dominated by traditional biomass (90 %), however, modern fuels are the primary energy sources for the population living in the cities and towns. The modern fuel is primarily used for transportation, commercial, industrial and household applications.

3.1.5.1 The woody biomass

Woody biomass is the major bioenergy source for the household sector in Ethiopia. Only 11.2 % of the country's surface forested (Emelie César and Anders Ekbom, 2013, p. 3). Standing timber amounts to some 285 million m^3, or about 22 m^3 per ha, indicating a preponderance of dry rather than wet tropical forest ecosystem. Total biomass in forest ecosystems amounts to 573 million metric tons, or 44 t per ha. In 2005, 108.879 million m^3 of timber were harvested for fuel wood (24.5 % more than in 2000) along with 2.982 million m^3 for industrial round wood (an increase of 21.3 %), all of which were consumed domestically; harvests of timber for other uses were insignificant in comparison (FAO, 2010, 6). In 2005, timber removals accounted for 39.3 % of total production an unsustainable state of affairs.

According to the Ministry of Water and Energy report (Table 3-6), in 2010 the total annual supply of biomass fuel in Ethiopia was about 990 billion tons excluding Addis Ababa and Somalia, while that of the woody biomass stock was 95 % of the total potential supply. Crop residues and animal dung accounted 2 % and 3 %, respectively. The Oromiya region supplies about 40 %, SNNP 24 % and Amhara 15 %.

Table 3-6: Regional potential supply of biomass in Millions of tons
Source: Minstry of Agriculture (MWE) WBISPP, 2004

REGION	Woody biomass stocks	Woody biomass annual yield	Crop residue	Animal dung	Total	Share
Tigray	30.99	0.08	0.86	2.09	33.95	0.03
Amhara	138.89	5.84	6.24	7.43	152.55	0.15
Oromiya	373.34	19.90	10.96	10.62	394.92	0.40
SNNP	227.95	10.10	5.67	4.01	237.63	0.24
Afar	21.64	1.44	0.12	2.64	24.41	0.02
Beneshangul-Gumuz	76.61	3.53	0.21	0.18	77.00	0.08
Gambela	69.16	3.32	0.08	0.12	69.36	0.07
Dire Dawa	0.06	0.03	0.04	0.04	0.13	10-4
Harari	0.09	0.01	0.05	0.02	0.15	$2(10^{-4})$
Total	1,149.5	50.1	10.1	5.5	2.1	8.2
Share	95 %		2 %	3 %	100 %	

According to MWE Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2004) report, household wood fuel consumption is higher in the rural areas. The annual biomass consumption per year is presented in Table 3-7, by fuel types.

Table 3-7: Annual biomass consumption in Tcal
Source: WBISPP, 2004

Region	Fuel wood	Charcoal	Residues	Dung	Total	Share
Tigray	6,865	249	435	2,260	9,809	0.044
Amhara	49,033	220	10,530	15,917	75,699	0.339
Oromiya	58,281	577	3,150	9,762	71,771	0.322
SNNP	44,138	75	4,971	677	49,862	0.223
Afar	1,813	18	0	2	1,833	0.008
Beneshangul-Gumuz	2,472	27	328	10	2,837	0.013
Gambella	771	1	3	0	775	0.03
Somali	3,293	118	118	132	3,662	0.016
Dire Dawa	196	22	24	0	164	0.001
Harari	128	6	30	0	164	0.001
Addis Ababa	5,617	429	78	392	6,517	0.029
Total	172,608	1,742	19,667	29,152	223,169	1
Share	77 %	1 %	9 %	13 %	100 %	

The per capita consumption rates of wood fuels vary region to region. The national average per capita wood fuel consumption is 400.3Kg/a (Ibid). Most wood fuel is used for Mitad baking and other baking. In some rural use systems heating or lighting are also significant end uses.

Table 3-8 shows the urban household fuel wood consumption patterns. A significant amount of fuel wood is consumed in the urban areas as well. Even though there are other competent fuels like electricity, LPG and kerosene, still the urban use accounts for significant amounts of the national consumption. From the data it is obvious that the Oromiya, Amhara and Addis Ababa regions are the largest urban consumers of fuel wood; partially a reflection of the relative sizes of their urban population.

Table 3-8: Total urban household consumption of wood and charcoal by region (tons)
Source: WBISPP, 2004

Region	Fuel wood	Charcoal as wood	Total wood	As % of Ethiopia
Tigray	185,523	255,380	440,903	7.4
Amhara	607,010	480,217	1,087,227	18.3
Oromiya	1,230,529	503,714	1,734,243	29.1
SNNP	349,317	87,324	436,641	7.3
Afar	30,402	4,764	35,166	0.6
Beneshangul-Gumuz	24,921	10,306	35,228	0.6
Gambella	33,348	3,014	36,362	0.6
Somali	226,048	450,407	676,455	11.4
Dire Dawa	40,324	32,168	72,492	1.2
Harari	24,487	23,714	48,202	0.8
Addis Ababa	445,578	908,135	1,353,713	22.7
Ethiopia	3,197,488	2,759,144	5,956,632	

3.1.5.2 Charcoal

In Ethiopia, charcoal is used for cooking mainly by urban households; however it is produced by rural households. The demand for charcoal has grown faster due to the increasing urbanization, increasing monetization o charcoal and increasing competitiveness of charcoal with kerosene. The annual demand for charcoal in Ethiopia was about 0.4 million tons with 3.2 million tons of wood consumed in 2010 (Lulie M. and Tesfaye G. 2012, p. 39).

Charcoal consumption was 43,818 tons. Moreover, the annual per capita rate of charcoal consumption by rural households was 0.8Kg/cap in 2010 (WBISPP, 2004). Whereas in the urban areas, charcoal is the dominant wood fuel consumption. The total urban consumption of charcoal was 413,706 but this translates into 2,759,144 tons of wood. Addis Ababa is by far the largest consumer of charcoal given the very high urban population. The annual per capita charcoal consumption rate in the urban areas was 42.2Kg/cap.a (Ibid, p. 21).

Charcoal production and marketing has almost been entirely informally organized and implemented by the private sector. Most charcoal is produced by farmers as a part-time occasional activity in small lots. The earth mound kiln with a capacity of about 4 to 7 cubic meters is used throughout the country. Conversion efficiencies are reported to be very low (8 to 12 %) probably because of the small size of the kiln and also because the wood is not dried out properly (Lulie M. and Tesfaye G. 2012, p. 39). Average production from such kiln is about 100Kg of charcoal.

According the findings of WBISPP, the supply of the charcoal market is normally carried out through a few charcoal wholesalers, although a small proportion of construction pole merchants are also selling charcoal. Retailers sell in small to very small quantities in all the urban markets and outside homes.

Addis Ababa consumes about one third of the charcoal consumed in Ethiopia, or about 136,000 tons per annum or nearly 357 tons per day. Most of this is produced up to 300 km from Addis Ababa (WBISPP, 2004). Afar region within close proximity to the Djibouti-Addis main road, Oromiya region along the same road between Methara and Nazereth, and in the Central Rift Valley lakes area in the East Shewa Zone along the Shashemene to Mojo road. Other sources are the Abay Gorge, West Shewa Zone and 50km around Addis Ababa.

3.1.5.3 Animal Dung

Animal dung is one of the most commonly used traditional biomass by households for cooking in Ethiopia. Animal dung is also uses for production of biogas (Lulie M. and Adamu M., 2012, p. 28). According to the report of Central Statistics Authority of Ethiopia (CSA), the live-stock population of Ethiopia is about 150 million (see Table 3-9). It is obvious that dung is burnt as a last resort when fuel wood supplies are exhausted or in the short supply. The Amhara region uses more than two thirds of the share from the national rural households dung consumption.

The main end uses for dung are mitad baking, followed by other cooking and then heating. In the urban areas, the amount of annual dung as household fuel was 266,297 tons, with Oromiya taking nearly half the share. The national average per capita rates of dung use as fuel was 15.45Kg/a (WBISPP, 2004).

The annual potential supply of dung can be calculated by considering livestock data, which mainly provides the numbers of animal types (cattle, sheep, goats and camels). The estimate is based on ENEC/CESEN study of 0.691 tons of dry dung per standard tropical live-stock unit (TLU) (Lulie M. and Tesfaye G., 2012, p. 19-20). The estimated production of dry dung by livestock is shown in Table 3-9.

Table 3-9: Estimated annual dung production
Source: Lulie M. and Tesfaye G., 2012, p. 19-20

Annual dry weight dung production			
Type	**Livestock (million)**	**Dry weight (Kg/livestock/year)**	**Annual Production (million ton)**
Cattle	50.9	691	35.2
Sheep	26	77	2
Goat	22	88.3	1.9
Horse	2	552	1.1
Donkey	5.7	220	1.3
Mule	0.37	331	0.12
Camel	0.81	104	0.08
Poultry	42.1	4.8	0.2
Total	**149.9**	**2,068.1**	**41.9**

The dung collection pattern in rural households is from two major sources: their own farmland and from communal lands. The dung is occasionally mixed with a small amount of earth and straw to make dung cakes. These are then sun-dried and can be stored for the rainy season.

While urban dung marketing and supply patterns are from the nearby rural areas, the quantity of dung transported to the urban areas can vary region to region. It is also observed that in some small towns the households obtain dung from their own cattle.

3.1.5.4 Crop and other Agricultural residues

The annual supply of crop residues is obtained by considering the crop area and production data. Agricultural residues fuel types are mostly used in the rural areas for cooking and baking where they can be obtained with ease. For instant, agricultural residues from Teff straw is usually used for cattle feed and mud reinforcement in home wall construction and not included in the energy analysis. In the year 2000, agricultural residues accounted for 22% of total biomass energy consumed in the household sector at the national level. In some Regional States they accounted for as much as 40% of the total biomass energy consumed by households (in Amhara, for example) (Lulie M. and Tesfaye G., 2012, p. 28). Table 3-10 shows the estimate of crop residues production by region.

Table 3-10: Regional crop residues
Source: WBISPP, 2004

REGION	Crop residues production (tons/year)
Tigray	782,439
Amhara	4,153,452
Oromiya	13,960,267
SNNP	452,656
Afar	121,807
Beneshangul-Gumuz	236,367
Gambella	39,867
Somali	316,837
Dire Dawa	40,644
Harari	43,070
Addis Ababa	0
Ethiopia	20,147,405

Agricultural residues supply is seasonal and usually available during the dry season. The collection pattern in rural households is from their own farm land. In larger towns where there are wood processing enterprises, saw dust is frequently sold as fuel. According to the WBISPP report, near Addis Ababa, households around such enterprises take the advantage of this fuel.

Although the main term “residues” encompasses all crop residues – stalks, roots and leaves, in practice, because of their values as livestock feed, households generally use the more unpalatable woody stalks of maize, sorghum, barley and wheat as fuel, in that order of preference.

1. *Ethanol*

The rise in oil prices and the associated increase in the prices of petroleum products that has occurred since the beginning of 2004 are showing adverse effects on the uses of petroleum products in all countries, including Ethiopia. To reduce petroleum imports, government of Ethiopia is started to produce ethanol from sugar factory and blend it with gasoline. Considerable potential from the sugar factories exists for the production of ethanol, which will reach an annual production level of 181, 604 m^3 in four years (Lulie M. and Adamu M. 2012, p. 16).

The raw materials used for ethanol production are sugarcane, sugar beet, corn, corn stover, wheat barely, molasses and cellulose biomass. In Ethiopia, 960,000 hectares of irrigable land is available for multipurpose. Out of this, an identified irrigation-suitable area for sugarcane plantations is 700,000 ha and this can yield more than 1 billion litres of ethanol (Ibid).

a. *Ethanol fuel and its blends*

Ethanol contains oxygen, which provides a clean and more efficient combustion of the fuel. When used in vehicles, ethanol reduces carbon dioxide, a major contributor to global warming. Although burning ethanol still releases carbon dioxide during production & combustion, it is recycled by the crops that are used as raw materials for the production of ethanol. This creates a cycle in which green-house gases are used instead of being emitted into the environment. Application of ethanol in Ethiopia is so far limited to blending of

20,500m^3 of ethanol with gasoil for transport use within Addis Ababa (Lulie M. and Adamu M., 2012, p. 16)

b. The existing and future ethanol production capacity

As of the year 2006, Finchaa sugar Factory has an ethanol plant with a capacity of 8,000 m^3 of ethanol per annum (Asfaw, M. 2007, p. 9). In the short term, the country can produce a total of 25,700 m^3 ethanol including the existing production of Finchaa sugar factory. The existing sugar factories are in a process to undergo expansion programs including ethanol production. According to the Ethiopian Sugar Development Agency, the sugar factories total annual ethanol production capacity in 2010/11 was 11.1 million liters (Hiben, 2013, p. 22).

The Biofuel industry development of the country encourages and facilitates development of the energy sector and the development of economic growth. The Government of Ethiopia has set ambitious plan to produce 1.8 billion liters of liquid biofuel by 2015, consisting of 195 million liters of ethanol and 1.6 billion liters of biodiesel (GTP, 2010, p. 37-38). The expansion plan of existing sugar factories and development of the new ones, the ethanol production capacity may reach 181 million liters per year (see Table 3-11).

Table 3-11: Ethanol production and projection in Ethiopia ('000 liters)
Source: Asfaw, M., 2007, p. 9

Ethanol Production	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Finchaa	8,000	8,448	17,000	18,600	18,600	18,600	21,221
Wonji/Shoa	-	12,245	17,809	20,836	25,153	28,153	35,527
Metehara	-	-	-	17,676	21,301	24,480	20,728
Tendaho	-	-	23,296	47,508	64,051	60, 616	50,689
Total	8,000	20,245	58,105	104,620	129,106	128,849	128,165

By 2014/15 nine new privately owned sugar factories are expected to start ethanol production while at the same time the production output of state owned sugar factories is expected to increase considerably. It is anticipated that the total national ethanol production capacity will reach 181,604 m^3 per annum. By 2015, this production capacity will enable the blending mix of 20-25% of ethanol [E20-E25] as well as the expansion of the sale of blended gasoil to regions outside of Addis Ababa (Lulie M. and Adamu M., 2012, p. 10). Figure 3-5 presents current and projected annual ethanol production in million litters.

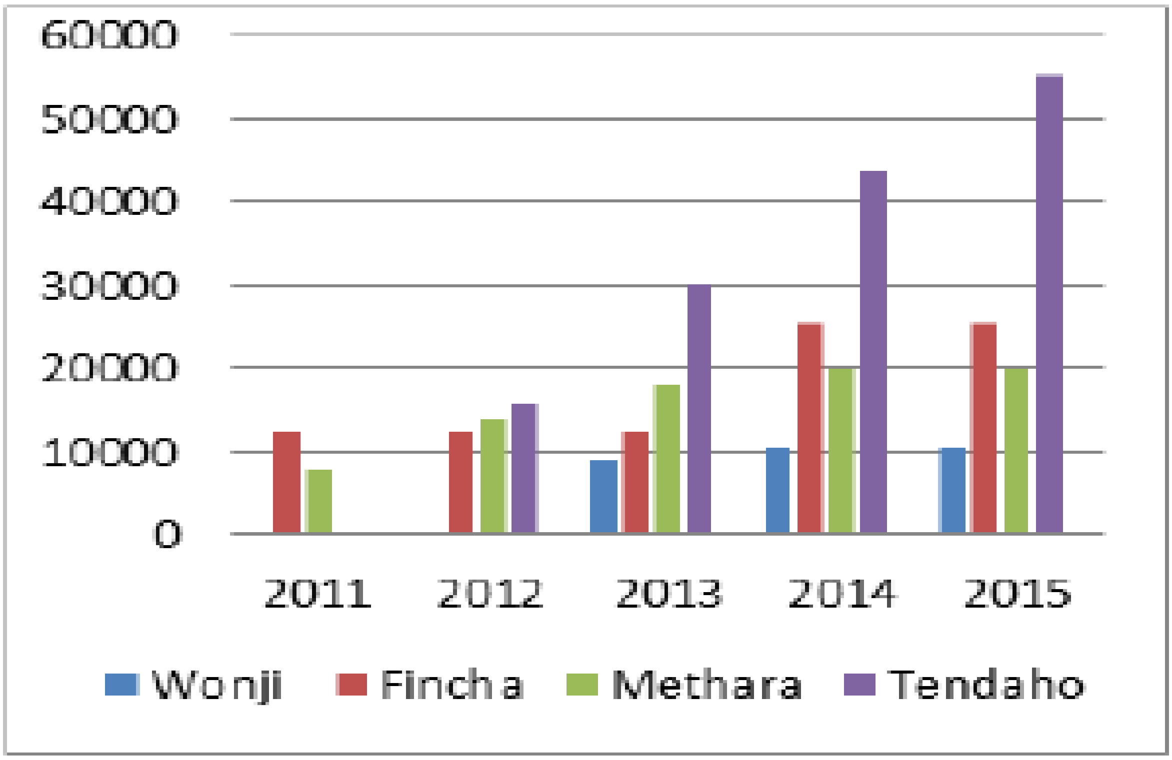


Figure 3-5: Current and projected annual ethanol production in state sugar factories (million liters)
Source: Guta D. 2012, p. 137

2. *Biodiesel*

Ethiopia has a large resource base for the production of biodiesel feedstock and biodiesel fuel that can reach a level of 5 to 10 million tons per annum (Lulie M. and Adamu M., 2012, p. 17). Large areas with suitable agro-ecology for production of other high yield oil crops such as palm trees and the castor plant are available in the country. The total available potential land for the production of feedstock for biodiesel is estimated at about to 23.3 million hectare of land, of which 17.2 million hectare is in Oromia, 3.1 in Benishangul-Gumuz, and 2.8 in Gambela regions (Forum for Environment (FfE), 2011, p. 11).

The major crops for biodiesel feedstock, Jatropha curcas, castor oil and palm tree are indigenous to Ethiopia. Based on the Government development strategy (Biofuel Strategy, 2007), several local and foreign companies have started growing plants for biodiesel feedstock. Regions that have received proposals include Benishangul-Gumuz, SNNP, and Oromiya. Sun Biofuels Eth/NBC Company has received 80,000 ha from the Benishangul-Gumuz region for Jatropha plantation (Ibid, p. 13).

3.1.6 Combustible waste

Bagasse energy, fuel based on the residual output of sugar factories, provides supplemental power in Ethiopia. Bagasse is an important source of fuel where the sugar factories of Metehara, Wenji and Fincha co-generate power for their consumption at installed capacity of 9.9 MW, 9 MW and 7 MW, respectively[43]. The Ethiopian sugar corporation has planned to contribute about 110 MW of electricity to the national grid by the end of 2015 from Methara, Wonji Shoa and Tendaho sugar factories (Ibid).

3.2 Other renewable sources of energy

Ethiopia is known to have a good potential for renewables, however to quantify this potential so far no detailed and systematic study has been done. This research estimates the technical potential of renewables in Ethiopia based on data from different studies.

Renewable alternative non-traditional resources comprise solar and wind energy. These resources while ideal for some specialist applications, such as serving and remote inaccessible sites, are not generally economically competitive with the traditional resources in terms of internal costs. But their potential may be vast and their environmental impacts are small.

[43] *Ethiopian Sugar Corporation (ESCo), Organizational Profile of ESCo, Available at http://www.etsugar.gov.et/en/about.html , Accessed December 2013*

Nevertheless, these alternative resources may be able to contribute economically to the needs of the nation, not only for the remote and specialist applications noted, but also to the grid. Any such renewable indigenous resources can be made economically competitive and financially viable if full costs are considered including external costs. Being relatively small, their introduction does not alter the large-scale generation expansion plan in the short term.

In the context of the Ethiopian power grid system, these small-scale developments would not be of critical importance to the reliability of the system. Consequently, the need for expensive electrical energy storage would be obviated, and the resource could be more competitive.

In as much as alternative energy resource developments could be smaller in size, thereby being less difficult to finance, developable within a relatively short time frame and able to sell their full output to the grid system immediately upon start-up, these could be attractive projects especially for independent power producers.

Ethiopia is rich in renewable energy reserves and is very willing to develop its renewable energy resources. Currently hydropower dominates the power supply of Ethiopia. In order to diversify energy supply, relieve power shortage and decrease electricity free regions, the Ethiopian government put forward a strategic plan of powerfully developing its wind energy and biomass energy in the GTP (MoFED, GTP, 2010, p. 38-39).

At present, there haven't been any large scale wind or solar photovoltaic projects put into commercial operation in Ethiopia, but the two wind farms Ashegoda in Mek'ele and Adama in Nazret are under construction. Grid-connected solar photovoltaic power generation projects have not been constructed so far Ethiopia.

In 2007, Solar and Wind Energy Resource Assessment (SWERA) organized by the United Nations Environment Program (UNEP) finished Ethiopian solar and wind energy resource assessment as the second systematic assessment of nationwide solar and wind energy resources of Ethiopia. According to related data in the SWERA report, Ethiopia has a total area of about 20,000 km^2 suitable for grid-connected wind power development and a potential annual power generation capacity up to 890TWh (EREDPC, 2007, p. iii).

3.2.1 Hydro power

Ethiopia is endowed with numerous rivers, lakes and ample water resources. The country's annual surface runoff is close to 122 billion cubic meters of water (EWRMP, 2001, p. ii). The Ethiopian Highlands are the origin of many North African rivers, and most of such rivers, e.g. the Blue Nile River (Abay), Atbara River, Sobat River, Shebeli River and Jubba River, radiate in all directions. In the dry season, rainwater is scarce, river levels drop, and flow quantity is small. In the rainy season, rainfall soars, river levels rise, flow quantity increases, and flow velocity accelerates, causing floods in many river valley regions across the lower reach. Regular flooding of main rivers makes the farmland in lower-reach river valleys fertile, provides favorable natural conditions for local agriculture and the brilliant long-history civilization of Nile Basin in North Africa. Ethiopia has an economic potential of around 45,000 MW distributed over four major river basins (Blue Nile, Baro Akobo, Tekeze and Omo Gibe) and others. However the current installed capacity is only 2,000MW (<5 %) (Gebreegziabher, Z. and A. Mekonnen. 2011, p. 6).

Ethiopia is undertaking several hydroelectric potential developments, it has implemented a series of projects since 2001 (Tis-Abay II, Gilgel III,Gibe I, Tekeze, Gilgel Give II and Beles), and plans to bring even more power through upcoming mega projects (Gilgel Gibe III, Genale Dawa III, Chemoga Yeda, the Renaissance Grand Millennium Hydroelectric project and others) (see Table 3-12). These projects are expected to raise the generation capacity from 2,000 MW to nearly 10,000 MW (MoFED, 2010, p. 36).

Table 3-12: Hydroelectric projects of Ethiopia: implemented and planned
Source: Gebreegziabher, Z. and A. Mekonnen. 2011, p. 21

Project	Capacity (MW)	Operational year	Investment cost in Million US$	Source of Finance
Tis-Abay II	73	2001	-	-
Gilgel Gibe I	184	2004	-	-
Tekeze	300	2009	-	-
Gilge Gibe II	420	2010	-	-
Beles	460	2010	-	-
Gilgel Gibe III	1,870	~2015	1,700	Bilateral
Genale Dawa III	254	~2015	408	Bilateral, China
Chemoga Yeda	250	~2016	555	Bilateral, China
Renaissance Grand Millennium	5,250	~2015	4,800	Domestic+Bilaterial
Other Projects	2,646	-	2,968	-

The Grand Ethiopian Renaissance Hydroelectric Project (also known as the Grand Millennium Dam) (see Figure 3-6), with a generation capacity of 6000 MW, is under construction on the Blue Nile river and will be the largest hydroelectric project in Africa, with water storage capacity of 66 billion m^3. When the project is completed, it will boost the country's electricity generation by an addition of 15,128 GWh annually (EEPCo, 2013)[44]. The Grand Ethiopian Renaissance Hydroelectric Project has drawn attention from Egypt

[44] *Ethiopian Electric Power Corporation (EEPCo), Grand Ethiopian Renaissance Dam Project, Available at* *http://www.eepco.gov.et/project.php?pid=1&pcatid=2* *Accessed December 2013*

(Nile upstream) for the tapping of the Nile River and this is because it's taking of the lion's share of Egypt's on-Nile water. However, the government of Ethiopia and other downstream countries are becoming increasingly vocal about their right to develop trans-boundary water resources outside the Nile water treaty, which they believe unfairly allocates the major use of all of the water to Egypt and Sudan (Hammond, 2013, p. 3).

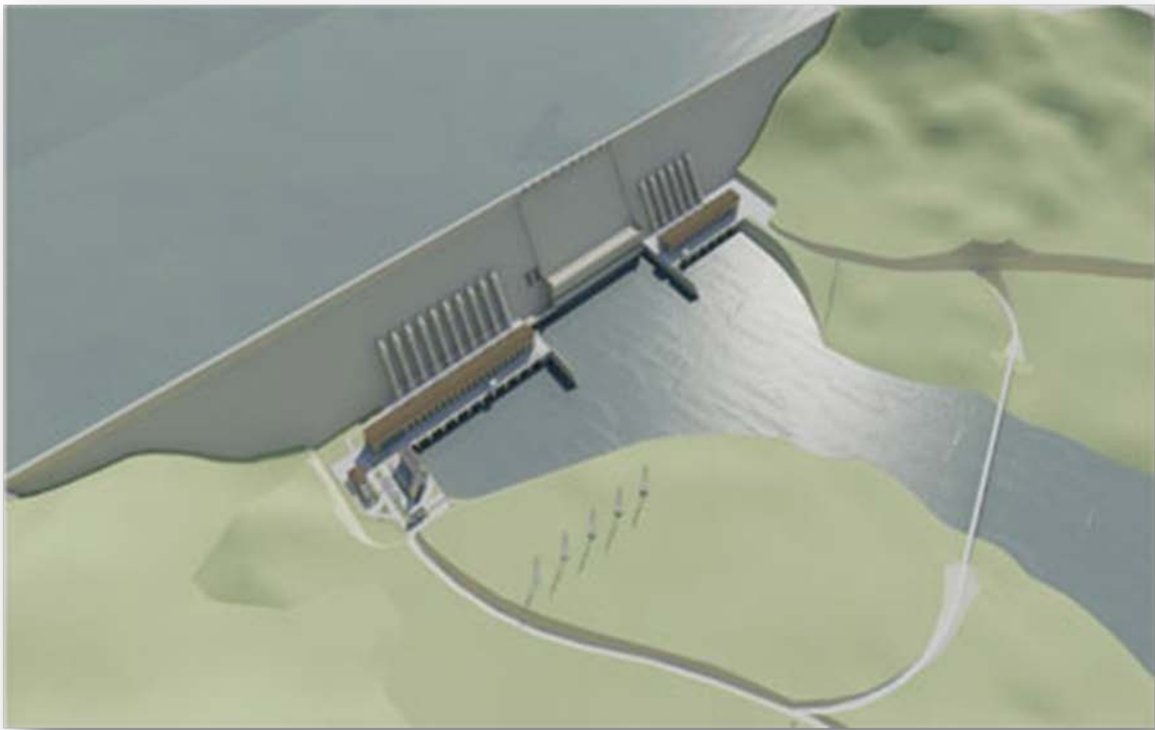


Figure 3-6: Grand Ethiopian Renaissance (GERD) hydroelectric power project[45]

3.2.2 Solar energy

Ethiopia is located in Eastern Africa with territory extending from 3 to 15 degrees North latitude and 33 to 48 degrees East longitude. Thus Ethiopia possesses quite large and fairly constant solar sources spread over the country. Nevertheless, solar energy development in Ethiopia is exploited less than 1 % (around 6 MW) (ECA/SRO-EA/ICE/2013/08, p. 112). According to the analysis of the Solar and Wind Master Plan developed in 2012 with the collaboration of Ethiopia and Chinese governments (Ministry of Water and Energy, June

[45] *EEPCo. http://www.eepco.gov.et/project.php?pid=1&pcatid=2 , Accessed December 2013*

2013, p. 4), Ethiopia's solar radiation ranges from 4 to 6 kWh/(m^2.a),with an annual total solar energy reserve of 2.199 million TWh (Figure 3-7).

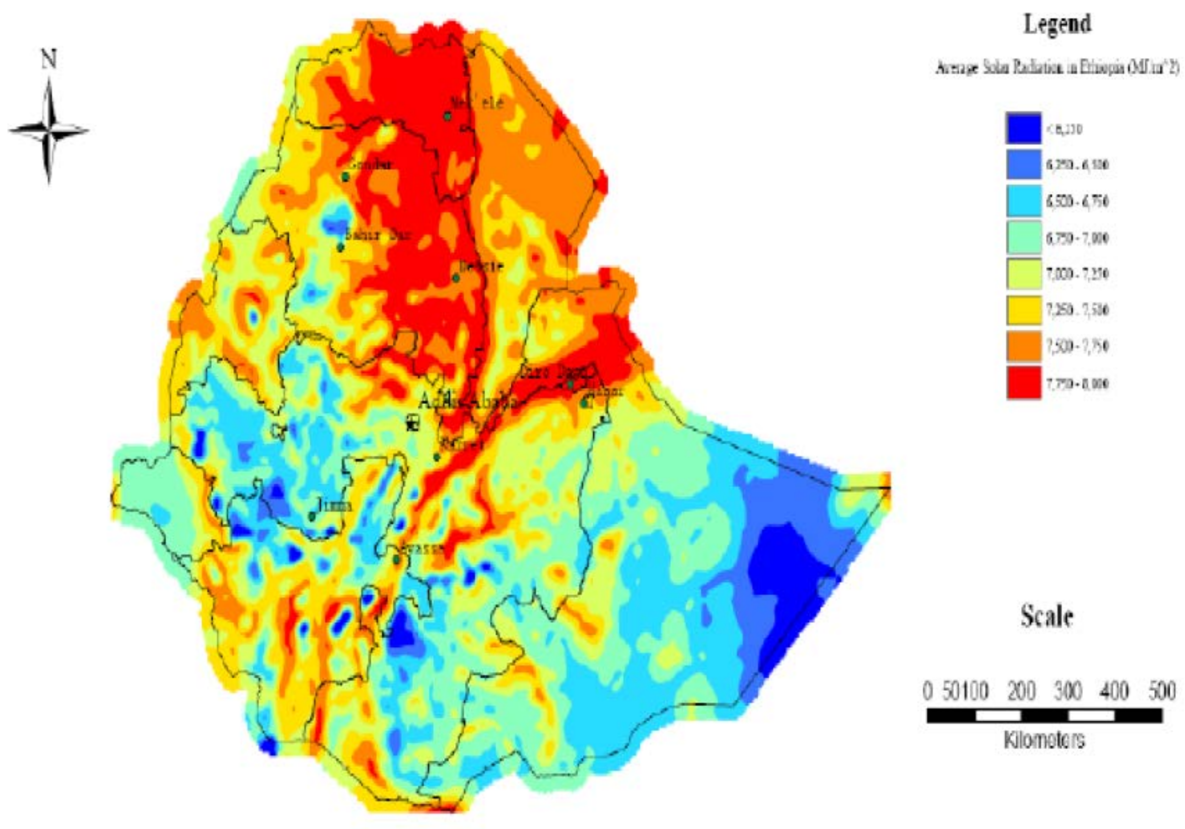


Figure 3-7: Total average annual solar radiation distribution in Ethiopia (1980-2009)
Source: Master plan report 2013, p. 54

According to the standard of Chinese meteorological industry Assessment Method for Solar Energy Resources (QX/T 89-2008), annual total solar radiation in any region of the country reaches class "very rich" (1400kW·h/(m^2·a) $\leq$ annual total solar radiation $\leq$ 1750 kW·h/(m^2·a)) or "richest" (annual total solar radiation$\geq$1750 kW·h/(m^2·a)) (Figure 3-8).

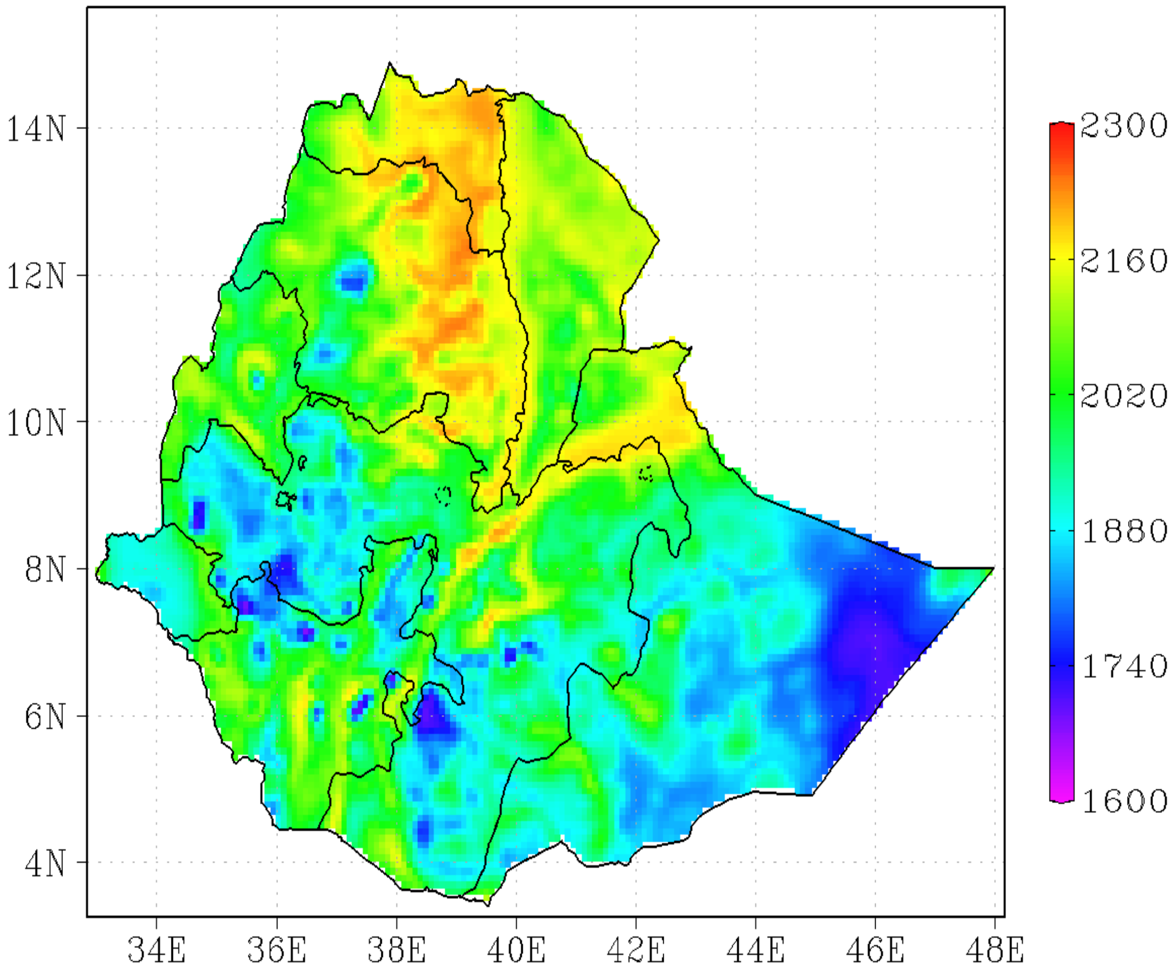


Figure 3-8: Distribution of average annual total solar radiation in kWh/ (m^2.a) (1980-2009)
Source: Master Plan report 2012, p. 51

Solar energy development in Ethiopia is for application of lighting and powering water pumps in rural areas and water heating in major cities and these accounts for only around 6 MW (ECA/SRO-EA/ICE/2013/08, p. 112). In remote telecom installations solar PV is used. Table 3-13 presents the list of recommended sites for short term solar PV power development by the government of Ethiopia.

Table 3-13: Recommended sites for short term solar PV
Source: Ministry of Water and Energy, 2013, p. 12

No.	Name	Capacity (MW)	Area (km2)	Region
1	Debre Berhan PV power station	10	0.39	Amhara
2	Metehara PV power station	50	1.6	Oromiya
3	Dera solar energy PV power station	60	1.59	Oromiya
	Total	120	3.58	

3.2.3 Wind energy

According the master plan report of solar and wind energy (2012) and the Ministry of Water and Energy, Ethiopia has a potential wind energy capacity of about 1,350 GW with highest potential in the Somali (1,060 GW) region followed by the Tigray (78GW), Oromyia (75GW) and Amhara (59GW) region (Ministry of Water and Energy 2013, p. 14). Figure 3-9 shows average wind speed of Ethiopia at 50 m height.

At present the country has an installed capacity of 51 MW from the Adam wind farm and 120 MW from the Ashegoda wind farm (Africa's largest wind farm at present--December 2013)[46]. Wind energy application in Ethiopia has been limited so far. The wind farm at Ashegoda, northern Ethiopia, has an installed capacity of 120 MW, the largest such farm in the country, and one of the largest in the sub-region. Utility scale wind energy projects of Adama, Ayesh, Debre Berhan and Messebo are also examples of large scale development (Table 3-14).

[46]*The Cable News Network (CNN),* *http://edition.cnn.com/2013/11/08/business/earth-wind-water-ethiopia/index.html Accessed December 2013*

Table 3-14: Wind energy development of Ethiopia

Source: Ministry of water and energy, Energy study and development follow-up direction, June 2011

Name		Wind energy Installed Capacity (MW)
Ashegoda	Wind farm	120
Adama	Power Plant	51
Ayesh	Power Plant	50
Debre Birhan	Power Plant	50
Messebo	Power Plant	51

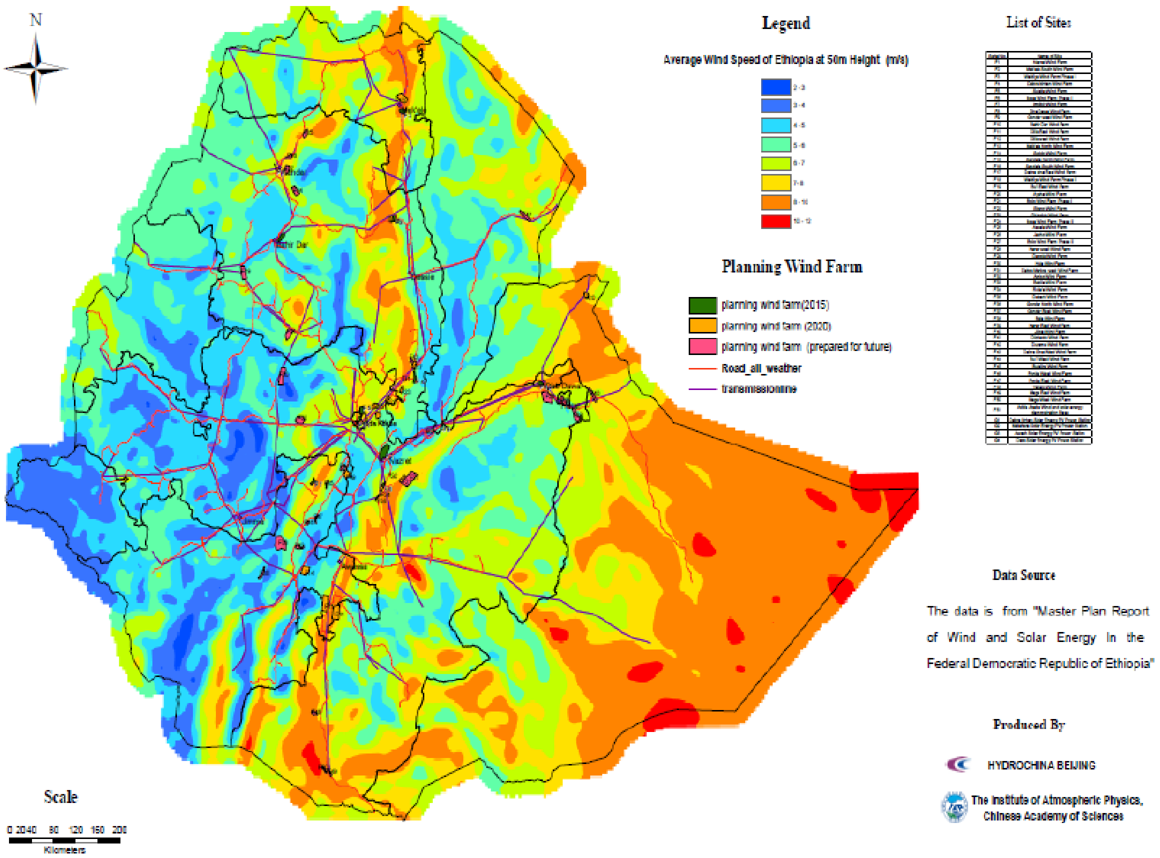


Figure 3-9: Average wind speed of Ethiopia at 50m height for 30-year period (1980-2009)

Source: Master plan report, 2012, p. 13

Figure 3-10 shows distribution of average wind speed at 1m height in m/s. Wind speed is high in both long and narrow zones in central Ethiopia, the border region Djibouti and the Somali Region. Wind speeds in some parts exceed 10m/s at a height of 50m. Wind speed is low at the sides of the two long and narrow zones and also in West Ethiopia. From 10m to 50m there is a significant shear, in that wind speed at a height of 50m is significantly higher than that at a height of 10m. Figure 3-11 presents the spatial distribution of the wind power density at 50 m height measured in W/m^2.

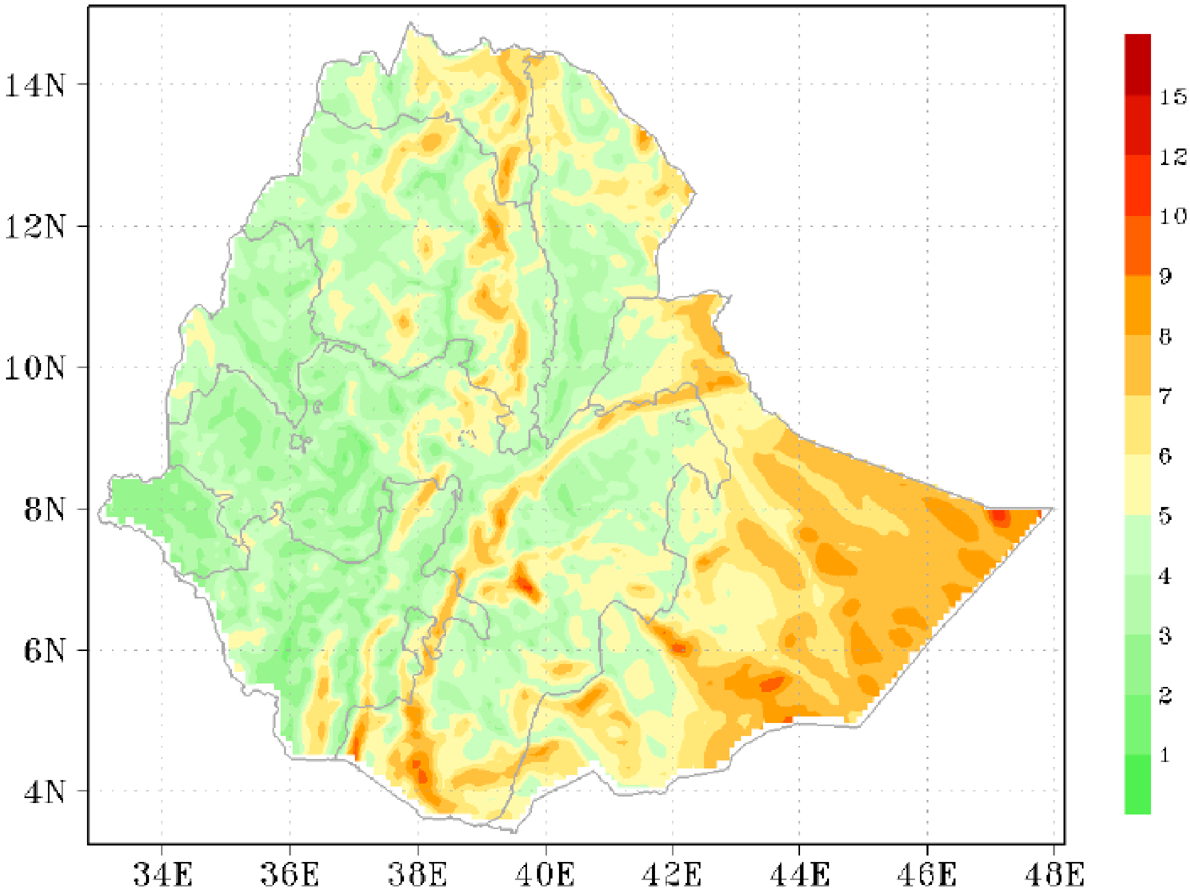


Figure 3-10: Distribution of average wind speed, m/s (Height: 10m, 1980-2009)
Source: Master plan report 2013, p. 22

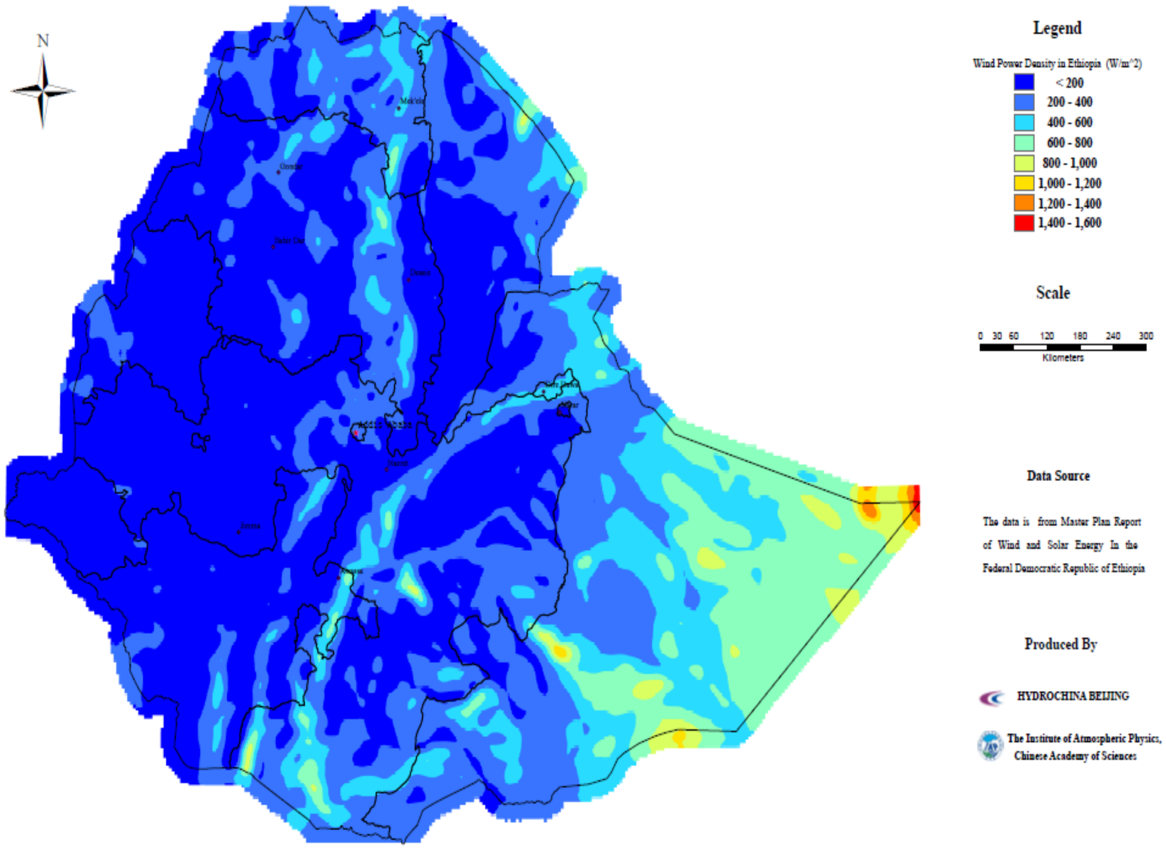


Figure 3-11: Average wind power density of Ethiopia at 50m height (1980-2009)
Source: Master plan report, 2012, p. 14

3.2.4 Geothermal

Ethiopia is well endowed with geothermal resources due its geographical position at the East Africa Rift Valley and the country is listed for its potential on the world map of geothermal energy[47]. The current exploration is believed to have studied only a fraction of the ultimate potential. The best prospective areas are distributed along the Ethiopian Rift system which runs in a northeasterly direction along the entire length of Ethiopia. Geothermal energy, given its estimated potential of 5,000 MW (thermal + electrical), is currently marginally utilized in Ethiopia (Kebede, 2012, p. 14). Aluto Langano is the sole existing geothermal plant with a capacity of only 7.3 MW (Ibid, p. 7). Table 3-15 identifies six sites (Aluto-Langano, Tendaho, Corbeti, Abaya, Tulu Moye and Dofan) of geothermal energy sources which could deliver new capacity of 440MW.

[47] *The Geothermal Resources Council, http://geothermal.org/what.html, Accessed November 2013*

Table 3-15: Geothermal energy installed capacity (MW)

Source: Ministry of Water and Energy, Energy Study and Development follow-up directorate, June 2011

Name		Geothermal energy Installed Capacity (MW)
Aluto Langano Geothermal	Operational	7.3
Aluto-Langano	Feasible Projects	75
Tendaho	"	100
Corbeti	"	75
Abaya	"	100
Tulu Moye	"	40
Dofan	"	50
Total		**440**

The 6 geothermal resource areas are all located within the rift and are well distributed (Figure 3-12). Three areas are in the Lake District, about 100 to 300 km south and southeast of Addis Ababa. The Aluto Volcanic Center, just north of Lake Langano, has been identified as the most attractive prospect in the Lake District. A total of 11 areas are located in the Afar region between Tullu Moye in the south and Tendaho in the north. The most promising area is the Tendaho Graben and two areas in the Danakil Depression in the northwest Afar area (Ministry of Water and Energy, 2013, p. 27-28). Actual reserves are believed to be much larger and further studies are required in order to quantify them.

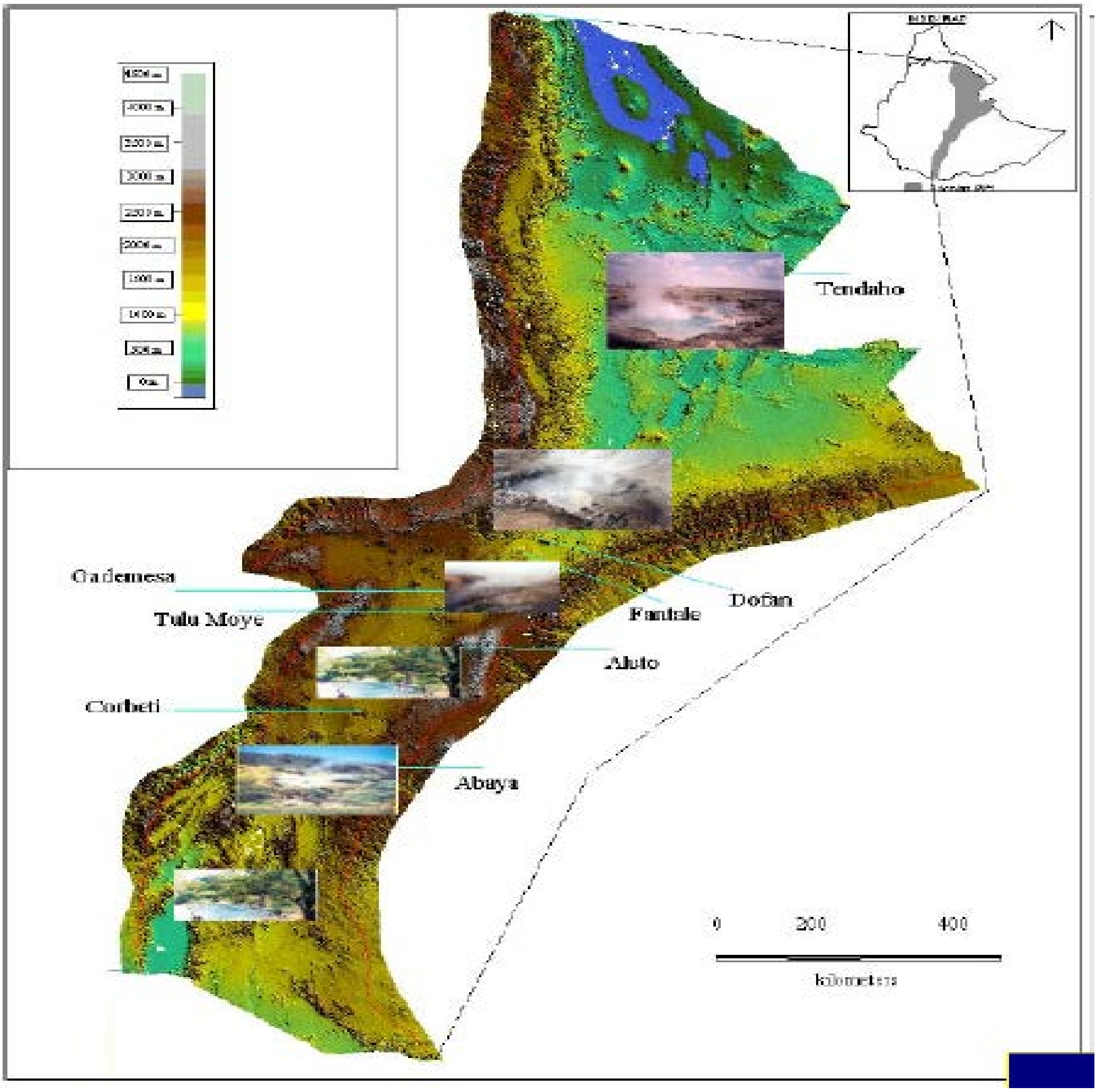


Figure 3-12: Location of geothermal energy sources
Source: Ministry of water and Energy, 2013, p. 27

3.3 Summary

Ethiopia is known to have abundant and various indigenous energy sources (renewable and non-renewable). The renewable energy resources encompass a broad width of energy sources including traditional resources, hydro, geothermal, solar and wind, however, no systematic study has been done so far to quantify non-renewable energy resources. Table 3-16 summarizes the available energy resources of Ethiopia, which was applied to specify the input for the LEAP model in Chapter 5.

In as much as alternative energy resource developments could be smaller in size, thereby being less difficult to finance, developable within a relatively short time frame and able to sell their full output to the grid system immediately upon start-up, these could be attractive projects especially for independent power producers.

As the country is located near the equator on the geographical map, solar energy is abundant almost throughout the year. Due to this it is labeled as a nation with thirteen months of sunshine (Ethiopian calendar has 13 months)[48].

The other still not yet exploited resource is wind. This alternative energy resource is abundant in several areas in the country. The wind resource could be exploited for power generation in synchronization with the hydropower resource as it is most abundant when the availability of the hydropower is least during the summer season and the converse during winter.

The famous East African Rift Valley crosses through the country dividing it into two. In the areas where this rift valley passes there is plenty of geothermal energy potential. This resource is not well exploited. There is, of course, a sort of minor attempt in this direction but still small.

One promising resource is biomass. As there is plenty of sunshine and rainfall, Ethiopia is suitable for the development of biomass energy. In most parts of the world, especially in the northern hemisphere like Western Europe, it takes 15 to 20 years for a tree to grow into maturity, whereas the same growth could be achieved in 2 to 4 years' in Ethiopia. Therefore, provided that a careful plan is set and implemented, the nation could foresee a lot of potential from bio-fuel development and generating electricity from it.

Even though the amount is small with regards to its potential the most exploited renewable energy resource in Ethiopia compared to other resources is hydropower. Currently more than 90 % of the country's electricity is generated from this resource. According to the Ministry of Water and Energy (2013, p. 4), Ethiopia has around 45 GW potential from this resource but what is developed is only less than 5 %.

[48] *The Ethiopian Herald*, *http://www.ethpress.gov.et/herald/index.php/herald/development/2202-13-months-of-sunshine-is-it-enough* , Accessed February 2013

Table 3-16: Indigenous energy resources potential of Ethiopia
Source: GTZ-TERNA, 2005; EREDPC, 2007; EEPCo, 2011; MoWE, 2013, EIGS, 2008 and SWERA, 2007

Resource	Unit	Exploitable Reserve	Exploited	
			Amount	%
Hydropower	MW	45,000	~2100	<5
Solar/day	kWh/m2	4-6		<1
Wind: **Power speed**	GW M/S	1350 >7	171 MW (under construction)	<1
Geothermal	MW	7000	7.3 MW (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

According to the government plan Scaling-up Renewable Energy Program (SREP, 2012, p. 5), the energy sector development of Ethiopia is likely to change the capacity and composition of its generation portfolio going towards 2030, while the energy sector is expected to remain predominantly sourcing green energy (see Table 3-16).

Table 3-17: Current and future generation portfolio of Ethiopia

Source: Ministry of Water and Energy of Ethiopia and Scaling-up Renewable Energy Program (SREP), 2012, p. 5

Type	Existing		2015		2030	
	MW	%	MW	%	MW	%
Thermal	79.2	6.9	79.2	1.4	79.2	0.57
Non-renewable Total	79.2	6.9	79.2	1.4	79.2	0.57
Hydro	1,850.6	92.5	10,641.6	90.8	22,000	87.26
Wind	-	0	772.8	4.8	2,000	4.05
Geothermal	7.3	0.6	77.3	1.4	1,000	7.49
Bagasse	-	0	103.5	1.6	103.5	0.63
Renewable Total	1,857.9	93.1	11,595.2	98.6	25,103.5	99.43
Total	1,937.1	100	11,674.4	100	25,182.7	100

4 ENERGY MODELING AND DEVELOPMENT

Energy planning is crucial for supporting decision and policy makers with respect to national and regional development. Energy models describe the relationship between economic development, energy use and CO_2 emissions and project the future energy demand and supply of a country (Van Beeck, 1999, p. 8). According to Herbst (Herbst, et al 2012, p. 112), "*Energy models assume certain boundaries of development such as economic activities development, demographic development, and world market of energy and technology prices*" Energy models outline the primary energy consumption, conversion and final consumption of energy. The primary energy used can be obtained domestically or imported from abroad. Also a part of domestic production can be exported. Further, there is final energy which is obtained by transformation of primary energy into secondary energy. This is primarily for electricity and heat, as in conversion, large source losses can occur. An adequate energy model, therefore, is able to calculate both primary and secondary energy, final energy and eventual loss of energy conversion. In addition, a differentiation of various energy model requirements as well as a sufficiently deep sectoral input is necessary.

This chapter explains the energy model requirements and application approach. The LEAP model employed in this research to model the scenarios and to conduct these assessments, as well as the LEAP Model set-up and LEAP database for Ethiopia and the structure of energy modeling is explained in more detail.

4.1 Requirements for the energy modeling

Impacts of future energy demand and supply can often be analyzed by different types of energy models. Models can simulate the market penetration and related cost changes of new energy technology or policy with a certain degree of technical detail. They are used in an exploratory manner by assuming certain developments of boundary conditions such as demographic manner development, economic development or energy prices on world markets. Models are also used to simulate policy and technology choices that may influence future energy supply and demand and investments in energy systems (Herbst, et al 2012, p. 112).

However, policy and technology choices induce a dilemma in the choices of energy models. "*Energy models can simulate sector specific future energy supply and demand including the* *impacts on economic growth, employment or foreign trade. Every modeling approach abstracts to a certain degree from reality using facts, statistical average figures as well as assumptions. Energy models have specific advantages and limitations of which modellers, policy makers and users are often not sufficiently aware of the result"* (Böhringer, C., 1998, p. 233). A large number of modeling approaches are developed depending on their intended use (data analysis, forecasting, optimization, simulation, estimation of parameters), target groups (research communities, policy makers, utility companies), the information available (useful energy, energy demand data on final energy, sector wise energy demand), regional (national regional multinational) and conceptual framework (top-down, bottom-up) (Figure 4-1).

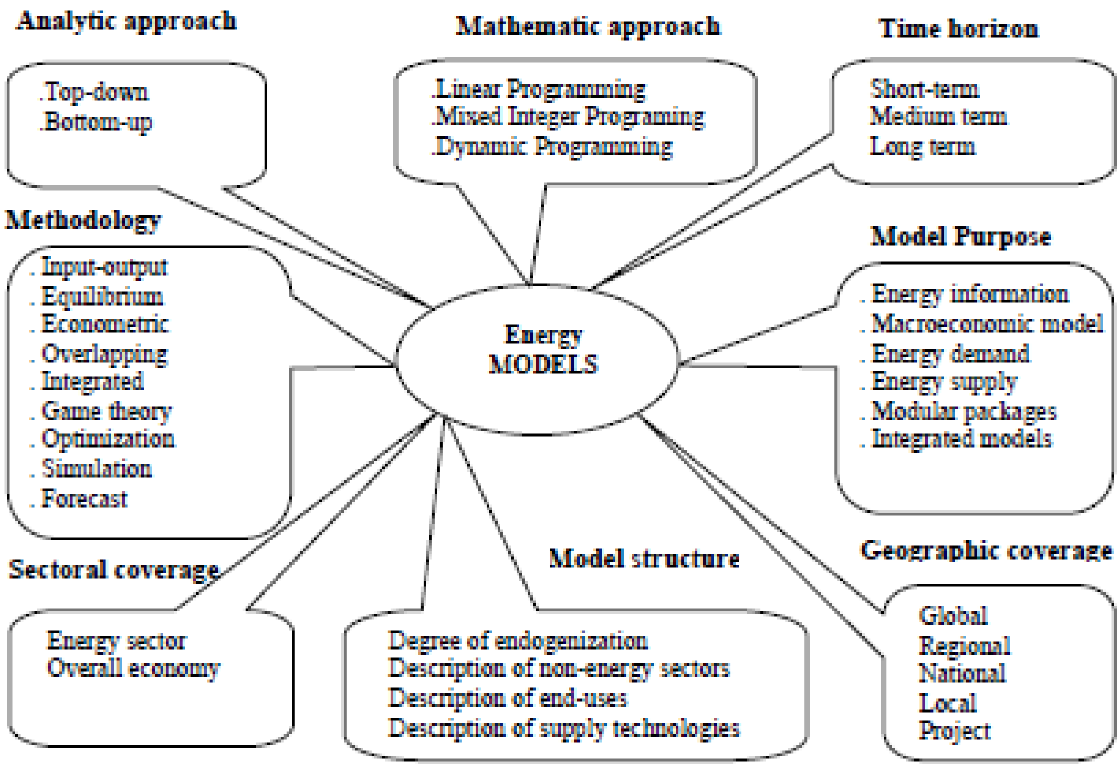


Figure 4-1: Criteria to classify energy planning models

Source: Nguyen, 2005, p. 13

4.2 Modeling approaches in energy sector

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

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

- Principle: Simulation and optimization
- Approach: sectoral ("top-down") or technology-oriented ("bottom-up")
- Structure: point model (reduced to the consideration of production and demand without power restrictions) or extended model (including grid considerations)
- Period: long-term study (typical input variables: years of integral power generation or work) or short-term resource planning (use of existing or specified power plants typical input: load profile and power).

(Source: Pandey, 2002, p. 100)

The purpose of using energy models in scenario analysis is the most commonly used parameter for model choice and relates to the different factors to organize large amounts of data, to provide framework for testing hypothesis and to reflect understandable form of complex systems (Heaps, 2002).

The increasing energy demand and environmental concerns have led to the creation of a number of energy models which can be classified in two major categories (Rivers and Jacard, 2005).

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

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

   (Source: UNFCCC, 2005, p. 6)

2. ***Bottom-up models*** which determine the financially optimized (cheapest) way based on available technologies and processes. Bottom-up energy models use highly disaggregated data on specific technologies such as estimated cost of energy technologies. This would make it possible to produce detailed and fair energy use projections by type and sectors, typically to identify least-cost configurations (Wilson et al 1993, p. 249). Bottom-up energy models are categorized as:
   i. Optimization models
   ii. Simulation Models
   iii. Accounting Frameworks

Van Beeck, 1999, p. 12, provides the principal characteristics of top-down and bottom-up models (Table 4-1).The bottom-up model types are explained in the next sections (4.2.1 & 4.2.2)

Table 4-1: Principal top-down models and bottom-up models
Source: Van Beeck, 1999, p. 12

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

Both types of models (top-down and bottom-up) have specific advantages and limitations of which users of the results, modellers and policymakers need to be sufficiently aware. The choice of models tends to reflect a trade-off between model performance and expected output from model use on the one hand and availability of resource data on the other hand. One major advantage of top-down energy models is their application of feed-back loops to economic growth and employment. In contrast, bottom-up modeling approaches incorporate a high degree of technological detail, which enables them to present very detailed output of energy demand and supply technologies (Herbst, et al 2012, and p. 124-125). According to a Danish energy report (Danish Energy Agency 2013, p. 19), the bottom-up model approach is missing out with broader macroeconomic developments, whereas top-down models lack detail of technological data. Table 4-2 presents an overview of energy models with their strengths and weaknesses in the application.

Table 4-2: Overview of Energy Models
Source: Danish Energy Agency 2013, p. 19

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

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

According to the theoretical approach, a further classification of energy models explains the basic methodological differences between bottom-up and top-down models (Heaps 2002, p2). Regarding the mathematical form, bottom-up energy models have been developed in the form of optimization models (e.g. MARKAL/TIMES), simulation (accounting) models (e.g. LEAP) and more recently multi-agent models "*Most of the bottom-up models limit their cost and investment* *calculations to the conversion sector and cross cutting technologies in the final energy sectors”* (Herbst, et al 2012, p. 119).

4.2.1 Optimization models

Optimization energy models incorporate some optimizing behavior for economic decisions. The methodologies are used to optimize investment decisions endogenously. The models are often used by utility companies or municipalities to derive their optimal investment strategies and are used for analyzing the future energy system for national energy planning. The models require a relatively high level of mathematical knowledge. The use of optimization models is limited to discrete energy conversion technologies and typified energy uses as the information on investment and operating cost are needed for the optimization (Heaps 2002, p. 6). *“It is impossible for optimization models, for instance, to simulate the demand of the services and industrial sector due to their technological variety where cost information cannot be made available”* (Herbst, et al 2012, p. 121). In addition, optimization models neglect the fact that severe market imperfections and obstacles in many final energy sectors and the conversion sector are not simulated which leads to unrealistically low projections of energy demand. MARKAL (MARket ALlocation) and MESSAGE (Global energy systems model) are the most widely used optimization energy models (Herbst, et al 2012, p. 121; Koch et al 2003, p. 65-66).

4.2.2 Simulation models

Simulation energy models allow users to simulate behavior of consumers and producers under various signals (policies, incomes, prices) to systematically analyze an assumed policy related development in each sector. The models allow the users to explore different scenarios and investigate technologically oriented measures. Accounting frameworks are considered to be a simple form of simulation models which aims to account for the physical and economic flows of the energy system (Heaps, 2002, p. 7). The models set up an accounting balance for the flow of energy through an economy for a period of time. The iterative approach is used to find the market clearing demand and supply equilibrium. These types of models enable the modeller to explicitly specify outcomes. This type of model accounts for the outcomes of the assumed development. *“This approach is commonly applied to project future energy demand of final energy sectors and the related emissions. Due to their simple structure, accounting frameworks* *are not commonly applied to simulate decision processes*" Herbst, et al, 2012, p. 123). LEAP is one example of an accounting framework and will be discussed in detail in the next sections (4.3).

4.2.3 Multi-Agent Models

Multi-agent modeling is a simulation approach which considers market imperfections like asymmetric information, strategic behavior and other non-economic influences. "*Multi-agent* models are limited to applications of the energy converting technologies and a few applications on final energy sectors" (Herbst, et al, 2012, p. 123). Major obstacle of multi-agent models is the demand on additional empirical data.

4.3 The LEAP model

The Long-Range Energy Alternatives Planning system (LEAP) is a modeling tool used to systematically analyze energy-environment interdependence, from primary energy development to end-use energy consumption based on the assumed inputs. The LEAP model simulates energy scenarios and consisting of several modules and a user-friendly interface developed by Stockholm Environment Institute's (SEI's) U.S. center[49]. For the demand side module, it requires energy consumption data, and future energy development plans, demographic and social estimates (GDP growth, Population, etc.) (SEI 2006, p. 1).

- **LEAP** is an integrated modeling tool (based on an accounting framework approach) used to analyze the national energy system by tracking energy consumption, production and resource extractions in all sectors of the economy.

- **LEAP** allows modellers to simulate different plausible scenarios of energy demand and carbon dioxide emissions

- **LEAP** consists of four modules: assumptions (to construct variables of the model), demand (different sectors of demand for energy services are specified), transformation (different supply and conversion technologies) and energy production (energy resources extraction and refining)

[49] *SEI, http://www.sei-us.org/Publications_PDF/SEI-LEAP-brochure-Jan2012.pdf, Accessed October 2013*

- **In LEAP**, *"the data is assembled in a hierarchical format based on four levels; sector level (residential, industrial, etc.), sub-sector levels (rural or urban), end use (lighting, cooling, etc.) and finally end uses according to the appliances (compact fluorescent lamp, etc.)*" (Monal. A H., 2010, p. 60)

- **LEAP** can calculate endogenously the demand by giving the energy intensities for all possible end uses, so the total demand is the sum of the product of all energy intensities and the number of end-uses.

(Sources: Heaps, 2002, p. 13-15; ERC, 2008, p. 1-2; SEI, 2012, p. 16)

The LEAP modeling methodologies are built in two conceptual levels. The first level is "basic physical accounting calculations handled internally within software (stock turnover, energy demand and supply, electric dispatch and capacity expansion, resource requirements, costing, pollutant emissions, etc.). The second is additional modeling which can be added by the user (e.g. user might specify market penetration as a function of prices, income level and policy variables).

– Users can specify spreadsheet-like expressions that define data and models, describing how variables change over time in scenarios:

– Expressions can range from simple numeric values to complex mathematical formulae. Each can make use of: math functions, values of other variables, functions for specifying how a variable changes over time, or links to external spreadsheets" (SEI, 2012, p. 42).

4.3.1 Structure of LEAP

LEAP provides a lot of flexibility in using demand data. "*These can range from highly disaggregated end-use oriented structures to highly aggregate analyzes. Typically a structure would consist of sectors including households, industry, transport, commerce and agriculture, each of which might be broken down into different subsectors, end-uses and fuel -using devices*" (SEI, 2006, p. 71). The structure of the data is adapted, based on purposes, on the availability of data, the types of analyzes to conduct, and unit preferences. The entire model system includes, at present, an economic model, an energy model, a material model and a foreign trade module (connection to the world model). Figure 4- 3 presents the calculation flow in the LEAP structure.

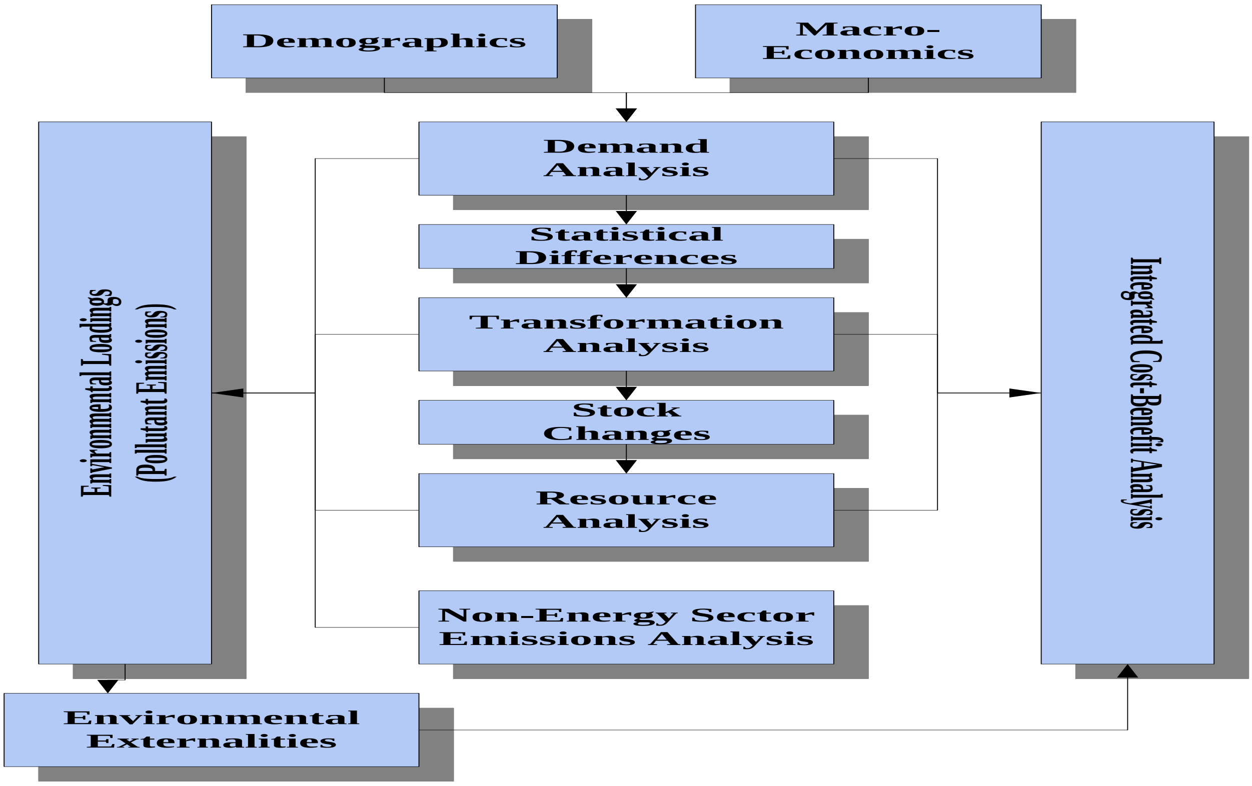


Figure 4-2: LEAP structure and calculation flows
Source: Heaps 2002, p. 16

4.3.2 Input and output of LEAP

Operating LEAP requires data input. The economic model essentially comprises an input-output model, a representation of the accounts system of national accounts. A detailed description of the economic model parts follows in Chapter 5. The material model assigns the domestic and imported material inputs to the extraction or import sectors of the economy. The sector wise input structure is shown in Table 4-3. The energy model describes the relationship between economic development, energy use and CO_2 emissions. It includes the primary energy consumption, the transformation and the energy consumption. It is divided into different economic sectors and distinguishes different fuels according to the energy balance statistics of Ethiopia.

Table 4-3: Sector wise input of LEAP
Source: Merven, 2012, p. 7; Heaps 2002

Sector	Disaggregation	Driver
Agriculture	Irrigation, transport, etc. (end use)	Agriculture GDP
Residential	High, medium and low income/ electrified and non-electrified	Population, Household income
	end use, cooking, lighting, etc.	
Commercial	end use, lighting, etc.	Commercial GDP, building stock
Industrial	sector, Iron and Steel, Pulp and paper, etc.	Sectoral GDP
	end use, thermal fuel or electricity (compressed air, cooling, motive, etc.)	
Transport	Air, Freight, passenger, pipeline end demand, passenger km, ton km	Transport GDP, Population and household income
	end use , diesel car, petrol car, taxi, etc.	

4.3.3 Interface of LEAP

LEAP model consists of four major modules with specific characteristics:

1. ***Assumptions of the model*** : allows to construct all the variables of the model: economic growth, population, urbanization
2. ***Demand:*** where different categories and sectors of demand for energy services are specified (Figure 4-4).
3. ***Production and Transformation***: Different supply and conversion technologies are available
4. ***Energy production:*** energy resources extraction and refining.

(Source: SEI, 2006, p. 51)

The LEAP model calculates the energy requirement of the demand sector from year to year by multiplying the activity (energy service) by the energy intensity for all end uses. The prediction of the growth rates of activities or energy intensity is exogenous to LEAP. The demand program uses the end use driven approach. *"The data is assembled in a hierarchical format based on four levels* (see Figure 4-3)*; sector level (residential, industrial, transport, etc.), sub-sector levels such as rural or urban, further end-use (lighting, cooling, etc.) and finally end-uses according to devices (fluorescent lamp, compact fluorescent lamp, etc.) or according to fuel use (diesel, electricity, etc.)"*(Mondal, A H. 2010, p. 60). In the energy demand program, the energy intensity values along with the type of fuel used in each device are required to estimate the energy requirements at sector, sub-sector and end-use level. Once energy demand (energy source, intensity) of the end users has been identified the energy flows will simultaneously be routed to the transformation module, where the model calculates the total energy consumption.

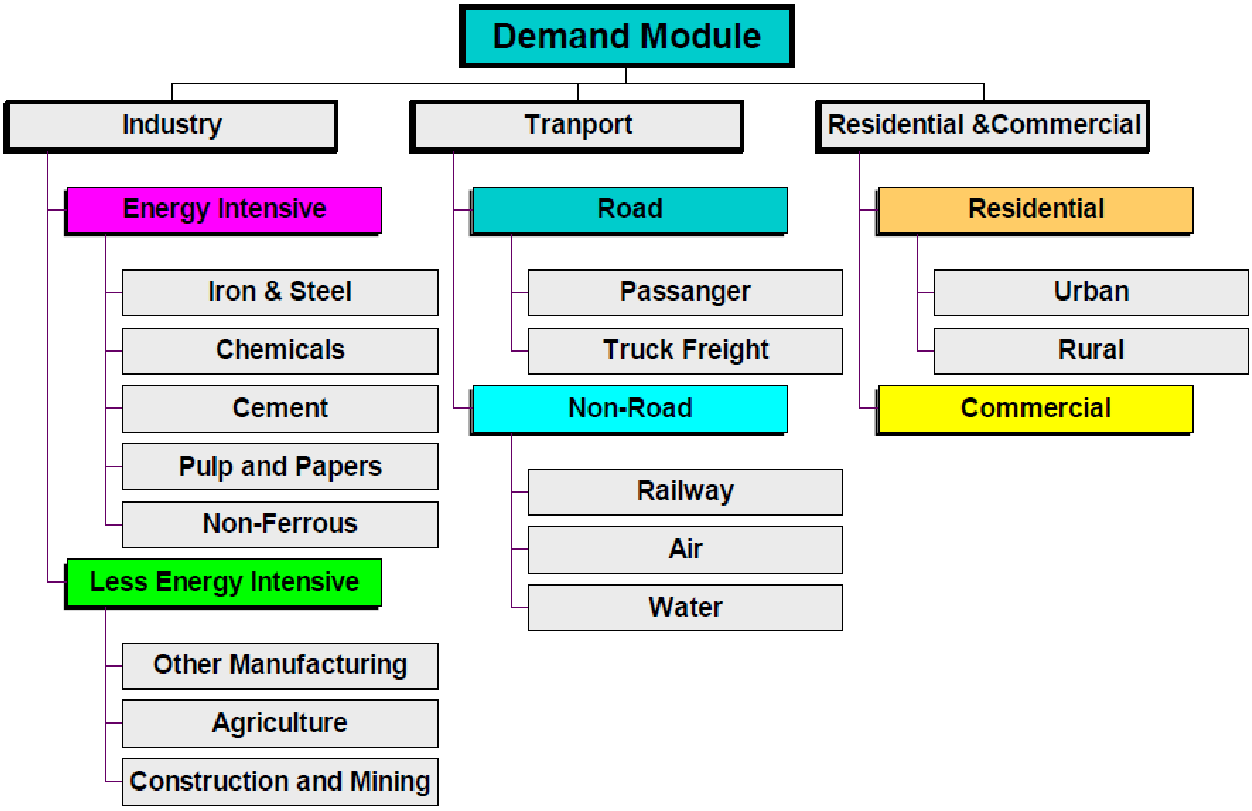


Figure 4-3: Levels of sectoral break-down
Source: SEI, 2012, p. 54

4.4 Basis of selection of energy model for Ethiopia

The choice of energy models tends to reflect a tradeoff between model performance and the expected use of model output on the one hand and data and resources availability on the other hand.

Most developing countries rely on bottom-up models (LEAP, MESSAGE/MEAD MARKAL/TIMES). Ethiopia relies on a combination of simplified top-down and simplified bottom-up models. The top-down model generates projections of broad emission trends, while the bottom-up model is used to produce additional detail at sectoral level (Danish Energy Agency, p. 20). The process of baseline calculation for the Climate Resilient Green Economy Strategy (CRGE)[50] implemented by the national environmental and development authorities have used simple extrapolation using spreadsheets and marginal abatement cost curves(MAC curves--Bottom-up) to specify the costs of technologies. The strength of this approach is the relative simplicity and the very short time necessary for completing the projection.

It must be pointed out that the main objective of this research work is to create a dialogue with decision makers by assessing the different energy strategies (demand and supply) in different time horizons. Hence this research work tries to develop a simulation model. This modeling focuses on different energy scenarios relating the technical choice to the economic assessment.

The energy scenario planning methodology followed in this research is supported by the LEAP model tool. The LEAP model is selected as the preferred framework for elaborating scenarios of the development of the Ethiopian energy system. This is mainly because of its transparency and user friendly characteristics, the integrated energy modeling tool that can be used to create models of different energy systems. It requires less data compared to other bottom-up models (MARKAL). Ethiopia has enough data to run the LEAP tool properly. Because of its simplicity, it is easier to introduce the LEAP model to regional energy bureaus. Furthermore, there are many local experts who are already experienced using the LEAP model. The IPCC tier 1-2 data for the energy sector is also a choice to use LEAP model.

In addition, LEAP is selected for this research work due to the following reasons:

1. LEAP allows the modeller to simulate different plausible scenarios of energy demand and CO_2 emissions

[50] *UNDP , http://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf Accessed December 2013*

2. The LEAP model is a transparent and flexible model that offers users a wide range of different modeling methodologies that support demand and supply analysis and consists of 4 major modules: assumptions, demand, transformation and energy production
3. Energy price is an exogenous variable in the model, this can facilitate the comparison of economic consequences of decision made now.
4. LEAP includes the Technology and Environmental Database (TED) which allows the analysis of different technology portfolios in a very detailed way. Providing costs and environmental effects for a wide range of energy technologies. This database offers a complete and up-to-date library for developing countries' analysts where data structures are spare and also poor in quality.
5. LEAP is used in more than 190 countries by more than 10,000 worldwide users[51] and most of them are from developing countries which offer significant advantages to users in terms of national starter data sets.
6. Since 2011 the new version (LEAP 2011) supports optimization modeling integrated with the OSeMOSYS optimization model[52].

By using LEAP's physical accounting calculations, technologies are selected in the expansion plan to meet a certain demand in the future. Scenarios are simulated and examined in terms of their CO_2 emissions. The model consists of four main components, the energy topology and organization, numerical database, mathematical structure and scenarios and strategies. The total cost of energy system consists of the technologies cost (e.g. investment cost, fixed and variable cost of power plants, refineries appliances), cost of energy sources and imports and cost of emissions.

This study identifies the need of model for the backcasting of future energy supply. Therefore the LEAP model is proposed after an extensive literature review about the model used in various studies of similar kind. The LEAP model examines the pathways for optimal energy supply to meet the end use services in energy-consuming sectors (e.g., residential, industrial, transport, commercial & services, agriculture, etc.) under various scenarios. The inputs of the model are the future energy demand, potential of energy resources and the technological options in demand and supply side. The availability and timeline of possible technological options (existing and futuristic for both demand and supply side) and their technological characterization is evolved

[51] SEI, http://www.energycommunity.org/default.asp?action=47 , Accessed December 2012
[52] SEI, http://www.energycommunity.org/webhelppro/Optimization/OptimizationIntroduction.htm , Accessed December 2012

on the basis of an extensive literature review. These inputs are provided to the model to obtain the results over the study. The results obtained from the model provide the following information.

• level of uptake of total energy resources.

• distribution of the energy resources across the consuming sectors.

• the choice of technological options.

A schematic representation of the LEAP modeling system employed in this research is shown in Figure 4-4.

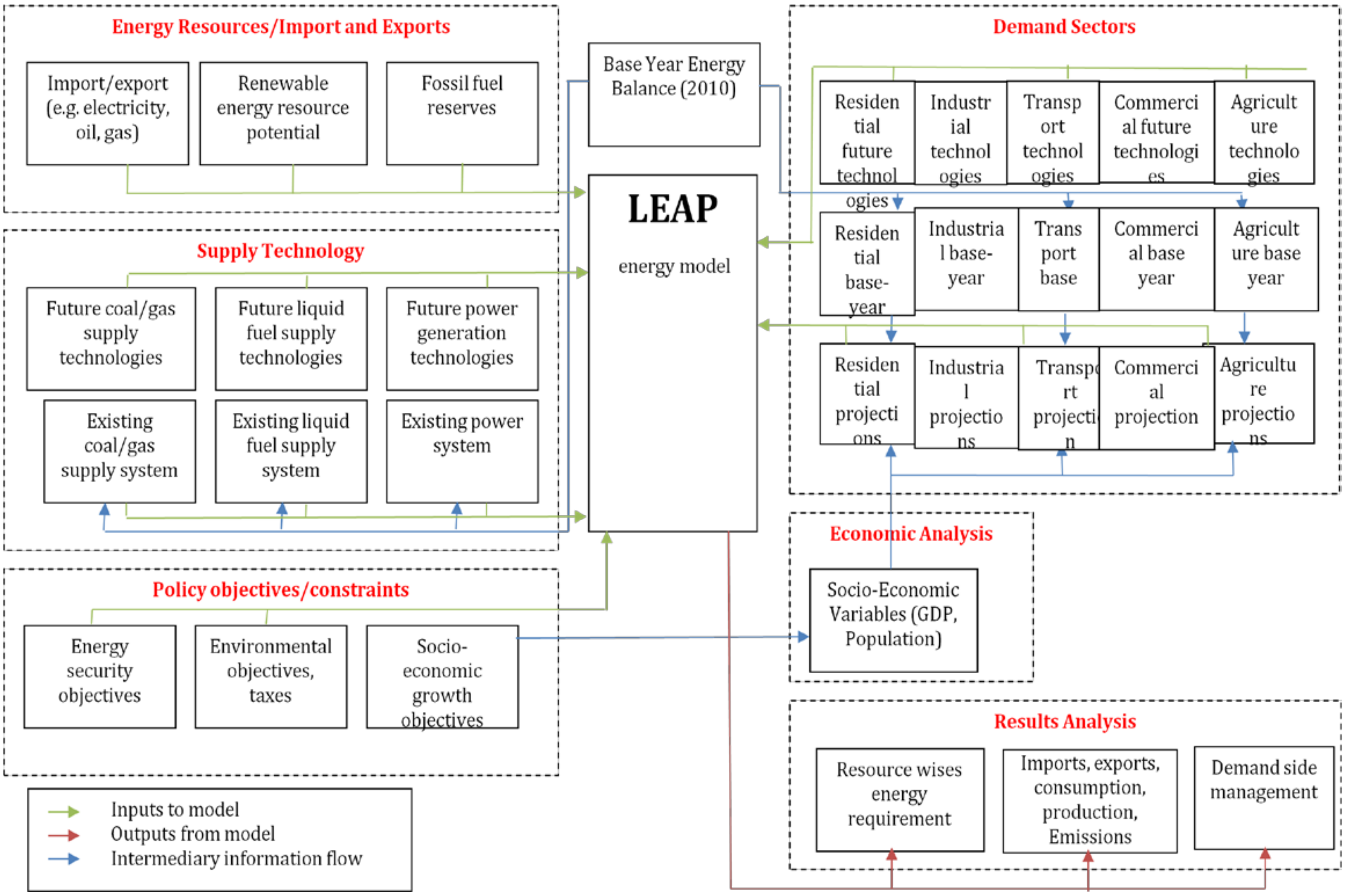


Figure 4-4: Schematic representation of methodological framework

Source: Adopted from the report "Tomorrow's Cities: Energy and Sustainable Urban Development"[53]

[53] *ERC Energy Systems Analysis Group, Available at* *http://www.cityenergy.org.za/files/resources/energy_courses/Adrian%20Stone_Integrated%20Energy%20Planning%20and%20Energy%20Modeling.pdf , Accessed December 2013*

5 LONG-TERM ENERGY SCENRAIOS FOR ETHIOPIA

One of the big challenges that Ethiopia is facing towards building a green economy is the provision of a modern, clean and affordable energy supply. In light of the climate change problem and the scarcity of fossil resources, it is necessary to develop long-term energy scenarios that can show sustainable energy pathways for Ethiopia. As already mentioned in the introduction, renewable energy sources, as climate friendly alternatives to fossil resources, should clearly contribute more to cover the energy demand of Ethiopia. As explained in Chapter 2, fossil fuels are becoming a high priority for energy production and consumption in Ethiopia. In terms of renewable energy at present, hydropower and the use of biomass make significant contributions, all other renewable energy sources have yet to make a significant contribution. This research intends to address the long-term sustainable energy scenario options which can meet the challenges of both energy security and means of climate change mitigation in Ethiopia.

In this chapter three long-term energy scenarios, representing the most likely energy pathways for Ethiopia, are developed. This chapter proposes the development of three scenarios that picture the development for Ethiopia’s long-term energy supply up to the year 2050. The study uses the scenario technique with five key drivers that could shape the future sustainable development of the country’s energy system. To this end, three long-term energy scenarios representing the most likely sustainable energy pathways for Ethiopia are developed. With the help of the developed scenarios, different energy and economic development paths for Ethiopia until 2050 can be made comparable.

This chapter is divided in three sections. The first section is scenario development, which includes scenario development techniques and processes; the second discusses key scenario variables in Ethiopian context and a specification of alternative energy scenarios. In the third section the main features of the scenarios are summarized.

5.1 Scenario development

5.1.1 Overview

The general approach to scenario development mostly considers the description of alternative options around different assumptions and the explanation of the characterizing parameters and criteria of scenario development. Subsequently, the importances of the modeled scenarios are quantitatively examined and their impacts for the future long-term energy pathways of a country are analyzed. The scenarios outline alternative future development paths that a common option space “windows of opportunity” shows. In principle, the development of scenarios beyond scenarios can help to highlight conflicts, target inconsistencies and illuminate knowledge gaps. Scenarios are therefore not to be construed as a forecast, rather they show future development paths that would result under the assumptions made.

The scenarios created in this sense are an important basis for the development of strategy and actions. In the 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. In scenarios’ options the objectives, intentions and actions are summarized. The IPCC (2000, p. 17-18) has employed five steps in the scenario development process. One is a review of the existing regional and global emissions scenarios from the literature; second is the analysis of different scenarios’ main characteristics, their driving force and their inter-relationship; third is the formulation of “storylines” to determine the main scenario characteristics, and development of prototype scenarios; the fourth is quantifying the different modeling approaches based on storylines; the fifth is incorporating feedback from experts worldwide and from modeling groups.

Scenarios face the task of producing consistent images of possible future developments in which specific conditions and socio-political conditions are properly managed. This allows, in contrast to forecasts, a description of possible futures. Scenarios are complex "if-then" statements. According to the UK Foresight Program report, the report orients in two directions, in principle:

- On the one hand, conditions such as policies, and partly also political individual instruments, and technical measures are established or derived. Their impact on the overall energy system over time (consumption, fuel mix, share of renewable, etc.) is determined. This is a "what happens if ...?” statement. This methodology is applied for the scenario “business as usual” (BAU).
- On the other hand, concrete or strategic objectives for a specific time can be specified. With the help of the model’s calculations a set of necessary measures and instruments

can be derived in order to achieve these goals. These statements are derived of the character "What needs to happen for a particular goal to be achieved?"

(Source: UK Foresight Program (2008, p. 11-12)

In this research, energy scenarios for Ethiopia are developed through three steps. The first step is identifying important key variables from the policy viewpoint, which could influence the future energy system development and energy policy strategies in Ethiopia. The second step is the construction of alternative scenarios by developing a logically consistent set of assumptions as a means of policy constraints. The third step is describing of the alternative energy scenarios which are provided for the modeling purpose. The detailed process of energy scenario development for Ethiopia is presented below.

5.1.2 Identification of key scenario variables

In order to develop long-term energy strategies and policies that address the challenges that Ethiopia has been facing, including the energy supply and protecting the environment, the following questions should properly be answered:

- What options, in term of energy resources, would be available for Ethiopia to meet its long-term energy requirements?
- How can the diversity of the energy mix be improved and clean technology utilization be increased?
- What options would be appropriate to reduce energy import dependency?
- How could advanced technologies affect the development of the country's energy system?
- What options would be useful to reduce the negative impacts of energy activities on the environment?
- How would these options affect the country's economy?

In order to analyze the above questions posed, this research selected key variables based on the appropriateness of addressing the energy challenges facing Ethiopia. The key selected variables include: socio-political and economic factors, energy diversity, energy import dependency, advanced technologies and CO_2 emissions.

i. Social, political and economic factors

The energy choice reflects predominantly personal decisions made market or collective decisions by the government and the public at large. Personal choices that reflect value, environment and lifestyles will also be influential and will be reflected in patterns of energy consumption. The attitude of the government and public opinion on questions, such as energy supply security and environmental impacts, will significantly influence the development of future energy systems. This support is especially important for those technologies that are associated with high investment costs since the effects of bad investments can be significant even for large utilities.

In addition, other factors, such as a growth of GDP and population, rural electrification and urbanization will also impact the patterns of energy consumption. The accessibility and affordability of energy, especially for the low-income people in developing countries like Ethiopia, are critical factors in energy policy formulation.

ii. Energy diversity

Currently, the primary energy mix in Ethiopia is dominated by two supply sources, namely biomass for most household use and hydropower for its electricity production. The high dependence of these two supply sources further underscores the vulnerability of the energy system and makes the need to ensure sustainable energy supplies even more pressing. Therefore, diversity of the energy supply mix is likely to be one of the most important issues for Ethiopia, especially in the context of rapidly increasing energy demand to support the country’s socio-economic development.

iii. Energy import dependency

Petroleum products have remained a major component of energy demand by the transport sector in Ethiopia. The demand for petroleum fuels is increasing with the increase of population and economic growth. Even though the share of petroleum fuels is less than 6 % of the total national energy consumption (IEA, 2011), the increasing demand for it, and the associated price hike, have hit the national economy very hard (ERG, FFE, 2009, p. 6). As a net importer of petroleum, Ethiopia is highly vulnerable to price shocks and supply problems on the world market. Therefore the urgency of reducing the dependency on imported fuels is another important factor that is likely to shape the future energy pathways of Ethiopia.

iv. Advanced technologies

The increased use of renewable energy sources can also have significant associated opportunities for the export of technologies and know-how which can positively affect international competitiveness. Energy technologies can play an important role in improving energy efficiency and hence energy security and reduce negative impacts on the environment. Therefore worth examining how advanced technologies, for example PV, wind and IGCC technologies for power generation and Bio-fuel for transport, could contribute to enhancing energy security and reducing the rate of growth of GHG emissions. In order to achieve a maximum energy output for given amounts of primary energy sources, the primary energy sources must be used efficiently. The efficiency of energy production depends on the used fuel, plant and process as well as the location of the power generation facilities. In addition to energy efficiency the efficient use of material resources in the provision of power needs to be considered. These materials, along with the entire production chain (from the construction of the facilities to the use of renewable energies), need to be used more sparingly and efficiently thereby reducing emissions and waste products. It is important that the balance and diversification of different energy sources is taken to into account.

v. CO_2 emissions

This parameter specifies how high the savings in CO_2 emissions by 2050 will be relative to the BAU scenario if renewable energy can replace fossil fuels. Basically, renewable energy is CO_2 neutral. Emissions from production or transportation systems of fuels may arise however, therefore both the use and the production technology need to be included in the assessment. An absolute reduction of emissions can only be achieved, however, when the saving effects from renewable energy are not overcompensated by a growth in demand.

5.1.3 Scenarios construction

Based on the above key variables and target parameters, three key scenarios are developed in this research which represent likely alternative energy pathways for Ethiopia.

i. **The Business As Usual scenario (BAU),** which reflects a continuation of the current energy sector's trend in Ethiopia, with low economic development and low commitment in application of clean technologies.

ii. **Scenario 1: Moderate shift,** represents a reference scenario with moderate economic growth to play a large role in addressing the challenges that Ethiopia faces in the energy sector (such as low energy efficiency; modern, clean and affordable energy supply; dependency on imported energy and environment pollution).

iii. **Scenario 2: Advanced shift,** also a reference scenario but with advanced economic growth with advance consideration of input key variables (such as advanced energy strategies, i.e. renewable energy, climate friendly energy production).

As these scenarios have been developed in detail, a description of each scenario with a number of proposed parameters is given in section 5.1.4. These parameters were proposed based on different workshop feedbacks from stakeholders and experts where they were explained and discussed. The parameters used include both input parameters and target parameters. Assumptions about the input parameters are necessary for the implementation of the scenarios in the model.

The specifications for the updating of the prices of energy sources are taken from various studies. Figure 5-1 shows how the key variables may influence the outcome of the scenarios.

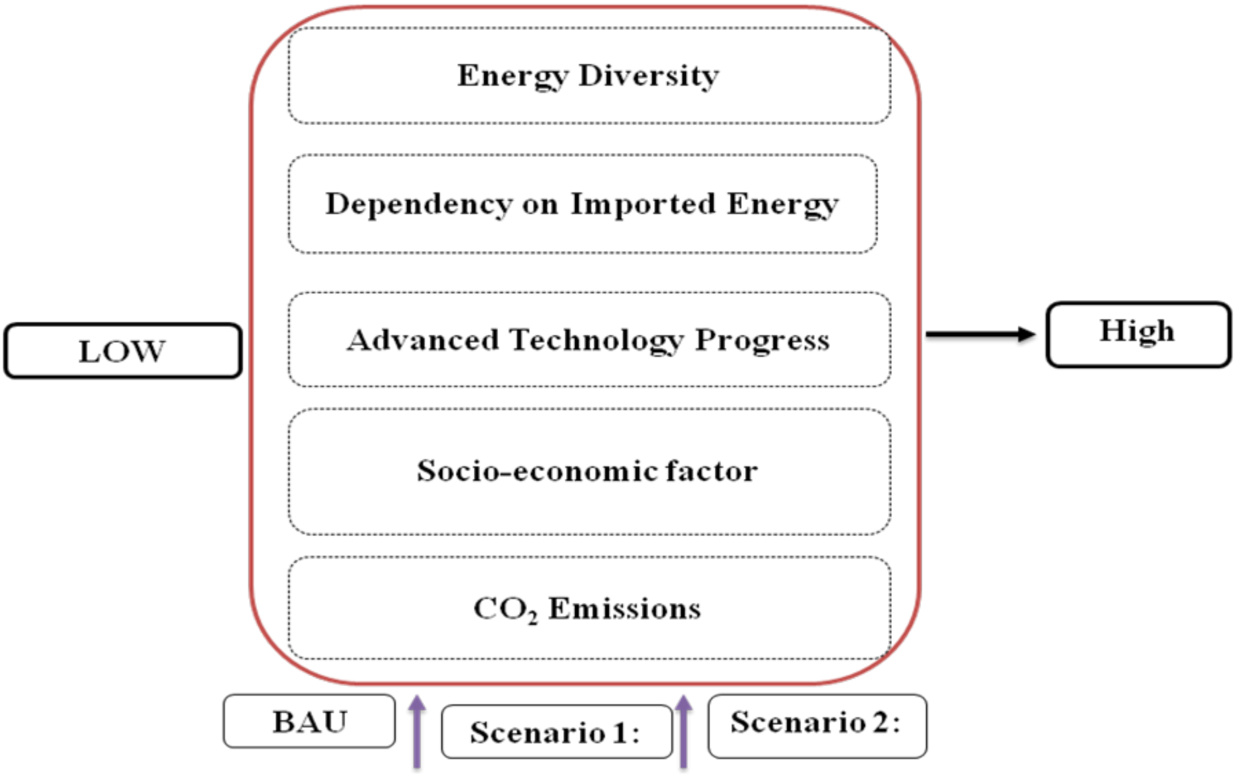


Figure 5-1: Key Scenarios Variables

5.1.4 Scenario descriptions

By raising key issues related to energy access and security in Ethiopia, by measuring and evaluating in depth the state of energy access and security and by engaging possible pathways to enhancing access and security, including frameworks, the report aims to deepen the policy discussion among stakeholders; increasing greater awareness about the issues and encouraging consideration of policy opportunities to enhance energy access and security in Ethiopia.

In this section the three scenarios are discussed on the basis of the presented parameters. Here it should be noted that not all aspects of the scenarios will be raised and discussed. Thereafter, the configuration of the input parameters necessary for implementation of the scenarios in the model is described. Finally the estimation of target parameters is discussed. Thus each scenario's storyline and quantitative modeling constitute the background against which the simulation results need to be interpreted.

iv. Business As Usual (BAU) Scenario

The Business As Usual (BAU), scenario or base scenario, describes the likely future development with the provision that, apart from an approved policy action, there will be no explicit promotion or commitment of renewable energy and economic development. This means that the status quo on the basis of the behavioral parameters of the past is in continuation without any major changes. The base run thus serves as a reference scenario to bridge the gap between the development defined in an expansion scenario and the likely development without further action. This scenario calculates the likely future development of the country with no restriction on fossil fuels and no specific commitment to CO_2 emission reductions and no further efficiency measures. The scenario Business As Usual indicates which energy demands or energy supplies arise when all measures, laws, etc. This scenario is based on an energy demand behavior which in principle remains unchanged.

Due to the available data and information on the energy situation of Ethiopia, the base year is taken as 2010. Some of the main implications for BAU scenario are discussed below (see Table 5-1).

Main characteristics of the BAU scenario

Despite the high economic growth rate experienced by Ethiopia over the last decade and the plans to achieve climate resilient and green (CRGE) middle income status by 2025, the country is still categorized as under developed. Therefore, promoting economic growth has become an issue of highest priority in the country's development strategies. However, the conventional development path for the country would result in an increase of GHG emissions and unsustainable use of natural resources. This scenario assumes an average economic growth of 7.0 % per annum over the period of 2010-2050[54]. This assumption is made in order to examine how technical measures and economic structure would be able to affect the energy pathways of Ethiopia. And further assumptions are discussed below (see Table 5-1):

- This scenario (BAU) assumes that Ethiopia would face no pressure to reduce CO_2 emissions over the period (2010-2050). This assumption is supported by the fact that currently the country's per capita CO_2 emission is low, which is less than 2 tons and modest compared with

[54] *The assumption of 7.0% is taken slightly higher than the average annual of GDP report of HSBC, Global research http://www.hsbc.com/~/media/HSBC-com/about-hsbc/advertising/pdfs/the-world-in-%202050.ashx Accessed September 2013*

10 tons per capita on average of the European Union (EU). However, according to the CRGE plan, the GHG emissions in the country will be double from the 150 million tons of CO_2 in 2010 to 400 million tons of CO_2 by the year 2030 (CRGE 2011, p1). More importantly, the country's strategy is targeting poverty reduction more than environmental protection.

- According to the Ethiopian Government's Growth and Transformation Plan (GTP) of 2011-2015, a reduction of biomass energy use is intended in both per-capita and aggregate terms. Dissemination of nine million household stoves, with 40 % savings over traditional stoves, will reduce aggregate biomass energy consumption within GTP period considerably (this is despite the 13 % increase of the population). Rapid dissemination of energy efficiency, especially in rural areas, must therefore be among the top priorities.
- Biofuels could be an important household fuel at the end of the period (mainly ethanol)
- Access to modern energy services and high commercial energy availability are assumed.

o Rapid rise of demand for solid fossil fuels in industry, particularly for cement and metal industries

- Increased use of fossil fuels in industry will increase greenhouse gas emissions from the sector; air pollution impacts will also rise.

o Increased use of petroleum in the agriculture sector. Energy requirement (mainly for diesel) for irrigation, cultivation and other farm activities will rise due to an expansion of large commercial farms.

o Requirements for commercial energy will rise. Indigenous resources would be developed at an accelerated rate and the balance must be met by imports. Resources available to meet requirements for development of indigenous energy sources and imports will be considerable.

o A growing economy requires growing energy services; this means that end use energy services must necessarily grow rapidly.

o Meeting one of the strategic goals for the energy sector, energy security, requires that Ethiopia accelerates its indigenous resource development, as such, extraction of gas and coal reserves will be given priority. The energy security goal will also be addressed by shifts towards indigenous resources; an example of this is the shift to electric railway for freight transport.

- Biomass energy consumption continues to be an important source of energy in both rural and urban areas and expected to grow as fast as population growth (ERG-FFE, 2009, p. 7). This will increase the pressure on natural resources.

- The speed and diversity of energy resource development and their use is increasing rapidly.

Table 5-1: BAU scenario assumptions

Indicators	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1. Socio-economic Indicators						
GDP Growth (%)	11.0 [55]	7.5 [56]	6.0	5.5	5.0	7.0
Growth by Sector						
Industry (%)	8.0	8.5	8.5	7.0	6.0	7.6
Agriculture (%)	3.5	3.0	2.5	2.0	2.0	2.6
Services (%)	5.5	6.5	6.0	6.5	3.4	5.6
2. Energy Indicators						
Electricity Generation	• No restriction on fossil fuel use in electricity generation • No restriction in addition of coal based generation • No specific commitment for renewable energy development					
End use Industry	• No immediate concern about reducing oil dependency • No restriction on fossil fuel use in industry • Technologies for cement and steel production remain in present state					
Residential & Commercial	• No promotion of solar water heaters • Some specific policies to promote energy efficiency,					
Transport	• No immediate concern about reducing oil dependency • No specific policies to promote alternative fuels and technologies in the transport sector					
3 Environment	• No restriction to reduce fossil fuels consumption and CO_2 emissions					

[55] *International Monetary Fund (IMF), 2013, World Economic Outlook – Transitions and Tensions, p 159*
56 Ibid

These assumptions are broadly in accord with the assumption in most recent energy studies and the country's present situation (GTP[57], CRGE[58], and EEPCo. 2010).

v. Scenario 1: Moderate Shift Scenario

The moderate shift (Scenario 1) represents a situation where by a moderate level of economic development and a moderate commitment to climate friendly energy production and advanced technologies is followed. The scenario focuses on a moderate level of development and promotion of renewable energy, energy efficiency, and energy diversity with limits to CO_2 emission. Therefore moderate expansion of renewable energy relies primarily on the expansion of hydropower, wind, and solar to generate electricity. The expansion of large-scale hydropower assumed moderately here, since this is the first priority of the Ethiopian Government stated in the GTP, and the impact of even a significant capacity expansion of small hydro power would be moderate. A shift from the current state of low energy diversity and carbon intensive fuels to a moderate energy efficient technologies initiative is assumed in this scenario.

This assumption is made in order to examine how the moderate level of economic development and climate friendly energy production would be able to affect energy pathways of Ethiopia.

Main characteristics of Scenario 1:

The moderate shift scenario (Scenario 1) assumes an average annual economic growth rate of 8.0 % for the planning period of 2010-2050[59], which is slightly higher than the BAU scenario. The service sector is expected to grow at a rate of 6.3 % per annum while the average annual growth rate of the service sector in BAU is 5.6 % over the period of 2010-2050. In this scenario there is a change to cleaner energy and increased energy diversity.

More than 90 % of the present total Ethiopian electricity generation is from hydropower (chapter 2), mainly from the large-scale hydropower. Large hydropower will continue to play an essential

[57] *Ministry of Finance and Economics, Ethiopia, Accessed December 2013* *http://www.mofed.gov.et/English/Resources/Documents/GTP%20Policy%20Matrix%20%28English%292.pdf*

[58] *UNDP, http://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf , Accessed December 2013*

[59] *The assumption of 8.0% is taken, higher than the average annual of GDP report of HSBC, Global research http://www.hsbc.com/~/media/HSBC-com/about-hsbc/advertising/pdfs/the-world-in-%202050.ashx 2012, p23 Accessed September 2013*

role in energy production. In the case of wind energy, an increase of installed capacity is assumed with technological knowhow, as increasingly more surface area can be used for wind production. To date, the electricity supply in Ethiopia has mainly been generated by central production units which distribute their generated electricity over transmission and distribution networks to the end use. Further assumptions are discussed below.

- New industrial fuels, such as coal and pet coke now being introduced in cement and other industries, will have a larger contribution for industrial energy.

- An increased use of electricity and liquid biofuels along with significant increases in the use of fossil fuels in industry.

- Reduced energy intensities for biomass fuels for the household sector will be achieved.

- An introduction of electricity and biofuels in the transport sector after 2015 in order to reduce CO_2 emissions and fossil fuel consumption.

By changing the technical and legal framework, and the availability of new or significantly improved generation technologies, distributed generation will become more prevalent. In this scenario, the deployment of small hydro power plants and photovoltaic systems will be increased compared to the baseline scenario.

Although the security of supply is due to the diverse energy mix support, the power supply from wind will be moderate in conjunction with other native power generation capacity. The percentage growth of renewable energy by 2020 will be higher than in BAU scenario. Some of the main implications for scenario 1 are presented on Table 5-2.

Table 5-2: Summary of key assumptions for scenario 1

	Indicators	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1	**Socio-economic**						
	GDP Growth (%)	11.0	7.7	7.7	7.0	7.0	8.0
	Growth by Sector Industry (%)	8.0	8.5	7.5	6.5	5.1	7.1
	Agriculture (%)	3.5	3.0	2.5	2.0	1.8	2.6
	Services (%)	5.5	6.5	7.3	7.1	5.2	6.3
2	**Energy indicators**						
	Energy Resources	• Moderate use of renewable energy • Moderate promotion of alternative fuels in transport sector. Biofuels and CNG[60] would account for 5 % of total fuel consumed by road transport vehicles from 2015 • Specific policies towards reducing fossil use rate. Overall, 5 % and 10 % of total fossil fuels in this scenario would be reduced by 2025 and 2050, respectively					
	Electricity Generation	• Specific restriction on fossil fuel use in electricity generation					
	End use Industry	• Advanced technologies, such as dry method for cement production, DRI, and EAF[61] for steel making would be promoted to reduce fossil energy consumption rate by 5 % and 10 % by 2025 and 2050, respectively					
	Residential & Commercial	• New Technologies for water heating and lighting , such as solar water heaters and compact fluorescent lamps are encouraged to reduce fossil energy consumption rate in these sectors by 5 % and 10 % by 2025 and 2050 respectively					
	Transport	• Alternative fuels and technologies, such as bio-fuels and CNG, are used in the transport sector to reduce oil dependency and CO_2 emissions. This scenario assumes that from the year 2015 onwards bio-fuels and CNG would account for 10 % of total fuel consumed by road transport vehicles					

[60] *Compressed Natural Gas*
[61] *DRI is Direct reduced iron and EAF is electric arc furnace*

vi. Scenario 2: Advanced shift

The high shift scenario (Scenario 2) reflects the high level of economic development and higher level commitment for climate friendly energy production than the moderate scenario. Unlike the moderate scenario, this scenario is developed to represent a future increased diversity of the energy supply mix, to promote advanced technologies, to reduce dependency on imported energy and to further lower CO_2 emissions. Major characteristics of this scenario are summarized in Table 5-3.

Main characteristics of Scenario 2:

The advanced shift scenario reflects the assumption that Ethiopia would achieve high economic growth, characterized by the annual economic growth rate of 10 %, over the period of 2010-2050. This scenario builds on a long-term investment strategy for promotions of more costly, but at the same time particularly promising, technologies (such as photovoltaic). In this scenario, sustainable sources of energy can be developed, a significant reduction of CO_2 emissions is reached and the dependence on resource imports decreases significantly.

The assumption of 10 % annual economic growth is slightly higher than the average annual GDP growth rate of the and much higher than the projection made by the HSBC Global research (HSBC, 2012, p. 23). This scenario assumes strong expansion of renewable energy use because the Ethiopian government would pay more attention addition to other renewable energy sources, energy security and environmental protection compared to the moderate shift scenario. It is expected that fossil fuel consumption would be reduced by 10 % and 15 % of total fossil fuels in this scenario by 2025 and 2050 respectively. To meet the environmental requirements, this scenario assumes that the power sector would be under high political pressure for generation of electricity with less CO_2 emission in comparison to the other scenarios (BAU, Moderate). Further assumptions are discussed below:

- Indigenous resources will play a great role for the energy security of the country with the entry of coal technologies such as IGCC and carbon capture sequestration into power generation

- The government would be expected to have an energy policy for the promotion of renewable energy (e.g. feed-in-tariff) in addition to the hydropower. Solar and wind based generation of electricity would become competitive compared to the fossil fuel based electricity production.

- There would be remarkable changes in employing energy diversity across end-use sectors. The residential and commercial sectors would prefer more efficient energy appliances such as compact fluorescent lamps, efficient cocking stoves, and roof top PV and solar hot water.

- The transport sector would assume a shift towards more energy efficient and environmentally friendly technologies. The share of the alternative fuels such as ethanol and methanol would be higher than the moderate shift scenario and would assume 10 % total fuel consumption by 2025 and 15 % by 2050.

- Compared to the scenarios of BAU with 7 % and Moderate Shift with 8 % economic growth rate, in the Advanced Shift scenario higher economic growth of 10 % is assumed. The government would support clean and efficient energy technologies to compensate for the additional CO_2 emissions.

These assumptions are made in order to examine how technical measures and economic structure would be able to affect energy pathways of Ethiopia. Some of the main implications for Advanced Shift scenario are discussed below (see Table 5-3).

Table 5-3: Summry of key assumptions for scenario 2

	Indicators	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1	**Socio-economic**						
	GDP Growth (%)	11.0	10.0	10.0	9.0	10.0	10.0
	Growth by Sector						
	Industry (%)	8.0	9.0	9.2	9.0	9.2	8.9
	Agriculture (%)	3.5	3.2	3.0	3.0	3.4	3.2
	Services (%)	5.5	7.5	7.8	7.9	8.0	7.3
2	**Energy Indicators**						
	Energy Resources	• Greater use of renewable energy compared to the Moderate shift scenario • Higher promotion of alternative fuels in transport sector. Biofuels and CNG would account for 10 % of total fuel consumed by transport from 2015 onwards • Specific policies towards reducing fossil use. Overall 10 % and 15 % of total fossil fuel reduction rate in this scenario by 2025 and 2050, respectively					
	Electricity Generation	• Specific restriction on fossil fuel use in electricity generation • Advanced share of renewable-based electricity in total generation mix					
	End use Industry	• Advanced technologies, such as dry method for cement production, and DRI and EAF for steel making would be promoted to reduce fossil energy consumption rate by 10 % and 15 % by 2025 and 2050, respectively					
	Residential & Commercial	• New Technologies for water heating and lighting , such as solar water heaters and compact fluorescent lamps, are encouraged to reduce fossil energy consumption rate in these sectors by 10 % and 15 % by 2025 and 2050 respectively					
	Transport	• Alternative fuels and technologies, such as bio-fuels and hybrid cars are used in the transport sector to reduce oil dependency and CO_2 emissions. This scenario assumes that alternative fuels, such as bio-fuels and CNG, would account for 10 % of total fuel consumed by road transport from 2015					

Table 5-4, below summarizes the assumed parameters of the three scenarios.

Table 5-4: Summary of scenarios key features

	Indicators	BAU	Scenario 1	Scenario 2
1.	**Socio-economic**			
	GDP Growth (%)	**7.0**	**8.0**	**10**
	Growth by Sector			
	Industry (%)	7.6	7.8	8.2
	Agriculture (%)	2.5	2.4	2.5
	Services (%)	5.6	6.8	7.8
	Transport (%)	3.4	6.6	7.2
	Population (%)	1.5	1.5	1.5
2.	**Energy**	Follow the current trends	Moderate use of Cleaner fuels + efficient use of energy	Advanced use of cleaner fuels + efficient use of energy
	Energy resources	No restriction on fossil fuel use No promotion of alternative fuels No intermediate concern towards energy import	Reduction of Fossil fuel rate by 5 % and 10 % by 2025 and 2050, respectively Alternative fuels in road transport: 5 % from 2008 onwards	Reduction of fossil fuel rate : 10 % and 15 % by 2025 and 2050, respectively Alternative fuels in road transport : 10 % from 2015 onwards
	Electricity Generation	No restriction on fossil fuel based generation No promotion of advanced technologies	Moderate promotion of advanced technologies (Wind, PV, IGCC etc.)	Advanced promotion of advanced technologies (Wind, PV, IGCC etc.)

5.2 Major energy and economic indicators

This study formulated a BAU Scenario and two additional alternative scenarios (section 5.1.4). The alternative scenarios are characterized by different requirements regarding the design or success of climate policy as well as different assumptions to cover the long-term demand for energy in Ethiopia. The objective of this section is to quantitatively model those scenarios and examine their long-term impacts on Ethiopia's energy sector, in terms of primary energy supply mix, electricity generation mix and CO_2 emissions. To model scenarios and conduct assessment, the LEAP energy model tool is employed in this research with key assumptions taken into account.

In addition to the above discussed main assumed characteristics for each proposed scenario, major energy and economic indicators of Ethiopia are summarized for the analysis with the three scenarios (BAU, Scenario 1, and Scenario 2). The past trends of macroeconomic indicators, population growth, sectoral energy and economic development are discussed.

5.2.1 Socio-economic assumptions

The future development of energy consumption in Ethiopia is not only a result of price developments and interventions for climate change policy, but also depends on demographic developments and the dynamics of sectoral and macroeconomic growth.

Since economic and population developments are the key determinants of the future energy consumptions, GDP is projected over the period of 2010-2050 for the proposed three scenarios with different growth rates (see Table 5-5).

1. Business-as-Usual (BAU) scenario uses a GDP growth rate of 7 %
2. Moderate shift (Scenario 1) with a GDP growth rate of 8 %
3. Advanced shift (Scenario 2) scenario uses a GDP growth rate of 10 %

Table 5-5: GDP in market exchange (US Dollar in 2005) (Billion)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR (%)
BAU	20.10	28.19	39.54	55.46	77.78	109.09	153.01	214.60	300.99	7
Scenario 1	20.10	29.53	43.39	63.76	93.69	137.65	202.26	297.19	436.66	8
Scenario 2	20.10	32.37	52.13	83.96	135.22	217.78	350.73	564.86	909.71	10

For the population development, the demographic model calculations are available based on relatively reliable data on the natural movement of the population, i.e. the evolution of population structure and based on age specific death rates. These figures have been proven in recent years to be reasonably stable, so that long-term population projections so far belong to the standard program of official statistics. The population growth and projection in this research work is based on the UN Population Projection data and presents the population growth rates for different periods (UN Population Prospects 2010, p. 97).

The population projection rates for different periods presented in Figure 5-2 for Ethiopia are based on the UN's population projections to 2050.

- The rural population of Ethiopia accounts for more than 80 %
- Annual population growth is assumed at a rate of 1.5 % over the period of 2010-2050 for all proposed scenarios
- Increase in life expectancy for men and in women is assumed to be 7 to 8 years.
- Based on the UN population projection, Ethiopia will reach 150 million inhabitants by the year 2050 (Figure: 5-2).

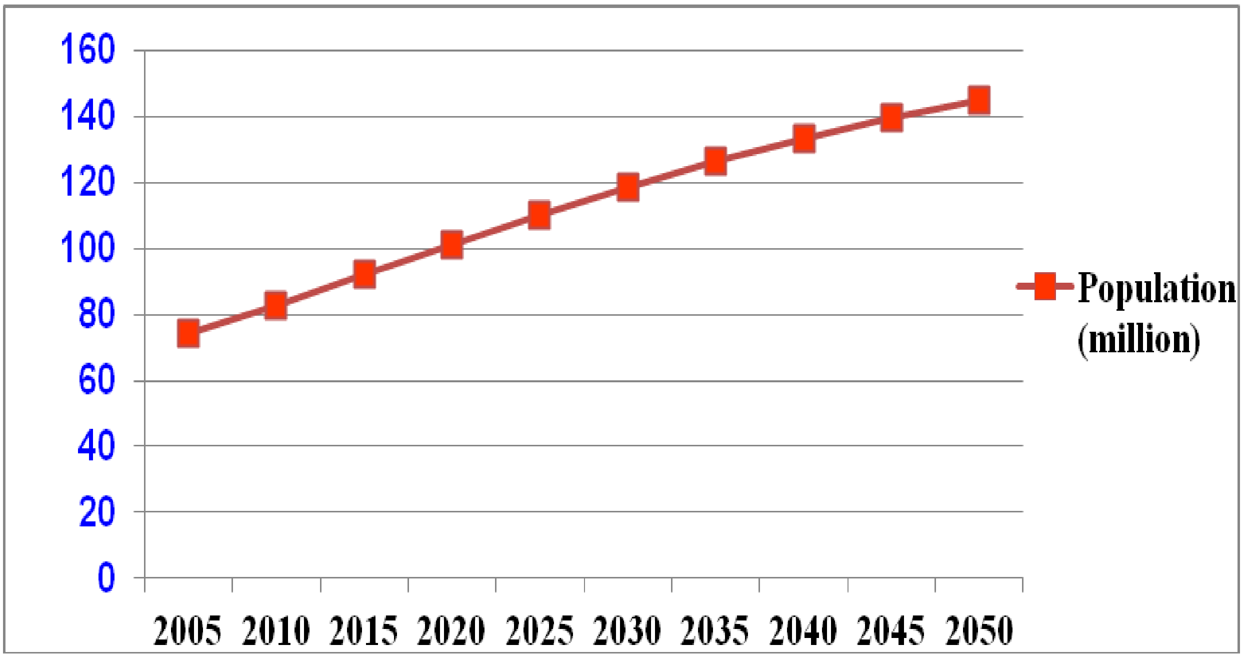


Figure 5-2: Population projection of Ethiopia (2010-2050)[62]

[62] *UN's population projections to 2050, http://esa.un.org/unpd/wpp/unpp/p2k0data.asp Accessed November 12, 2010*

Ethiopia has been experiencing a remarkable economic development and has seen a strong increase in energy consumption pattern over the last few decades. The energy consumption of 8.15 MTOE in the year 1971 increased to 30.02 in 2008, growing at 3.6 % per annum. And also, the per-capita energy consumption of the country increased by 1.0 % over the same period (Figure 5-3).

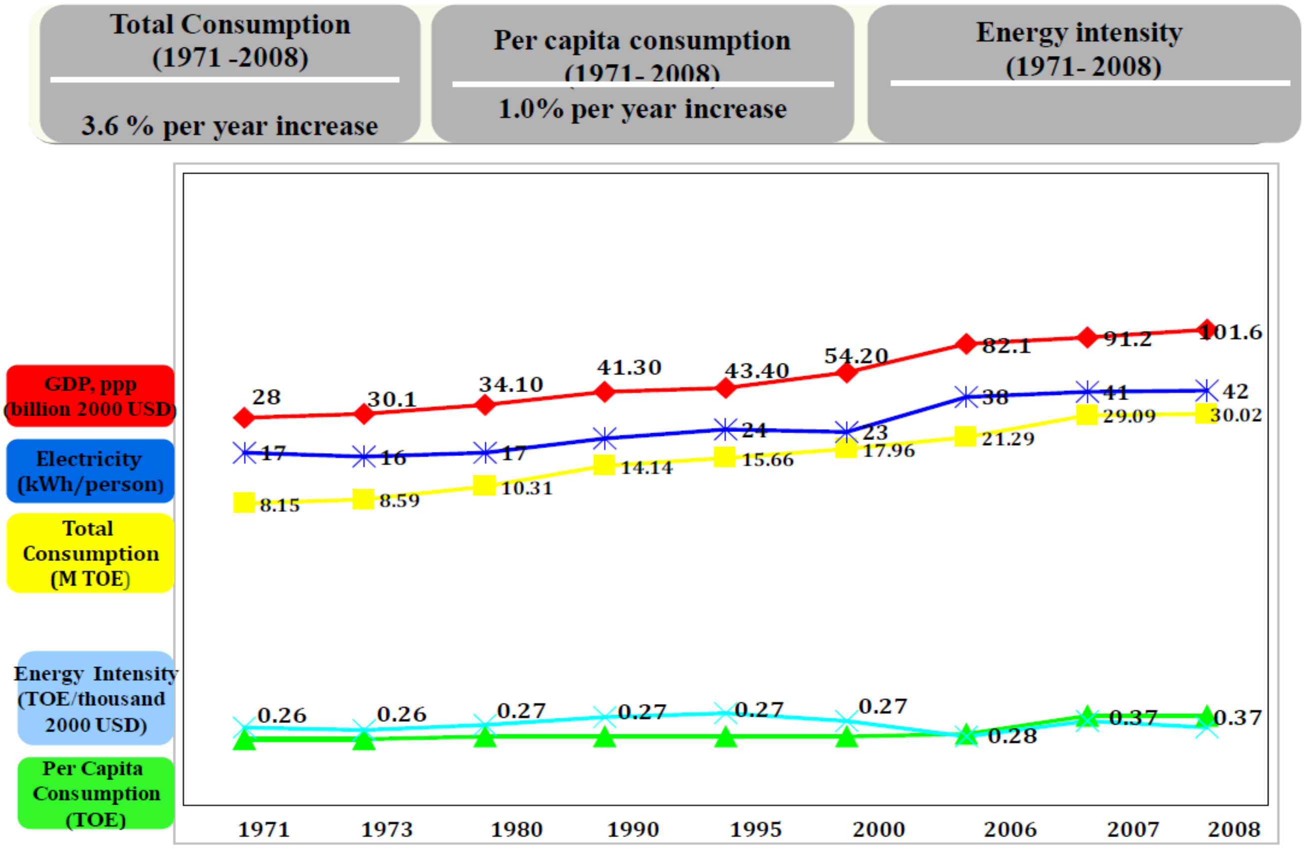


Figure 5-3: Major energy indicators
Source: Based on IEA data, 2010

5.2.2 *Technology assumptions*

In Ethiopia, the power sector relies mainly on hydropower stations. A comprehensive energy strategy is required to implement the expansion of other indigenous energy resources, natural resource conservation, and local capacity development. As explained in Chapter 3, Ethiopia has good sources of renewable energy that can generate electricity with proven technologies. For the power generation of Ethiopia the conventional and non-conventional technologies are provided to the LEAP model in this research. The model requires creating detailed profiles for two sets of energy conversion technologies, converting primary into final energy carriers and converting final energy carriers into energy services. Reasonably representative sets of conversion technologies are compiled based on a literature review on the technologies internationally available. For each technology type, current investment as well as operation and maintenance costs are assessed. The result for current renewable and conventional technology costs are given in 2005 US$ (see Table 5-6). For the conventional technologies, the performance and cost levels are assumed to be constant over the whole period, for technologies using renewable energy sources future, cost digressions are assumed. In this modeling the most reliable studies are selected and evaluated to yield a consistent as possible set of cost data.

Table 5-6: Investment costs of renewable energy technologies

Sources: Mora 2012, p. 113; based on data sources from IEA (ETP) 2008; ECN 2004, Blok 2007; Greenpeace 2008

Technology		*Units*	Greenpeace (2005 USD)	ETP (2005 USD)	IEA (2005 USD)	ECN (2001 USD)	Blok (2001 USD)
Wind Onshore	Investment costs	$/kW	1,510	1,200	1,322	960 – 1,384	850 – 1,700
	O&M	$/kW/year	58		19.83	19,2 - 55,2	
		%	3.8		1.5	2 - 4	
Wind Offshore	Investment costs	$/kW	3,760	2,600	2,814	1,887 – 2,322	850 – 1,700
	O&M	$/kW/year	166		42.21	56.4 – 92.8	
		%	4.4		1.5	3 – 4	
PV	Investment costs	$/kW	6,600	5,500	4,245	6,029	5,000 – 18,000
	O&M	$/kW/year	66		14	60.2	
		%	1		0.3	1	
Concentrating Solar Power	Investment costs	$/kW	7,530	4,500	2,315		2,500 – 6,000
	O&M	$/kW/year	300		30		
		%	4		1.3		
Biomass combustion	Investment costs	$/kW	3,040	1,975 – 3,085		1,775 – 6,699	500 – 6,000
	O&M	$/kW/year	183			71 – 334.5	
		%	6			4 - 5	
Biomass IGCC	Investment costs	$/kW		4,320 - 6170	2,500	3,796	
	O&M	$/kW/year			50	189.8 – 246.7	
		%			2	5 – 6.5	
Co-firing with Coal	Investment costs	$/kW		123		212 - 245	
	O&M	$/kW/year					
		%					
Geothermal Hydrothermal	Investment costs	$/kW		1,700 – 5,700	946 – 2,838	1,898 – 2,791	800 – 3,000
	O&M	$/kW/year		33 - 97	18.92 – 56.76	37.8 – 55.8	
		%		1.9 – 5.7	2	2	
Geothermal Hot Dry Rock	Investment costs	$/kW	17,440	5,000 – 15,000	2,365 – 7,094		
	O&M	$/kW/year	404	150 – 300	47.3 – 141.8		
		%	2.3	3 – 2	2		

Photovoltaic and wind energy technologies are commercially available with hydrothermal and geothermal technologies already in use. The renewable energy sources of Ethiopia can be exploited using these technologies.

Table 5-7 presents capital cost of power plants which are considered in the LEAP analysis.

Table 5-7: Capital cost power plants
Source: DOE/EIA – 0554 (2009), p. 89 and 2010 p. 91

Technology	Values considered in LEAP	
	2010 (US$/KW) (NP)	2050 (US$/KW) (IP)
Hydropower	1 479,76	1428,73
Wind Energy	1 500,00	1235,29
Geothermal	2 000,00	1722,22
Solar PV	(IV)1 297,56	908,29
Biomass	(IV)2 540,34	2143,41
Cov. Gas/Oil Turbine	450,00	450,00
Cov. CC	647,37	647,37
Coal	(IV)1 467,18	1467,18

The values for the year 2050 are determined by taking as reference the costs of 2010 taken for LEAP. These were decreased or increased according to the variations projected by DOE/EIA annual energy outlook report of 2008, p. 165.

The investment costs of conventional technologies compiled and listed in Table 5-8 are based on different literature review (Mora 2012, p. 114, based on data sources from IEA (ETP) 2008, ECN 2004, Blok 2007, and Greenpeace 2008).

Table 5-8: Investment costs of conventional technologies

Sources: Mora 2012, p. 114, based on data sources from IEA (ETP) 2008, ECN 2004, Blok 2007, and Greenpeace 2008

Technology		*Units*	Greenpeace (2005 USD)	ETP (2005 USD)	UPME (2005 USD)	IER (2005 USD)	IEA (2005 USD)
Coal Power Plant	Investment costs	$/kW	1,320	1,400 – 2,000[1]	1,322	1,145	1,500 – 2,200
	O&M	$/kW/year			73	51	60 – 88
		%			5.5	4.4	4
Natural Gas Combined Cycle Power Plant	Investment costs	$/kW	690	600 - 750	683	548	660 – 750
	O&M	$/kW/year			36	28.6	26.4 – 30
		%			5.2	5.2	4
IGCC Power Plant	Investment costs	$/kW		1,800		1494 [2]	1,600 – 2,300[3]
	O&M	$/kW/year				66	64 – 92
		%				4.4	4
Hydropower	Investment costs	$/kW		2,500	1,055		
	O&M	$/kW/year			18.7		
		%			1.7		

[1] Cost range of a typical coal fired plant. The cost of ultra-supercritical is from 12% to 15% higher than the cost of a sub-critical

[2] Cost estimation by 2015

[3] Cost estimation by 2010.

Basically, the future development of prices on the world energy markets also depends on climate policy decisions. Failure of the international climate change negotiations could not only cause the price of CO_2 emission rights to fall, but rather increase the global demand for fossil fuels and the world market prices associated with it. This affects the demand-driven price momentum in failure of the international climate change policy, the price ratio of coal to gas. Regardless of whether the international negotiations on climate change fail or not, an accurate forecast of supply and demand developments on the international energy markets is currently more difficult than ever. Table 5-9 presented below fossil fuel prices considered in LEAP.

Table 5-9: Fossil fuel prices considered in LEAP

		Real (NP)		Imported (IP)	
Fossil-fuel	Unit	2010	2030	2010	2050
Crude oil	US$/barrel	73,0	97,0	100,0	122,0
Natural Gas	US$/Mbtu	2,2	2,9	13,7	27,3
Coal	US$/tonne	124.3	128.8	161,6	186,1

Source: DOE/EIA – 0554, 2009, p. 89 and 2010 p. 91

Capital cost projection for Ethiopia's energy model

The levelized generation cost of electricity is 0.045 US$/kWh, the transmission cost is US$0.007/kWh, and distribution cost is US$0.014/kWh, making the levelized cost of power supply for the period 2011-2015 US$0.067/kWh (Ministry of Water and Energy, 2012)[63]. This makes Ethiopian power among the cheapest in the world. In 2006, a 22 % tariff hike was introduced, keeping it at US$0.06/kWh with some variation by consumption type. Due to inflation, some argue that the real tariff was around US$0.032/kWh in 2011(USAID, 2013, p. 28).

To evaluate the likelihood of whether lower cost electricity, hence affordability (including exporting markets), will continue or not depends on the cost of hydroelectric units in the system, including upcoming projects. Most of the large-scale hydroelectric developments have a generation cost profile at or below US$0.045/kWh, except Chemega Yeda (slightly above US$0.05), Aleltu East (slightly above US$0.065/kWh), Gojeb (around US$0.075/kWh) and Aleltu West (slightly above US$0.0825). Therefore, the bulk of capacity added will continue to remain at lower generation cost, with some projects introducing higher marginal costs.

Price for CO_2 emission right

The future development of CO_2 prices depends mainly on the specific structure of the world emissions trading for the period after 2020.

5.3 Results and discussions

As a result of the application of the three scenarios outlined (BAU, Scenario 1 and Scenario 2) in the previous section (section 5.14 and 5.2), this section, based on the application of the LEAP model, presents the result of the modeling which aimed at assessing the energy impacts of the alternative scenarios. Based on the assumptions of socio-economic development and the various parameters listed, this section evaluates the calculated final energy requirements, primary energy supply and CO_2 emissions over the period of 2010-2050.

[63] *Ministry of Water and Energy of Ethiopia and SREP. 2012. "Ethiopia Investment Plant." Addis Ababa, Ethiopia.*

5.3.1 BAU scenario

5.3.1.1 Future energy demand

In the BAU scenario, the current trends in energy sector have been assumed to continue. The economy and the energy sectors will follow the past trends, the scenario takes into account the new developments in policies outlined in Ethiopia's development plans.

The results show that (see Table 5-10 and Figure 5-4) over the period of 2010-2050, the development of primary energy requirement in the Ethiopia BAU scenario is expected to grow at an annual rate of 4.1 %. In absolute terms, the energy requirement in 2050 in this scenario will be 5 times the requirement of the base year (1,313 PJ in 2010 to 6,553 PJ in 2050). The increased economic activities, population growth and transport needs are the major contributors of such increase. The share of the residential sector in the final energy demand is expected to fall from 89 % at the base year (2010) to 55 %, while the share of all other sectors increase. The most significant change occurs in the transport sector as its share increases from 6.1 % to 21.4 %, while the industry sector share increases from around 1 % to 14 %. In absolute figures, the final energy demand in the transport sector will increase from 80.12 PJ in 2010 to 1,401 PJ in 2050 with an average annual growth rate of 7.42 %. The energy demand of the industry sector increases, from 6.57 PJ to 923 PJ with an average annual growth rate of 13 % over the period of 2010 to 2050. The annual growth rate of the industry sector will be higher, due to the government policies to shift from an agricultural based economy to industrialization.

The energy demand will increase over the study period due to the government policies and technological changes. Overall, the demand for energy is mainly due to the increase in population, urbanization and economic activities in those sectors. The declining share of the household sector has been attributed to the government policies promoting the replacement of biomass as fuel for cooking by modern and efficient technologies (LPG, efficient cooking stoves, and efficient lamps).

Table 5-10: Energy demand by sector share (BAU scenario)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR[64] 2010-2050 (%)
Agriculture	11.82	16.06	23.55	33.60	58.67	78.90	100.84	131.32	173.65	6.95
Commercial	45.97	62.62	80.48	134.38	170.15	215.54	280.61	364.48	459.35	5.92
Transport	80.12	147.72	264.01	361.87	499.01	646.63	836.99	1076.30	1401.63	7.42
Residential	1168.92	1316.62	1472.18	1690.82	1965.54	2279.53	2620.15	3097.04	3609.24	2.86
Industry	6.57	64.23	124.64	179.74	254.35	359.72	545.86	701.10	922.62	13.16
Total	**1313.39**	**1605.64**	**1962.91**	**2399.69**	**2933.65**	**3586.43**	**4384.45**	**5360.05**	**6552.73**	

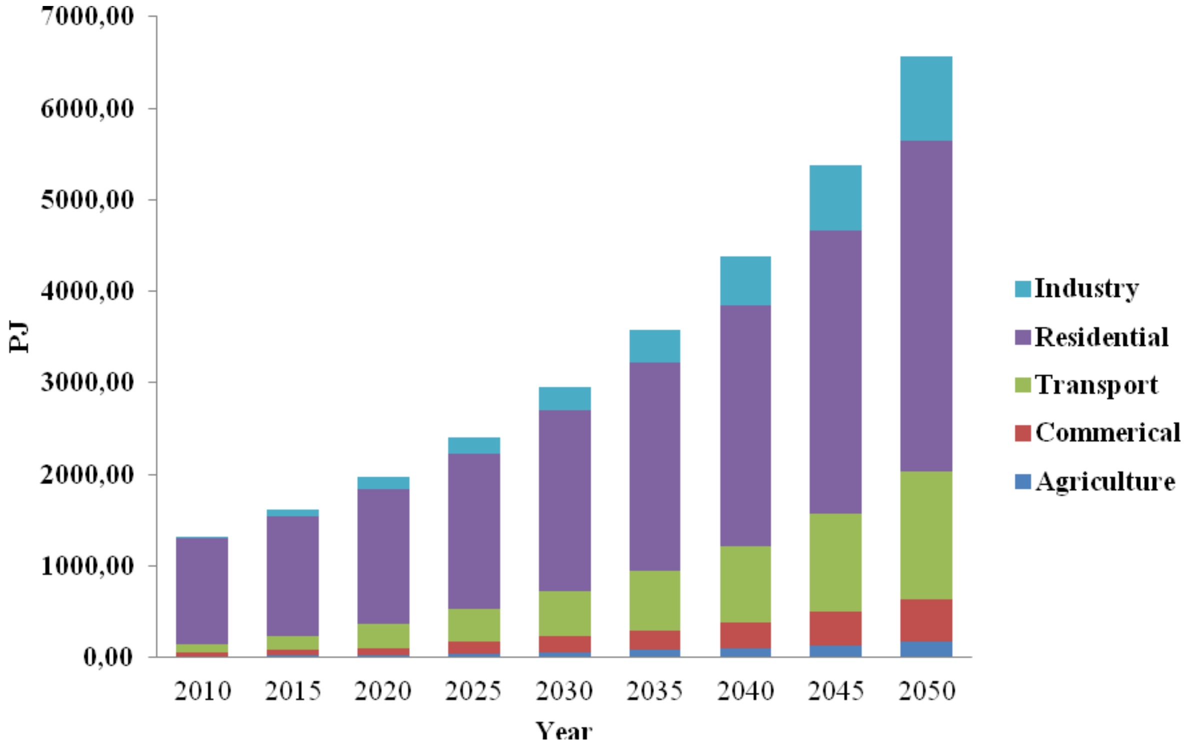


Figure 5-4: Final energy demand development between 2010-2050-BAU scenario

[64] *Average Annual Growth Rate*

5.3.1.2 Primary energy supply

The total energy supply according to the BAU scenario is 1,392 PJ in 2010 and will increase by around 5 fold to 6,904 PJ by 2050 (see Figure 5-5). Biomass energy remains the main energy supply for meeting the domestic energy need, however, the share will be expected to decline, from above 90 % (1,224.07 PJ) in 2010 to a share of 55.9 % (3,663 PJ) in 2050. This is attributed to the promotion of modern energy technology usage and efficient technology introduction in the household sector. Whereas the shares of oil products was 5.8 % in 2010 and at the end of the study period (2050) the share of oil increases to 17.7 %, coal will have a share of 11.29 % while renewable energy sources will be at 11.1 % and natural gas at 3.98 % within the BAU scenario.

The share of the household sector is expected to decline, this is attributed to the promotion of modern energy technology usage and the introduction of efficient technologies for the household sector, biomass as fuel for cooking is being replaced by kerosene, electricity (income per capita increase) and LPG.

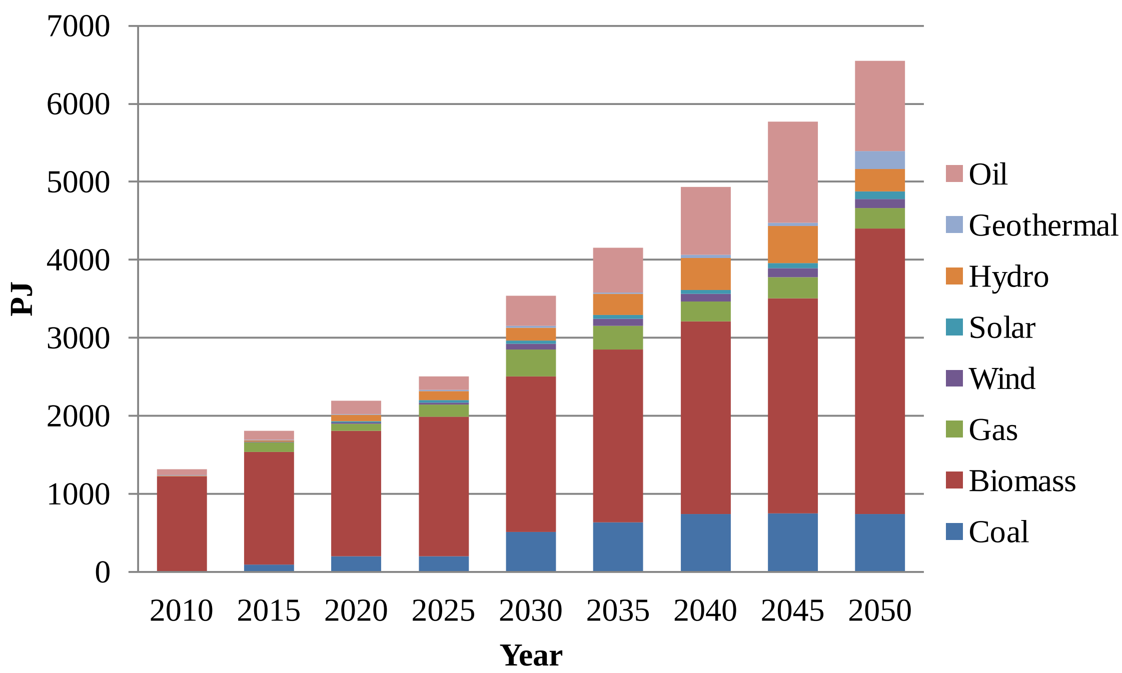


Figure 5-5: Total primary energy supply for Ethiopia (2010-2050) - BAU scenario

*N.B: The renewable energy resources in the context of this research consist of hydro-power, solar, geothermal and wind.

In the BAU scenario, the share of renewables is expected to increase from 1.3 % to 11.1 % over the period of the study 2010-2050.

Oil product demand will have growth of about 7.05 % annual average, increasing from 76 PJ in 2010 to 1,161.2 PJ in 2050. The demand for coal, biomass and renewables will grow by 6.07, 2.78., and 9.63 % respectively.

5.3.2 Scenario 1

5.3.2.1 Future energy demand

In the analysis of the Moderate Shift scenario (Scenario 1), energy demand is expected to grow faster than the BAU scenario, since the scenario assumes higher economic growth (8 %). In addition, the scenario also assumes that energy conversion implementation takes place over the period (2010-2050).

According to this scenario, the total energy demand grows at rate of 4.9 % annually starting at 1,313 PJ in 2010 and reaching 8,900 PJ in 2050, which is much higher than compared to 6,553PJ in the BAU scenario (Figure 5-8). The household sector is the largest energy consuming sector with an 89 % share in 2010, but this decreases to 55.4 % by the end of the period (2050). Unlike the household sector, the transport and industry sectors' shares are expected to increase. The transport sector from 6 % in 2010 to 22.0 % in 2050 and the industry sector from around 1 % share to 16.2 % share over the same period (see Table 5-11 and Figure 5-6).

Table 5-11: Energy demand by sector share (Scenario 1)

Sector	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR 2010-2050 (%)
Agriculture	11.82	46.71	52.98	53.83	58.12	60.80	71.71	84.08	97.91	5.43
Commercial	45.97	108.44	144.10	174.96	208.56	260.57	336.50	379.78	453.04	5.89
Transport	80.12	116.95	183.09	405.37	597.31	847.29	1079.00	1404.20	1966.10	8.33
Residential	1168.92	1336.30	1589.31	1782.17	2128.01	2609.63	3254.66	4085.07	4934.37	3.67
Industry	6.57	67.40	149.61	275.36	427.037	564.57	774.50	1053.85	1448.98	14.44
Total	**1313.39**	**1668.29**	**2119.09**	**2691.70**	**3419.03**	**4342.87**	**5516.38**	**7006.99**	**8900.39**	

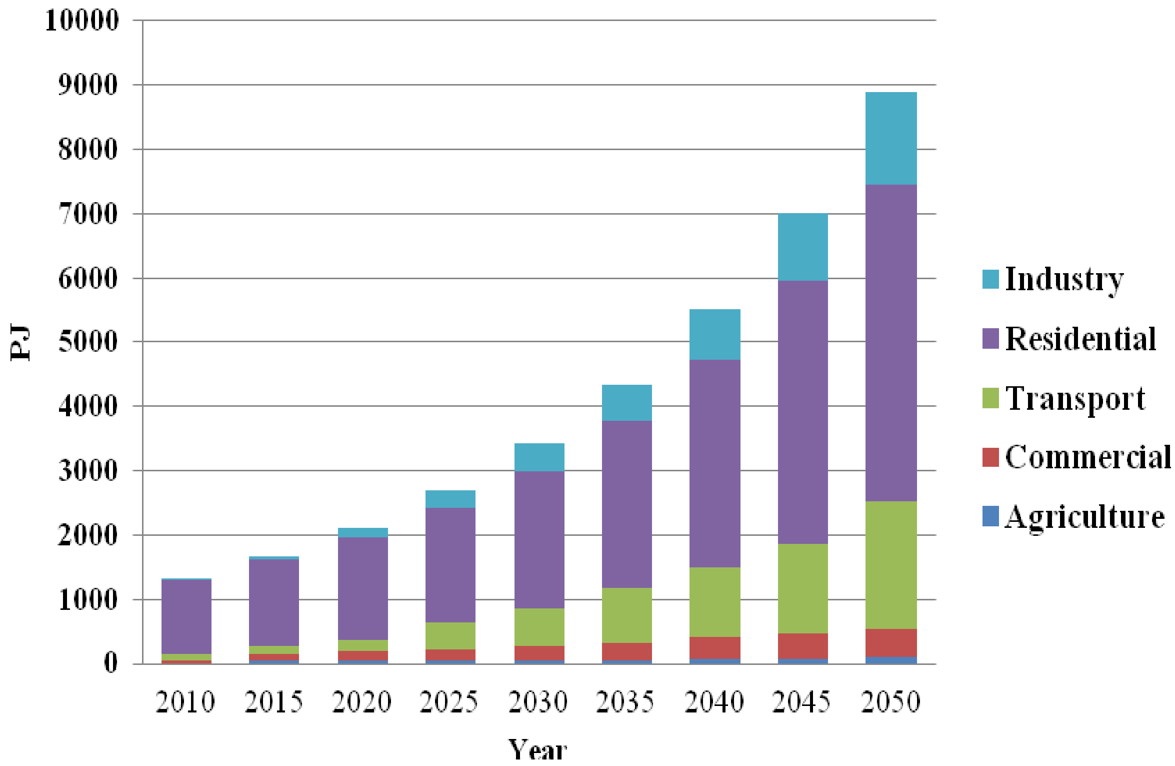


Figure 5-6: Final energy demand development between 2010-2050- Scenario 1

5.3.2.2 Primary energy supply

Figure 5-7 shows the total energy supply according to the Moderate scenario (Scenario 1) which is 1,392 PJ in 2010 and will increase by around 6 fold to 8,900 PJ in 2050. The biomass share is expected to decline, from over 90 % in 2010 to 52.4 % in 2050. This is due to the promotion of modern energy technologies and the introduction of efficient technologies in the household sector.

In Scenario 1 the share of new renewable energy in the total country's primary energy mix is expected to increase from 1.32 % in the base year (2010) to 23.4 % by 2050. This is due to an increased introduction of wind and solar energy in power generation.

The demand for oil in Scenario 1 is estimated to grow at annual rate of 6.7 percent over the period of 2010-2050. This is mainly due to few energy inefficient technologies employed and demands for industrialization at this time. In absolute terms, by 2050, the oil demand in Scenario 1 would increase by around 13 fold over the period of 2010-2050. Despite measures to encourage oil savings, such as promotion of bio-fuels (e.g. ethanol), the share of oil in the total primary energy mix still increases very substantially.

Ethiopia has modest proven indigenous coal and natural gas reserves (coal, more than 300 million tons, and natural gas 113 Billion m^3) (section 3.3). Coal is expected to play a major role in the country's total energy mix, especially in the second term of the Ethiopian Government's Growth and Transformation Plan (GTP 2)[65].

Industrialization will drive a vast increase in oil demand, which will have the highest growth of oil consuming sector of about 6.7 % of annual average growth, increasing from 76 PJ in 2010 to 1019.9 in 2050. The demand for coal and biomass will grow at annual rates of 5.5 % and 3.4 % respectively. However, the share of biomass decreases from 93.2 % in 2010 to 52.4 % in 2050.

[65] *GTP 2 is still under draft and received the information from experts who are drafting the plan*

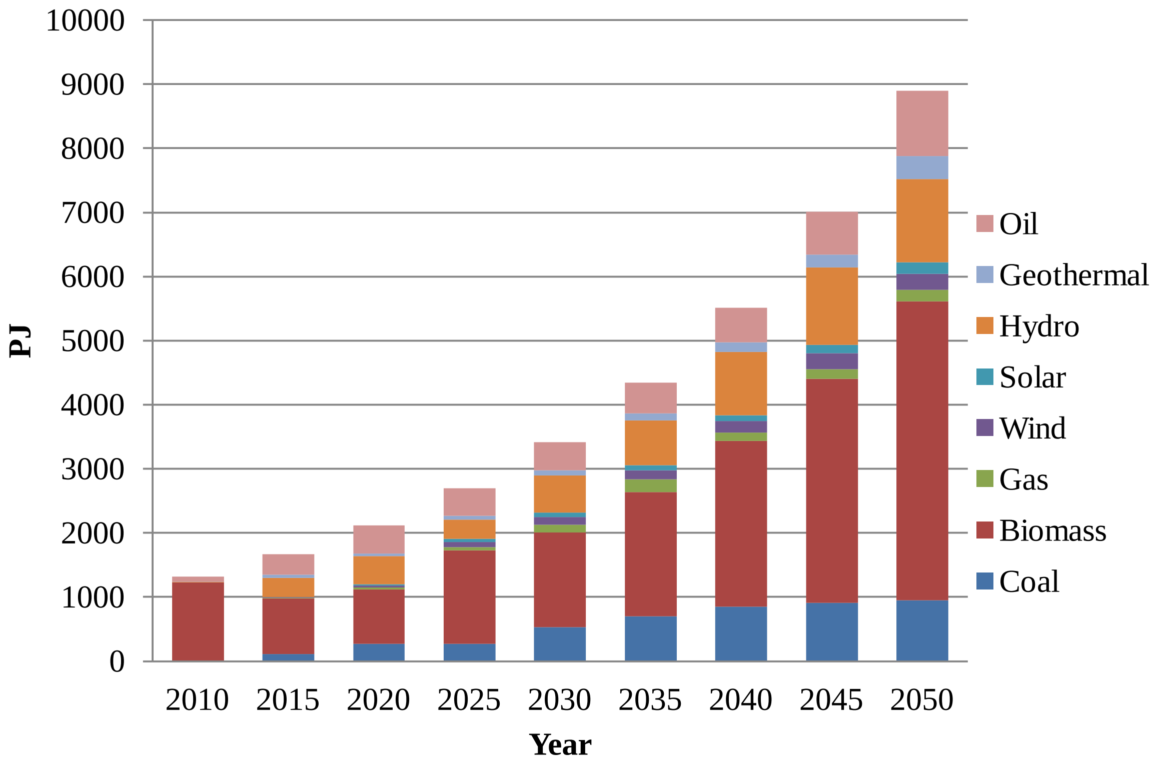


Figure 5-7: Total primary energy supply for Ethiopia-Scenario 1

5.3.3 Scenario 2

5.3.3.1 Future energy demand

The Advanced Shift scenario (Scenario 2) produces a different result with the assumed economic growth of 10 % over the period of 2010-2050. According to this scenario, energy demand grows at 5.7 % annually (as compared to 4.1 % of BAU and 4.9 % in Scenario 1). The demand in 2010 is 1,313 PJ and increases to 12,061 PJ in 2050 (see Table 5-12 and Figure 5-8). Like in the other scenarios, the household sector consumes the biggest share, 89 % in 2010; however, this figure declines to 51 % in 2050 in Scenario 2. The second largest consumer is the industry sector with 1 % in 2010 increasing to 20 % in 2050, followed by the transport sector, which grows from around 6 % in 2010 to 24 % in 2050. The higher economic growth compared to the other scenarios stimulates a higher increase of energy demand than in the other sectors.

Table 5-12: Energy demand by sector share (Scenario 2)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR 2010-2050 (%)
Agriculture	11.82	45.05	48.01	51.28	51.74	57.76	62.36	82.27	96.49	5.4
Commercial	45.97	104.15	148.61	184.01	226.87	346.59	464.21	548.49	487.28	6.1
Transport	80.12	144.00	228.64	452.49	672.64	996.70	1348.99	1895.04	2903.15	9.4
Residential	1168.92	1369.50	1697.16	2023.54	2551.64	3133.99	4041.43	5257.29	6153.66	4.2
Industry	6.57	70.18	163.93	305.28	477.21	716.28	1012.26	1358.43	2415.87	15.9
Total	**1313.39**	**1732.88**	**2286.35**	**3016.61**	**3980.10**	**5251.32**	**6928.57**	**9141.52**	**12061.27**	**5.7**

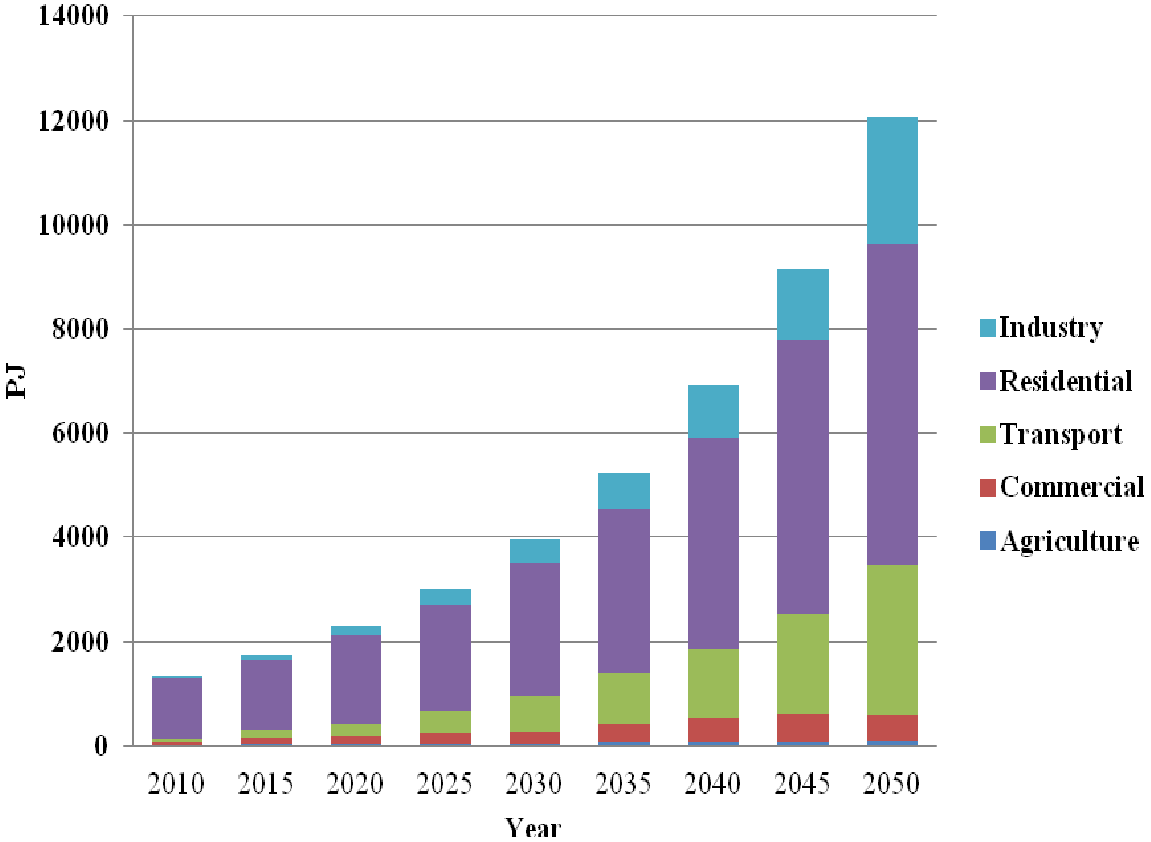


Figure 5-8: Final energy demand development between 2010-2050-Scenario 2

5.3.3.2 Primary energy supply

In the Advanced Shift scenario, the use of biomass decreases from 93.2 % in 2010 to 42.3 % in 2050. The share of oil increases from 5.47 % in 2010 to 7.4 % in 2050. The share of the three other energy sources shows an increase over the period, i.e. coal to 11.4 %, renewables from 1.32 % to 36.6 % and natural gas increases to 2.34 % (Figure 5-9). The demand for renewables was 18.3 PJ in 2010 escalating to 4,410 PJ in 2050, which is more than a 240 times increase in term of demand. As in the other scenarios, biomass is the largest source of energy even at the end of the study period (2050) supplying almost 42.3 % of the total energy demand, followed by other renewables (36.56 %), coal (11.4 %), oil (7.4 %) and natural gas (2.34 %).

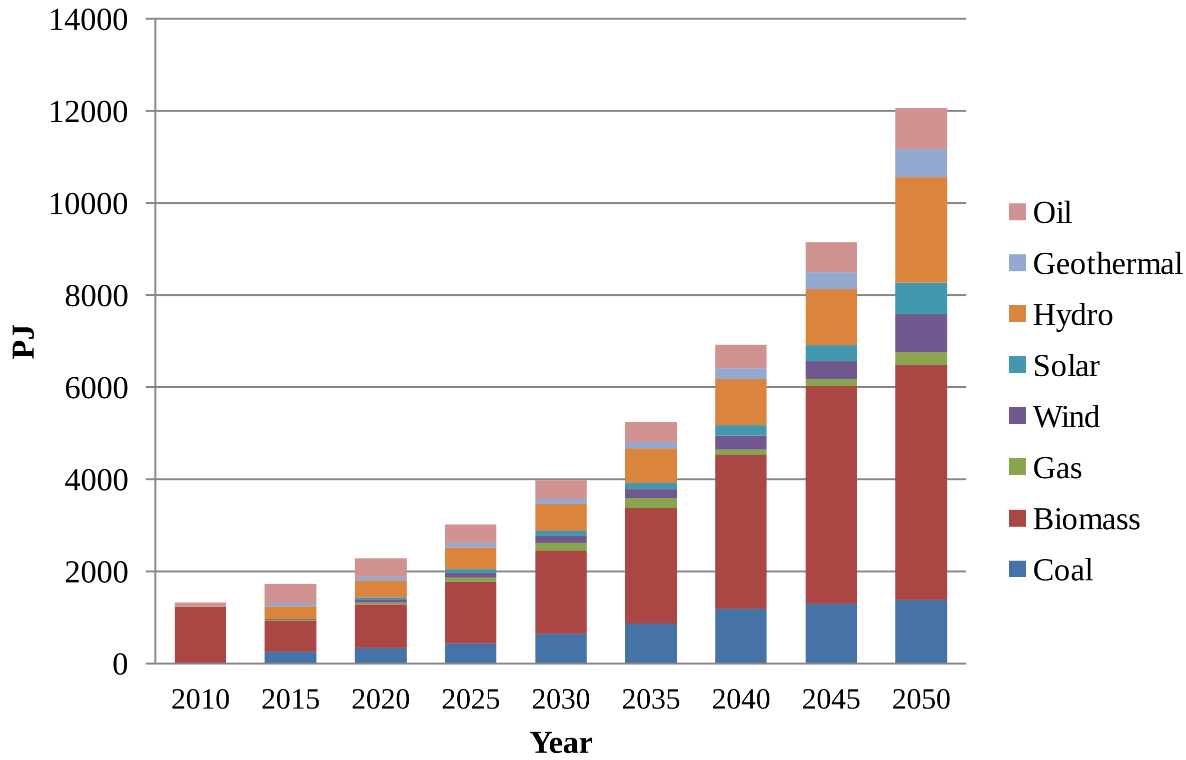
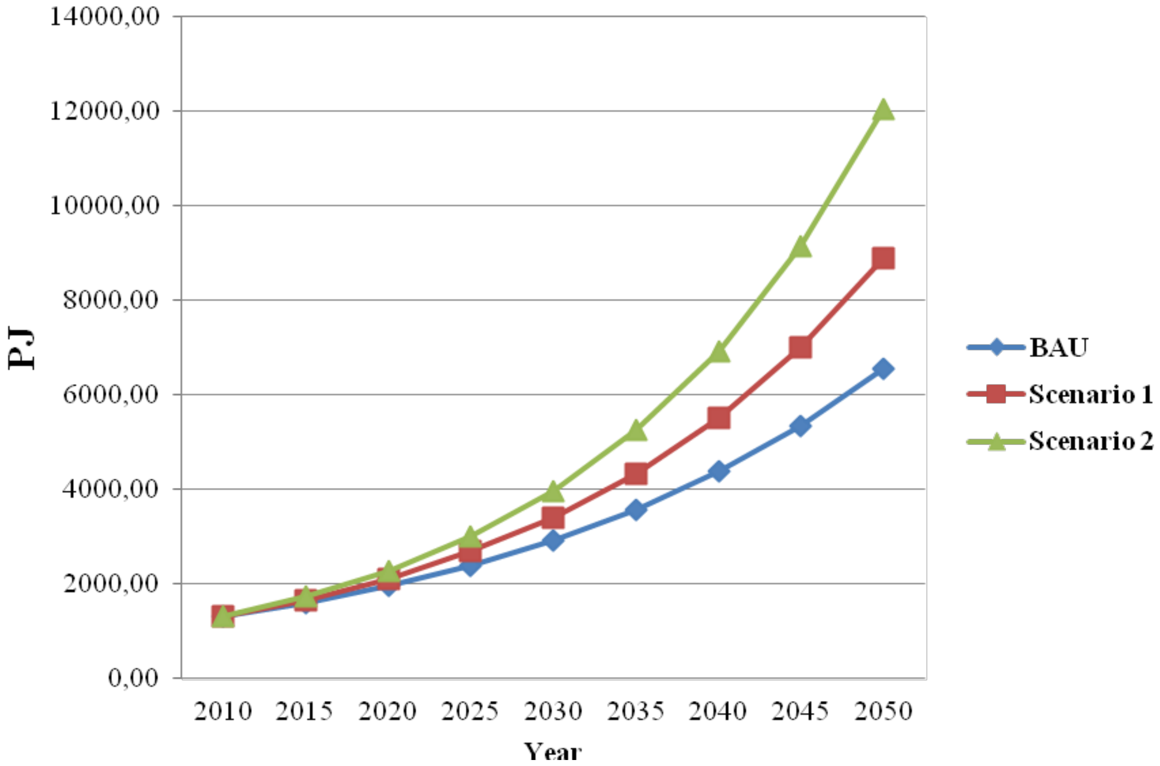


Figure 5-9: Total primary energy supply for Ethiopia – Scenario 2

5.3.4 Summary and assessment of scenarios' results

Based on the assumptions of socio-economic development in Ethiopia and the various assumed parameters, the energy implication of the three possible pathways for Ethiopia have been analyzed using LEAP model for the BAU, Moderate Shift scenario (Scenario 1) and Advanced Shift scenario (Scenario 2) over the period of 2010 to 2050. The key findings of this analysis are:



Energy demand increases sharply from 2010 to 2050 with annual growth rates of :
- **BAU: 4.1 %**
- **Scenario 1: 4.9 %**
- **Scenario 2: 5.7 %**

Figure 5-10: Total energy demand comparison of scenarios' results

- The results show that over the period 2010-2050, the final energy consumption in Ethiopia for the BAU, Moderate Shift scenario (Scenario 1) and Advanced Shift scenario (Scenario 2) are expected to grow at annual rates of 4.1, 4.9 and 5.7 % respectively. The energy consumption under Scenario 2 will reach 12,061PJ in 2050, with an annual growth rate of 5.7 %/; the highest among the three scenarios (see Figure5-10). The increased economic activity, population growth and transport needs are the major drivers of such increase.

- The share of energy consumption for the transport and industry sectors is expected to increase in all three scenarios, while the share of the residential sector decreases over the period 2010-2050. The share of industry increases from around 1 % in the base year (2010), to 14 %, 16 % and 20 % in 2050 for the BAU scenario, Scenario 1 and Scenario 2 respectively. The absolute size energy consumption of the industry and transport sectors highlights the important roles these sectors will continue to play in defining Ethiopia's overall energy pathways (see Figure 5-11).

- Compared to the residential sectors energy consumption, the transport and industry sectors' shares in final energy consumption will increase in all three scenarios at different rates over the period (2010-2050). The share of the transport sector in 2050 will be 21 %, 22 % and 24 % for the BAU scenario, Scenario 1 and Scenario 2 respectively.

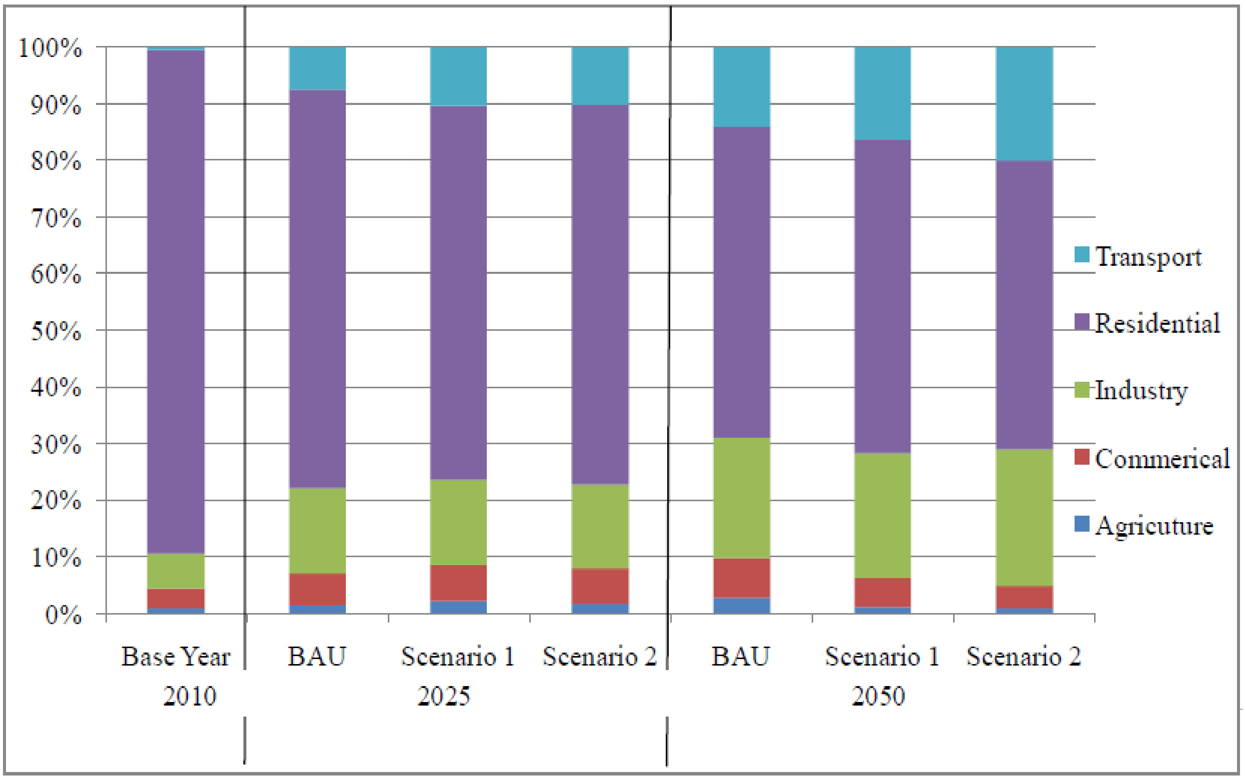


Figure 5-11: Share of final energy requirements by sector

Per capita primary energy consumption (in GJ/person) for Ethiopia gradually increases in all three scenarios, reflecting the trend of energy consumption in developing countries (see Figure 5-12). Over the study period (2010-2050), the per capita primary energy consumption is expected to grow at annual rates of 2.6 %, 3.3 % and 4.1 % for the BAU scenario, Scenario 1 and Scenario 2, respectively. The changes in per capita primary energy consumption are driven by increased economic activity.

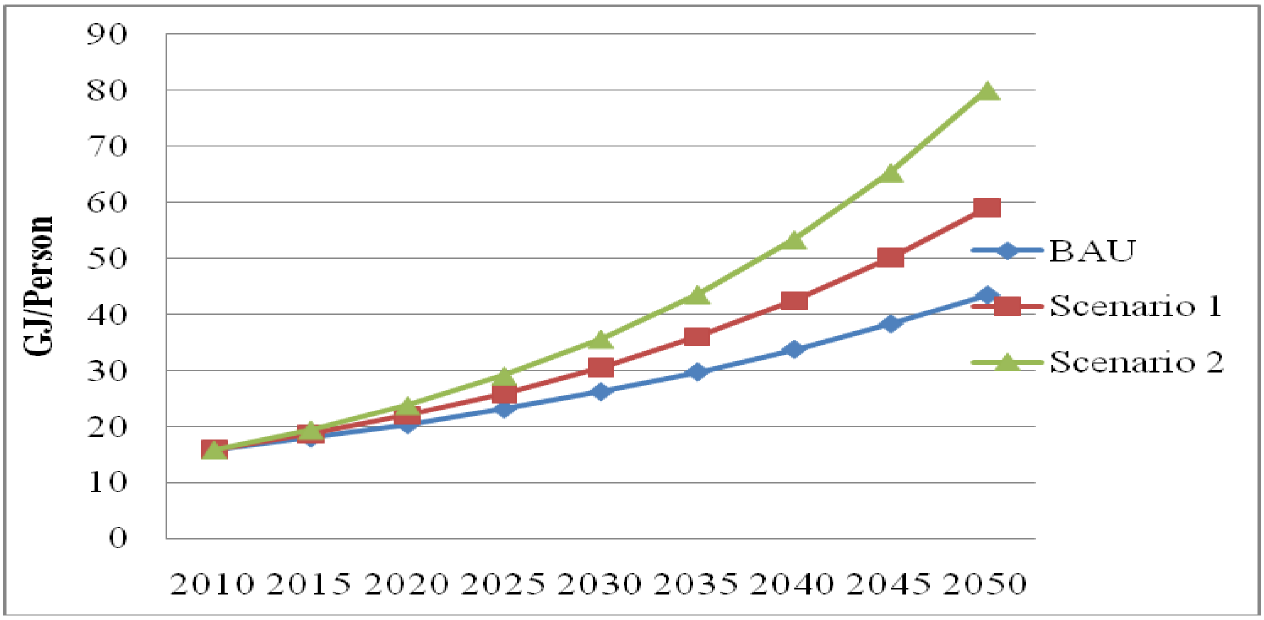


Figure 5-12: Per capita energy consumption

Correspondingly, the energy consumption intensity, measured by consumption per unit GDP, will decrease from 65 MJ/US$ in 2010 to 22 MJ/US$ and 20 MJ/US$ in 2050 for the BAU and Scenario 1, respectively (Figure 5-13). Therefore, the annual rate of decrease of the energy intensity is 2.7 % for the BAU and 2.9 % for Scenario 1. Importantly, under Scenario 2, the energy intensity will decrease to 13 MJ/US$, with an average annual rate of decrease of 3.9 %. Certainly, Scenario 2 has the largest capability for energy savings and emissions reductions in terms of slowing down the growth rate, but it does not achieve a real decline in total energy consumption.

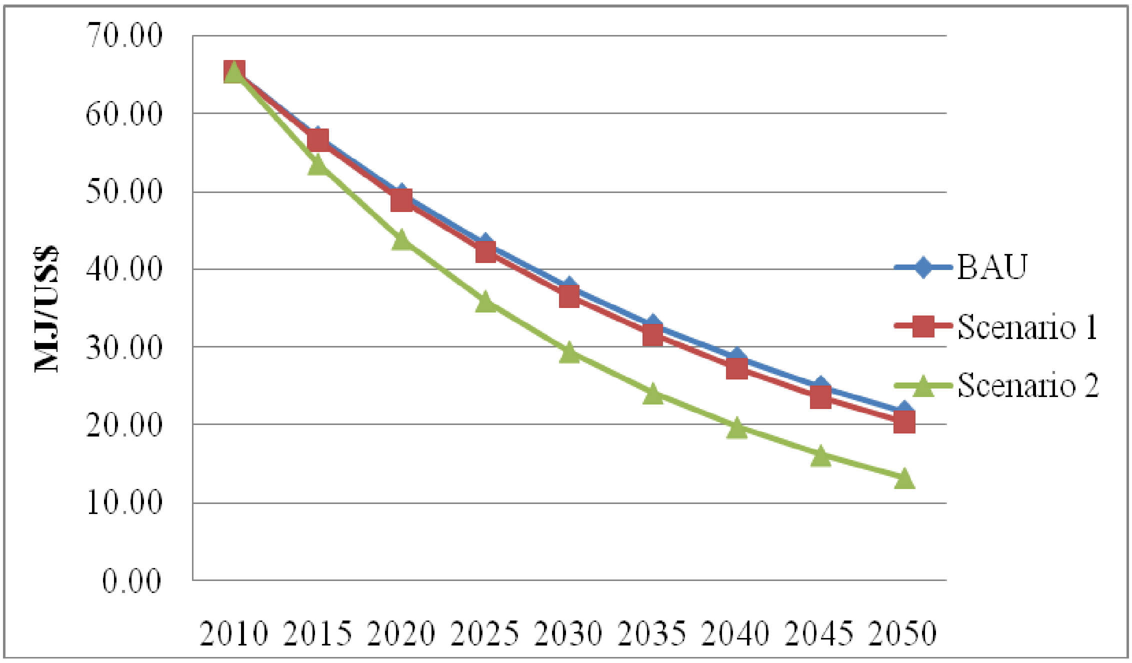


Figure 5-13: Energy intensity

- The share of oil in final energy is expected to decrease steadily and accounting average annual growth rate of 7.05, 6.7 and 6.35 % for the BAU scenario, Scenario 1 and Scenario 2 over the planning period of 2010-2050. Renewable are expected to play an increasingly important role in all three scenarios. The promotion of clean technologies, the rural electrification program and strong economic growth will lead to an increased demand for renewables.

- The renewable energy resources in the context of this study consist of hydro-power, wind, geothermal and solar. The demand for renewables is expected to increase significantly in all three scenarios, from around 1 % in 2010 to 11.1 %, 23.4 % and 36.6 % for the BAU scenario, Scenario 1 and Scenario 2 respectively, over the period of 2010-2050. Compared to the BAU scenario, the uses of renewable energy in the two alternative scenarios (Scenario 1 and Scenario 2) are much higher as a result of renewable energy promotion measures, such as solar and wind energy in power generation to increase diversity of energy supply and reduce CO_2 emissions. The increasing renewable energy demand is attributed to high demand for electricity, to increased economic activity and to population growth. The industry sector is the primary party responsible for the increased electricity demand. In 2010, the industry sector accounted for more than 32 % of electricity consumption and the rate is expected to increase in the future due to the electricity intensive industries employed, such as cement and steel. Over the planning period of 2010-2050, the annual growth rates of electricity generation in the BAU scenario, Scenario 1 and Scenario 2 are 6.0 %, 7.7 % and 8.4 % respectively.

- The structural changes in energy usage in 2050 under the three scenarios are shown in Figure 5-14. In Scenario 2, the proportion of oil consumption will decrease to 6.35 %/a, i.e., 7.05 %/a and 6.7 %/a lower than the values for the BAU and Scenario 1, respectively. Overall, under Scenario 2, the energy usage structure will gradually become environmentally friendly in Ethiopia, with rapid growth in the use of alternative clean energy.

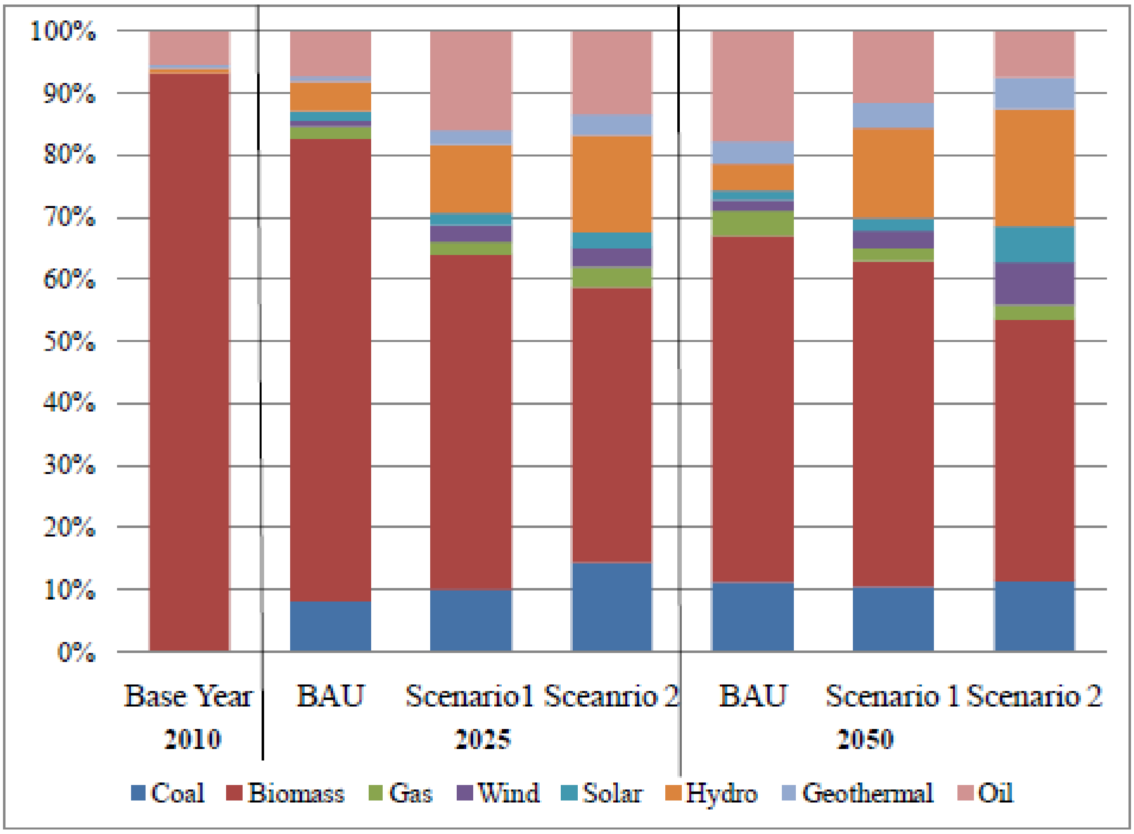


Figure 5-14: Share of final energy requirements by fuels

- The electricity sector is most likely to undergo a significant shift in technology and fuel mix. This would happen mainly driven by the need to ensure electricity supply security and reduce CO_2 emissions.

- The energy mix is expected to change substantially over the study period (2010-2050). Changes in the past to until now, the energy mix in Ethiopia have been dominated by traditional biomass and hydropower, which makes up more than 80 % of the total consumption. In response to the government's future plans and the pressure to reduce CO_2 emissions, the energy mix would shift towards other renewable energy sources.

- In the development of the three scenarios in this research, the scenarios assume that Ethiopia would not face pressure for reducing the CO_2 emissions. This is due to the fact that Ethiopia's CO_2 emissions per capita is one of the lowest in the world and accounts for 0.06 tons/cap compared to the world per capita CO_2 emissions of 4.8 tons/cap in 2010. Furthermore, the country's economic growth would be given priority and Ethiopia targets poverty reduction rather than environmental protection. Figure 5-15 shows the expansion of CO_2 emission from the energy sector in Ethiopia under the three scenarios from 2010 to 2050. The energy related CO_2 emissions are expected to increase in all three scenarios throughout the study period (2010-2050) as result of increased use of fossil energy resources. The total emissions in the base year (2010) were 5.4 Mt. These are expected to increase to 30.2Mt, 33.9Mt and 44.3Mt in the absolute terms resulting from, an average increment of 4.4, 4.7, and 5.4 %/a by the year 2050 for the BAU scenario, Scenario 1 and Scenario 2 respectively. The per capita carbon emissions under the three scenarios are presented in Figure 5-16.

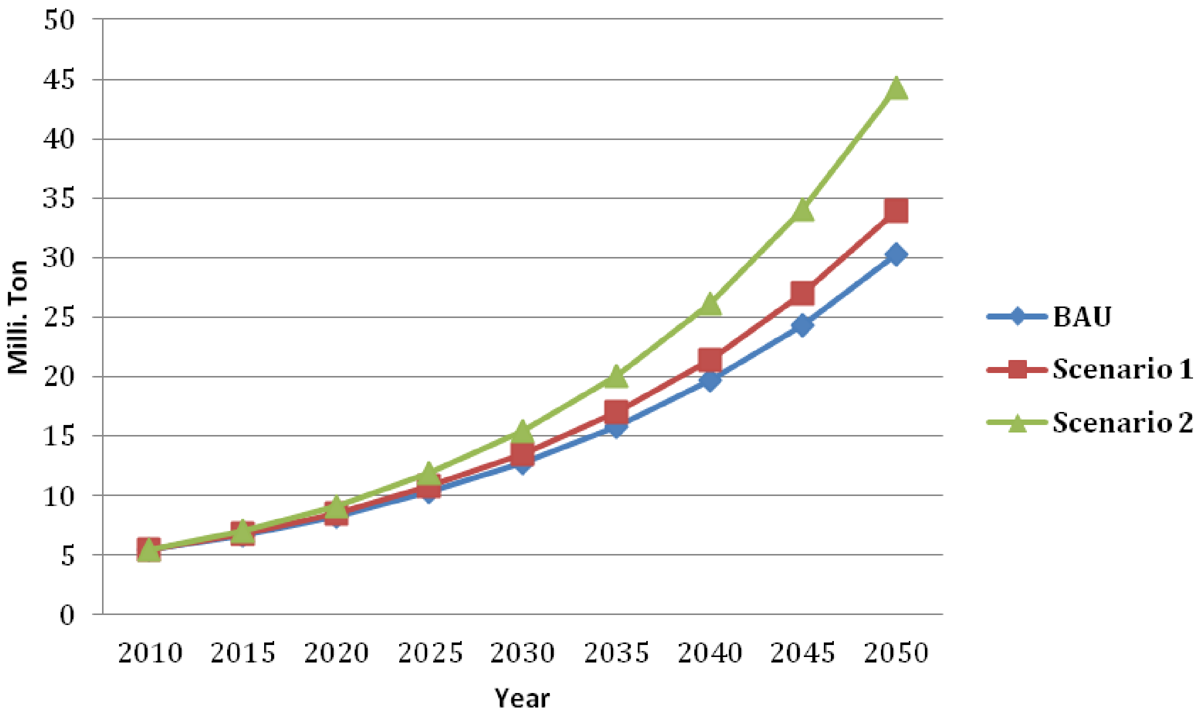


Figure 5-15: CO_2 Emission in alternative scenarios

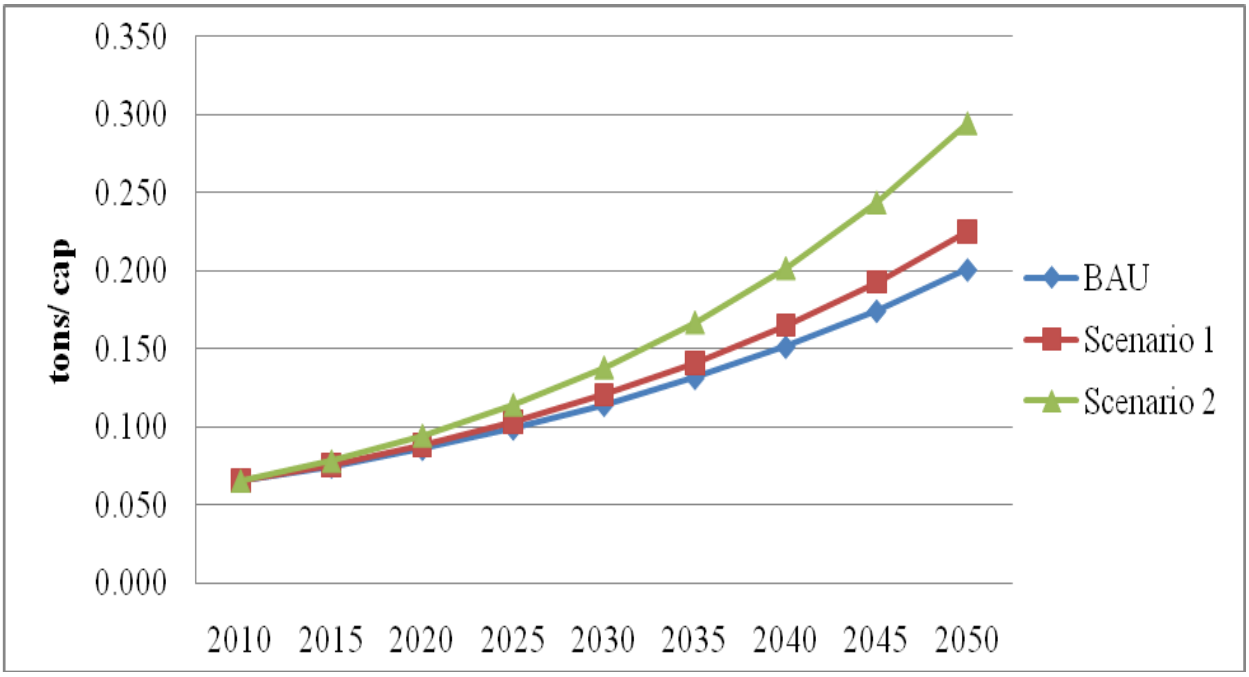


Figure 5-16: CO_2 emission per capita

Figure 5-17 shows the CO_2 emission intensity using Market Exchange Rates (Metric tons of Carbon dioxide per thousand year-2005 U.S. Dollars) values under the three scenarios considered in this study, which all present an overall declining trend, with average annual rates of 3.09 %, 3.09 %, and 4.21 % for the BAU scenario, Scenario 1, and Scenario 2, respectively. Compared to BAU and Scenario 1, Scenario 2, which is characterized by the highest economic growth rate (10 % per year, over the study period 2010-2050), produces the largest quantities of CO_2 emissions. However, Scenario 2 has the lowest CO_2 emission intensity, followed by Scenario 1 and the BAU scenario. By the year 2050 the CO_2 emissions intensities of the BAU, Scenario 1 and Scenario 2 are 0.10, 0.08 and 0.05 kg CO_2 per US$ of GDP respectively. This reduction is attributed to reduction measures such as fossil fuel savings and the promotion and application of clean technologies as envisaged in Scenario 1 and Scenario 2.

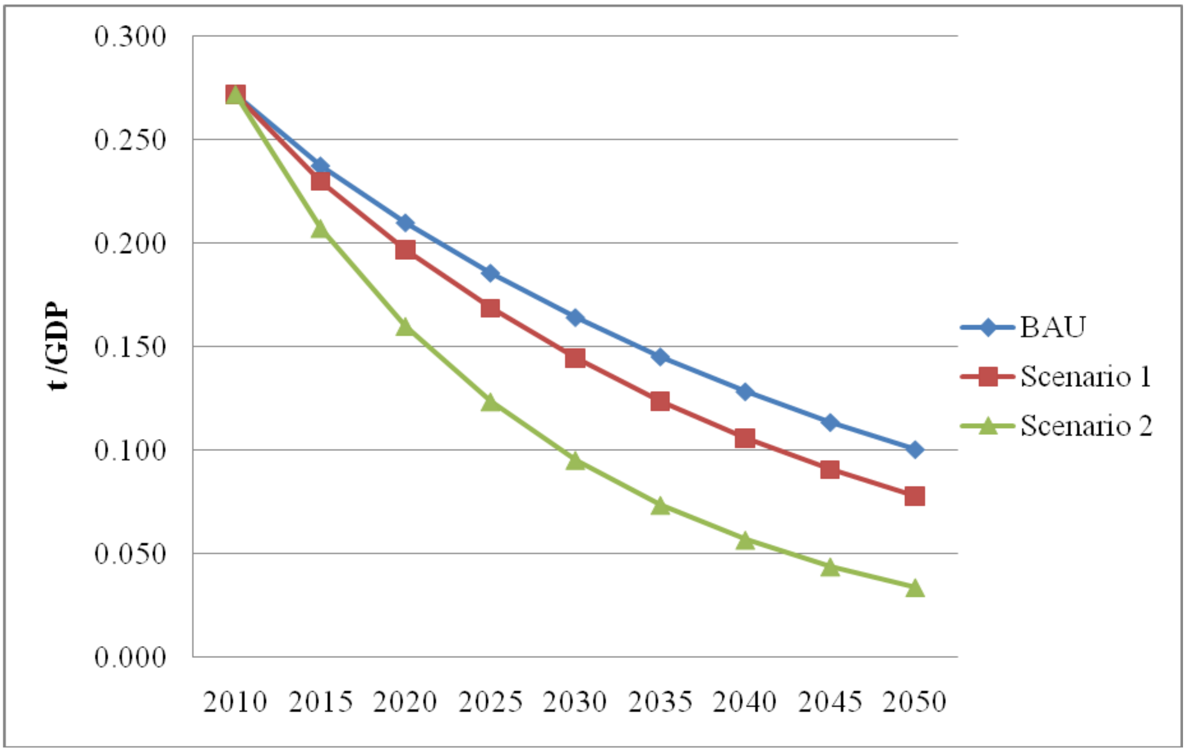


Figure 5-17: CO_2 emission intensity

In summary, it is critical for Ethiopia to find the potential energy pathways that could meet the country's energy need in a balanced manner in the coming decades. For this purpose, three energy scenarios representing possible futures of the energy system that might unfold are examined using the LEAP model. The analysis were demonstrated that plausible alternative energy pathways do exist and the questions of what forces would shape the future development of the Ethiopia's energy system and how the country will move forward in the next 40 years are also discussed.

6 ASSESSMENT OF SUSTAINABLE ENERGY IMPACTS OF SCENARIOS

In chapter 5, three scenarios were created taking into account the assumptions of socio-economic development and the various assumed key drivers that are likely to shape the future development of the energy system in Ethiopia. The objective of this chapter is to assess and examine the long-term impacts of the proposed scenarios; with a view to identify an energy pathway that would meet the country's energy needs in a sustainable manner. The energy impacts are likely to impact the country's economy to varying degrees, due to the fact that a strong relationship exists between economy and energy. The scenarios are also important in guiding the implementation of policies for future energy supply towards clean energy pathways as represented by the alternative scenarios (Moderate and Advanced shift) in this research.

In order to assess the impact of the created scenarios, this research will examine sustainability indicators for long-term energy pathways in Ethiopia. This chapter is organized into three sections, first identifying sustainability indicators in context of Ethiopia's energy sector development, followed by assessing the already develop scenarios' (Chapter 4 & 5) impacts on sustainability. The last section summarizes the overall impacts of the scenarios in view to identify an energy pathway that would meet the country's energy needs in a sustainable manner to derive key policy implications for Ethiopia's energy future.

6.1 Sustainability Concept

Sustainable development is an approach to the continued economic development of the world which balances equally the "three pillars" of sustainability which emphasizing the interdependence of environmental, social and economic systems (World Bank, 2001)[66]. In a sustainable world society, the social, economic and environmental dimensions of sustainable development would be integrated into policy making at international, regional and national levels. Sustainable development, of which sustainable energy is a major part, is intended to help connect short-term gain to long-term gain that can bring economic development.

[66] *World Bank, 2001. http://www.worldbank.org/depweb/english/sd.html , Accessed December 2013*

6.1.1 Defining sustainability

According to the Brundtland commission's brief definition, of sustainable development is defined as "the *development that meets needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 16). "Achieving sustainable economic development will require the judicious use of resources, technology, appropriate economic incentives and strategic policy planning at the local and national levels*" (Ibid). It will also require continuous monitoring of the impacts of selected policies and strategies to distinguish whether they are fostering sustainable development or whether they should adjusted.

6.1.2 Energy and sustainable development

According to Agenda 21, energy is one of the significant issues of sustainability (UNCSD, 1992). The energy sector is a major contributor to economic and industrial activities as well as a pre-requisite for the provision of basic human needs. It has a potential to contribute to sustainable development. Energy is central to improved social and economic welfare and is indispensable to commercial and industrial wealth generation. It is key in relieving poverty and raising living standards. Energy in sustainable development is related to the elements of energy supply and equity in the energy sector which are key elements of sustainable development. Efforts towards sustainable energy development are progressively becoming more important for policy and decision makers worldwide. Some of the main global energy policy objectives include mitigating the effects of climate change, reducing energy costs and improving security of energy supply (IEA/OECD, 2008)[67]. Meeting these policy aims is predicated on the identification of sustainable energy options based on various technical, economic, environmental and social sustainability indicators.

6.2 Selecting sustainable energy indicators

Sustainability indicators point a direction for the development of certain practices and policies. They are used extensively at international, national and local levels to report on

[67] *IEA/OECD, http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf , Accessed December 2013*

progress towards sustainable development. Indicators are important tools, serving as instruments of decision-making in the context of sustainability policy. According to Segnestam (2002, p. 3), indicators are the first most basic tools for analyzing change in society. The most comprehensive set of sustainable energy indicators developed to date is a set of "Energy Indicators for Sustainable Development" (EISD) developed by the international Atomic Energy Agency and International Energy Agency. An initial list of 41 indicators was developed and subsequently refined to 31 (IAEA & IEA 2001)[68].

In the assessment of the scenarios' sustainability for Ethiopia, indicators have been selected in accordance with wellbeing of current and future generations by ensuring energy access, energy security and energy efficiency. In order to quantify criteria for sustainability evaluation in the created scenarios (Chapter 4 & 5), the basic sub-energy indices defined for Ethiopia based on some of the sub-indices of the sustainable development approach of Jovanovic are used (see Figure 6-1).

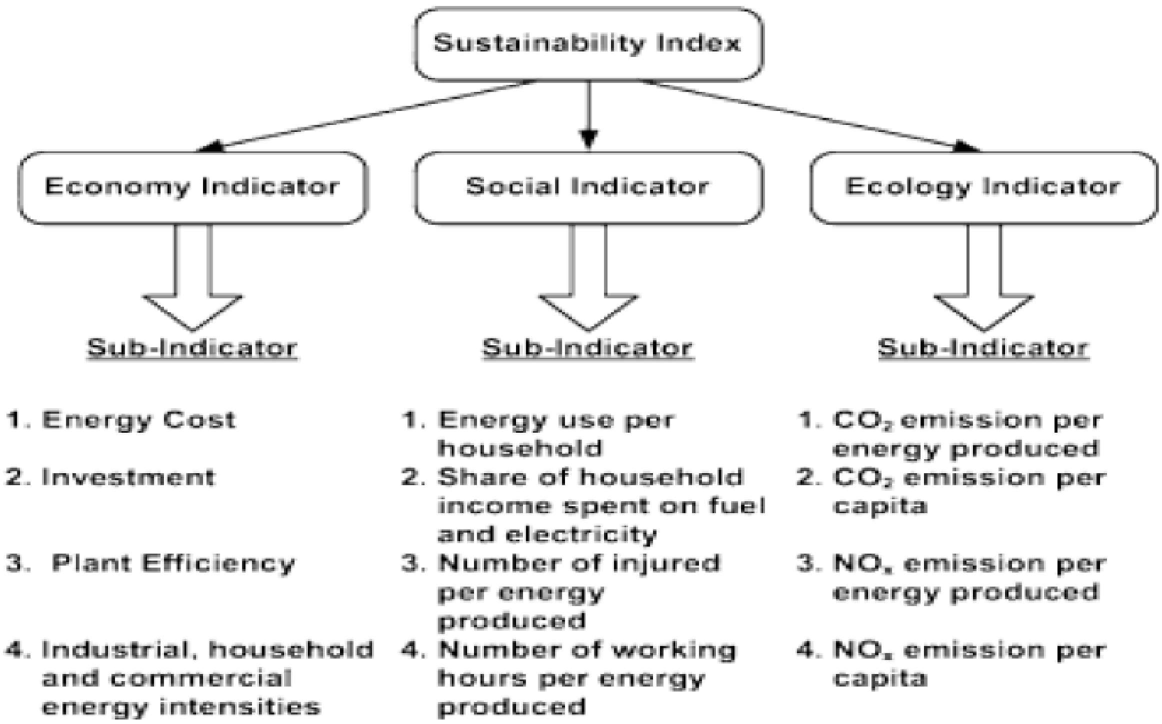


Figure 6-1: Scheme of energy indices and sub-indices of sustainable development
Source: Jovanovic, et al, 2009, p. 535

[68] *IAEA & IEA, 2001. Indicators for Sustainable Energy Development, IEA, Paris* *http://www.iaea.org/OurWork/ST/NE/Pess/csd9/isedindicatorspaper.pdf , Accessed December 2013*

6.3 Assessment of Ethiopia's energy system sustainability

The majority of Ethiopia's population lives in rural areas where modern energy services are rarely available. The World Energy Council comparatively ranks countries in terms of their ability in providing a secure, affordable and environmental-sustainable energy system (World Energy Council, 2013, p. 9), and Ethiopia is ranked 112 in the world (97 in energy security, 119 in energy equity and 47 in Environmental sustainability) in 2013 (Ibid, p. 21). As it is indicated, in energy equity and energy security Ethiopia lags behind the world.

This research study proposed the alternative scenarios in the previous chapters mostly to address the development the country's energy security as well as equity.

Ethiopia's energy system sustainability is examined using a few indices for the proposed scenarios (BAU, Scenario 1 and Scenario 2). Sustainability indicators considered in this research work are based on the following major areas:

Energy sustainability dimensions are:

1. **Energy security**: The effective management of primary energy supply from indigenous and external sources, the reliability of energy providers to meet current and future demand
2. **Energy equity**: The accessibility and affordability of energy supply access across the population
3. **Environmental sustainability**: The achievement of supply and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon source system.

(Source: World Energy Council, 2013, p. 9)

6.3.1 Energy intensity

The energy intensity is used as a means of sustainable energy assessment for scenarios. The energy intensity is measured by consumption per unit of GDP (total energy in MJ needed to produce one dollar worth of output)[69]. Over the period of 2010-2050, the energy intensity expected to decrease gradually across the three scenarios, from 65 MJ/$ in the base year (2010) to 22, 20 and 13 MJ/$ in 2050 for the BAU, Scenario 1 and Scenario 2 respectively (see Table 6-1 and Figure 6-2). The annual rate of decrease for energy intensity is 2.7 % for the BAU, 2.9 % for Scenario 1 and 3.9 % for Scenario 2. The decline in energy intensities reflects the improvements in energy efficiency. The BAU Scenario has the largest potential for energy savings and emissions reduction in terms of slowing down the growth rate, although it does not achieve a real decline in total consumption.

Table 6-1: Energy intensity

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AARG (%)
BAU	65.34	56.96	49.64	43.27	37.72	32.88	28.66	24.98	21.77	-2.7
Scenario 1	65.34	56.49	48.83	42.22	36.49	31.55	27.27	23.58	20.38	-2.9
Scenario 2	65.34	53.53	43.86	35.93	29.43	24.11	19.75	16.18	13.26	-3.9

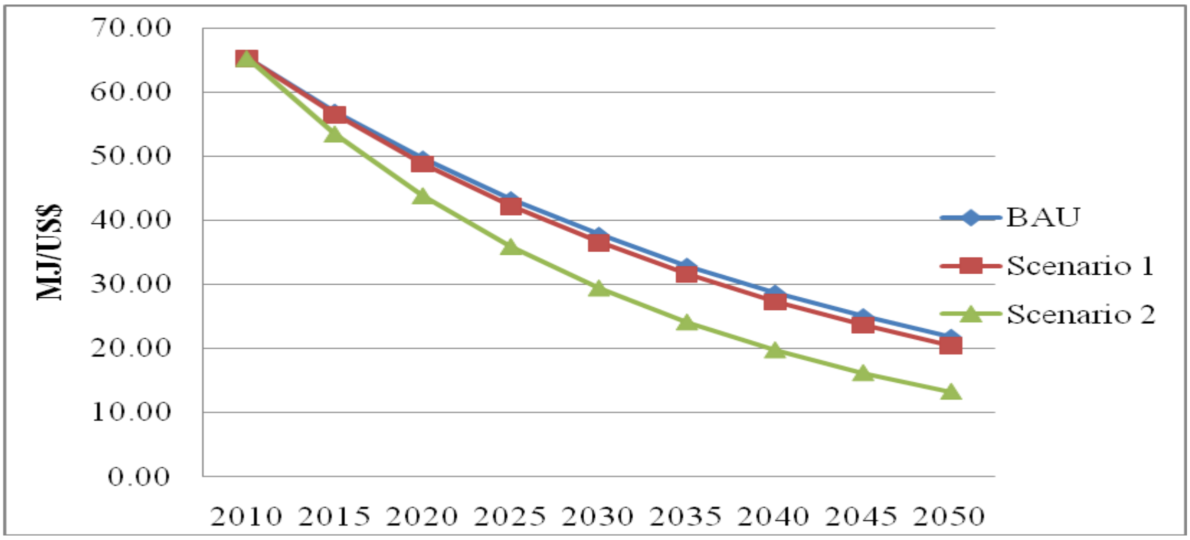


Figure 6-2: Energy intensity in three scenarios

[69] *United Nations (UN).* *http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/consumption_production/energy_use_intensity.pdf*

Ethiopia is characterized by low per capita energy consumption as compared to sub-Saharan Africa countries. The result of this study shows that the primary energy consumption per capita for Ethiopia gradually increases in the three scenarios, which reflects the trend in developing countries energy consumption (Figure 6-3). The per capita primary energy consumption over the study period of 2010-2050, is expected to grow at annual rates of 2.6, 3.3 and 4.1 % for the BAU scenario, Scenario 1 and Scenario 2 respectively. Increased economic activity is driving the per capita primary energy consumption.

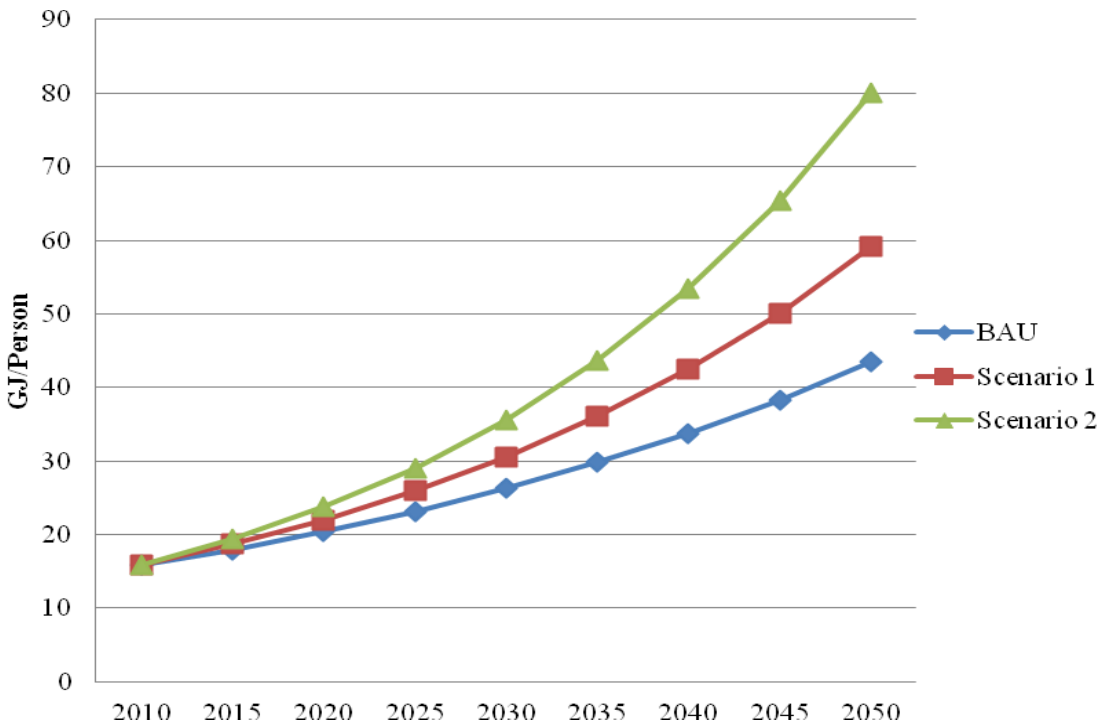


Figure 6-3: Per capita energy consumption in all scenarios

6.3.2 Diversity of energy supply

The energy mix in Ethiopia is expected to undergo a significant change over the study period of 2010-2050. The past trends shows, the energy mix in Ethiopia has been dominated by biomass which made up more than 90 % of the primary energy supply in 2010. Over the period of 2010-2050, the share of biomass in the total energy mix would decrease from 93.2 % to 55.9 % in the BAU scenario, to 52.4 % in Scenario 1 and to 42.3 % in Scenario 2 in 2050 respectively. In contrast, the share of new renewables, coal and oil in the total energy mix are expected to increase in all scenarios. Renewables from 1.32 % in the base year (2010), to 11.1 %, 23.4 % and 36.6 % in 2050 for BAU, scenario 1 and Scenario 2 respectively. Coal would be 11.29, 10.7 and 11.4 % in 2050 for BAU, Scenario 1 and Scenario 2 respectively. Oil increases from 5.47 % in the base year to 17.7, 11.5 and 7.4 % in 2050 for the BAU, Scenario 1 and Scenario 2 respectively. With limited indigenous reserves, the shares of gas would be expected to remain a small share of the total energy mix.

6.3.3 Oil import dependence

If the current trends in energy policies and strategies continue over the period of 2010-2050 without major changes, Ethiopia would increase its dependence on imported energy, mostly on oil imports (17.7 %). This is potentially inviting an energy insecurity, which the country would face together with serious environmental pollution. However, the result of the scenario analysis of this study shows that Scenario1 and Scenario 2 formulated in this study indicating energy saving strategies and alternative fuels in transport sector, as well as renewable energy promotion, will depend mainly on in indigenous energy resources, which can significantly reduce the CO_2 emissions and import dependence over the period of 2010-2050, the average annual growth rate of oil consumption could be reduced for Scenario 1 and Scenario 2 to an average annual growth rate of 6.7 % in Scenario 1 and 6.35 % respectively in Scenario 2 as compared with the BAU scenario of 7.05 %.

6.3.4 CO_2 emission intensities

The CO_2 emissions from energy are likely to increase in all three scenarios over the study period (2010-2050). The transport sector is the major contributor. Figure 6-4 shows the carbon dioxide emission performance under the three scenarios over the period of 2010 to 2050.

Under the BAU scenario the CO_2 emissions will increase from 5.4 million tons in 2010 to 30.2 $MtCO_2$ in 2050 with an annual growth rate of 4.4 %. Under Scenario 1 emissions will increase to 33.9 $MtCO_2$ in 2050 at a significantly lower annual rate of 4.7 % compared to Scenario 2. Under Scenario 2 the emissions will reach a peak value of 44.3$MtCO_2$ in 2050 increasing at a rate of 5.4 %.

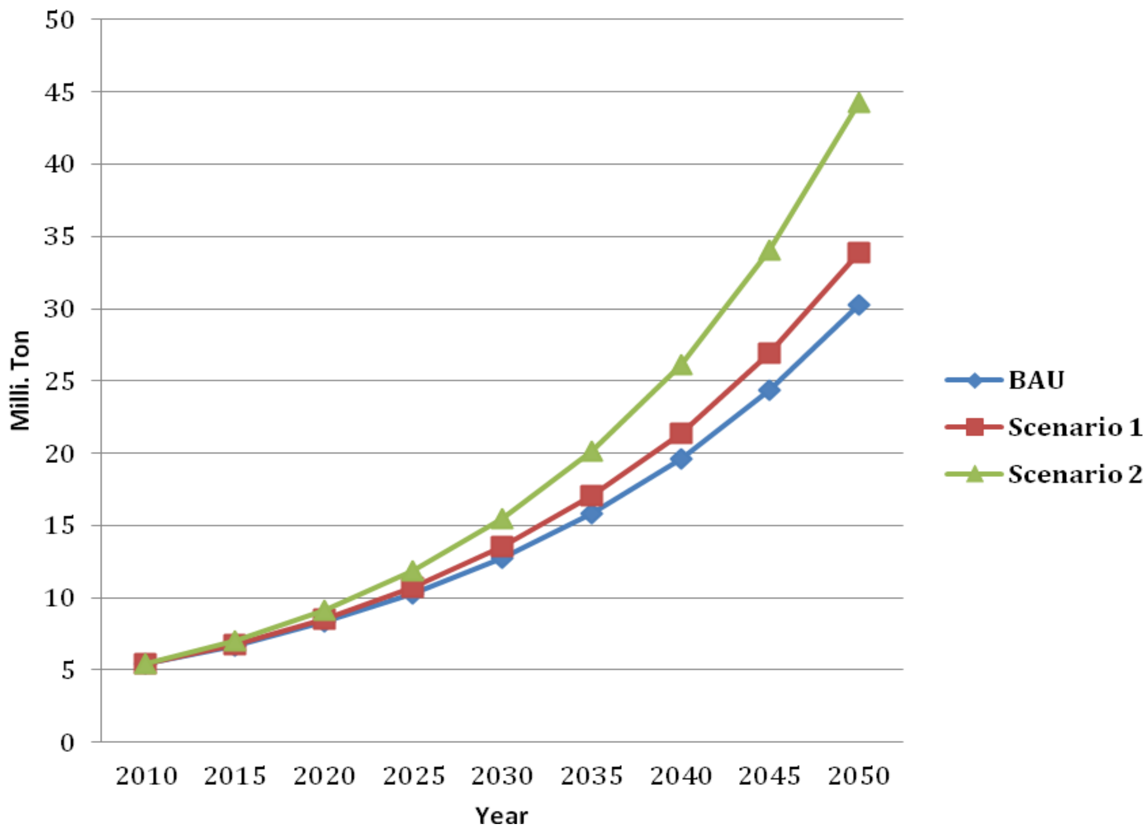


Figure 6-4: CO_2 Emission in three scenarios

However, the CO_2 emission intensities are generally lower in both Scenario 1 and Scenario 2 as compared to the BAU scenario in 2050. The analysis show that by 2050 the CO_2 emission intensities of the BAU scenario, Scenario 1 and Scenario 2 are 0.1, 0.08 and 0.05 kg CO_2 per US$ of GDP respectively. The reduction of energy intensities of Scenario 1 and Scenario 2 compared to the BAU scenario are due to reduction measures like fossil fuel savings, promotion and application of clean energy technologies envisaged.

Table 6-2 and Figure 6-5 below presentCO_2 emission intensities in kg of CO_2/US$ of the three scenarios (BAU, Scenario1, Scenario 2).

Table 6-2: Carbon emission intensity under the three scenarios

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR (%)
BAU	0.272	0.238	0.210	0.186	0.164	0.145	0.128	0.114	0.100	-3.09%
Scenario 1	0.272	0.230	0.197	0.169	0.144	0.124	0.106	0.091	0.08	-3.09%
Scenario 2	0.272	0.217	0.175	0.142	0.114	0.092	0.075	0.060	0.05	-4.21%

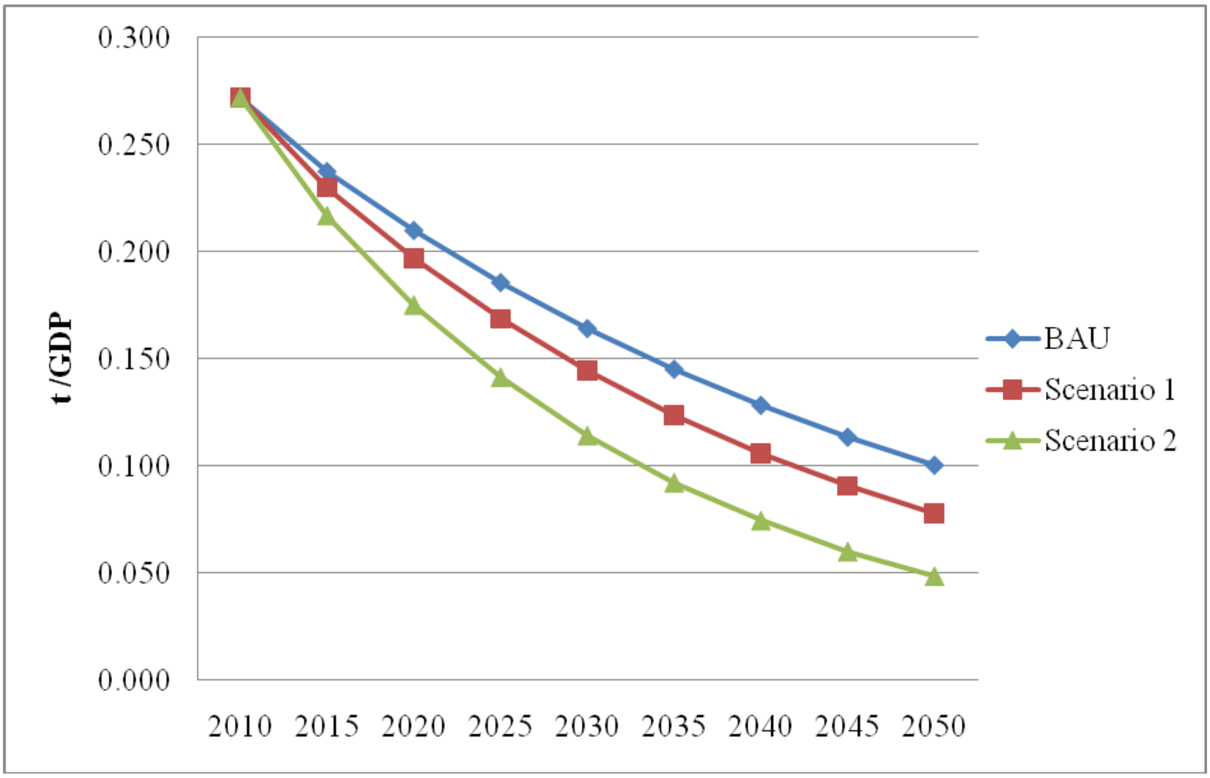


Figure 6-5: Emission intensity under three scenarios

The per capita CO_2 emissions under the three scenarios are presented in Table 6-3. The per capita emissions will reach a value of 0.2 tons in the BAU scenario, while under Scenario 1, the per capita CO_2 emissions will increase steadily to 0.23 tons per capita in 2050, slightly higher than BAU. However under Scenario 2, the per capita value will be the highest with 0.294 tons per capita in 2050 with an average annual growth rate of 4.05 %, a 4 to 5 fold increase from the year 2010 value of 0.066t/cap.

Table 6-3: Per capita carbon emission under three scenarios (ton CO_2/ capita)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR (%)
BAU	0.066	0.075	0.086	0.099	0.114	0.132	0.151	0.174	0.201	2.82%
Scenario 1	0.066	0.076	0.089	0.104	0.121	0.141	0.165	0.193	0.23	3.12%
Scenario 2	0.066	0.079	0.095	0.115	0.138	0.167	0.202	0.243	0.29	3.81%

6.4 Summary

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 the three 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 the alternative scenarios (Scenario1 and Scenario 2) would result in outputs that would be comparatively higher for those sectors which are characterized by low energy intensities and CO_2 intensities (see Figure 6-6).

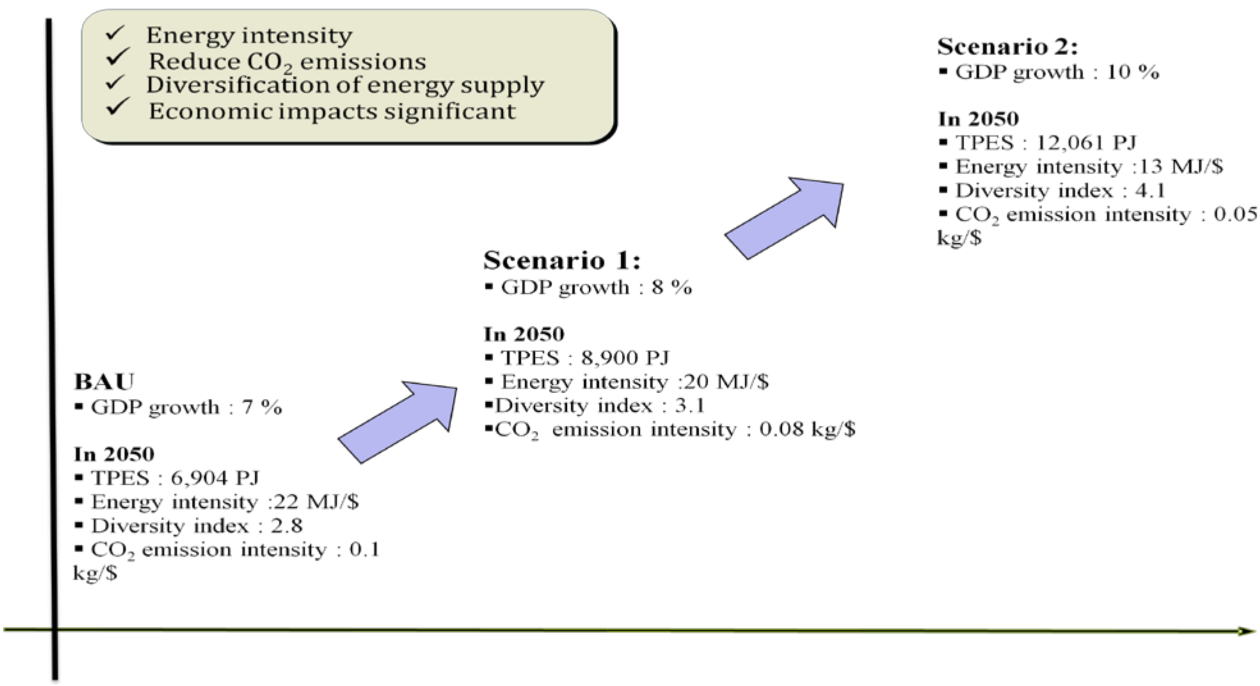


Figure 6-6: Summary of scenarios' impact

In summary, the scenarios' possible energy pathways 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 into consideration the wider impacts of various energy options (such as economic-wide impacts). This task could be carried out by the next researcher who can use this study as a first input source. This research study recommends some policy perspectives for the country in the next section 6.5.

6.5 Policy perspective for Ethiopia's energy future

On the basis of this research study, a number of policy recommendations can be made aimed at promoting sustainable development of the energy sector in Ethiopia. This section aims at recommending policy strategies of each scenario developed from the results and indicator variables used in modeling of Ethiopia's energy system in the previous chapters and sections. The future policies and measures of these three scenarios are discussed in the following:

6.5.1 Scenario 1: policy implications

In the moderate shift scenario (Scenario 1), the government will need to enforce the policy on energy conservation standards to encourage users (especially industry and household sectors) to implement energy conservation technologies.

As the scenario outcomes in this research suggests, the country would need the following energy strategies in order to increase the diversity of the energy mix and to limit CO_2 emissions:

- Awareness creation through training and campaigning programs combined with energy auditing to identify energy saving potential in the industry and household sectors.
- New technologies for water heating and lighting, such as solar water heaters and fluorescent lamps are encouraged
- Improving the energy efficiency in both supply and demand sides through modern and advanced technologies, such as IGCC (Integrated Gasification Combined Cycle)

technology, DRI (Direct Reduced Iron) in big industries (steel and cement), hybrid car technology in road transport.

- Alternative fuels and technologies, such as bio-fuels and CNG (compress natural gas) or LPG (Liquid petroleum gas) would help the transport sector to reduce the oil dependency and limit CO_2 emissions.
- The government should encourage the use of renewable energy through providing incentives for use of renewable energy technologies, such as investment tax credits, low cost loans for power generation or feed-in tariffs.

6.5.2 Scenario 2: policy implications

The advanced shift scenario (Scenario 2) puts higher emphasis on economic growth and environmental protection. Like Scenario 1, Scenario 2 was developed to demonstrate how the alternative energy path could enable Ethiopia to meet the country's energy need in a sustainable manner.

In order to diversify the energy supply mix and to limit CO2 emissions, the country would need the following energy strategies:

- Shift energy system from the current biomass-based system to a system which would become diverse in energy resources and which would rely on an increased use of low carbon energy sources, such as renewables.

- Stronger promotion of alternative fuels in transport sector, such as Biofuels and CNG accounting for 10 % of total fuel consumed by transport from 2015 onwards

- An increase in the uptake of advanced technologies, such as dry method for cement production, and DRI and EAF for steel making could help to reduce fossil energy consumption by 10 % and 15 % by 2025 and 2050, respectively

An increase in the use of new technologies for water heating and lighting, such as solar water heaters and compact fluorescent lamps should be encouraged to reduce fossil energy consumption in these sectors by 10 % and 15 % by 2025 and 2050 respectively

7 CONCULSIONS AND RECOMMENDATIONS

This study aimed to identify long-term energy pathways that would meet Ethiopia's energy needs in a sustainable manner with special reference to the potential of indigenous energy resources. In fulfilling this broad objective, the LEAP model was selected and adapted to the specific energy conditions in Ethiopia. In this research, three energy scenarios (BAU, Scenario 1 and Scenario 2) were developed, taking into account different strategies for Ethiopia from 2010 to 2050. The analysis was carried out in order to examine the energy and economic impacts associated with these scenarios. In line with this objective, various activities were undertaken as important contributions to this study.

This research reviewed the country's current energy status and existing energy policies and found out that the existing energy policy settings are short term perspectives, fragmented and internally inconsistent. These policies, therefore, are incapable of addressing the long-term energy challenges facing the country. In order to address this shortcoming and to provide meaningful insight, this research has developed an analytical framework as a scenario based approach.

The three scenarios developed in this research are based on the key variables that have the potential to influence future pathways of Ethiopia's energy sector. These are energy diversity, advancement of technologies, reduced dependency on energy imports and a reduction of specific CO_2 emissions. The features of the three scenarios include:

- The BAU scenario represents the continuation of the current trends in which the level commitments to economic development (economic growth rate of 7 % per annum over the period of 2010-2050) and climate friendly energy production are low.

- The moderate shift (Scenario 1) scenario represents the situation, where there is a moderate level of commitment to economic development (economic growth rate of 8 % per annum, over the period 2010-2050), as well as more climate friendly and technological commitment in comparison to BAU. This scenario expects some initiative higher share renewable energy.

- The advanced shift (Scenario 2) scenario reflects the situation where a level of commitment to economic development (economic growth rate of 10 % per annum) and climate friendly energy production higher than Scenario 1.

The results show that the choice of development model adopted by the country will have a significant impact on energy consumption and carbon dioxide emissions. If the current policy trends continue, as represented by the BAU scenario, by the year 2050 Ethiopia's primary energy requirement would increase from 1,313 PJ in 2010 to 6,553 PJ and CO_2 emissions would be expected to increase from 5.4 $MtCO_2$/a in 2010 to 30 $MtCO_2$/a tons in 2050. The Scenarios 1 and 2 are alternative energy paths for Ethiopia that could help to meet the energy demand for even higher economic growth rates. In 2050, total primary energy requirements for Scenario 1 and Scenario 2 would be 8,900 PJ and 12,061 PJ, respectively. At the same time, the total CO_2 emissions of Scenario 1 and Scenario 2 would be 33.9 $MtCO_2$/a and 44 MtCO2/a, respectively.

The share of energy consumption by the transport and industry sectors is expected to increase in all three scenarios, while the share of the residential sector decreases over the period 2010-2050. The share of industry increases from around 1 % in base year (2010), to 14 %, 16 % and 20 % in 2050 for BAU, Scenario 1 and Scenario 2 respectively. The absolute size of industry and transport sector energy consumption highlights the important roles these sectors will play in defining Ethiopia's overall energy pathways.

In the coming decades, the dominant role of biomass in the total primary energy mix is likely to be continued. However, its share in the energy mix is likely to decrease considerably from the base year (2010). In 2050 this share is expected to decline from 93.2 % in the base year to 55.9 %, 52.4 % and 42.3 % in BAU scenario, in Scenario 1 and Scenario 2, respectively

The demand for renewable energy (except biomass) is expected to increase significantly in the future, from around 1 % in 2010, to 11.1 %, 23.4 % and 36.6 % for the BAU, Scenario 1 and Scenario 2 respectively over the period of 2010-2050. The increasing renewable energy demand is attributed to high demand for electricity due to increased economic activities and population growth. The industry sector is primarily responsible for the increased electricity demand. In 2010, the industry sector accounted for more than 32 % of electricity consumption and the rate is expected to increase in the future due to the electricity intensive industries employed, such as cement and steel. Over the planning period of 2010-2050, the annual growth rates of electricity generation in BAU, Scenario 1 and Scenario 2 are 6.0 %, 7.7 % and 8.4 % respectively.

The proportion of oil will be 17.72 % of the final energy consumption in 2050 under the BAU, in contrast to a contribution of 11.5 % and 7.4 % to the total energy consumption under the Scenario 1 and the Scenario 2, respectively.

Compared to residential sector energy consumption, the transport and industry sectors shares in final energy consumption will increase in the three scenarios with different rates over the period (2010-2050). The share of the transport sector will be 21 %, 22 % and 24 % for the BAU scenario in 2050, Scenario 1 and Scenario 2 respectively.

The results also show that the degree of diversification in the total energy requirement would increase in alternative scenarios (Scenario 1 and Scenario 2). The primary energy supply system would diversify from a system dominated by biomass in the later period to the use of renewable resources and other indigenous resource.

Limitations and recommendations

Some limitations of this study are presented and recommendations are made on how these limitations could be overcome in future research work. Some of these limitations are due to the very nature of the research methods applied; others are due to the time and resource constraints, still others due to the unavailability of required information.

Limitation of the study

- One of the difficulties in conducting this research was the availability of data on the energy sector of Ethiopia, due to the fact that there is exists no systematic practice of collecting energy statistics in Ethiopia. Therefore data used in this research has been collected from different sources; from the Ethiopian Electric and Power Corporation (EEPCo.), from the Ministry of Water and Energy, from numerous research studies and from national and international publications. In the course of processing these data sets, special attention has been paid to make the data consistent in order to improve the quality of future energy studies and energy planning activities, this research strongly recommends that further efforts be undertaken to ensure data consistency.

- The three scenarios developed in this study do not exhaust the possible solutions for sustainable energy supply in Ethiopia. The technologies and measures nor futures are evaluated from the cost perspective. This means the study does not estimate, how much investment is required to realize these pictures hence it does not answer whether they are feasible from a cost perspective or even desirable. The study also leaves out other perspectives like emissions reductions or earnings through the clean development mechanism (CDM).

Outlook

The standard version of the LEAP Ethiopia model can be applied for various energy-related studies including the assessment of air pollution control strategies. An expansion of the model can be done, using total energy system, by linking the model with the MACRO model so that end-use demand can be adjusted internally depending on the concluded supply solutions.

The study offers the overall picture of renewable energy potential and points out the extent that renewable energy technologies can penetrate into the energy market of Ethiopia based on obtained results. With it planners and policy makers can visualize proper policies and guidelines to promote renewable energy technologies for a more sustainable and secure energy system.

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APPENDICES

APPENDIX A: Types and sources of data (LEAP)

Source: UNFCCC, 2005, p. 18; Heaps, 2002, p. 43

Category	Types of Data	Common Data Sources
Macroeconomic Variables		
Sectoral driving variables	GDP/value added, population, household size	National statistics and plans; macroeconomic studies; World Bank, GDP data, UN Population data, World Resources Institute.
More detailed driving variables	Physical production for energy intensive materials; transportation requirements (pass-km/year); agricultural production and irrigated area; commercial floor space, etc.	Macroeconomic studies; national sectoral studies, household surveys, UN FAO Agrostat database; etc.
Energy Demand		
Sector and subsector totals	Fuel use by sector/subsector	National energy statistics, national energy balance, energy sector yearbooks (oil, electricity, coal, etc.), International Energy Agency statistics.
End-use and technology	Energy consumption by end-use and device: e.g. new vs. existing building stock; vehicle stock; breakdown by type,	Local energy studies; surveys and audits; studies in similar countries; general rules of thumb from end-use literature.
Response to price and income changes	Price and income elasticities	Econometric analyses of time-series or cross-sectional data.
Energy Supply		
Technical characteristics	Capital and O&M costs, performance, efficiencies, capacity factors, etc.	Local data, project engineering estimates, EPRI Technical Assessment Guide,
Energy prices		Local utility or Govt projections. IEA World Energy Outlook and fuel price projections.
Energy supply plans	New capacity on-line dates, costs, characteristics.	National or electric utility plans & projections; other energy sector industries.
Energy resources	Estimated recoverable reserves of fossil fuels; estimated costs and potential for renewable resources	Local energy studies; World Energy Council Survey of Energy Resources.
Technology Options		
Costs and performance	Capital and O&M costs, performance (efficiencies, unit intensities, capacity factors, etc.)	Local energy studies and project engineering estimates; technology suppliers; other mitigation studies,
Penetration rates	Percent of new or existing stock replaced per year; overall limits to achievable potential	Extrapolation of trends & expert judgment, optimizing or simulation models.
Administrative and program costs	For efficiency investment, often expressed in cost per unit energy saved.	Local and international studies.

APPENDIX C: Primary energy consumption (PJ)

BAU

	2010	2015	2020	2025	2030	2035	2040	2045	2050	**AAGR (%)**
Coal	0.00	94.02	203	199.17	508.51	634.01	737.98	752.95	739.54	6.07%
Biomass	1224.07	1446.60	1608.3	1785.81	1993.42	2219.33	2470.8	2750.76	3663.13	2.78%
Gas	0.00	124.10	86.5	156.13	348.03	304.14	256.18	277.04	261.011	2.15%
Wind	0.00	3.70	19.01	24.23	73.11	86.24	96.16	112.12	112.21	10.23%
Solar	0.00	1.20	16.11	34.35	42.17	48.13	54.31	65.21	101.57	13.52%
Hydro	12.53	14.34	78.03	115.18	168	269.07	411.23	478.11	284.4	8.12%
Geothermal	5.85	7.02	12.02	17.24	18.23	20.33	42.21	43.10	230.01	9.61%
Oil	76.15	114.13	171.21	175.65	384.3	575.97	863.27	1293.87	1161.19	7.05%
Total	**1313.39**	**1605.60**	**1962.91**	**2399.65**	**2933.7**	**3586.41**	**4384.50**	**5360.03**	**6552.71**	**4.10%**
Renewables[70]	18.38	26.24	125.11	191.01	301.23	423.33	603.27	698.00	727.981	**9.63%**

Scenario 1:

	2010	2015	2020	2025	2030	2035	2040	2045	2050	AAGR (%)
Coal	0.00	112	267	271.59	530	694.86	849.51	903.91	952.14	5.50%
Biomass	1224.07	866	851.9	1454.594	1477	1945.6	2587.24	3496.53	4663.82	3.40%
Gas	0.00	15.00	27.60	53.90	116.25	191.08	132.43	154.15	178.01	6.38%
Wind	0.00	6.17	34.80	74.14	121.00	142.31	173.12	249.41	252.03	9.79%
Solar	0.00	2.08	20.31	52.25	72.22	85.32	92.00	125.32	178.89	11.89%
Hydro	12.53	302.00	432.22	296.08	575.80	694.61	990.00	1217.00	1290.50	12.28%

[70] *Renewables energy resources in the context of this research, consists of hydro-power, solar, geothermal and wind*

Geothermal	5.85	41.72	43.24	64.27	86.00	112.16	146.23	195.00	364.93	10.89%
Oil	76.15	324.72	442.90	426.63	441.21	477.71	546.00	665.73	1019.94	6.70%
Total	**1313.39**	**1668.30**	**2119.10**	**2691.70**	**3419.00**	**4342.87**	**5516.40**	**7007.00**	**8900.01**	**4.90%**
Renewables	18.38	351.70	529.80	486.09	854.81	1033.60	1401.12	1786.00	2086.29	**12.56%**

Scenario 2:

	2010	2015	2020	2025	2030	2035	2040	2045	2050	**AAGR(%)**
Coal	0.00	251.27	331.50	437.41	644.8	866.47	1184.9	1298	1374.99	4.98%
Biomass	1224.07	672.36	955.70	1336.36	1806.96	2520.6	3346.5	4726	5101.93	3.63%
Gas	0.00	22.53	41.15	96.53	167.16	199.55	117.79	146.264	282.23	6.52%
Wind	0.00	10.00	63.26	94.33	154.07	198.00	305.00	388.38	831.02	11.68%
Solar	0.00	7.04	46.32	77.41	111.38	136.00	221.44	345.22	685.08	12.13%
Hydro	12.53	276.33	355.12	471.24	573.31	746.41	996.16	1235.15	2289.23	13.91%
Geothermal	5.85	76.32	90.11	102.56	121.00	138.11	231.32	353.02	604.27	12.29%
Oil	76.15	417.63	404	401.44	406.33	441.48	526.60	649.00	892.536	6.35%
Total	**1313.39**	**1732.88**	**2286.35**	**3016.60**	**3980.10**	**5251.30**	**6928.57**	**9141.51**	**12061.30**	**5.70%**
Renewables	18.38	369.04	554.00	744.56	959.00	1218.03	1753.11	2321.14	4409.61	**14.68%**

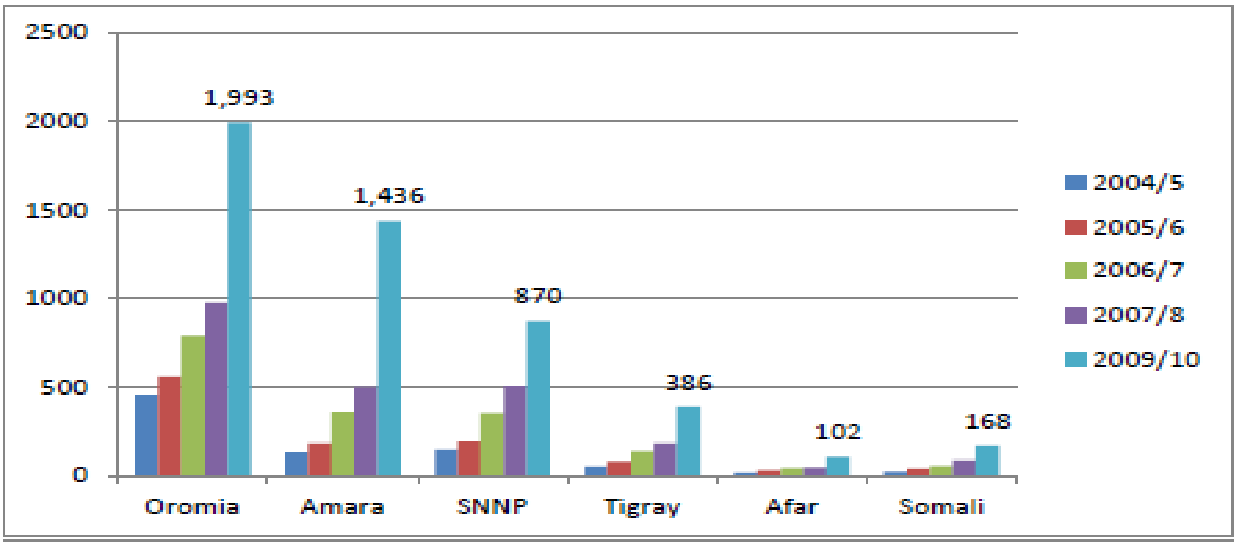
APPENDIX D: Current and future generation portfolio of Ethiopia

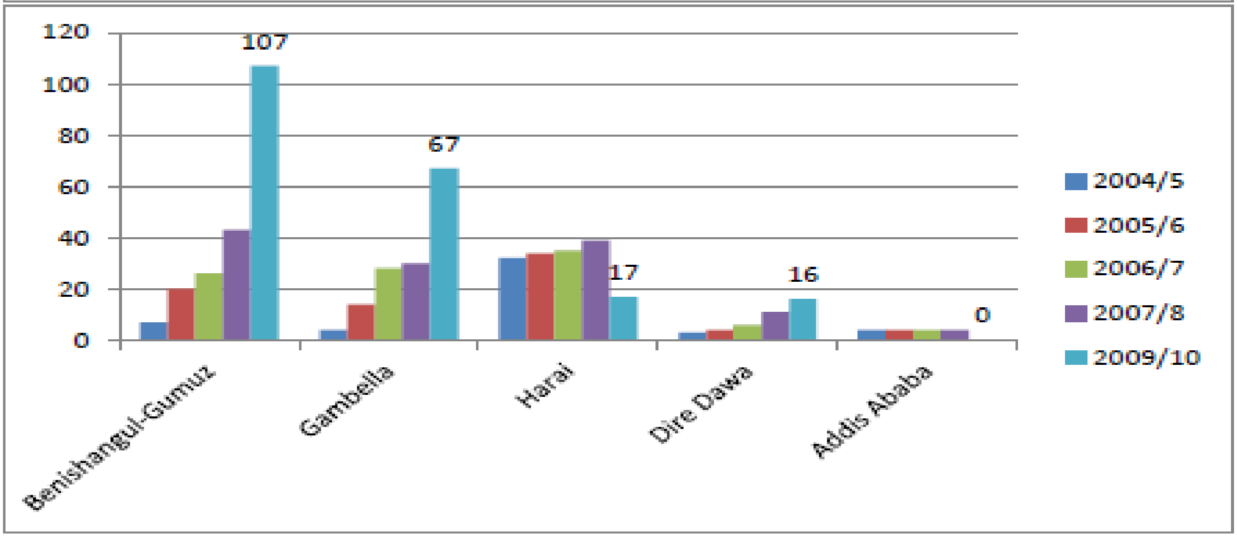
Source: Ministry of Water and Energy of Ethiopia (SREP), 2012, p. 5

Type	Existing		2015		2030	
	MW	%	MW	%	MW	%
Thermal	79.2	6.9	79.2	1.4	79.2	0.57
Non-renewable Total	79.2	6.9	79.2	1.4	79.2	0.57
Hydro	1,850.6	92.5	10,641.6	90.8	22,000	87.26
Wind	-	0	772.8	4.8	2,000	4.05
Geothermal	7.3	0.6	77.3	1.4	1,000	7.49
Bagasse	-	0	103.5	1.6	103.5	0.63
Renewable Total	1,857.9	93.1	11,595.2	98.6	25,103.5	99.43
Total	1,937.1	100	11,674.4	100	25,182.7	100

APPENDIX E: Number of electrified towns and villages in Ethiopia: 2004/05-2009/10

Source: EEPCo. 2009





APPENDIX F: Tariff structure of Ethiopia from 2006 to present -Ethiopia

Source: EEPCo. Corporate planning department, 2011

Tariff Category	Consumption (kWh/month)	Tariff Rate (Birr/kWh)
Domestic Equivalent Flat Rate		0.3897
First Block	First 50 kWh	0.2730
Second Block	Next 50 kWh	0.2921
Third Block	Next 100 kWh	0.4093
Fourth Block	Next 100 kWh	0.4508
Fifth Block	Next 100 kWh	0.4644
Sixth Block	Next 100 kWh	0.4820
Seventh Block	Above 500 kWh	0.5691
General Equivalent Flat Rate		0.5511
First Block	First 50 kWh	0.4990
Second Block	Above 50 kWh	0.5691
Low Voltage Time-of-Day Industrial Equivalent Flat Rate	-	0.4736
High Voltage Time-of-Day Industrial 15 kv Equivalent Flat Rate	-	0.3349
High Voltage time-of-Day Industrial 132 kv Equivalent Flat Rate	-	0.3119
Street Light Tariff Equivalent Flat Rate	-	0.3970

Note: Exchange rate of the Birr against the dollar is 18.1597Birr per US$ as of December, 2012 (data from National Bank of Ethiopia, http://www.nbe.gov.et/market/banksexchange.html).