KTH Industrial Engineering and Management

Modeling and Analysis of Long-Term Shifts in Bioenergy Use-With Special Reference to Ethiopia: Improving Sustainable Development

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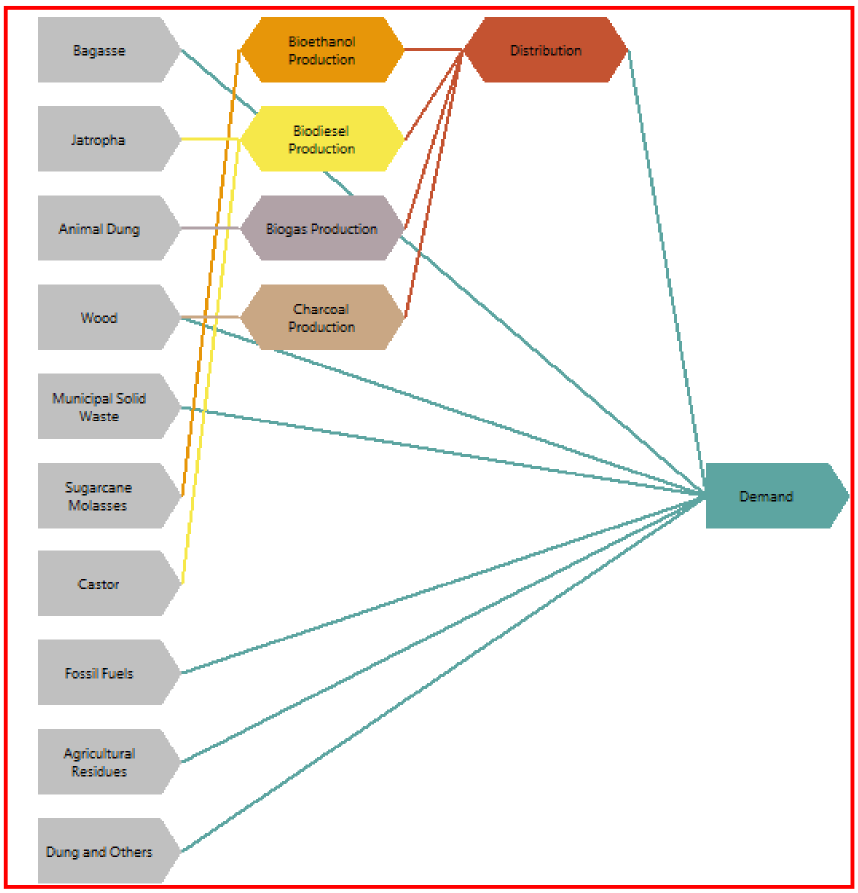

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Modeling and Analysis of Long-Term Shifts in Bioenergy Use

(With Special Reference to Ethiopia)

Azemeraw Tadesse Mengistu

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Abstract

Ethiopia is one of the sub-Saharan Africa countries whose energy depends on traditional use of biomass such as wood, charcoal, agricultural residues and animal dung. The traditional use of biomass mainly wood and charcoal leads the country to massive deforestation and forest degradation. Negative environmental impacts from poorly managed municipal solid waste are also serious problems in the country. Moreover, there is a wide range of fossil fuels demand in the country fully covered by importing which results to a significant expenditure from the country's budget. This study investigates the long-term shifts in bioenergy use of the country and evaluates the expected social, environmental and economical implications. For this purpose, three scenarios are formulated within a timeframe that goes from 2013 to 2030. The baseline scenario assumes the existing energy practices of the country would undergo no significant change in the future while the moderate shift and high shift scenarios consider the long-term shifts in bioenergy use with and without considering constraints respectively. In this context, long-term shifts means: transition from traditional use of biomass to efficient and modern in the household sector, biofuels deployment in the transport sector, introduction of agricultural residues as a fuel for cement production, and electricity generation from bagasse and municipal solid waste. To model and analyze the scenarios, the long-range energy alternatives planning system (LEAP) software tool is used. Taking the results of high shift scenario by 2030, the use of improved wood stoves and fuel switch stoves could save 65 million tons of wood. The foreign currency saving from using biofuels and agricultural residues as fossil fuels substitute would reach to 674 million USD. The greenhouse gas emissions reduction is equivalent to 46 million tons of CO_2e which is about 18.4% of the CO_2e abatement target of the country for 2030. The corresponding revenue from carbon trading schemes would reach to 231 million USD. Electricity generation from bagasse and municipal solid waste would be 3,672 GWh that is around 3.7% of the total electricity generation target for 2030.

Keywords: *Bioenergy, Traditional Use of Biomass, Efficient and Modern Use of Biomass, Fossil Fuels, Deforestation and Forest Degradation, Greenhouse Gas Emissions, Foreign Currency, Carbon Trading Schemes, Scenario, Modeling and Analysis, and Long-Term Shifts*

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List of Acronyms

AfDB	African Development Bank
BADEA	Arab Bank for Economic Development in Africa
CSA	Central Statistics Agency
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EEA	Ethiopian Electricity Agency
EEPCo	Ethiopian Electric Power Corporation
EIA	Energy Information Administration
EPA	Environment Protection Agency
EPSE	Ethiopian Petroleum Suppliers Enterprise
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ESCo	Ethiopian Sugar Corporation
ETB	Ethiopian Birr
EU	European Union
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GTP	Growth and Transformation Plan
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
HoAREC	Horn of Africa Regional Environment Center
MDGs	Millennium Development Goals
LPG	Liquidified Petroleum Gas
LHV	Lower Heating Value (i.e. Net Calorific Value)
MoA	Ministry of Agriculture
MoI	Ministry of Industry
MoME	Ministry of Mines and Energy
MoWE	Ministry of Water and Energy

NBPCO	National Biogas Program Coordination Office
NGOs	Nongovernmental Organizations
ORDA	Organization for Rehabilitation and Development in Amhara
SEI	Stockholm Environment Institute
SNNP	Southern Nations, Nationalities and Peoples
SNV	Stichting Nederlandse Vrijwilligers
SSA	sub-Saharan Africa
toe	ton of oil equivalent
UEMOA	West African Economic and Monetary Union
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
USA	United States of America
USD	United States Dollar
WB	World Bank
WHO	World Health Organization

List of Conversion Factors

1 Megajoule (MJ)	=	10^6 Joules
1 Gigajoule (GJ)	=	10^9 Joules
1 Terajoule (TJ)	**=**	10^{12} Joules
1 Petajoule (PJ)	**=**	10^{15} Joules
1 Exajoule (EJ)	**=**	10^{18} Joules
1 toe	=	$41.868 * 10^9$ Joules
1 ton	=	1,000 Kilogram
1 Cubic Meter	=	1,000 Liters
1 Gallon	=	3.785 Liters

1 Chapter One: Introduction

1.1 Background Information

In recent years, due to growing concerns of environment protection, energy security and price of fossil fuels, there is strong interest in renewable energy development such as hydro, wind, solar, geothermal and bioenergy **[7]**. Bioenergy accounts for about 10% of the global primary energy supply **[54]**. Generally, *bioenergy can be defined as energy derived from the conversion of biomass where biomass may be used directly as fuel for generation of heat and electricity, or processed into biofuels which includes liquid and gaseous fuels. Biomass is any decomposing organic matter derived from plants or animals available on a renewable basis* [**77**]. Biomass includes wood, charcoal, forest residues, agricultural residues, energy crops, animal dung as well as municipal organic wastes **[58]**; and it is the oldest fuel used by mankind and has been its main source of energy for cooking **[55]**. Traditional use of biomass accounts for the largest share of bioenergy **[19]**; and it includes the use of wood, charcoal, agricultural residues and animal dung for cooking, heating and lighting especially in developing countries **[55]**. Such biomass resources are often used unsustainably, inefficiently and under poorly ventilated space causing indoor air pollution **[58]**. However, there has been a rapid increase in modern use of biomass resources in response to policies and strategies aimed at improving energy security and mitigating climate change. In many countries, the promotion of modern use of biomass is also considered as a possible driver of rural development with the potential to improve energy access, increase employment, and stimulate positive development in agriculture and forestry. Modern use of biomass primarily includes production of biofuels, heat and power using advanced conversion technologies. According to IEA world energy outlook (2012), the primary bioenergy demand in 2010 was 1,277 Mtoe of which, the share of traditional use of biomass was 58%; and the share primary bioenergy used for power generation was 9%. The share of transport and industrial sectors was 15% and 5% respectively **[54]**.

The traditional use of biomass could continue as an important source of energy in many parts of the world, and represents the largest contribution to the energy supply of many rural communities across the developing world **[58]**. In sub-Saharan Africa (SSA), the largest portion of their primary energy supply is from biomass; and wood is the dominant source of energy for households. About 81% of households relied on wood to fulfill their energy demand **[32]**. The unsustainable and inefficient use of wood for cooking using traditional cooking stoves leads the SSA to massive deforestation and forest degradation. In addition, indoor air pollution from incomplete combustion has potential health problem to women and children.

Ethiopia is the third large and second most populous country in the SSA **[7]**. It is landlocked and has an area of 1.1 million square kilometers of which, agricultural area, arable land and forest area accounted for 32%, 13% and 11% respectively in 2011 **[73]**. Its population growing rapidly with average annual growth rate of 2.4%; and it was 84.7 million in 2011. The economy the country is growing fast for the last decade with average annual growth rate of 8.4%; and its GDP (current USD) was 30.25 billion in 2011 **[92]**.

Figure 1.1: Location of Ethiopia

The country has large potential of hydro, geothermal, wind solar and bioenergy. However, its energy is highly dominated by traditional use of biomass such as wood, charcoal, agricultural residues and animal dung. According to IEA country's statistics database (2009), biomass accounted for around 92% of the total energy consumption of the country in 2009 **[76]**. Most of the biomass has been consumed by households for cooking using traditional cooking stoves. The average share of biomass consumption for the last ten years (i.e. from 1999/00 to 2009/10) was 86.42% by rural households, 8.18% by urban households, 0.46% by commercial and public institutions, and 4.93% by others **[7]**. Wood is the most common cooking fuel by both rural and urban households. From CSA welfare survey (2011), around 63% of the urban households used wood for cooking in 2011; and about 91% of the rural households used wood as cooking fuel (see annex) **[41]**.

Electricity accounted for 1% of the energy consumption of the country in 2009. Hydro is the main source of electricity generation, about 87% of the country's electricity has been generated from hydro **[76]**. The country has one of the lowest electricity access rates in the world. According to IEA world energy outlook (2012) preview on measuring progress towards energy for all report, 65 million people (i.e. 78% of the total population) were without access to electricity in 2010; and at the same time, the number of people without electricity in SSA was 589 million (i.e. 68% of the total population in SSA) **[56]**. Currently, the country is establishing several electricity generation and transmission expansion projects to increase the access.

The country spend huge amount of foreign currency to import petroleum products and other fossil fuels. It spent about 1.8 billion USD (i.e. about 6% of the GDP) to import 145,276 tons of gasoline and 1,069,350 tons of diesel respectively in 2011 alone. To facilitate production of biofuels from indigenous resources and substitute imported petroleum, biofuels development and utilization strategy has been formulated by the Ministry of Mines and Energy in 2007 **[17]**. Following this strategy, E5 (i.e. 5%

bioethanol blend with gasoline) was introduced since 2008 and increased to E10 since 2011. The current production capacity of bioethanol is 20.5 million liters from Fincha and Methara Sugar Factories; and the plan is to increase the capacity to 182 million liters by 2015 **[69]**. The country is also doing several activities like land allocation to the investors for biodiesel feedstock plantation. The suitable land for biodiesel feedstock cultivation estimated at 23.3 million hectares suitable **[45]**.

The country has implemented ambitious growth and transformation plan (GTP) since 2011 to reach the target of middle status economy by 2025 while developing green economy. And, to shift from the current conventional economy development to green economy, the climate resilient and green economy strategy has been implemented as a part of its GTP. One of the main issues of this strategy is to improve energy efficiency and security in the household, transport and industry sectors **[44]**. Moreover, the country has energy policy to enhance energy development, energy convservation and efficiency, and energy institutilization **[53]**; and environmental policy to promote sustainable social, economic and environment development to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. Generally, the availability of policies, strategies, plans, governmental organizations and developmental partners are some of the factors to support sustainable development in the country.

1.2 Statement of the Problem

The heavy dependence on traditional use of biomass especially wood causes high depletion of forest resources in Ethiopia **[2]**. Accelerated soil erosion and land degradation are severe problems in the country **[1]**. Deforestation for fuel wood is one of the main causes of soil erosion and land degradation. Moreover, it is one of the main sources of GHG emissions. For instance, from 150 million tons of CO_2e emission of the country in 2010, about 17% of the total emission was due to deforestation for fuel wood **[44]**. Due to very low energy efficiency, only a very small portion of biomass (i.e. less than 10%) converted into useful energy. In other words, the energy from traditional use of biomass is 'less useful more waste energy (LUMWE)'. The use of traditional cooking technology is the main cause for the inefficient and unsustainable utilization of biomass that leads to massive deforestation. Incomplete combustion under poorly ventilated space causes indoor air pollution that has a potential health problem especially to women and children **[2]**. According to WHO statistics (2009), indoor smoke from solid fuels is responsible for 2.7% of the total burden of disease **[60]**. Moreover, women and children travel a long distance frequently to collect the fuel wood and carry it on their back which leads to the loss of natural posture of their back and serious pain in the long-term. In addition, women are sexually abused in the forest while collecting fuel wood; and children spend more time for collecting wood than going to school and learn. On the other hand, negative environmental impacts from poorly managed municipal solid waste such as GHG emissions, creating bad odor, blocking sewerage system and decreasing the beauty of the city are also serious problems in the country.

In addition to the above problems which are related to traditional use of biomass, there is a wide range of fossil fuels demand in the country for different sectors such as transport, industry, household and others which is fully covered by importing. This leads to a significant expenditure from the country's budget. Solving all the problems needs a shift from existing energy practices of the country to efficient and modern; and it is one of the main tasks of the government and developmental partners.

1.3 Objective of the Study

The main objective of the study is to investigate the long-term shifts in bioenergy use of Ethiopia from demand to supply by formulating alternative scenarios, and to evaluate expected economical, social and environmental implications of the shifts. To achieve the main objectives, the specific objectives are:

- To study the shifts in household energy from traditional use of biomass to efficient and modern by improving energy efficiency and evaluate the resulting outcomes
- To evaluate the transport sector energy shifts by deploying biofuels and assess the corresponding implications
- To analyze the shifts in cement industries energy by introducing agricultural residues as a fuel for cement production and evaluate the associated results
- To assess the potential of bagasse and municipal solid waste by handling them for electricity generation in the long-term

Note that, the above specific objectives are chosen because they represent the main types of shifts to modern use of bioenergy resources that are achievable in the near to medium-term. On the other hand, they are the potential intervention areas for the shifts in bioenergy use of the country.

1.4 Significance of the Study

The output of the study can be used by researchers and students as input for further research, by experts and officials to formulate energy policies and strategies. On the other hand, since it provides important information about future trend of bioenergy demand, it can also be used by investors and small scale enterprises who are interested in bioenergy market.

1.5 Scope of the Study

This study is the part of the project being conducted by Stockholm Environment Institute on future transitions in bioenergy use and expected changes in terms of energy access and socio-economic and environmental impacts in selected regions of SSA. It models and analyzes the long-term shifts in bioenergy use of Ethiopia by formulating alternative scenarios in the LEAP. It covers demand to transformation to primary resources requirement analysis and its implication in term GHG emission saving, cooking fuel saving, foreign currency saving and land use. For this purpose, household, transport, industry and electricity generation are identified in the modeling of the demand. The bioenergy demand of agriculture and service sectors is insignificant and do not represent major opportunities for shifting to modern use of bioenergy, and thus is not considered in the demand analysis. In the household sector, the largest amount of bioenergy resources is consumed by cooking; and its use for heating and lighting is insignificant and neglected from the analysis. The blending of bioethanol with gasoline and biodiesel with diesel has been modeled and analyzed. The cement industries have been chosen for the analysis since they are most energy intensive in the country. Electricity generation from cogeneration of bagasse and incineration of municipal solid waste is among those considered in the demand analysis. In the transformation analysis, production of bioethanol, biodiesel, biogas and charcoal has been modeled and analyzed by selecting the conversion technologies and the feedstock used to produce them. However, marketing, investment cost, and operation and maintenance costs associated to production of the above fuels are not analyzed because of unavailable data. The scope of the LEAP model and analysis of the study is presented below (see figure 1.2).

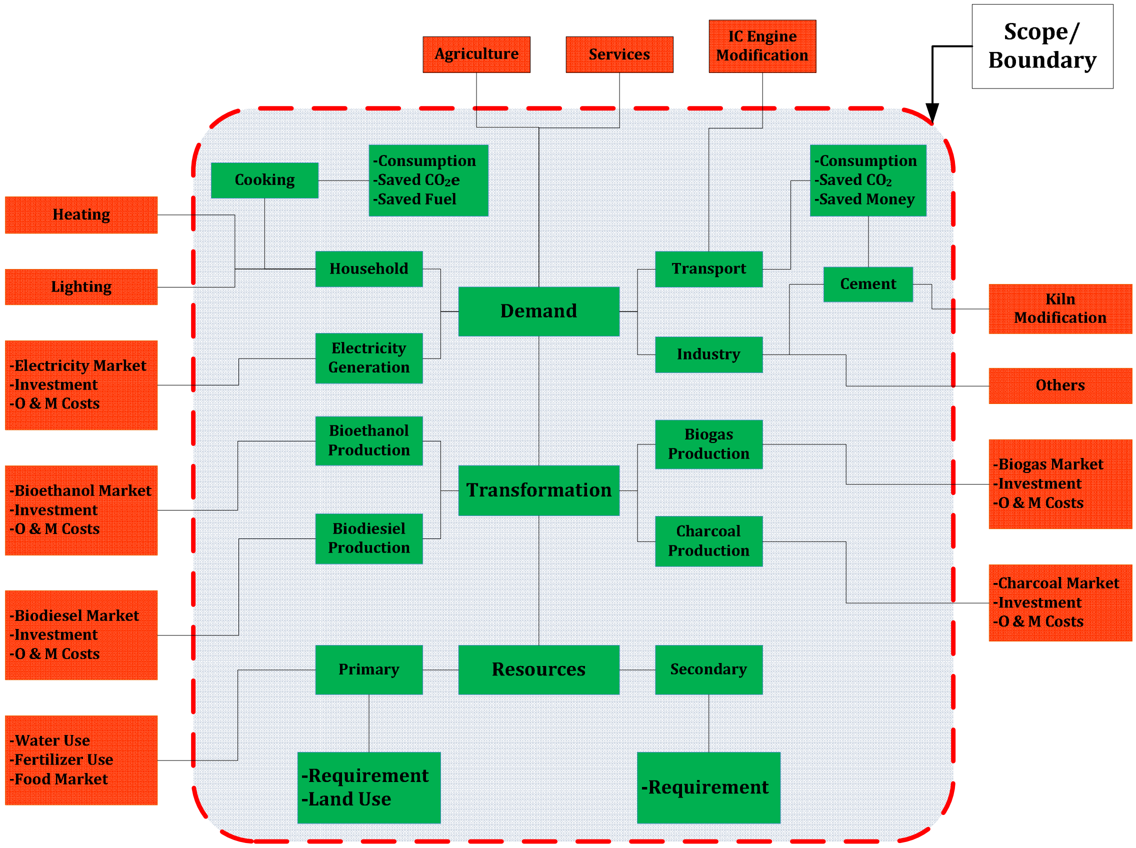


Figure 1.2: Scope/boundary of the study

1.6 Research Methodology

Modeling and analysis of future energy system of any country requires significant amount of data. Hence, efforts have been garnered to gather as much data as possible so that the conclusions finally drawn from the study have practical significance. In this endeavor, the data have been collected from both primary and secondary sources. The primary data have been collected by dispatching questionnaires, and interviewing officials and experts during the fieldwork which was conducted from April 23 to May 24, 2013. During the fieldwork, various stakeholders such as MoWE, EEPCo, EPSE, EPA, ESCo, MoA, MoI, CSA and GIZ have been surveyed. In addition, the fieldwork has included a visit to small scale enterprises that manufacture cooking stoves and participation in an international conference in 'Science and Technology towards the Development of East Africa' organized by Institute of Technology, Bahir Dar University in 17 and 18 May, 2013. In general, the fieldwork was important to get the required data for the analysis and to support scenarios formulation. On the other hand, the secondary data have been collected from related publications, various documents of the stakeholders, and various related websites.

Three scenarios namely, 'baseline', 'moderate shift' and 'high shift' scenarios are formulated. The baseline scenario assumes the existing energy practices of Ethiopia would undergo no significant change in the future. Whereas, the two alternative scenarios consider future shifts in the bioenergy use of the country that include energy efficiency improvement in the household sector, biofuels deployment in the transport sector, the introduction of agricultural residues as a fuel for cement production as well as bagasse and municipal solid waste for electricity generation. The moderate shift scenario is formulated based on the most likely achievable parameters taking into consideration the possible constraints such as financial, technical, technological and management inefficiency that hinder implementation process of the shifts. On the other hand, the high shift scenario is formulated based on optimistic parameters considering if there would no significant constraints that could affect the implementation process.

Mean a while, the following bioenergy resources utilization strategy has been formulated to model and analyze the scenarios using LEAP (see table 1.1).

Table 1.1: Bioenergy resources utilization strategy

Bioenergy Resource	Technology/Fuel	Substituted Technology/Fuel	Status
Wood	Improved Wood Stove	Traditional Wood Stove	Started but insignificant
Charcoal	Improved Charcoal Stove	Traditional Charcoal Stove	Started but insignificant
Agricultural Residues	Agricultural Residues	Fossil Fuels Consumption in Cement Industries	Not yet started however, it is promoted in the green economy strategy of the country.
Bioethanol	Bioethanol	Gasoline	Started with E5 in 2008 and E10 since 2011
	Bioethanol Stoves	Traditional Wood and Charcoal Stoves, and Kerosene Stoves	Started but insignificant
Biodiesel	Biodiesel	Diesel	Not yet started
Biogas	Biogas Stoves	Traditional Wood and Charcoal Stoves, and LPG Stoves	Started but insignificant
Bagasse	Cogeneration	No substitution but to generate excess electricity to the national grid	So far, sugar industries produce both heat and power from cogeneration of bagasse for self-consumption.
Municipal Solid Waste	Incineration	No substitution but to generate electricity	Not started however, there is a project in memorandum phase to build waste to energy plant at 'Rappi', Addis Ababa; and expansion of waste to energy plants will continue to other major cities of the country.

Based on the above bioenergy resources utilization strategy, the demand-resource tree is formulated to build the modeling and analysis framework in the LEAP (see figure 1.3).

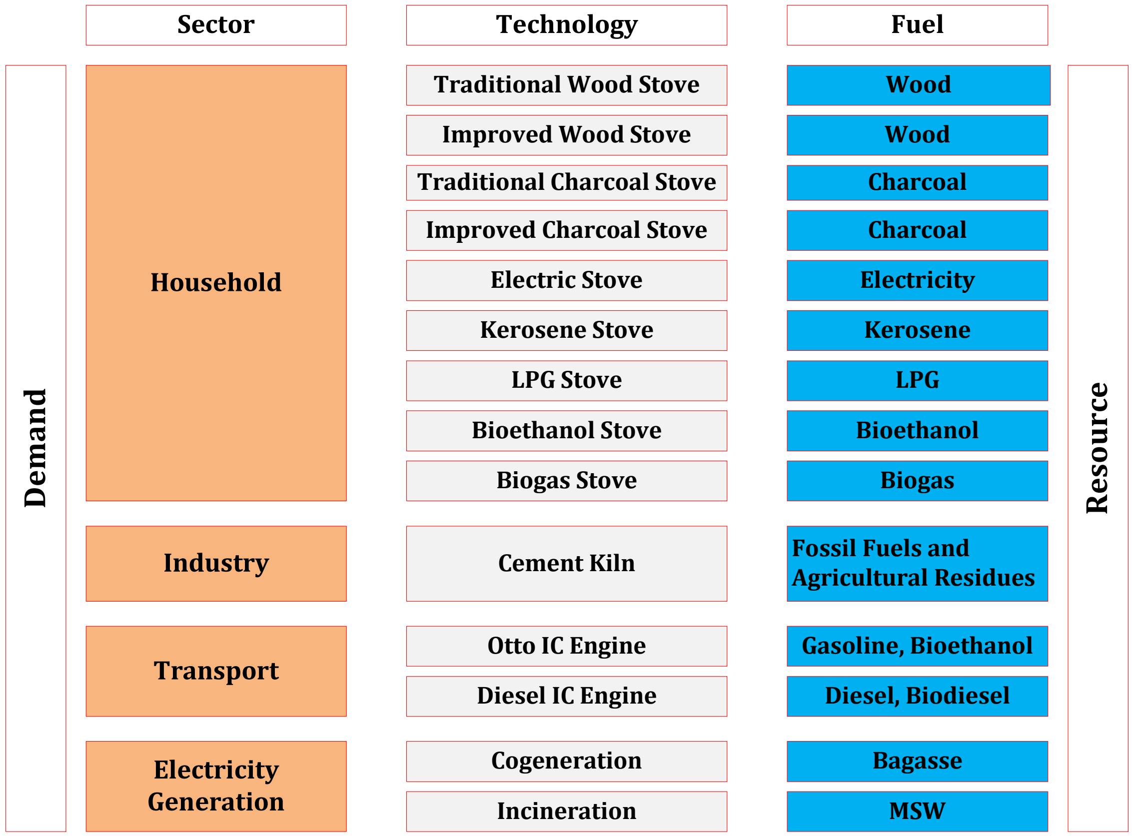


Figure 1.3: Demand-resource tree

Finally, based on the results and discussion of the analysis, this study is finalized with concluding remarks and recommendations on the future energy direction of the country.

1.7 Organization of the Study

The thesis is organized by nine chapters. The first chapter introduces the background, statement of the problem, objective, scope and methodology of the study. The second chapter states an overview of global bioenergy. The Ethiopian energy outlook is briefly described in chapter three. Chapter four discusses in detail the bioenergy resources of Ethiopia. The policy background, green economy strategy and stakeholders of Ethiopian energy system are discussed in chapter five. Chapter six explains the process of the LEAP modeling and analysis of the long-term shifts by justifying the different data inputs and parameters/targets established for the scenarios. The results of the analysis are expressed in chapter seven. Chapter eight presents the discussion on the results and concluding remarks. The final chapter illustrates the recommendation and future work of the study (see figure 1.4).

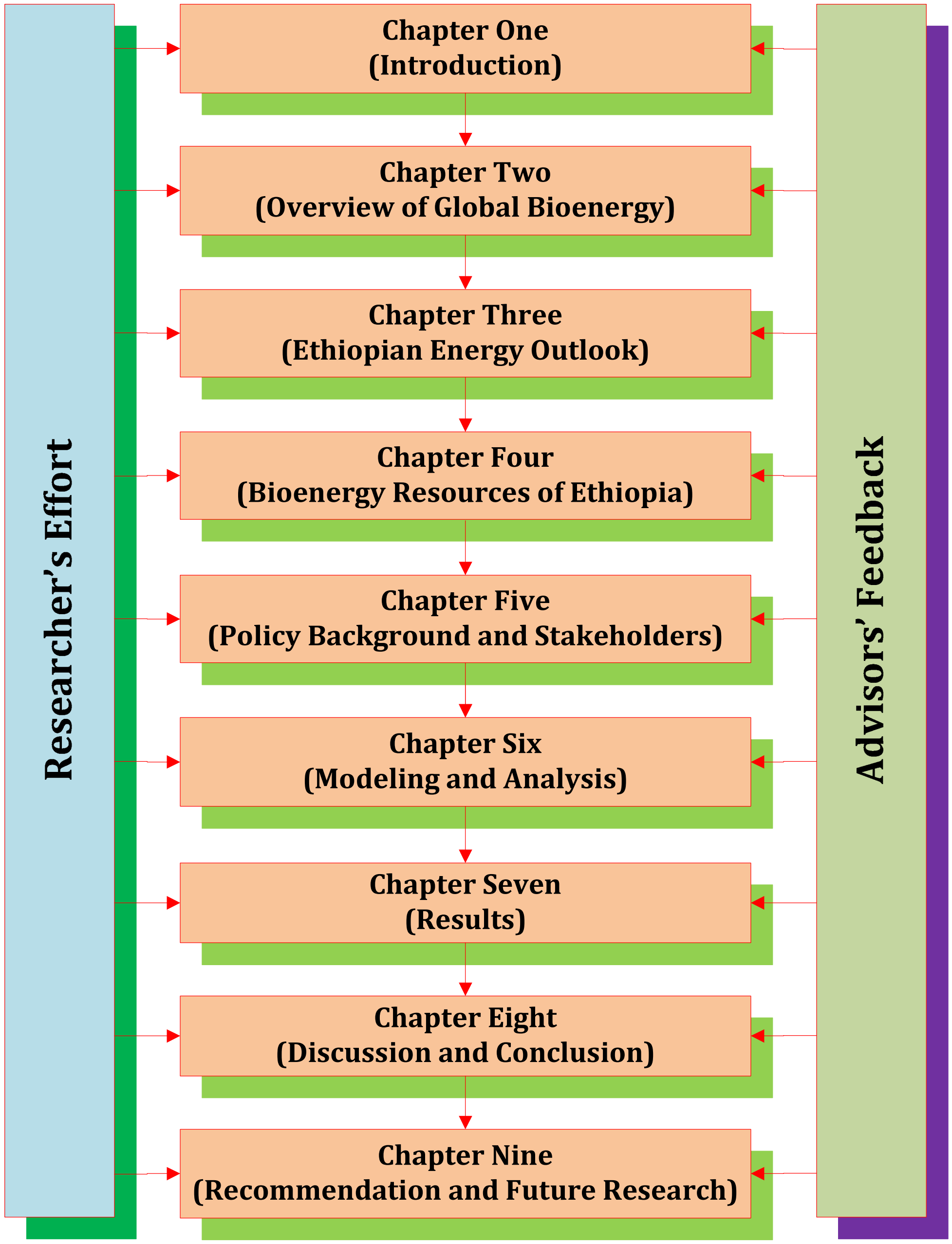


Figure 1.4: Schematic diagram for organization of the study

2 Chapter Two: Overview of Global Bioenergy

In order to establish a conceptual framework of the study, it is important to review related issues. The next four chapters (i.e. from chapter two to five) emphasize topics which are related to the study.

2.1 Global Energy Balance

Global energy balance is dominated by fossil fuels such as oil, natural gas and coals; and fossil fuels will remain the principal sources of global energy demand, though renewable sources grow rapidly. The share of fossil fuels in the global primary energy demand mix is expected to fall from 81% in 2010 to 75% by 2035 under new policies scenario of IEA world energy outlook (2012). The global primary energy demand was increased from 10,102 Mtoe in 2000 to 12,730 Mtoe from which, fossil fuels accounted for 80% and 81% in 2010 and 2010 respectively. Bioenergy accounted for 10.17% and 10.03% in 2000 and 2010 respectively (see table 2.1 and figure 2.1). The primary energy demand of Africa was also increased from 395 Mtoe to 624 Mtoe. The different scenarios analysis of IEA world energy outlook (2012) indicates that primary energy demand will increase in the future **[54]**.

*Table 2.1: Global primary energy demand in 2000 and 2010 (Source: **[54]**)*

Global Primary Energy Demand (Mtoe)				
Resource	**2000**	**2000**	**2010**	**2010**
Coal	2,378	23.5%	3,474	27.3%
Oil	3,659	36.2%	4,,113	32.3%
Natural Gas	2,073	20.5%	2,740	21.5%
Nuclear	679	6.7%	719	5.6%
Hydro	226	2.2%	295	2.3%
Bioenergy	1,027	10.2%	1,277	10.0%
Other Renewables	60	0.6%	112	0.9%
Total	**10,102**	**100%**	**12,730**	**100%**

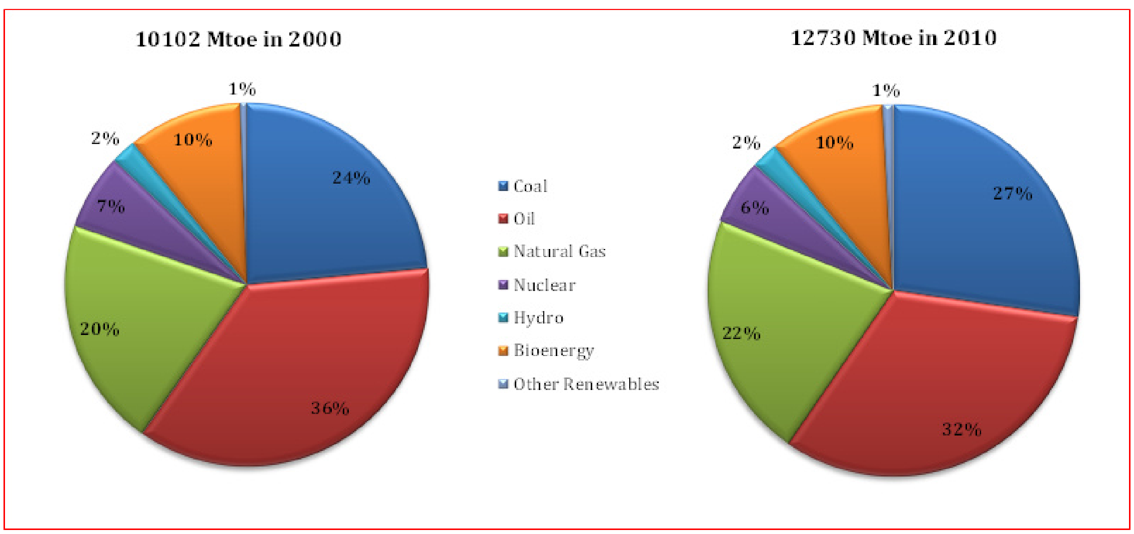


*Figure 2.1: Share of global primary energy supply mix in 2000 and 2010 (Source: **[54]**)*

The global primary bioenergy demand will also increase from 1,277 Mtoe in 2010 to 1,881 Mtoe in 2035 under new policies scenario of IEA world energy outlook (2012). The industrial sector was the largest consumer of bioenergy in 2010 about 192 Mtoe and will increase to over 300 Mtoe by 2035. However, the power sector is expected to have a larger share of bioenergy demand by 2035 which is about 414 Mtoe. Bioenergy consumption in the transport sector will increase by about 225% from 2010 to 2035, reaching around 207 Mtoe by 2035 from 64 in 2010. The traditional use of biomass declines over time as access to modern fuels increase and it will decline from 753 in 2010 to 696 Mtoe by 2035 (see figure 2.2) **[54]**.

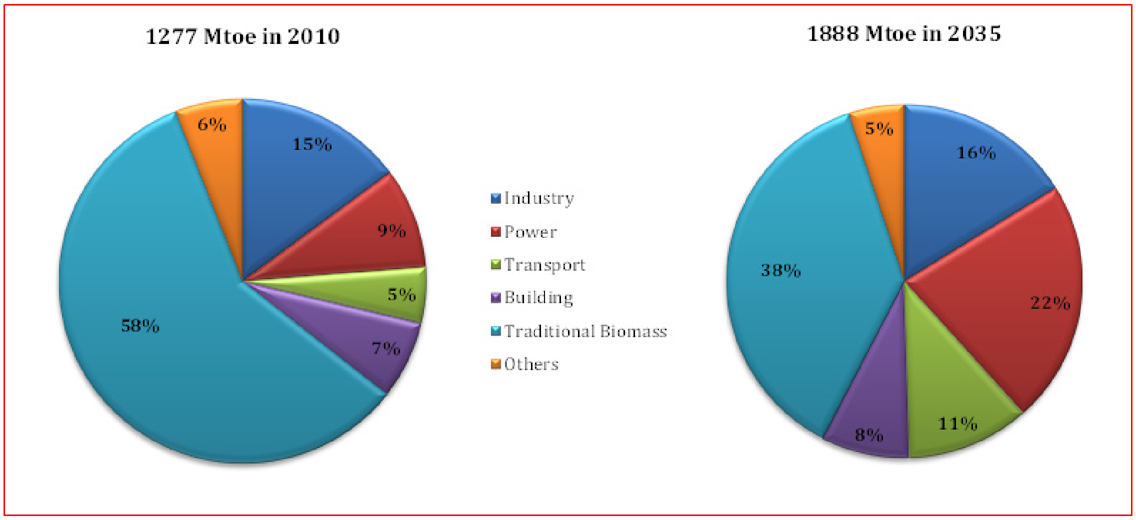


Figure 2.2: Share of global primary bioenergy supply mix in 2010 and by 2035 (Source: [54])

2.2 Biomass Conversion Processes

The use of modern biomass primarily involves heat and power production from wood, agricultural residues, municipal organic waste and the like; anaerobic digestion of organic wastes to produce biogas; and production of bioethanol and biodiesel from potential biofuels feedstocks. There are different technologies which are used to convert biomass into electricity, heat, biofuels and other products; and these technologies have been continuously developed into increasingly sophisticated processes. The biomass conversion processes are generally categorized into thermochemical, biochemical and physiochemical conversion processes (see figure 2.3) **[28]**.

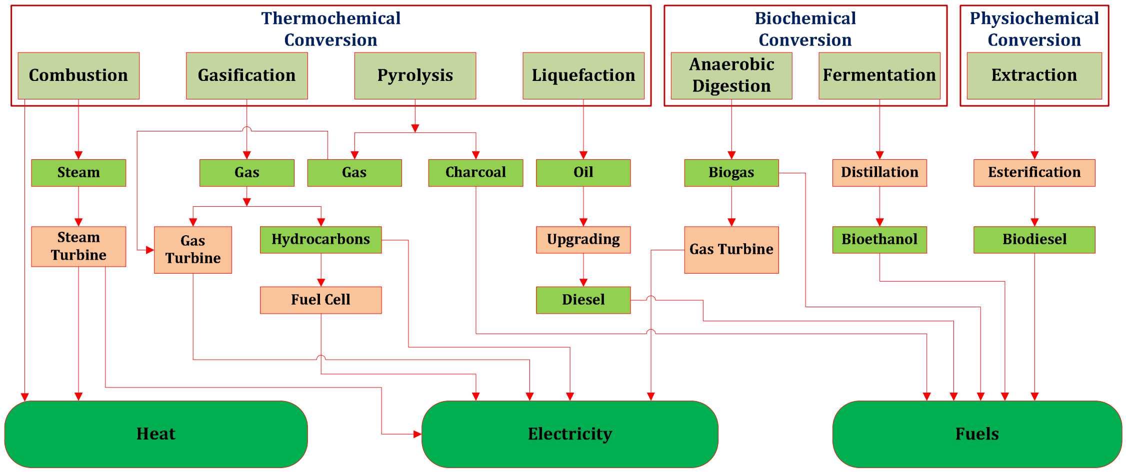


*Figure 2.3: Biomass conversion processes and technologies (Source: **[28]**)*

2.3 Bioethanol Production

Bioethanol is seen as a good alternative fuel because the feedstock can be grown renewably and in most climates around the world. Bioethanol is produced from first generation and second generation feedstock. The amount of bioethanol production from first generation feedstock is large than that of second generation feedstock. Some of the first generation feedstock are wheat, corn, barley, rye, sugarcane and sugar beet and sweet sorghum. Whereas, eucalyptus tree, miscanthus, hemp and giant reed are some of second generation feedstock used for bioethanol production (see figure 2.4) **[51]**. Sugarcane is mainly used for bioethanol production in Brazil, India and Africa whereas corn and wheat are mostly used in USA and Europe respectively.

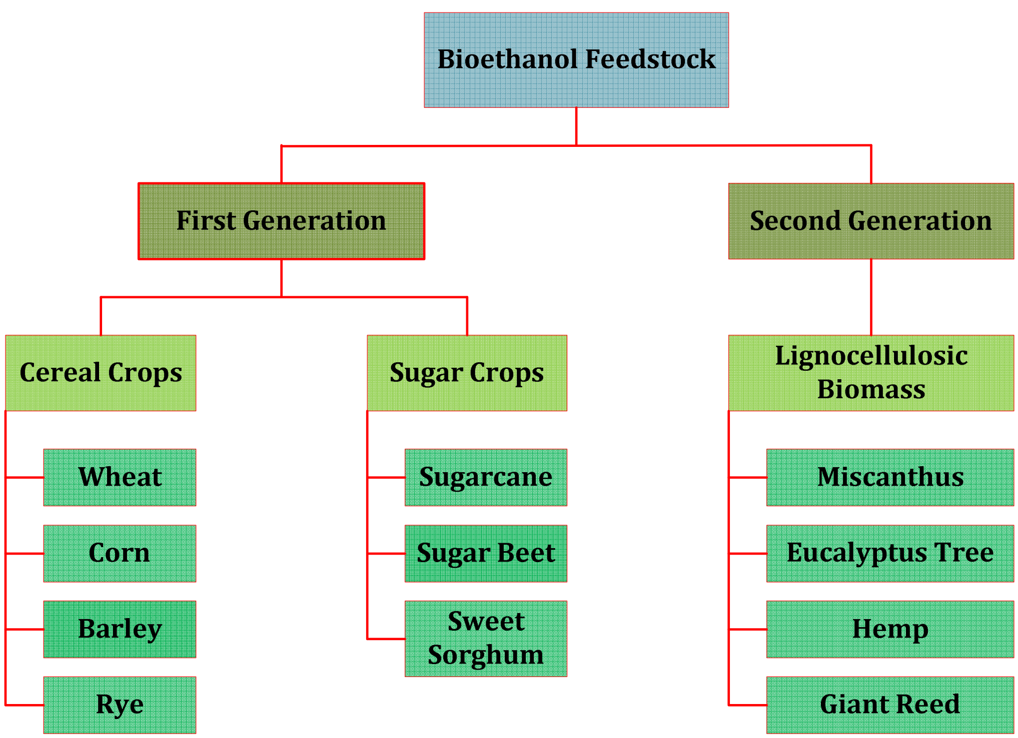


*Figure 2.4: Feedstock used to produce bioethanol (Source: **[51]**)*

The global bioethanol production was about 86,691.7 million liters in 2010 out of which, North and Central America accounted for the highest share about 60% followed by South America. The share of bioethanol production of Africa was the least from the world, less than 1% (see table 2.2) **[81]**. Fragmented infrastructure development, financial and technical constraints are causing slow growth in biofuel development of Africa. However, the long-term biofuel development potential could be strong if the right economic environment is created.

*Table 2.2: Global bioethanol production in 2010 (Source: **[81]**)*

Global Bioethanol Production in 2010		
Region	**Production (million liter)**	**Share (%)**
North and Central America	51,934	59.9%
Europe	4576.1	5.3%
South America	26,956.8	31.1%
Asia	2975	3.4%
Oceania	249.8	0.3%
Africa	166.5	0.2%
Total	**86,691.7**	**100%**

United States was the top bioethanol producer in 2010 accounting for about 58% of the global bioethanol production. Brazil and Europe were the second and third bioethanol producing countries/regions accounting for about 29% and 5% of the global bioethanol production respectively **[81]**.

The typical first generation bioethanol production process flow diagram from sugarcane is shown below (see figure 2.5)[21].

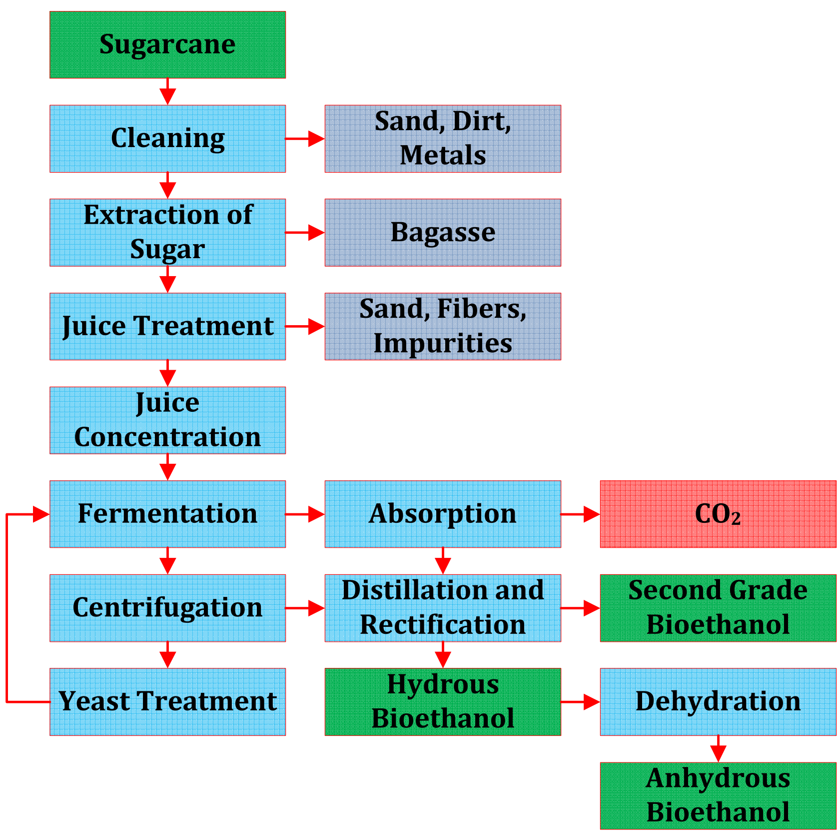


*Figure 2.5: Bioethanol production process flow diagram from sugarcane (Source: **[21]**)*

The typical second generation bioethanol production process flow diagram from cellulosic biomass is presented below (see figure 2.6).

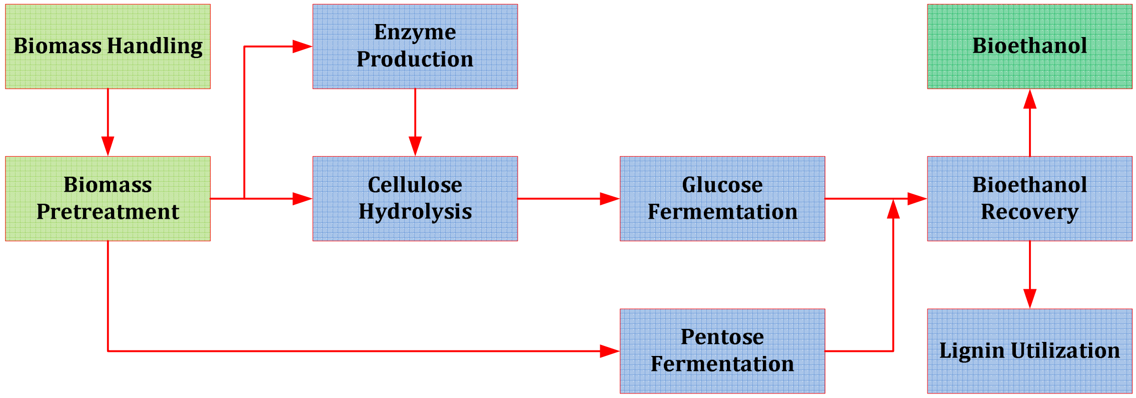


*Figure 2.6: Bioethanol production process flow diagram from cellulosic biomass (Source: **[82]**)*

2.4 Biodiesel Production

Biodiesel is made by a chemical process called transesterification in which the glycerol is separated from the fat or vegetable oil using methanol or ethanol. The products of transesterification process are methyl esters (i.e. the chemical name for biodiesel) and glycerol which is used for making soaps and other products **[88]**. Jatropha, palm, coconut, canola, corn, cottonseed, soybean, flaxseed, peanut, sunflower, rapeseed, castor and algae are some of the feedstock used to produce biodiesel (see figure 2.7) **[59]**.

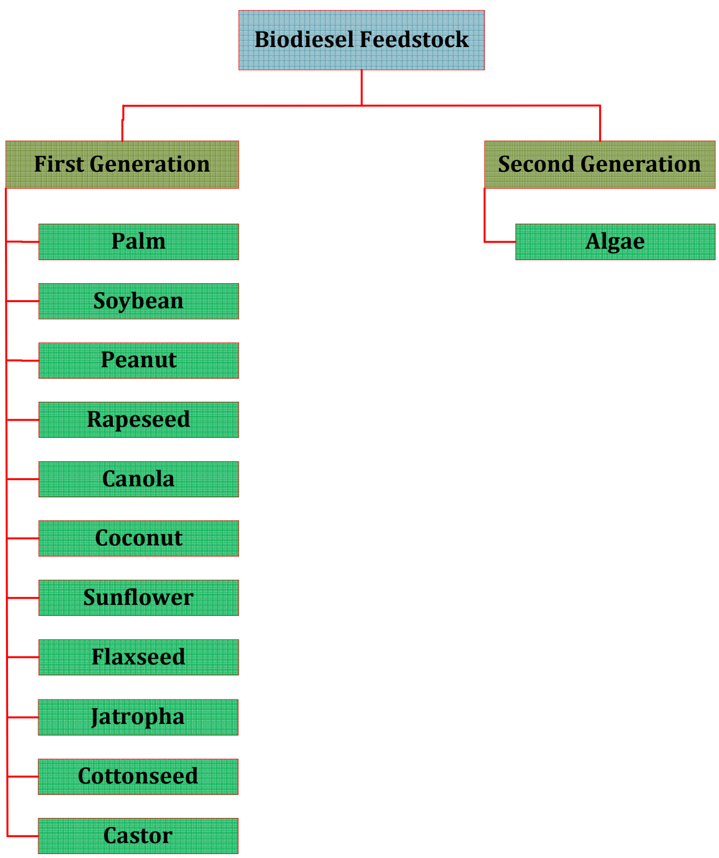


*Figure 2.7: Feedstock used to produce biodiesel (Source: **[59]**)*

The global production of biodiesel was about 21,390.9 million liters from which about 80% was produced by the following top ten world biodiesel producing countries (see table 2.3).

*Table 2.3: Top biodiesel producing countries in 2010 (Source: **[63]**)*

Top Biodiesel Producing Countries in 2011	
Country	**Production (million liter)**
United States	3,183.2
Germany	3,160.5
Argentina	2,759.3
Brazil	2,641.9
France	1,589.7
Indonesia	1,362.6
Spain	711.6
Italy	590.5
Thailand	590.5
Netherlands	442.8

The typical biodiesel production process flow diagram is presented below (see figure 2.8).

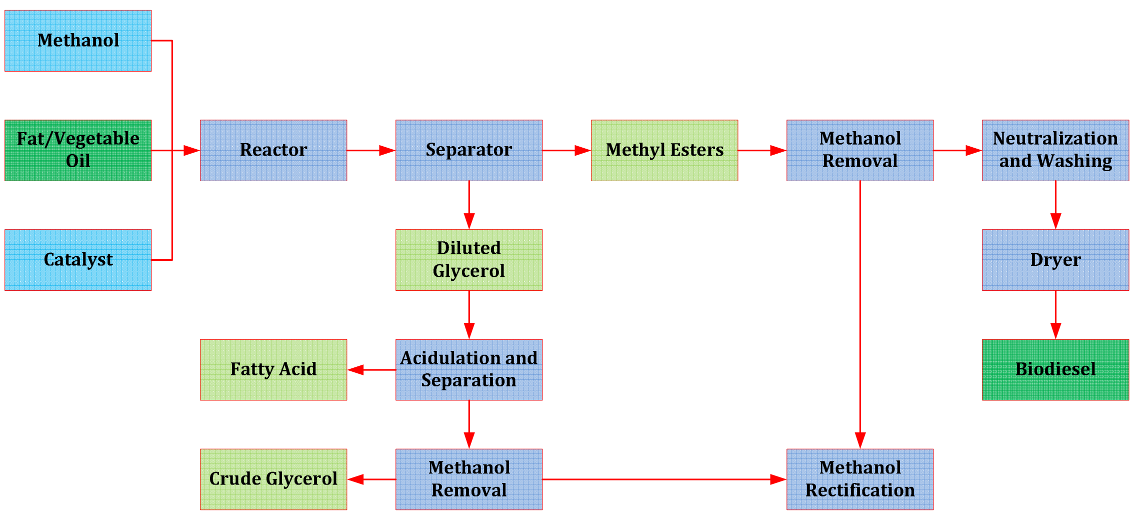


*Figure 2.8: Biodiesel production process flow diagram (Source: **[25]**)*

Both first and second generation biofuels has advantages and disadvantages. The primary advantage of first generation biofuels is the availability of matured technologies for biofuels production and possibility of large scale production. The disadvantages include emissions produced in growing and refining the feedstock, land use concerns, effect on food price and supply, and only limited crops can be used in biofuels production. In case of second generation biofuels, a larger variety of non-food feedstock can be used; the energy input for agriculture and feedstock production could be significantly reduced. However, the conversion technologies are not matured for second generation biofuels production **[29]**.

2.5 Biogas Production

Biogas is produced by anaerobic digestion of animal dung, municipal waste, toilet waste and waste water treatment sludge. Anaerobic digestion is a natural process whereby bacteria existing in oxygen free environments to decompose organic matter using anaerobic digesters which are designed to accomplish the decomposition. Anaerobic digestion of animal dung for production of biogas is a widely used method especially in developing countries. In developing countries there are several digesters used to produce biogas, the most familiar one is the fixed dome digester, in addition the floating dome digester and bag digester are found in many developing countries (see figure 2.9) **[18]**.

A fixed dome digester is a closed dome shaped digester which is originated from China. In this digester, the organic waste is fed to the digester then the methanogenic bacteria digest the organic waste and produce biogas and slurry (digested waste); and the gas is captured in the gasholder and the slurry is displaced in the compensating tank. The more gas is produced, the higher the level of slurry at the outlet will be available which can be treated for further application like fertilizer. Floating dome digester is mainly found in India. In this digester, the produced biogas is collected in a movable steel drum called the gasholder. The steel drum is guided by a guide frame; and when the biogas is consumed the drum sinks. The slurry is pushed out of the digester after the digestion. A bag digester is a plastic or rubber bag combining the gas holder and digester. In this digester, gas is collected in the upper part and organic waste in the lower part; and the inlet and outlet are attached to the skin of the bag. The pressure of the gas is adjustable by laying stones on the bag **[18]**.

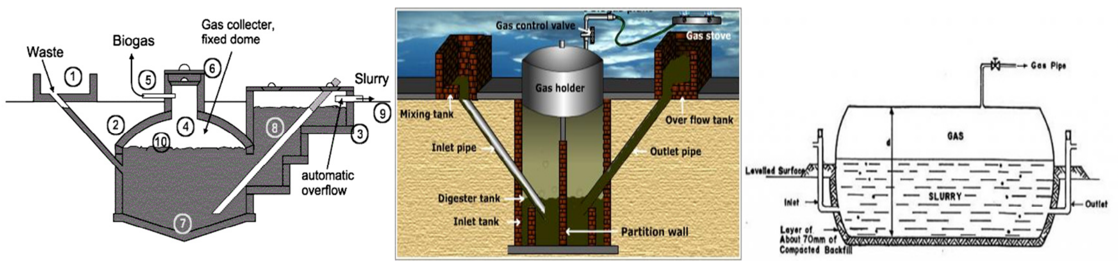


Figure 2.9: Fixed dome, floating dome and bag digesters

The typical biogas production process flow diagram is shown below (see figure 2.10).

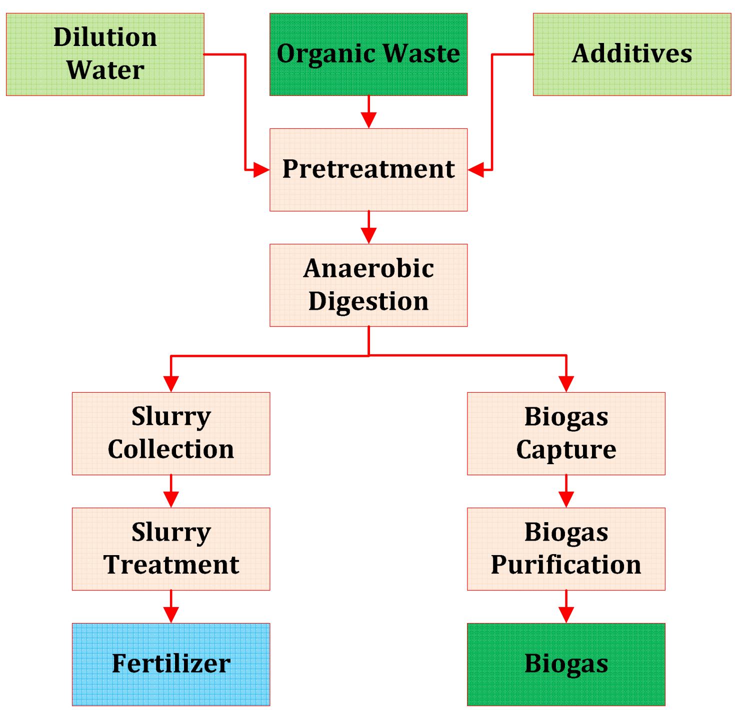


*Figure 2.10: Biogas production process flow diagram (Source: **[36]**)*

2.6 Charcoal Production

Charcoal is the world's most significant fuel which is produced from wood and other bioenergy resources. In addition to its use as a cooking fuel, it is also significantly used in the production of pig iron as case of Brazil **[31]**. The global production of wood charcoal from wood was estimated at 47 million metric tons in 2009 and increased by 9% compared to 2004 (i.e. about 43 million metric tons). The growth of charcoal is being strongly influenced by Africa. Africa is the region with the highest charcoal production, accounted for 63% of global charcoal production in 2009 (see table 2.4). Brazil was the highest charcoal producing country in 2009 out of the top ten charcoal producing countries of the world; and seven of them are found in Africa **[35]**.

*Table 2.4: Global charcoal production in 2009 (Source: **[35]**)*

Global Charcoal Production (million ton)		
Region	**Production**	**Share (%)**
Africa	29.4	62.6%
Asia	7.4	15.7%
Europe	0.5	1.1%
Latin America and Caribbean	8.8	18.7%
Northern America	0.9	1.9%
Oceania	0.0	0.0%
World	**47**	**100%**

Pyrolysis is a thermochemical process used to produce charcoal in kilns or retorts. Traditionally, charcoal is still made in earth mound kilns in developing countries as well as in some emerging economies such as Brazil. Over the past century the kilning technology of producing charcoal has been improved. Some examples of such improved kilning techniques are Missouri kilns, Argentine kilns, and Brazilian Beehive kilns (see figure 2.11). Beehive kilns can be found in large industrial application for example, for making charcoal for the steel industry in Brazil and to manufacture metallurgic charcoal in USA. Charcoal production using kilning method is a strong emitter of GHG due especially to un-burnt methane and other carbon compounds **[22]**.

Figure 2.11: Traditional earth mound kiln and beehive kiln

Most modern industrial charcoal producers use retorts method for charcoal production (see figure 2.12). In this method, the pyrolysis vapors are separated from the biomass feed before being combusted. Only the vapors are used to provide the energy sustaining the process. If the feed material is too wet additional fuels are used for start-up purpose. Direct contact of the biomass feed with oxygen from air is prevented. In this manner, it is ensured that the entire biomass feed available for the conversion is changed to charcoal. Charcoal production yield using this method can be very high if carried out properly **[22]**.

Figure 2.12: Typical retorting kiln

2.7 Electricity Generation

As it was discussed above, the share of primary bioenergy supply used for power generation was 9% in 2010 and will reach to 22% by 2035 according new scenario of IEA world energy outlook (2012). Electricity from bioenergy resources can be produced using steam cycle, gas cycle and combined cycle. Electricity can be produced by direct combustion of wood, bagasse and agricultural residues, and incineration of municipal solid wastes in the steam cycle by producing steam using steam boiler for rotating the steam turbine then mechanical power is converted to electrical power using generator coupled with the steam turbine. The average electrical efficiency of steam cycle is about 33%, and 25% for incineration of municipal solid waste. Electricity can also be generating from syngas produced by gasification of wood, agricultural residues and bagasse in the gas cycle or combined cycle. Biogas or landfill gas can also be used for electricity generation by replacing natural gas. The average electrical efficiency of gas and combined cycles is about 30% and 50% respectively. In most cases, such power plants are used for the production combined heat and power (CHP) at the same time so that the overall efficiency is improved.

3 Chapter Three: Ethiopian Energy Outlook

3.1 Energy Balance of Ethiopia

Ethiopia has large potential of hydro, wind, geothermal, wind, solar and biomass as indigenous energy resource. Moreover, the country imports oil products and other fossil fuels to satisfy its energy demand. In addition to the above renewable energy sources, the country has proved non-renewable resource like coal and natural gas. The energy balance of country is dominated by traditional use of biomass mainly wood, charcoal, animal dung and agricultural residues. Electricity, oil products and biofuels also have small contribution to the energy balance. Electricity production in the country begins during late 1890s when King Menelik II acquired the first generator to light his palace **[9]**. Today electricity is produced from hydro, geothermal, wind and diesel.

By using the IEA (2009) statistics of the country, the energy balance of Ethiopia is briefly described below.

3.1.1 Primary Energy Supply

The primary energy supply of Ethiopia is from oil products, hydro, biomass and geothermal of which, only oil products have been imported. From 32,678 ktoe of primary energy supply in 2009, the share of biomass was 91.96%; and oil products, hydro and geothermal accounted for 7.05%, 0.94% and 0.04% respectively (see figure 3.1).

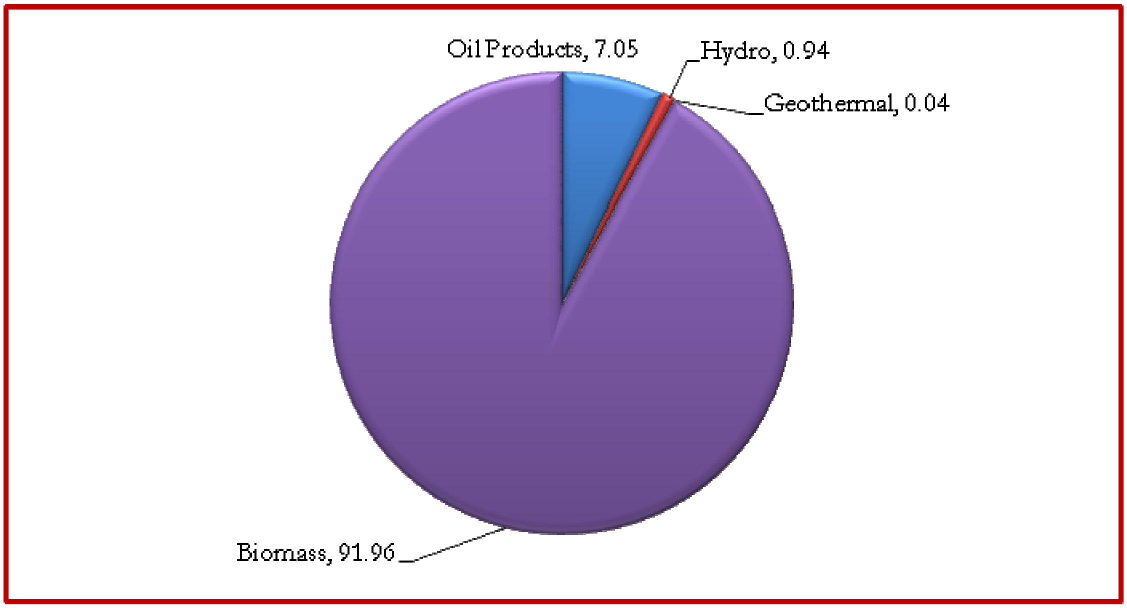


*Figure 3.1: Share of total primary energy supply of Ethiopia in 2009 (Source: **[76]**)*

3.1.2 Electricity Production

As it is mentioned above, electricity is produced from hydro, geothermal, wind and diesel in the country. The annual electricity production of Ethiopia in 2009 was 4,106 GWh of which, 87.26% was produced from hydro; and 12.37% and 0.37% was from oil (i.e. diesel) and geothermal respectively (see figure 3.2).

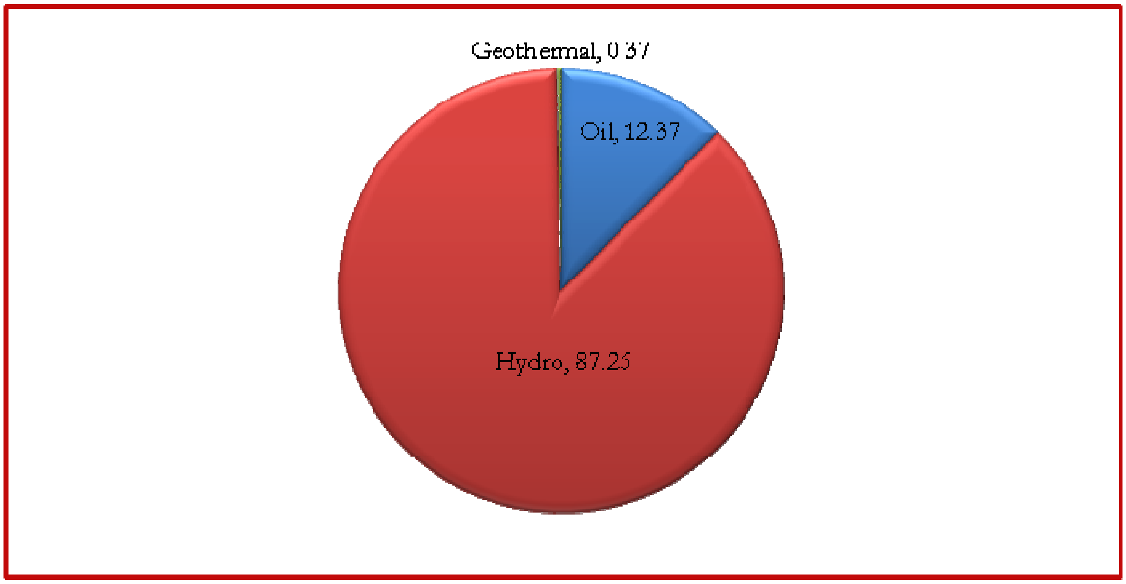


*Figure 3.2: Share of electricity generation of Ethiopia in 2009 (Source: **[76]**)*

3.1.3 Energy Consumption

The energy consumption of Ethiopia was 30,947 ktoe in 2009 from which, biomass accounting for 91.67%; and 7.38% and 0.94% was fulfilled by oil products and electricity (see figure 3.3). The transport sector accounted for 60.42% of the total oil products energy consumption followed by industry (24.9%), residential (13.57%) and non-energy use (1.62%). From the total biomass energy consumption, 99.27% was by residential, and 0.73% by commercial and public services. Industries accounted for 38.01% of the total electricity consumption followed by commercial and public services (23.63%) and residential (13.57%).

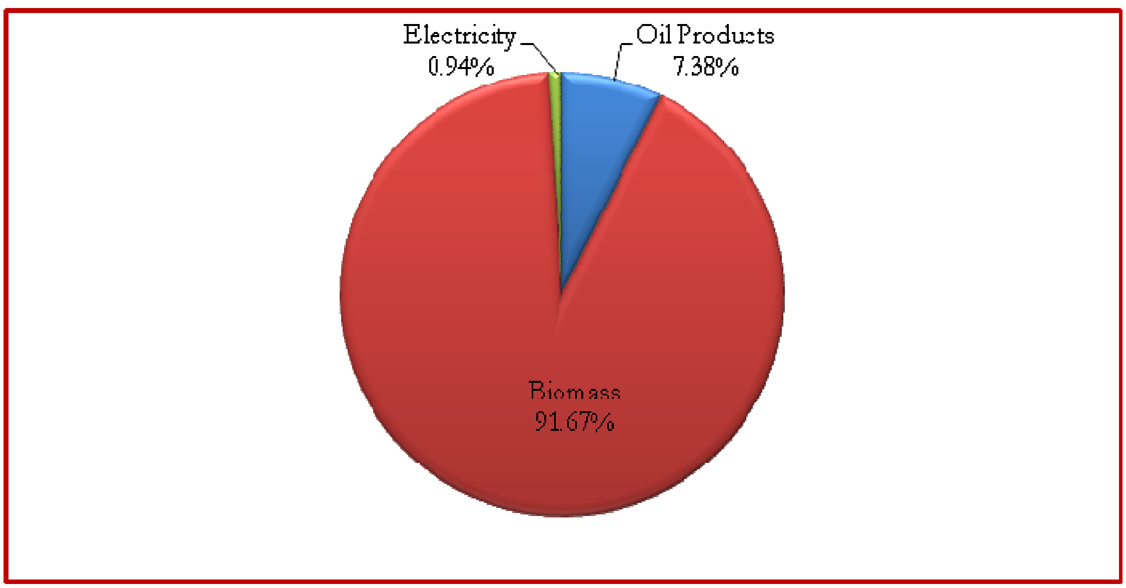


*Figure 3.3: Share of energy consumption of Ethiopia in 2009 (Source: **[76]**)*

In general, the energy profile of Ethiopia can broadly be defined by biomass energy specifically traditional use of biomass for cooking. Most of the biomass energy is used for cooking in the household sector.

Being dependent on traditional use of biomass, the energy utilization of the country is inefficient and unsustainable. The largest portion of biomass energy is lost as waste energy to the environment due to the use of very low energy efficiency traditional cooking technology; consequently, only a very small portion of it becomes useful energy (see figure 3.4).

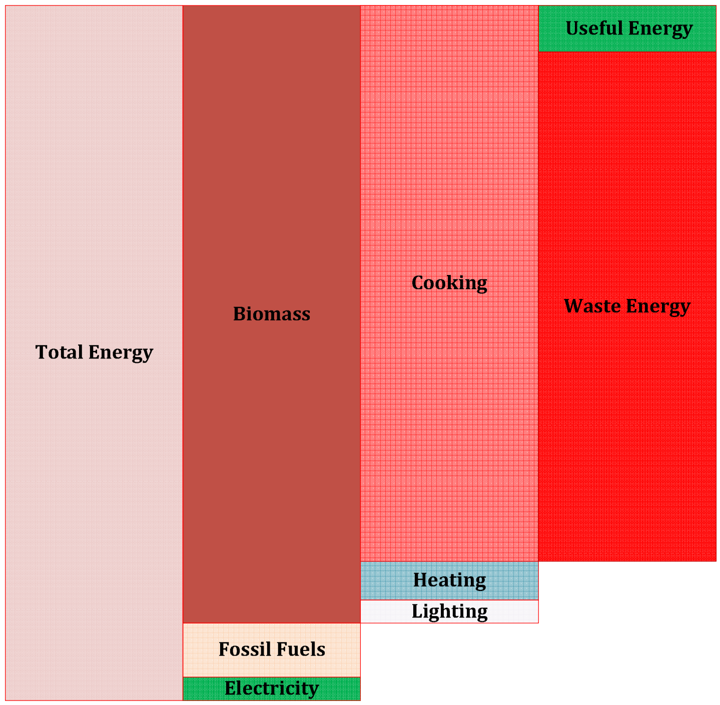


Figure 3.4: Schematic energy profile diagram of Ethiopia

Note that, the energy from bioethanol in the transport sector is very small when compared to the above and considered as insignificant at the moment.

3.2 Energy Trends of Ethiopia

In general, the energy consumption of Ethiopia has shown an increasing trend; and the growth is mainly driven by population and GDP growth of the country. By using United States EIA-International Energy statistics, the trends of petroleum consumption, hydroelectricity generation, and non-hydro electricity generation are discussed below.

3.2.1 Trend of Petroleum Consumption

Petroleum consumption had shown increasing trend from 2000 to 2008 then decreased from 2008 to 2010 due to rise in price (i.e. subsidy of petroleum has been removed since 2008); and after 2010 the trend increased which is driven by economy growth (see figure 3.5).

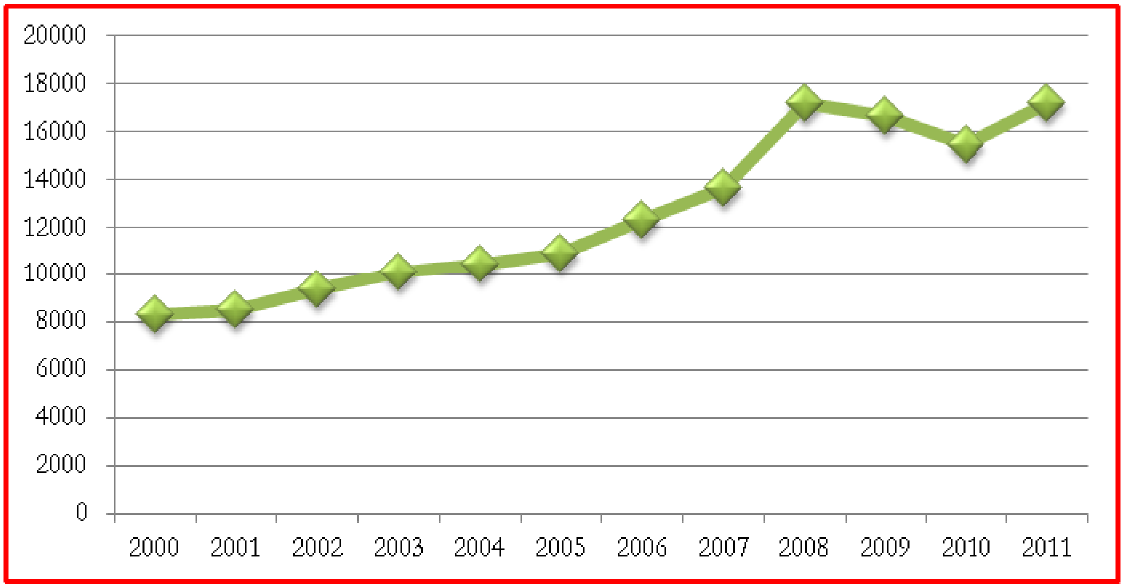


Figure 3.5: Trend of petroleum consumption of Ethiopia ('000 Barrels) (Source: ***[87]****)*

3.2.2 Trend of Hydroelectricity Generation

Generation of hydroelectricity has been grown from time to time; and the country has been established several hydroelectric projects (see figure 3.6).

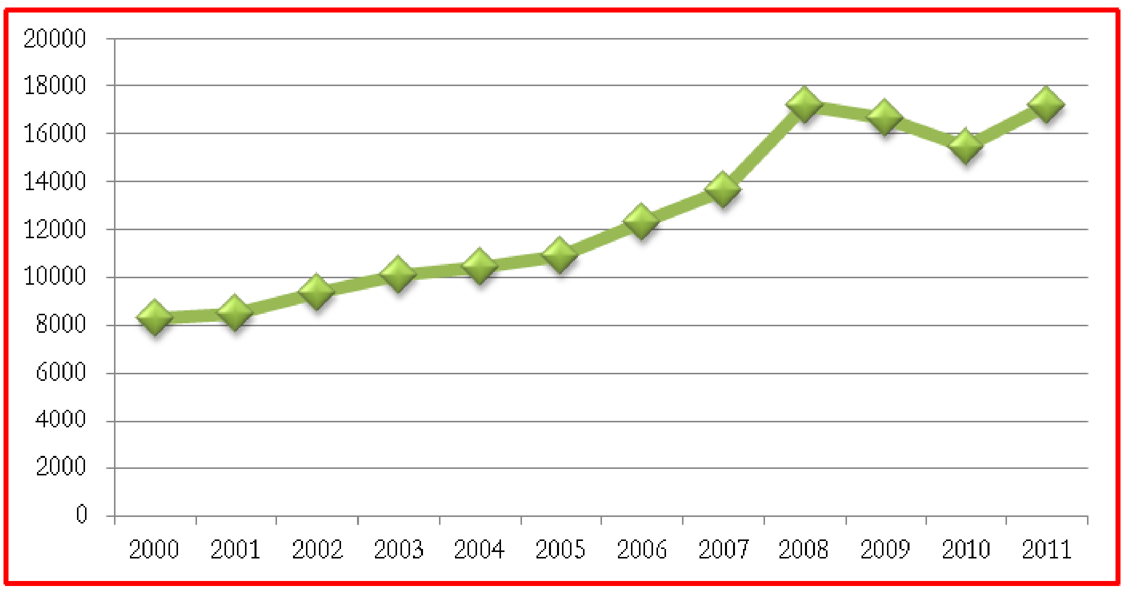


Figure 3.6: Trend of hydroelectricity generation of Ethiopia (TWh) (Source: ***[87]****)*

3.2.3 Trend of Non-Hydro Electricity Generation

Generation of electricity from geothermal (i.e. Aluto Langano pilot plant) had shown decreasing trend from 2000 to 2002 then from 2002 to 2007 there is no electricity generation due to technical failure of the plant; and after 2007, the pilot plant has started to generates electricity again (see figure 3.7).

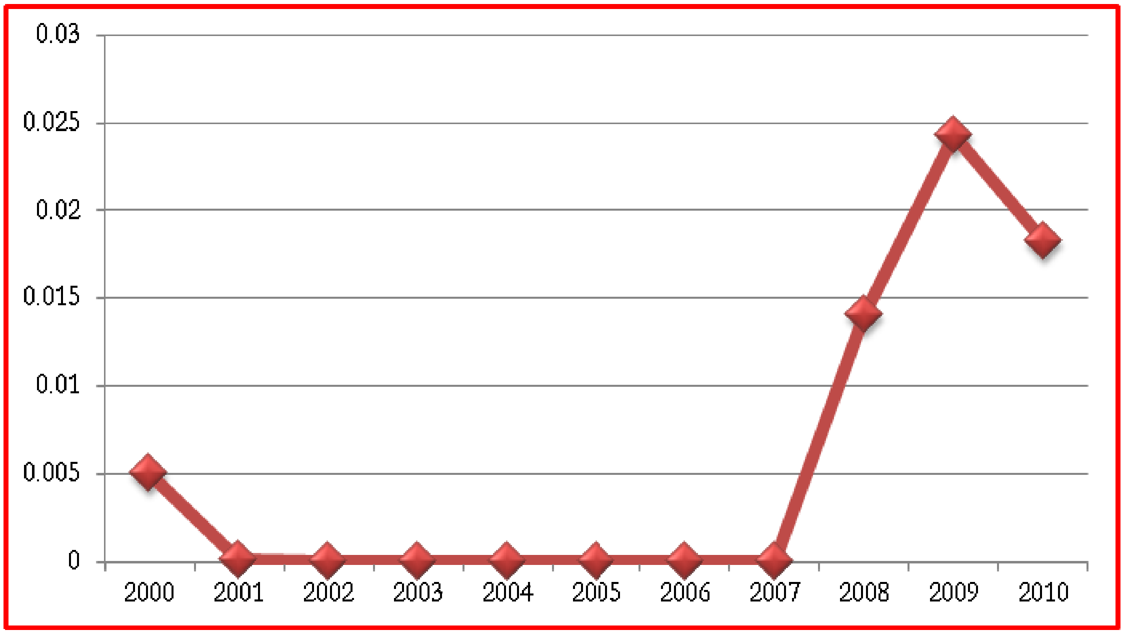


*Figure 3.7: Trend of non-hydro electricity generation of Ethiopia (TWh) (Source: **[87]**)*

3.3 Energy Resource of Ethiopia

As it is mentioned above, Ethiopia has both renewable and non-renewable energy resource. The renewable energy sources includes hydro, geothermal, wind, solar and bioenergy; and the non-renewable energy resources are coal and natural gas however, none of the non-renewable energy resources are exploited sources so far.

3.3.1 Hydro

Ethiopia is endowed with a huge amount of water potential. Preliminary studies and professional estimates indicate that the country has an annual surface runoff close to 122 billion cubic meters of water excluding ground water. From 80% to 90% of the country's water resources is found in the four river basins namely, Abay (Blue Nile), Tekeze, Baro Akobo, and Omo Gibe in the west and south-western part of the country whereas only 10% to 20% of the water resources available in the east and central river basins **[78]**. The water resource of the country is used in many different ways including electricity generation, irrigation, fishery, tourism, drinking, cleaning and other processes.

The hydro energy potential of Ethiopia is estimated to be 30 to 45 GW **[43]**. Currently, the country has around 2 GW installed capacity from operational hydropower plants **[68]**. And this shows that only 4.4% of the hydro energy potential has been exploited. The country is also undertaking several hydropower projects which vary from feasibility study to construction phase. The Grand Ethiopian Renaissance Dam is under construction on the Blue Nile River in the Benishangul Gumuz Region which is about 750 kilometers away from capital city, Addis Ababa. The dam will be the largest hydroelectric plant in Africa when completed with installed capacity of 6 GW and 15,128 GWh of annual electricity generation. The reservoir of the dam will create 63 billion cubic meters which can be used for agriculture and fishing **[66]**. The hydro power projects including Grand Ethiopian Renaissance when completed will boost the country's electricity generation with installed capacity of 19,524 MW and annual electricity generation of 81,843 GWh **[3]**.

3.3.2 Geothermal

The geothermal potential of Ethiopia both thermal and electrical is estimated to be about 5 GW. However, the geothermal resource suitable for electric power generation is about 700 MW. There is one geothermal pilot plant called Aluto Langano with installed capacity of 7 MW which is 1% of the available geothermal potential for electricity generation **[43]**. The country is committed to explore the available potential by undertaking several projects in different geothermal sites. The geothermal projects are projected to add up to 3,154 GWh of electricity by the end of 2018; and the total installed capacity will reach to 457 MW **[3]**.

3.3.3 Wind

The gross wind energy potential for power generation is about 169 GW and this potential can be raised to 350 GW if areas which are moderately suitable for wind power are also included to the gross potential. In the past, wind energy application in Ethiopia has been limited to water pumping. However, currently there is a definite plan to exploit wind for power production **[43]**. In this regard, the country has 81 MW installed capacity from Adama I wind farm (51 MW) and Ashegoda wind farm (30 MW). The Ashegoda wind farm will have installed capacity of 120 MW when fully completed. The wind power projects when completed will also increase the country's electricity generation with annual electricity generation of 2,409.7 GWh of electricity and installed capacity of 593 MW **[3]**.

3.3.4 Solar Energy

Ethiopia receives 5.5 to 6.5 kWh/m2/day of solar radiation thus has a great potential for the use of solar energy. Solar energy availability is fairly constant throughout the year in the lowland areas of the country but varies substantially in the highlands. The theoretical potential of solar energy is about 500 MW thermal/km^2 and 100 MW electricity/km^2. Solar energy application in the country consists of water heating in major cities; and lighting and water pump powering in rural areas **[43]**. Solar energy is also used in telecommunication applications of the country; and Ethiopia Telecommunications Corporation is the major user of solar PV to power its remote telecom installations **[65]**.

3.3.5 Bioenergy

The different bioenergy resources of Ethiopia have been discussed in detail in chapter four.

3.3.6 Fossil Fuels

Fossil fuel resources discovered in Ethiopia are coal, oil shale and natural gas. However, none of them have been developed and utilized so far. The coal resource of the country is estimated about 260 million tons distributed in 9 sites manly located in the northern, central and south-western part of the country. The quality of this coal resource ranges from medium to low grade (bituminous to lignite). Better quality coal deposits are located in the south-western high forest areas of the country where development of sites will potentially have serious environmental consequences. Oil shale deposit is estimated at 112 million tons. The country also has 4 tera cubic feet of natural gas deposit in the eastern part of the county **[12]**.

3.4 Electricity Generation Targets of Ethiopia

As discussed above, electricity generation of the country is highly dominated by hydropower. The abundance of the resource and its relatively low cost of electricity generation make hydropower the first choice for expansion. The country has set a long-term energy production target which is dominated by renewable energy resources as shown below (see table 3.1).

*Table 3.1: Electricity generation targets of Ethiopia (Source: **[46]**)*

Type	2015			2030		
	MW	GWh	%	MW	GWh	%
Thermal	79.2	563.6	1.42	79.2	563.6	0.57
Non-Renewable Total	**79.2**	**563.6**	**1.42**	**79.2**	**563.6**	**0.57**
Hydro	10,641.6	36,506	92.26	22,000.0	86,724.0	87.81
Wind	772.8	1,928.2	4.87	2,000.0	4,029.6	4.08
Geothermal	77.3	571.0	1.44	1,000.0	7,446.0	7.54
Renewable Total	**11,491.7**	**39,005.2**	**98.58**	**25,000.0**	**98,199.6**	**99.43**
Total	**11,570.9**	**39,568.8**	**100**	**25,079.2**	**98,763.2**	**100**

Note that, the country also considers 103.5 MW excess electricity generation target from bagasse by 2015 and 2030. However, this target does not consider the expansion of the sugar industries that will have a potential of producing more excess electricity to the national grid.

4 Chapter Four: Bioenergy Resources of Ethiopia

In Ethiopia, energy demand has increased both in terms of aggregate amount and diversity of resources. Wood, charcoal, agricultural residues and animal dung are the most common traditional bioenergy resources which are primarily used for cooking by households and services.

4.1 Wood

Wood is the most important bioenergy resource in the household sector of Ethiopia. It is also used for cooking food and drinks in restaurants, bakeries, local drink houses, and in institutions such as schools, universities, hospitals, detention centers and military camps. Small and micro enterprises use wood to fire brick and clay products **[13]**. In rural areas most of the wood demand is fulfilled by collecting whereas the urban households fulfill most of their wood demand by purchasing. According to CSA welfare monitoring survey (2011), about 87.2% of the rural households used collected wood and 3.6% purchased wood. Whereas, 18.6% of the urban households consumed collected wood and about 44.7% purchased wood **[41]**.

The standing stock of woody biomass of the country is estimated at 1,150 million tons **[12]**. The amount of wood used as cooking fuel in the country is far larger than the amount used for other purposes such as construction, furniture and the like **[11]**. Demand for fuel wood is growing rapidly while its supply is shrinking and increasing access distance which leads especially women and children to travel a long distance for collecting it (see figure 4.1).

Figure 4.1: Fuel wood collection in Ethiopia

Deforestation for fuel wood is one of the largest sources of GHG emissions in Ethiopia. In 2010, about 17% of the country's GHG emission is caused by deforestation for fuel wood **[48]**.

4.2 Charcoal

In Ethiopia, charcoal is commercially produced from wood. Charcoal is used for cooking mainly by urban households; however it is produced by rural households. Charcoal is produced in a very small scale which is about 100 to 300 Kg per batch using the earth mound kiln. To produce 1 Kg of charcoal about 8 Kg of wood is consumed which results a great deal of waste in this traditional process (i.e. earth mound kiln) (see figure 4.2). Charcoal production earth mound kiln is still the dominant method despite some pilot programs like producing briquetted charcoal from agricultural residues and bamboo residue to introduce more efficient techniques using mobile and stationary kilns have been promoted. However, agricultural residues conversion to charcoal should be promoted only where utilization of the residues as animal feed or organic fertilizer is not viable **[11]**.

Figure 4.2: Charcoal production in Ethiopia using traditional earth mound kiln

The demand for charcoal has grown faster because of increasing urbanization, increasing monetization of charcoal and increasing competitiveness of charcoal with kerosene **[11]**.

Figure 4.3: Charcoal ready for selling

4.3 Agricultural Residues

Scarcity of wood leads to greater use of agricultural residues and animal dung for cooking which could otherwise have been used to enhance the nutrient status and texture of the soil and contribute positively to agricultural production. For instance, agricultural residues from teff, wheat, maize and barley can be left on the ground or burned in the field to recycle soil nutrients; and some parts can also used as animal feed, building materials and cooking fuel. Agricultural residues are mostly used by the rural household for cooking and baking, using very low efficiency cooking stoves. Agricultural residue supply is seasonal and hence its use as fuel is also seasonal. Agricultural residues are seasonal therefore, collection and storage of residues during the months of availability will be necessary; and alternatively different residues could be sourced at different times of the year to fill the gap of scarcity **[14]**.

In different parts of the country, various types of crops are cultivated as a result considerable amount of crop residues is produced. Generally, for the use as fuel, crops with a higher residue-to-seed ratio provide the largest amount of agricultural residues. However, it is often not socially, environmentally and economically desirable to divert all types of agricultural residue for fuel. In the small scale farming context, residues are generally better used for ecological, agricultural or construction purposes than for fuel. However, in large commercial farms and in agro-industries a large proportion of the residues available cannot be used on-site due to limited demand in the immediate vicinity. As a consequence, the residue supply exceeding the local demand tends to be disposed of wastefully and harmfully by burning in the field or at agro-industrial sites, or dumping into streams **[14]**.

Agricultural and agro-industrial residues are bulky and have low energy density, and for these reasons can not be transported far from production sites without some form of processing. Therefore, the residues should be converted to relatively high quality and high energy density fuels to use in the household, commercial and industrial sectors through a number of physical, biological and thermo-chemical conversion processes. The typical agricultural residues densification process has to undergo a number of stages including collection, storage, cleaning, drying, and size reduction. Depending on the types of residue, each of the above stages will require a certain expenditure on equipment, materials and labor **[14]**. Coffee husk, cotton stalk, sesame husk and chat stem are some of the commercially available agricultural residues in the country.

4.4 Animal Dung

Animal dung in the form of dung cake is one of the most commonly traditional biomass used by households for cooking. Animal dung is also for production of biogas. In some rural parts of the country biogas production from Animal dung is started at household level. According to CSA (2009/10) survey, the country's livestock population is about 150 million (see table 4.1).

Table 4.1: Estimated annual animal dung production (Source: ***[11]****)*

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**		**41.9**

It is seen that about 42 million tons of dry weight dung is produced annually from the total livestock from which, cattle (cows and oxen) are accounted for the highest share of dung production about 84% of the annual total dung production.

4.5 Sugarcane

Ethiopia is endowed with suitable land, climate and immense water for sugarcane cultivation. The identified land suitable for sugarcane plantation is about 700,000 hectares **[26]**; and currently, around 412,300 hectares of land is allocated for sugarcane cultivation (see annex 4). The average productivity of sugarcane is about 105 to 145 tons per hectare; and there is an anticipation to reach 155 tons per hectare **[70]**. Sugarcane is mainly used for the production of sugar in the country; and bioethanol is produced from molasses, the byproduct of sugar industries. According the current practice of the sugar industries, from 1 ton of crushed cane about 3% to 4% final molasses can be found; and 1 ton of molasses can produce about 250 liters of bioethanol (i.e. 8.25 liters of bioethnol from 1 ton of crushed cane).

4.6 Bagasse

Bagasse is the byproduct of sugar industries; and from one ton of crushed cane about 27% to 33% of bagasse can be produced. Bagasse used for steam production and electricity generation to fulfill the requirement of the mills. The steam requirement of sugar mills per ton of crushed cane is between 0.4 and 0.55 tons; and the electricity requirement per ton of crushed cane varies between 15 and 35 KWh depending on the efficiency of the mills. About 60% to 70% of bagasse produced is used for steam production and electricity generation for the mills. The remaining quantity can be used as raw material for paper production, other fibrous products or for excess electricity generation to contribute for the national grid **[5]**. The Ethiopian sugar corporation has planned to contribute about 101 MW of electricity to the national grid by the end of 2015 from Methara, Wonji Shoa and Tendaho sugar factories; and the amount will be increased following the expansion of sugar industries **[70]**.

4.7 Jatropha

Jatropha is one of the potential biodiesel feedstock which can be grown in arid climates (rainfall of 200 mm and mean temperature of 20 to 25^{o}C) and marginal soils to produce 1000 kg of oil per hectare **[26]**. The productivity of jatropha ranges from 0.5 to 12 ton of seed per hectare. The productivity depends on soil and rainfall for example; production of 5 tons of seed per hectare can be gained in good soils and rainfall (900 to 1200 mm) **[26]**. The productivity is expected to drop to as low as 2 tons per hectare on soils of marginal productivity and in an arid climate. Jatropha can be produced in degraded land and could not be compute land for food production. In rural areas jatropha plant is used as a living fence to keep away animals due to its toxicity. Jatropha cultivation could improve food productivity as its seed cake can be used as fertilizer. An average farmer can easily produce 2000 Kg of jatropha by intercropping with food crops and planting for the fence purpose. Therefore, the farmer could generate income by selling the jatropha seed for biodiesel producers **[45]**. On average to produce 1 liter of biodiesel about 4 Kg of seed is required for large-scale production **[71]**.

4.8 Castor

Castor is widely distributed plant among different regions of Ethiopia. The castor plant grows in diverse climates. Warm and dry climate (600 to 700 mm of rainfall and 1600 to 2600 meters above sea level altitude) is suitable for its cultivation in addition to this climate condition, caster needs moist, deep and drained soils for optimal yield. It can yield 260 to 1250 kg of oil per hectare **[26]**, **[45]**. According to FAOSTAT (2011), the productivity of caster seed in the country was about 1030 Kg per hectare in 2011 **[72]**.

4.9 Palm

Unlike the above biodiesel feedstock, biodiesel production from palm is computing with food since palm is also used for edible oil production. Ethiopia imports significant amount of palm oil for cooking. Over the past 5 years, the country imported on average 160,000 tons of vegetable oil per year, primarily palm oil [20]. Therefore, biodiesel production from palm than edible oil production might not be viable considering the growing demand of edible oil. However, palm is considered as one of biodiesel feedstock in the biofuel strategy of the country. It is mostly grown within 10 degrees north and south of the Equator. It needs temperature of roughly 22 to 32°C and its rainfall demand is usually about 2000 mm. By planting 150 palm plants per hectare, it is possible to get 5 to 30 tons palm seed per hectare. The productivity of palm depends on harvesting time, 5 tons per ha in year 1 of harvest, and 20 tons per hectare in year 4 harvest. In a mature plantation of 8 to 20 years of age, good management should produce up to 30 tons per hectare **[26]**, **[45]**.

4.10 Municipal Solid Waste

Municipal solid waste commonly called “trash” or “garbage” includes wastes such as tires, furniture, newspapers, plastic plates, plastic cups, milk cartons, plastic wrap, yard waste, food and the like. This category of waste generally refers to common household waste, as well as office and retail wastes **[50]**. It is one of the potential bioenergy resources of Ethiopia accumulated in cities in the form of landfill. The amount of municipal solid waste depends on the number of population of the cities. The major cities of the country are highly populated; for instance, the population of Addis Ababa was 2,960,000 in 2007. Considering the daily average municipal solid waste generation rate at 0.25 Kg per capita per day, the daily and annual solid waste output of Addis Ababa would be about 740 and 270,100 tons respectively. The other major cities of the country such as Bahir Dar, Awassa, Mekelle, Adama, Diredawa and others have produced significant amount of municipal solid waste **[11]**. Municipal solid waste can be used for electric generation using incineration technology; and the landfill gas released from municipal solid waste can also be used for electric generation using gas turbine and as cooking fuel. The country has not yet used its municipal solid waste potential for such application. However, there is a project to establish waste to energy plant at “Rappi”, Addis Ababa where largest landfill of municipal solid waste is found; and the power plant will have electric generation capacity of 50 MW (i.e. about 360 GWh per year).

4.11 Bioethanol Production in Ethiopia

Considerable potential from the sugar factories exists for the production of ethanol, which will reach an annual production level of 182 million liters by the end of first GTP that is 2015. Currently, bioethanol blending with gasoline is limited within Addis Ababa and its surroundings which accounts for about 70% of the total gasoline consumption. Production capacity and infrastructure limitation constrain the expansion bioethanol blend in the regional areas of the country. According to the country’s biofuel development and utilization strategy (2007), bioethanol is produced for the transport sector as well as for cooking **[45]**.

The amount of gasoline import which is predominantly used for transport. A potential replacement of portion of the gasoline with domestically produced bioethanol will reduce import of gasoline and enhance security of energy supply for transport sector. Blending of 5% bioethanol with gasoline was started in 2008 where the supplier of bioethanol is Fincha Sugar Factory which had annual production capacity of 8 million liters **[10]**. The blend has been increased to 10% since 2011. Currently, there are several sugar industries which are under construction and the existing sugar industries are also expanding their capacity (see annex 3). The ultimate goal of this expansion is to increase production capacity of sugar (i.e. 2.25 million tons by 2015, bioethanol (i.e. 182 million liters by 2015), and excess electricity generation for contributing to the national grid (i.e. 101 MW by 2015) **[69]**, **[70]**. The other main goal of the sugar development projects is to create job opportunity for more than 162,000 peoples by 2015 **[70]**. Moreover, there are private sugar industry projects like Hiber Sugar Share Company which will be expected to increase the sugar and bioethanol production capacity of the country. Currently, there are three bioethanol blending stations namely, Nile Petroleum, Oil Libya and National Oil Company. The trend of bioethanol blend by each of the station is shown in annex 5.

4.12 Biodiesel Production in Ethiopia

Biodiesel production is not yet started in the country. However, the country has a considerable potential for growing biodiesel feedstock that can reach a biodiesel production level of 5 to 10 million tons per annum ; and 20% of this amount could be sufficient to fully replace the volume of diesel utilized in 2010 **[10]**. The country has suitable climate and soil for growing biodiesel feedstock Jatropha, castor and palm are some of the feedstock used to produce biodiesel. It is estimated that there is 23.3 million hectares suitable land for cultivation of biodiesel feedstock in the country **[45]**. For large scale biodiesel production, around 300,000 hectares of land has been reserved to investors. Currently, about 26,000 hectares of land is covered with plantation but the production of biodiesel has not yet started. The lists of investors for biodiesel development are shown in annex 6. The vegetable oils can be produced at small-scale, but refining into biodiesel is at much bigger scale. However, the expansion of biodiesel feedstock plantations should be managed not to cause competition with food production **[10]**. According to the country's biofuel development and utilization strategy (2007), biodiesel production is necessary for energy security especially in the transport sector which will be achieved by blending of biodiesel with diesel so that to decrease consumption of diesel as well as GHG emissions. Electricity generation and cooking fuel are other applications of biodiesel. The byproduct of biodiesel production could also be used to produce soaps and cosmetic products **[45]**.

4.13 Biogas Production in Ethiopia

Historically, biogas technology was introduced in Ethiopia as early as 1979, when the first batch type digester was constructed at Ambo Agricultural College **[6], [16]**. In the country there are various organic wastes potential to biogas production some of them are animal dung, municipal solid waste, toilet waste and waste water treatment waste. However, only animal dung and toilet wastes are being used for biogas production. Biogas is produced from animal dung at household level in rural areas where as in urban areas mostly biogas is produced from toilet waste institutional level. Biogas has a many advantage of providing energy for cooking and lighting especially for rural households while at the same time providing high quality organic fertilizer from the slurry produced after the biogas is extracted. Consequently, biogas production increases agricultural productivity as it provides the necessary organic fertilizer. Biogas also improves indoor climate as it reduces dramatically indoor air pollution and hence improves health **[10]**. Biogas production is promoted by SNV and MoWE. In the year 2007, the national biogas program was initiated with a project target of constructing 14,000 biogas digesters in 5 years **[10]**, **[16]**, **[83]**. On average, from 1 Kg of animal dung 38 liters of biogas be produced **[16]**.

4.14 Cooking Stoves in Ethiopia

The three stones fire is the most common and dominant traditional cooking stove used in Ethiopia. It uses wood, charcoal, animal dung and agricultural residues as a cooking fuel. There is also insignificant number of other stoves used in the country. The country's energy policy (1994) gives priority to the household sector particularly to provision of sustainable energy for cooking by taking measures to achieve gradual transition from traditional use of cooking fuels to efficient and modern **[47]**. Increasing the use of efficient cooking stoves is one of the main issues of the green economy strategy of the country to decrease forest degradation and GHG emissions; and for this purpose, the country has prepared national cooking investment plan. MoWE, EPA, GIZ, SNV, UNDP are some of the organizations that support the implementation of this plan. According to the cooking investment plan, the percentage distribution of rural and urban households that will use improved wood stoves could reach to 80% and 5%, for biogas stoves it could reach to 5% and 1%, and for electric stove 5% and 53% respectively. By using efficient stoves, about 2.2 tons of CO_2e per household can be saved annually from the carbon sink by reducing deforestation and forest degradation **[48]**. The following are the cooking stoves available in the country.

4.14.1 Three Stones Fire

This traditional cooking stove is made up of three stones called 'Sosit Gulicha' in Amharic (i.e. national language of Ethiopia). It used for cooking and baking with low thermal efficiency of between 5% and 10%. Thermal efficiency of 10% means that 90% of the cooking fuel energy does not reach the cooking pot rather it is just lost to the surrounding in the form of waste energy **[28]** (see figure 4.4).

Figure 4.4: Baking with three stones fire

4.14.2 Traditional Charcoal Stove

The traditional charcoal stoves are mainly made up of clay and steel. Both the clay and steel made traditional charcoal stoves have thermal efficiency of about 10% on average and used for cooking especially by urban households.

4.14.3 Improved Wood Stove

There are different improved wood stoves promoted in Ethiopia some of them are 'Mirt' stove, 'Tikikil' stove and 'Gonziye' stove. Wood consumption and indoor air pollution reductions are the basic advantage of improved wood stoves. The improved wood stoves are made locally by small scale enterprises which creates job opportunity for many people. Mirt is made from sand mixed with cement and still, Gonziye from clay and Tikikil from steel. The thermal efficiency of these stoves is between 18% and 25%. Tikikil is only used for cooking whereas the other two stoves are used for both cooking and baking **[28]**. The selling price of improved wood stoves is between 4 to 8 USD with an average service life of 2.5 years (for cooking) and 4.5 years (for baking) **[48]**.

4.14.4 Improved Charcoal Stove

Like improved wood stoves, the basic advantage of improved charcoal stove is reduced charcoal consumption and indoor air pollution. 'Lakech' is the improved charcoal stove promoted in Ethiopia and used by small number of households especially in urban areas. Lakech is made locally by small scale enterprises from clay and steel. The thermal efficiency of improved charcoal stoves ranges from 20% to 30% **[28]**.

4.14.5 Electric Stove

Electric stoves are mainly used by urban households of Ethiopia. They are used for baking and cooking. Electric stoves which are used for baking called 'electric mitads'; and they are made locally by small-scale enterprises from steel, clay and cooper. On the other hand, the electric stoves which are used for cooking manufactured locally and imported from abroad. The thermal efficiency of electric stoves is ranges from 70% to 80% which is the highest efficiency from all types of cooking stoves **[28]**. The selling price of electric stoves ranges from 20 to 63 USD with an average service life of 7 years **[48]**.

4.14.6 Kerosene Stove

Kerosene stoves are used for cooking mainly by urban households of Ethiopia. The share of households that uses kerosene stoves is decreasing from time to time due to increasing price of kerosene. The use of kerosene stoves is declining due to rising price of kerosene. They have thermal efficiency ranging from 30% to 40% **[28]**.

4.14.7 LPG Stove

LPG stoves are used by households, institutions, hotels and restaurants for cooking. Like kerosene stoves, the share of households that use LPG stoves is decreasing from time to time. The thermal efficiency of stoves is relatively high and ranges from 60% to 70% **[28]**. The average selling price of LPG stoves is 107 USD with an average service life of 7 years **[48]**.

4.14.8 Bioethanol Stove

Bioethanol stoves are also used for cooking; and the current use of bioethanol stoves in Ethiopia is insignificant. They have average thermal efficiency of 55%. The selling price of imported single and double burner bioethanol stoves is 530 (i.e. 34 USD at current exchange rate) and 1000 ETB (i.e. 54 USD) respectively with an average service life of 10 years. When they are locally produced, the selling price would be reduced to 267 ETB (i.e. 14 USD) and 468 ETB (i.e. 25 USD) respectively **[8]**.

4.14.9 Biogas Stove

Biogas stoves are also insignificantly used for cooking in Ethiopia. They are more suitable in rural households since there is abundant animal dung for production of biogas at household level. The selling price of biogas stoves including digester infrastructure is 912 USD with an average service life of 20 years **[48]**. Currently, there are activities carried out to manufacture biogas stoves locally to reduce the price.

5 Chapter Five: Policy Background and Stakeholders

5.1 Energy Policy of Ethiopia

The first energy policy of Ethiopia has been formulated in 1994. The main goal of the energy policy is to ensure the availability, accessibility, affordability, safety and reliability of energy to support accelerated and sustainable social and economic development of the country and reduce poverty **[12]**.

5.1.1 Objectives of Energy Policy

Basically the energy policy of the country has been formulated to achieve the following objectives **[12], [46]**:

- To ensure security supply of energy to support development of the country
- To promote to indigenous energy resources for self sufficiency
- To increase the access of modern energy
- To promote efficient, cleaner and modern energy conversion technologies
- To increase energy conservation and efficiency
- To ensure environmental safety and sustainability of energy supply and utilization
- To improve energy sector governance and management systems

Promoting sustainable forest management, promoting diverse and efficient bioenergy production, promoting carbon neutrality and climate resilience, ensuring supply for bioenergy, promoting biofuels production, and improving access to bioenergy are specific objectives of the energy policy with respect to bioenergy.

5.1.2 Main Issues of the Energy Policy

The main issues of the energy policy of the country are energy resource development, energy supply, energy convservation and efficiency, comprehensive measures, and energy institutilization.

Energy Resource Development

This issue of the policy first focuses on sustainable development traditional fuels by afforestation and reducing the impact of deforestation. Modern energy development is one of the main points under this policy issue by prioritizing hydro power development, to develop geothermal and coal resources on the basis of their economic profitability, and to initiate private companies to explore oil and natural gas by providing incentives. The other point adressed under this policy issue is alternative energy resources development which deals with the use of solar and geothermal energy for process heat and power generation; and wind energy for water pumping and irrigation **[15]**, **[53]**.

Energy Supply

This issue focuses on households energy supply balancing between the supply and demand for household fuels; transport energy supply policy by giving emphasis to the introduction of improved transport technologies to reduce the use of fossil fuels in the transport sector; agriculture energy supply by increasing the supply of modern energy sources to the agriculture sector; and industry energy supply by ensuring compatibility with industrial development program of the country **[15]**, **[53]**.

Energy Conservation and Efficiency

It is devoted in increasing energy efficiency in the household sector by instituting conservation and energy saving measures; improving the efficiency of industrial equipment to conserve and reduce energy consumption; improving energy utilization and conservation in the transport sector in order to decrease fossil fuels consumption; fulfilling energy demand of agriculture sector through locally produced modern energy resources; adopting energy efficiency measures to eliminate energy waste in the commercial and service sectors arising from inefficient devices; and implementing energy saving measures to decrease waste of energy in the mining and construction sectors **[15]**, **[53]**.

Comprehensive Measures

To ensure the development of energy projects, energy generation, transmission are environmental friendly; to create awareness about energy science and technology; to onduct research that helps for increasing the reliability of energy supply, minimizing deforestation, controlling environmental pollution and increasing the efficiency of energy conversion devices; to build national capacity in design, development, operation, maintenance and consultancy in the electricity subsector; Gradually build local manufacturing capability of electrical equipment and appliances; to create energy data base to assist in energy planning, management and informed decision making; and to human development and energy education **[15]**, **[53]**.

Energy Institutionalization

It focuses on establishing and supporting institutions which are responsible for policy formulation, priority setting and coordination of all energy sector development activities **[15]**, **[53]**.

5.2 Environmental Policy of Ethiopia

The overall goal of the environmental policy of the country is to improve and enhance health and quality of life of the people, and to promote sustainable social and economic development, and the environment as a whole so as to meet the needs of the present generation without compromising the ability of future generations to meet their own needs **[42]**. The specific objectives of the environment policy are:

- ☞ To ensure that essential ecological processes and life support systems sustainability, biological diversity preservation and renewable natural resources utilization
- ☞ To ensure the exploitation of non-renewable resources to use it in the future by minimizing negative impacts on the environment
- ☞ To identify natural resources that are currently underutilized and find appropriate technologies to use them properly
- ☞ To incorporate economic, social and environmental costs and benefits of natural resource development into the planning, implementation and accounting processes
- ☞ To improve the environment of human settlements to satisfy physical, social, economic, cultural and other needs on a sustainable basis
- ☞ To prevent the pollution of land, air and water in the most cost-effective way
- ☞ To conserve, develop, sustainably manage and support diverse cultural heritage of the country
- ☞ To ensure the empowerment and participation of the people and organizations at all levels in environmental management activities

- ☞ To raise public awareness and promote understanding of the essential linkages between environment and development

The environmental policies related to energy resources are presented as follows.

- ☞ To adopt an integrated process of planning and development among different sectors for energy development
- ☞ To promote renewable energy development and reduce the use of fossil energy resources
- ☞ To make institutions and industries which consume large amounts of wood fuel establish their own wood plantation
- ☞ To encourage private sectors for wood plantation in peri-urban areas
- ☞ To ensure energy development projects are environmentally feasible and viable
- ☞ To encourage private sectors to develop and market environmentally sound energy
- ☞ To ensure that each homestead grows enough trees to satisfy its wood requirements through extension programs
- ☞ To develop and adapt modern energy sources and technologies to reduce traditional biomass use

5.3 Green Economy Strategy of Ethiopia

Ethiopia aims to achieve middle income status by 2025 while developing climate resilient green economy (CRGE). However, the conventional development path of the country would result in an increase in GHG emissions and unsustainable use of natural resources. To avoid such negative effects, the country has developed a strategy to build a green economy in every economic sector since 2011. The green economy plan is based on the following four pillars **[44]**:

1. Improving crop and livestock production practices for higher food security and farmer income while reducing emissions
2. Protecting and establishing forests for their economic and ecosystem services
3. Expanding electricity generation from renewable sources for domestic and regional markets
4. Shifting to modern and energy efficient technologies in transport, industry and buildings.

The GHG emissions contribution of the country is very low on a global scale (i.e. 0.3% of the global GHG emissions in 2010). The per capita emission of Ethiopia is less than 2 tons of CO_2e which is modest compared with 10 tons CO_2e emissions per capita on average in the EU and 20 tons CO_2e emissions per capita in the US and Australia. However, the projected environmental impact of the conventional economic development shows that GHG emissions in the country will be more than double from 150 million tons of CO_2e in 2010 to 400 million ton of CO_2e by 2030. The country's target for 2030 is to maintain the GHG emission to 2010 level (i.e. 150 million tons of CO_2e by abating 250 million tons of CO_2e) **[44]**.

From the 150 million tons of CO_2e emissions in 2010, more than 85% came from the agricultural and forestry sectors followed by transport, industry, power and buildings (see figure 5.1) **[44]**.

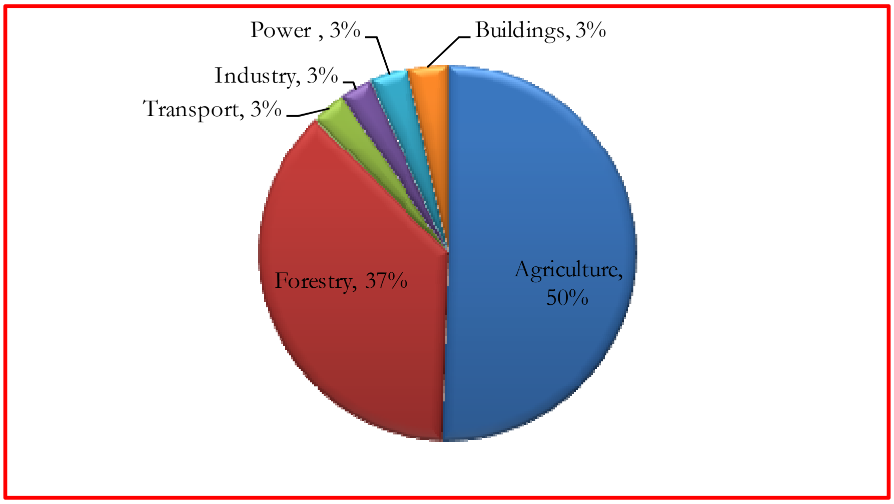


*Figure 5.1: Share of GHG emissions by sectors of Ethiopia in 2010 (Source: **[44]**)*

In agriculture, GHG emissions are caused by livestock and crop production. Ethiopia has about 150 million livestock population. Livestock GHG emissions are mainly in the form of methane arising from anaerobic digestion and nitrous oxide emissions arising from excretions. Livestock GHG emissions was estimated at 65 million tons of CO_2e. The cultivation of crops contributes about 10 million tons of CO_2e and 3 million tons of CO_2e by using fertilizer and emitting N_2O from crop residues respectively.

In forestry, GHG emissions are driven by human activities mainly deforestation for agricultural land, forest degradation for wood fuel, and formal as well as informal logging. Forestry GHG emissions was about almost 55 million tons of CO_2e in 2010. Deforestation for agricultural land, forest degradation for fuel wood and informal logging accounted for 50%, 46% and 4% share of the total forestry GHG emissions.

Minor amount of GHG emissions is contributed by transport, power, industry, and buildings, as stated below.

In transport, about 75% of the GHG emissions come from road transport, particularly freight and construction vehicles, and lesser amount from private passenger vehicles. Air transport contributes around 23% of transport related emissions. GHG emissions from inland water transport are minimal about 2%.

In power sector, the power sector GHG emissions come from the use of diesel generators of EEPCo. The amount of power sector GHG emissions is estimated below 5 million tons of CO_2e.

In industry, about 4 million tons of CO_2e are from industry out of this amount, nearly 50% is from cement industries followed by mining (32%), and textile and leather industry (17%). GHG emissions from steel, engineering, chemical, pulp and paper, and food processing industries together account for around 2% of the total industrial GHG emissions.

In buildings, the main drivers of GHG emissions of buildings are solid and liquid waste (3 million tons of CO_2e), and private power generators (2 million tons of CO_2e).

5.4 Stakeholders of Ethiopian Energy System

There are governmental organizations, and developmental partners directly or indirectly play key role in the energy sector of Ethiopia. In this part, the major stakeholders and their roles are described below.

5.4.1 Governmental Organizations

The following are the main governmental organizations responsible for energy system of Ethiopia with respect to their assigned mandate from the government.

Ministry of Water and Energy (MoWE)

The Ministry of Water and Energy (MoWE) of Ethiopia is a federal organization established to management of water and energy resources of Ethiopia which involves development, planning and management of water and energy resources, development of polices, strategies and programs, develop and implement water and energy sector laws and regulations, conduct study and research activities, provide technical support to regional water and energy bureaus and offices and sign international agreements **[79]**.

Ethiopian Electric Power Corporation (EEPCo)

The Ethiopian Electric Power Corporation (EEPCo) is a state owned organization and it was established for indefinite duration by regulation No. 18/1997 with a purpose of the corporation is to engage in the business of producing, transmitting, distributing and selling electrical energy in accordance with economic and social development policies and priorities of the government and to carry out any other related activities that would enable it achieve its purpose **[67]**.

Ethiopian Electricity Agency (EEA)

The Ethiopian Electricity Agency (EEA) functions under MoWE with a mandate to regulate the energy sector mainly in terms of efficiency, conservation, safety, quality and the like based on rules, regulations, directives and standards **[80]**.

Ethiopian Rural Energy Development and Promotion Center (EREDPC)

The main function of EREDPC is to promote energy technologies which are efficient and environmentally sound to bring sustainable development in the rural areas of Ethiopia. The center is also undertaking the facilitation of energy development in rural areas through the provision of information; and technical assistance loan financing to private sector, community organization, non-governmental and governmental organizations in order to contribute to accelerated economic and social development **[84]**.

National Biogas Program Coordination Office (NBPCO)

The National Biogas Program Coordination Office was established to facilitate the national and regional government institutions for training, promotion and extension services; the private sector for the actual construction of biogas digesters; NGOs for promotional activities; microfinance institutions for the provision of micro-credit for biogas; and end users for sound operation **[16]**.

Ethiopian Petroleum Suppliers Enterprise (EPSE)

The Ethiopian Petroleum Suppliers Enterprise (EPSE) is responsible for procurement, import of petroleum products and distribution to local oil companies. It is also responsible of testing the quality of the petroleum products.

Ethiopian Sugar Corporation (ESCo)

The Ethiopian Sugar Corporation (EPCo) is established in 2010 by the Council of Ministers Regulation No.192/2010 replacing the former Ethiopian Sugar Development Agency with the major purpose of growing sugarcane and other sugar yielding crops; producing sugar and byproducts, selling sugar and byproducts in the domestic and export markets; undertaking of feasibility studies, design preparation, technology selection and negotiation, erection and commissioning of new sugar development and expansion projects; and to engage and support the private sector in the sugar development **[70]**.

Environmental Protection Authority (EPA)

The Environmental Protection Authority (EPA) is responsible for formulating policies, strategies, laws and standards, which foster social and economic development to enhance the welfare of humans and the safety of the environment sustainably, lead in ensuring the effectiveness of the processes for their implementation **[64]**.

5.4.2 Developmental Partners

Below are the major developmental partners that support the energy sector of Ethiopia in addition to other several activities in the socio-economic development of the country.

World Bank (WB)

The World Bank (WB) helps Ethiopia to fight poverty and improving living standards by promoting rapid economic growth and improving service delivery **[89]**. It is a leading institution with financial and technical assistance in almost all developing countries. The bank involves in the energy sector of Ethiopia by providing critical financial and technical support needed to enable EEPCo and MoWE to scale up electrification and energy access projects.

European Union (EU)

The European (EU) through European Union Energy Initiative (EUEI) financed capacity building for off-grid rural electrification planning) within Rural Electrification Executive Secretariat (REES) and on the regional level **[52]**. The EU also gives financial support to enhance energy development projects in Ethiopia.

African Development Bank (AfDB)

The African Development Bank (AfDB) is one the leading organization that supports the socio-economic development of Africa. The bank supports energy development projects in Ethiopia like wind power (i.e. Aluto Langano geothermal project) and wind power (i.e. Assela wind farm project); and power transmission lines extension projects **[46]**.

Arab Bank for Economic Development in Africa (BADEA)

The Arab Bank for Economic Development in Africa (BADEA) was established for supporting sustainable development and poverty reduction in Africa by providing technical and financial support. The bank supports the country to extend the national electricity grid to supply electricity to rural towns and villages; and improve the national electricity access rate **[46]**.

United Nations Development Program (UNDP)

The United Nations Development Program (UNDP) is supporting to strengthen the national capacity of 135 developing countries to manage the environment in a sustainable manner to advance poverty reduction efforts. The office of UNDP in Ethiopia has facilitated the formulation of the national Climate Resilient Green Economy (CRGE) document as well as sector and regional plans; and provided finances for the establishment of a national CRGE facility. It strongly advocates and facilitates Ethiopia's access to new, modern and environmentally friendly practices **[85]**.

United Nations Environment Program (UNEP)

The main mission of United Nations Environment Program (UNEP) to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations. It has liaison office in Addis Ababa, Ethiopia with the purpose collaborating, facilitating and consulting of environmental issues with partners and stakeholders **[86]**.

GIZ's Energy Coordination Office

The GIZ's Energy Coordination Office (ECO) is supporting to improve access to modern energy in Ethiopia through its Energizing Development Program. The program involves capacity development measures for all the partners in the program, such as governmental and non-governmental organizations, and for representatives of the private sector and local communities which includes the use of pilot projects and other support measures to promote sustainable energy in the country. The interventions of ECO are summarized into following three areas **[61]**.

- Advising the government on policies, strategies, laws and program so that to increase private sector involvement in renewable energy.
- Promoting rural electrification by building up local capacities and international linkages for the provision of small-scale solar energy and hydropower systems.
- Promoting the use of energy efficient cooking technologies, such as 'Mirt' wood stove, the 'Tikikil' wood stove, and the institutional rocket stove (IRS).

Stichting Nederlandse Vrijwilligers (SNV)

Stichting Nederlandse Vrijwilligers (SNV) is the Netherlands development organization which provides capacity development, facilitates knowledge development and networking, and creates policy dialogue at the national and international levels. It has supported the preparation and implementation of the national biogas development program of Ethiopia in cooperation with EREDPC. The main role of SNV in national biogas development program is technical advice, promotion, network creation and building partnership **[16]**.

Stiftung Solarenergie

The Stiftung Solarenergie is a community based solar energy foundation founded by a charity community` from Germany and Switzerland with major objective of providing electricity from solar power to rural Ethiopia like small farmer's house, schools, health centers and religious institutes. The foundation has been operating in Ethiopia since 2005, and the first pilot project was done in a village called Rema which 230 kilometers north of the capital city, Addis Ababa. Following the findings in the pilot project, Stiftung has opened solar energy training center in the pilot project area since 2007 to promote solar energy in the country with long-term and to prepare solar energy technicians to open their own small enterprises in the rural Ethiopia **[33]**.

Gaia Association

Gaia Association is non-profit organization that promotes clean cooking stoves, particularly ethanol cooking stoves in few developing countries. It is working with a clean ethanol cooking stove project by undertaking pilot studies in Ethiopia since 2005. About 3,400 Somali families in the Kebribeyah and Awbarre refugee camps use clean ethanol cooking stoves as a result of the pilot studies **[74]**. Gaia Association is currently partnering with local enterprise Makobu PLC to manufacture the stoves locally and produce ethanol from agricultural and waste **[4]**.

Horn of Africa Regional Environment Center (HoAREC)

The Horn of Africa Regional Environment Centre and Network (HoAREC) deals with environmental concerns and sustainable development options within the Horn of Africa. The Centre works as an autonomous institution under Addis Ababa University. It facilitates, strengthens and advocates the initiatives related to environmental conservation and natural resource management to reduce deforestation and forest degradation **[75]**.

6 Chapter Six: Modeling and Analysis

This part of the study has been done using LEAP, a software tool developed by Stockholm Environment Institute that is widely used for energy policy analysis and climate change mitigation assessments. LEAP is an integrated modeling tool used to analyze energy consumption, production and resource extraction in all sectors of an economy **[57]**. Moreover, it can be used for the evaluation of GHG emissions associated with different technologies in energy consumption and production **[27]**. The different input data for the LEAP and parameters/targets which are established for each of the formulated scenarios are briefly described below.

6.1 Data Organization and Justification

6.1.1 Population and Gross Domestic Product (GDP)

Population and GPD are the main drivers of energy demand. Household energy demand increases when population increases. With an increase in GDP, the consumption of energy in transport and industry is also increased. The trend of population and GDP (constant 2000 USD) is shown below (see table 6.1).

*Table 6.1: Trend of population and GDP of Ethiopia (Source: **[90], [91]**)*

Population (million People)												
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Population	65.6	67.3	69	70.8	72.5	74.3	76	77.7	79.4	81.2	82.9	84.7
USD (billion USD)												
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
GDP (2000 USD)	8.1	8.8	8.9	8.7	9.9	11.1	12.3	13.7	15.2	16.5	18.1	19.5

From the above trend, the average annual growth rate of population and GDP is 2.4% and 8.4% respectively; and taking these growth rates, the population and GDP for 2012 are estimated at 86.7 million people and 21.1 billion USD respectively.

6.1.2 Percentage Distribution of Households by Cooking Stove

The percentage distribution of households by cooking stove is taken from the percentage distribution of households by cooking fuel which is collected from CSA welfare monitoring survey (1996, 1998, 2000, 2004 and 2011) (see annex 2). Both the urban and rural households are used wood as cooking fuel using traditional cooking stoves. There are small numbers of households especially in the urban areas that use improved wood and charcoal stoves. However, the percentage distribution of these households is insignificant and taken as negligible. The percentage distribution of households by cooking stove is shown below (see table 6.2).

Table 6.2: Percentage distribution of households by cooking stove

Percentage Distribution of Urban Households by Cooking Stove					
Cooking Stove	**1996**	**1998**	**2000**	**2004**	**2011**
Traditional Wood Stoves	61.7	62.9	57.9	65.33	63.31
Improved Wood Stoves	-	-	-	-	-
Traditional Charcoal Stoves	4.3	5	8.3	7.65	17.54
Improved Charcoal Stoves	-	-	-	-	-
Electricity Stoves	2.7	3.8	2.2	2.36	6.18

Kerosene Stoves	18.9	17.2	21.5	13.84	4.93
LPG Stoves	1	2.5	1.4	2.69	1.05
Biogas Stoves	-	-	-	-	0.01
Bioethanol Stoves	-	-	-	-	-
Others	11.4	8.5	8.7	6.1	3.4
Number of Households	**1,583,823**	**1,603,869**	**1,666,208**	**2,112,957**	**3,437,158**
Percentage Distribution of Rural Households by Cooking Stove					
Cooking Stove	**1996**	**1998**	**2000**	**2004**	**2011**
Traditional Wood Stoves	75.5	78.2	78.8	84.45	90.85
Improved Wood Stoves	-	-	-	-	-
Traditional Charcoal Stoves	0.1	0.1	0	0.16	0.23
Improved Charcoal Stoves	-	-	-	-	-
Electricity Stoves	-	-	-	0.05	0.01
Kerosene Stoves	0.2	0.2	0.3	0.21	0.17
LPG Stoves	0	0.1	0.1	0.07	0.04
Biogas Stoves	-	-	-	-	-
Bioethanol Stoves	-	-	-	-	-
Others	24.6	21.5	20.8	14.99	8.6
Number of Households	**8,856,288**	**9,683,035**	**9,853,558**	**11,325,052**	**12,707,493**

Note that, others represent traditional stoves that use animal dung, sawdust, crop residues and other residues.

6.1.3 Energy Efficiency of Cooking Stoves

It is thermal efficiency of the cooking stoves that determines the consumption of the cooking fuel. Obviously, the use of traditional wood stoves with low thermal efficiency (i.e. less than 10%) has resulted in high consumption of wood. The thermal efficiency of the cooking stoves available in Ethiopia is summarized below (see table 6.3).

*Table 6.3: Thermal efficiency of cooking stove (Source: **[8], [28]**)*

Cooking Stove	Thermal Efficiency (%)
Traditional Wood Stoves	7.5
Improved Wood Stoves	21.5
Traditional Charcoal Stoves	10
Improved Charcoal Stoves	25
Electric Stoves	75
Kerosene Stoves	35
LPG Stoves	65
Biogas Stoves	55
Bioethanol Stoves	55
Others	7.5

Note that, the thermal efficiency of biogas stove is considered the same as that of bioethanol stoves.

6.1.4 Average Annual Consumption of Cooking Fuels per Household

The average annual consumption of cooking fuels per household has been calculated from the annual useful thermal energy for cooking per household and thermal efficiency of cooking stoves. The annual useful thermal energy is calculated by taking biomass energy consumption of the households in 2009. The biomass energy consumption of the households was 27.37 Mtoe (i.e. 1.14 EJ gigajoules) **[49]**. Considering that only 97% of this biomass energy (i.e. 1.11 EJ) was used for cooking with 7.5% average thermal efficiency of cooking stoves, the useful thermal energy for cooking is estimated at 83.25 PG in the same period. On the other hand, the number of households in 2009 is estimated at 15.4 million from CSA welfare monitoring survey (2000, 2004 and 2011) and of which about 96.6% (i.e. 14.9 million households) used biomass energy for cooking. Therefore, the average annual useful thermal energy for cooking per household is about 5.6 GJ; and this average useful thermal energy value is assumed to be the same for every household considering that majority of the households have more or less similar living standard and household size. Then using thermal efficiency of cooking stoves, the value of average annual useful thermal energy per household is converted into average annual consumption of respective cooking fuels per household (i.e. 5.6 GJ/thermal efficiency of cooking stoves) and summarized below (see table 6.4).

Table 6.4: Average annual consumption of cooking fuels per household

Cooking Fuel	Unit	LHV (GJ/Ton)	Cooking Stove	Thermal Efficiency (%)	Consumption (Tons/HH)	Consumption (GJ/HH)
Wood	Ton	15.6	Traditional Wood Stoves	7.5	4.79	74.7
			Improved Wood Stoves	21.5	1.67	26
Charcoal	Ton	29.5	Traditional Charcoal Stoves	10	1.9	56
			Improved Charcoal Stoves	25	0.76	22.4
Kerosene	Ton	35.3	Kerosene Stoves	35	0.37	16
LPG	Ton	47.3	LPG Stoves	65	0.18	8.6
Biogas	Ton	20	Biogas Stoves	55	0.51	10.2
Bioethanol	Ton	26.8	Bioethanol Stoves	55	0.38	10.2
Dung and Other Residues	Ton	14	Others	7.5	5.33	74.7

Following the same procedure and taking 75% average thermal efficiency of electric stoves, the annual electricity consumption for cooking per household is calculated at 7.5 GJ (i.e. 5.6 GJ/0.75).

It is seen that about 3.1 tons of wood (i.e. 4.79 - 1.67) and 1.3 tons of charcoal (i.e. 1.96 - 0.76) per household can be saved annually by using improved wood and charcoal stoves respectively.

6.1.5 Consumption of Bioethanol

Bioethanol is used as a transport fuel, and as an input in food and beverage industries. It can also be used for as raw material in biodiesel production. The transport sector is major consumer of bioethanol which is started in 2008 with E5 (i.e. 5% blend with gasoline) for Addis Ababa and its surroundings. Starting from the year 2011, E10 has been introduced. The country's long-term plan is to increase the blend considering the expansion of bioethanol production from sugar industries, engine modification and the introduction of flex engine cars. The distribution loss of bioethanol is about 2.2% which is from movement loss, underground tank loss, vehicle tank loss and evaporation loss.

6.1.6 Consumption of Gasoline

Gasoline is used as transport fuel for light vehicles. According to the study conducted by an expert from MoWE, Addis Ababa and its surrounding accounted for about 70% of the total gasoline consumption. The trend of gasoline import is shown below (see table 6.5).

Table 6.5: Trend of gasoline import in Ethiopia

Gasoline Import (million ton)												
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Gasoline	0.136	0.132	0.141	0.139	0.138	0.142	0.140	0.141	0.145	0.153	0.150	0.145
Gasoline Import (petajoule)												
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Gasoline	5.91	5.71	6.11	6.05	6	6.15	6.1	6.14	6.28	6.64	6.5	6.3

From the discussion with officials and experts of EPSE and MoWE during the fieldwork, it is found that about 98% of the imported gasoline is directly consumed by the transport sector, and the rest 2% is taken as a distribution loss mainly from movement loss, underground tank loss and vehicle tank loss.

Note that, the original data from EPSE is in the form of Ethiopian fiscal year which starts at July 1 and ends with June 30, and covers six month from each consecutive Gregorian calendar years. For example, the fiscal year 2012/13 started at July 1, 2012 and ended at June 30, 2013 which means six months from 2012 and six months from 2013. In this analysis, the annual raw data in Ethiopia fiscal year has been changed to Gregorian calendar by adding two consecutive raw data of Ethiopian fiscal year and then divided by 2. For instance, Ethiopia imported 142,526.1 and 129,964.4 tons of gasoline in 1999/00 and 2000/01 Ethiopian fiscal year respectively; therefore, the gasoline imported in 2000 Gregorian calendar year has been calculated as (142,526.1 + 129,964.4)/2 which is equal to 136,245.25 tons and similar calculation has been done for other years.

6.1.7 Consumption of Biodiesel

The use of biodiesel in the transport sector is not started so far but expected to begin in the near future.

6.1.8 Consumption of Diesel

In Ethiopia, diesel is used by heavy vehicles, public transportation, construction machines and agricultural machines for road transport, and by diesel generators for electricity generation. The trend of imported diesel is presented below (see table 6.6).

Table 6.6: Trend of diesel import in Ethiopia

Diesel (million ton)												
Year	**2000**	**2002**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Diesel	0.522	0.555	0.586	0.616	0.658	0.713	0.773	0.890	1.02	1.1	1.08	1.07
Diesel (petajoule)												
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Diesel	22.13	23.55	24.85	26.10	27.89	30.24	32.76	37.75	43.44	46.58	45.95	45.34

As per the discussion with officials and experts of EPSE and MoWE during the fieldwork, from the imported biodiesel about 90% is used for transport, 8% for electricity generation and the rest 2% is taken as a distribution loss in the from movement loss, underground tank loss and vehicle tank loss.

6.1.9 Energy for Cement Production

The production process of cement in Ethiopia is the most energy intensive and requires a large amount of fossil fuels such as furnace oil, coal and petroleum coke. The minimum energy consumption for the pyroprocessing is about 4.2 gigajoule per ton of cement (i.e. taking the existing practice of Mugher Cement Factory's furnace oil consumption) **[14]**. The trend of cement production in the county is shown below (see table 6.7).

Table 6.7: Trend of cement production in Ethiopia (Source: MoI)

Cement Production (million ton)											
Year	**2000**	**2002**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Cement	0.816	0.819	0.919	0.890	1.42	1.25	1.32	1.46	1.96	2.27	2.61	3.24

Taking the average annual growth rate of cement production (i.e. 14.74%), cement production for 2012 is estimated at 3.72 million tons. The demand of cement is growing due to the growth of construction industry; and cement industries are expanded for increasing production to satisfy the growing demand.

6.2 Scenario Formulation

Scenario represents a self-consistent story line about how an energy system might evolve over time. LEAP supports long-range scenario analysis; and different researchers have used LEAP for scenario analysis to simulate the future trend of an energy system. For instance, Nilsson *et al.* (2012) formulated three scenarios to examine how energy needs for human and economic development can be met in a way that is compatible with long-term sustainable development at the global scale. The first one is a baseline scenario that considers business as usual trends for population growth, GHG emissions, macroeconomic indicators, energy consumption and production, and resource use, and assumes that current economic and energy policies will broadly continue, and that major efforts to tackle climate change will not materialize. The second one is the basic energy access scenario which explores trends similar to those in the baseline scenario but imposes a constraint on energy systems by assuming that there will be major global efforts to tackle climate change, keeping the global average temperature increase to below 2°C, and provisioning of basic energy access for all by 2050. The third one is the shared development agenda scenario which takes basic energy access scenario as a starting point and explores the implications of more equitable trajectories of income growth **[30]**. Islas *et al.* (2006) explored and evaluated three scenarios to analyze the bioenergy resource potential of Mexico for residential, transport and electric generation sectors. The first one is the base scenario in which fossil fuels are assumed to be the dominant source of energy. Whereas in the other two scenarios, moderate penetration and high penetration scenarios, the long-term shifts in bioenergy use were analyzed on the basis of technical and economic feasibility of bioenergy resources **[27]**. Fol (2012) analyzed the long-term renewable energy transition of Namibia using three alternative scenarios. The first scenario is 'business as usual scenario' which considers Namibian energy system undergoes no institutional change in the future. The second progressive renewable scenario considers the development of grid-connected renewable energy was considered. The third high renewable scenario considers the maximum utilization of renewable energy resources (wind, biomass and sun) to replace fossil fuels such as oil and coal **[23]**.

In this study, three scenarios namely, 'baseline' and other two alternative scenarios (i.e. 'moderate shift' and 'high shift') are formulated within a timeframe that goes from 2013 to 2030. The main bases for formulating the alternative scenarios are green economy strategy of Ethiopia (2011), cooking stoves investment plan (2011), biofuel development and utilization strategy (2007), energy policy (1994), environmental policy (1997), and information gathered using fieldwork (2013). The baseline scenario assumes the existing energy practices of Ethiopia would continue without significant change in the future. Whereas, the other two alternative scenarios considers future shifts in the bioenergy use of the country that include energy efficiency improvement in the household sector, biofuels deployment in the transport sectors, the introduction of agricultural residues as a fuel for cement production as well as bagasse and municipal solid waste for electricity generation. The moderate shift scenario is formulated based on the most likely achievable parameters taking into consideration the possible constraints such as financial, technical, technological and management inefficiency that would hinder implementation process of the shifts. On the other hand, the high shift scenario is formulated based on optimistic parameters/targets considering if there would not be significant constraints that could affect the implementation process.

The parameters/targets taken into consideration for each scenario have been presented below with justification.

6.2.1 Baseline Scenario

- From the total number of households of Ethiopia, 80% are taken as rural households and the rest 20% as urban households. The average household size is considered as 5 people per household and taken as common to all scenarios.
- The population is assumed to grow with annual growth rate of 2.4% which is average annual growth rate of population trend data.
- GDP (constant 2000 USD) is also considered to grow with annual growth rate of 8.4% which is average annual growth rate of GDP trend data.
- The annual growth rate percentage distribution of both rural and urban households by cooking stove is formulated taking the percentage distribution of 2004 and 2011 and it is summarized below (see table 6.8)

Table 6.8: Annual growth rate of household percentage distribution by cooking stove

Growth Rate of Urban Household Percentage Distribution			
Cooking Stove	**2004**	**2011**	**2012**
Traditional Wood Stoves	65.33	63.31	63.03
Growth Rate (%)		-3.1	-0.44
Traditional Charcoal Stoves	7.65	17.54	20.78
Growth Rate (%)		129.3	18.5
Electric Stoves	2.36	6.18	7.61
Growth Rate (%)		161.9	23.1
Kerosene Stoves	13.84	4.93	4.68
Growth Rate (%)		-64.4	-9.2
LPG Stoves	2.69	1.05	0.96
Growth Rate (%)		-610	-8.7
Others	6.1	3.4	3.19
Growth Rate (%)		-44.3	-6.3
Growth Rate of Rural Household Percentage Distribution			
Cooking Stove	**2004**	**2011**	**2012**
Traditional Wood Stoves	84.45	90.85	90.9

Growth Rate (%)		7.6	1.1
Traditional Charcoal Stoves	0.16	0.23	0.24
Growth Rate (%)		43.8	6.3
Electric Stoves	0.05	0.01	0.01
Growth Rate (%)	-0.3	-0.04	-0.006
Kerosene Stoves	0.21	0.17	0.17
Growth Rate (%)		-19	-2.7
LPG Stoves	0.07	0.04	0.04
Growth Rate (%)		-42.9	-6.1
Others	14.99	8.6	8.08
Growth Rate (%)		-42.6	-6.1

The shaded growth rates are the annual growth rates which are calculated by dividing the growth rates from 2004 to 2011 by 7; and these annual growth rates have been used to calculate the percentage distribution of households by 2012 and for baseline scenario. As shown in the above table, Kerosene, LPG stoves and other traditional stoves that use animal dung, sawdust, crop residues and other residues have shown decreasing trend from 2004 to 2011. In this scenario, the percentage distribution of urban households that will use kerosene stoves, LPG stoves and other traditional stoves are assumed to decline by -9%, -9% and -6% respectively; and the percentage distribution of rural households that will use kerosene stoves, LPG stoves and other traditional stoves is expected to decrease by -3%, -6% and -6% respectively. The percentage distribution of urban households that will use electric stoves is considered to increase by 3% following the expansion of electricity generation and access; and the percentage of distribution of rural households is also assumed to grow by 1% following the expansion of rural electrification. The trend shows that the percentage distribution of households for traditional charcoal stoves increased both in urban and rural areas; and considered to continue growth by 1% and 6% respectively. Currently, the use of bioethanol stove is insignificant and limited to refugee camp in Somali region and in a very few urban households. The use of biogas stoves can also be considered as insignificant like bioethanol stoves. The rest majority of the households are expected to use traditional wood stoves. Also, there are a small number of non-cook households (i.e. households who do not cook) in both urban and rural areas. The percentage distribution of urban and rural non-cook households is taken as 2% and 1% respectively and common to all scenarios.

- ☞ In this scenario, the use of E10 by Otto IC engine cars is assumed to continue in Addis Ababa and its surroundings. For the purpose of LEAP modeling and analysis, the volume composition of the blend is changed to energy composition using LHV and density of bioethanol (i.e. 26.8 MJ/Kg and 0.789 Kg/liter) and gasoline (i.e. 43.4 MJ/Kg and 0.741 Kg/liter); and the energy composition of the blend is a factor of these LHV and density (i.e. (26.8 * 0.789 * share of bioethanol (%)) /(26.8 * 0.789 * share of bioethanol (%) + 43.4 * 0.741 * share of gasoline (%)). Therefore, 10% of bioethanol blend by volume is equal to about 7% by energy content.
- ☞ Currently, since there is no large-scale biodiesel production for transport sector, this situation is assumed to continue as usual in this scenario.
- ☞ Currently, the use of agricultural residues as fuel for cement production is not started. In this scenario, this condition is assumed to continue as usual.
- ☞ Currently, there is no electricity generation from municipal solid waste and no excess electricity generation from cogeneration of bagasse by sugar industries to contribute for the national grid. In this scenario, these situations are assumed to continue as usual.

- From the existing practices, the conversion efficiencies of bioethanol, biodiesel, biogas and charcoal productions are taken at 42%, 33%, 7% and 24% respectively; and used to calculate the primary resources requirement. Common for all scenarios.
- Distribution loss of 2.2%, 2%, 2% and 5% are considered for bioethanol, biodiesel, biogas and charcoal productions respectively. Common for all scenarios.
- The complete combustion of bioethanol and biodiesel can produce 79.6 Kg and 70.8 Kg of CO_2 per gigajoule respectively while the combustion of gasoline and diesel can emit 69.3 Kg and 74.1 Kg of CO_2 per gigajoule respectively (see annex 1). However, the CO_2 emitted during combustion of bioethanol and biodiesel is part of the cycle in which CO_2 is absorbed from the atmosphere while growing of their feedstock crops. Therefore, the net emission of bioethanol and biodiesel can be considered as zero; and considering zero net CO_2 emission, 69.3 Kg and 74.1 Kg of CO_2 per gigajoule can be saved from using bioethanol and biodiesel as substitution of gasoline and diesel respectively. This is applied for all scenarios.
- By taking the average market price of volunteer and bilateral dealing, the revenue from carbon trading schemes is taken at 5 USD per ton of CO_2e abated **[44]**. This is also applied for all scenarios.

The summary of the parameters/targets for the baseline scenario is shown below (see table 6.9).

Table 6.9: Summary of parameters for the baseline scenario

Description	Growth Rate (%)	
Population	2.4	
GDP (Constant 2000 USD)	8.4	
Distribution of Urban Households by Cooking Stove (%)		
Cooking Stove	**Growth Rate (%)**	**Remark**
Traditional Wood Stove	Remainder (98)	2% Non-Cook
Improved Wood Stove	0	
Traditional Charcoal Stove	2	
Improved Charcoal Stove	0	
Electric Stove	4	
Kerosene Stove	-9	
LPG Stove	-9	
Biogas Stove	0	
Bioethanol Stove	0	
Others	-6	
Distribution of Rural Households by Cooking Stove (%)		
Cooking Stove	**Growth Rate (%)**	**Remark**
Traditional Wood Stove	Remainder (99)	1% Non-Cook
Improved Wood Stove	0	
Traditional Charcoal Stove	6	
Improved Charcoal Stove	0	
Electric Stove	1	
Kerosene Stove	-3	
LPG Stove	-6	
Biogas Stove	0	
Bioethanol Stove	0	
Others	-6	
Biofuels Blending (%)		

Biofuels	Share (%)	Remark
Bioethanol by Volume	10	No Change
Bioethanol by Energy	6	No Change
Biodiesel by Volume	0	No Change
Biodiesel by Energy	0	No Change
Substitution of Fossil Fuels in Cement Industries (%)		
Resource Type	**Share (%)**	**Remark**
Agricultural Residues	0	Not Started
Electricity Generation (GWh)		
Resource Type	**Generation**	**Remark**
Bagasse	0	Not Started
Municipal Solid Waste	0	Not Started

Note that, sugar industries generate electricity from bagasse for self-consumption but excess electricity generation from bagasse for the national grid is not yet started.

6.2.2 Moderate Shift Scenario

In this scenario as well as in high shift scenario, the values of most parameters/targets have been established based on the timeframe of each GTP of Ethiopia. GTP is a five year ambitious development plan used to increase growth, development and industrialization of the country to reach to middle-economy status by 2025 while developing green economy. The country's GTP1 is already implemented since 2011 and will end by 2015. GTP2 will be implemented from 2016 to 2020, GTP3 from 2021 to 2025 and GTP4 from 2026 to 2030.

- The population by GTP 4 (i.e. 2030) is considered to reach 120,000,000 from which 25% will live in urban areas. And this common for high shift scenario.
- The GDP of the country is estimated to reach 117.3 Billion USD considering annual GDP growth of 10% which is slightly higher than the average annual GDP growth rate of the GTP trend data.
- According to cooking investment plan of the country, 80% of the total rural households (i.e. about 14.4 million rural households) are expected to use improved wood stoves by 2030 **[48]**. In this scenario, considering financial constraints, technical constraints, management inefficiency and others constraints, about 75% of this target is assumed to be achieved which means 10.8 million rural households will use improved wood stoves (i.e. 60% of the total rural households). Considering evenly distribution for each GTP, the percentage distribution of rural households that use improved wood stoves will be 15%, 30% and 45% in 2015, 2020 and 2025 respectively. Similarly, 5% of the total urban households (i.e. about 0.3 million urban households) are expected to use improved wood stove by 2030. In this scenario, considering 75% of this target will be achieved, about 0.225 million of urban households (i.e. 3.75% of the total urban households) will use improved wood stoves by 2030; and the percentage distribution of urban households that use improved wood stoves by 2015, 2020 and 2025 will be 0.94%, 1.88% and 2.81% respectively considering evenly distribution for each GTP.
- The percentage distribution of urban households that will use improved charcoal stoves is assumed to be 9% by 2015 and increases to 15%, 20% and 25% by 2020, 2025 and 2030 respectively; and the percentage distribution of rural households that will use improved charcoal stoves is also considered to increase to 0.1%, 0.2%, 0.3% and 0.4% by 2015, 2020, 2025 and 2030 respectively. Due to the implementation of improved charcoal stoves, the number of households that use traditional charcoal stoves will decreases. As a result, the percentage of distribution of urban households that use traditional charcoal stoves will decrease to 15%, 10%, 5% and 0% by 2015, 2020, 2025 and 2030

respectively; and the percentage distribution of rural households will also decrease to 0.2%, 0.15%, 0.1% and 0.05% by 2015, 2020, 2025 and 2030 respectively.

- The number of urban households that use electric stoves will increase following the expansion of electricity generation projects and electricity access. From the cooking stoves investment plan, 53% of the total urban households (i.e. about 3.18 million urban households) are expected to use electric stoves by 2030 **[48]**; and considering 75% of this target will be achieved, 2.39 million urban households (i.e. 39.7% of the total urban households) will use electric stoves by 2030; and about 9.9%, 19.8% and 29.7% of the urban households by 2015, 2020 and 2025 respectively. The number of rural households that will use electric stoves is also expected to increase following the expansion of rural electrification; and 5% of the total rural households (i.e. about 0.9 million rural households) are expected to use electric stoves by 2030. Assuming 75% achievement for this scenario, 0.675 million rural households (i.e. 3.75% of the total rural households) will use electric stoves by 2030; and about 0.94%, 1.88% and 2.82% of rural households by 2015, 2020 and 2025 respectively.
- In this scenario, the use bioethanol stoves by urban households is considered to become significant since there are several initiatives like MoWE, GAIA and others for manufacturing, promotion and adoption of such stoves. Bioethanol stoves are better used in urban areas than rural areas because of lack of infrastructure to reach rural areas (i.e. poor access to bioethanol). Moreover, bioethanol is not competitive in terms of price with wood and biogas which are more accessible in rural areas. Consequently, 0.75%, 1.5%, 2.25% and 3% of the urban households are assumed to use bioethanol stoves by 2015, 2020, 2025 and 2030 respectively.
- Biogas stoves are more suitable for rural households due to the availability of animal dung for biogas production at household level; and according to the cooking investment plan, 5% of the total rural households (i.e. 0.9 million rural households) are expected to use biogas stoves by 2030. In this scenario, considering 75% achievement of this target, 0.675 million rural households (i.e. 0.375% of the total rural households) will use biogas stoves by; and the percentage distribution of rural households that use biogas stoves by 2015, 2020 and 2025 will be 0.94%, 1.88% and 2.82% respectively.
- Mainly due to the price increment of kerosene, the use of kerosene stoves is decreased in both urban and rural areas as shown in CSA welfare monitoring survey (2000, 2004 and 2011). In this scenario, the percentage distribution of urban households that will use kerosene stoves is considered to be 3.5% by 2015 and decrease to 2%, 0.5% and 0% by 2020, 2025 and 2030 respectively; and the percentage distribution of rural households that will use kerosene stoves is also assumed to decrease from 0.15% by 2015 to 0.05%, 0% and 0% by 2020, 2025 and 2030 respectively.
- Like kerosene stoves, the percentage distribution of households that use LPG stoves has also shown deceasing trend both in urban and rural areas. In this scenario, it is assumed that there will not be households that use LPG stoves after 2020. The percentage distribution of urban households that use LPG stoves will be 0.7% and 0.5% by 2015 and 2020 respectively; and the percentage distribution of rural households that use LPG stoves will be 0.03% and 0.01% by 2015 and 2020 respectively.
- The use of other traditional stoves for animal dung, agricultural residues, sawdust and other residues has shown decreasing trend by both urban and rural households. In this scenario, the urban households that will use other traditional stoves is assumed to decrease from 2.5% by 2015 to 1%, 0% and 0% by 2020, 2025 and 2030 respectively; and the percentage distribution of rural households that will use kerosene stoves is also considered to decrease from 6% by 2015 to 4%, 2% and 0% by 2020, 2025 and 2030 respectively.
- Considering 2% of the urban households and 1% rural households to be non-cook, 55.71%, 46.52%, 37.73% and 26.55% of the urban households will use traditional wood stove by 2015, 2020, 2025 and 2030 respectively; and the percentage distribution of rural households that use traditional wood stoves will be 75.64%, 60.83%, 45.96% and 31.05% by 2015, 2020, 2025 and 2030 respectively.

- In this scenario, 10% and 15% bioethanol blend with gasoline by volume (i.e. 7% and 10.5% by energy content) is assumed for Addis Ababa and its surroundings by 2015 and 2020 respectively; and 15% (i.e. 10.4% by energy content) and 20% (i.e. 14% by energy content) for the whole country by 2025 and 2030 respectively considering bioethanol blending stations will be expanded throughout the country. Biodiesel blend with diesel is assumed to be started by 2017 with B2 (i.e. 2% biodiesel blend diesel by volume). Considering the LHV and density of biodiesel (37.5 MJ/Kg, 0.88 Kg/liter and diesel (42.4 MJ/Kg and 0.844 Kg/liter), 2% biodiesel blend by volume is equal to about 1.8% by energy content. The blend by 2025 and 2030 is assumed to reach 5% and 7% by volume which means 4.6% and 6.5% by energy content respectively.
- One of the strategies of the green economy of the country is to use biomass resources like agricultural residues as a fuel for cement production so that to reduce fossil fuels consumption and GHG emissions. To achieve this objective, there is a target to replace 20% of the fossil fuels consumption of cement industries with biomass by 2030 **[44]**. In this scenario, 2% by 2015 to 5%, 10% and 15% of fossil fuels consumption is assumed to be replaced with agricultural residues per total production of cement by 2020, 2025 and 2030 respectively.
- Excess electricity generation from cogeneration of bagasse for the national grid is considered to be started in 2015 with 101 MW (558 GWh) from Methara, Wonji Shoa and Tendaho Sugar Factories, and assumed to be increased by same amount by 2020 and 2025 following the expansion of sugar industries; and excess electricity generation after 2025 is assumed to remain the same considering if there will not be expansion of sugar industries due to market saturation and other constraints. As a result, the excess electricity generation from cogeneration of bagasse will be 1,116 GWh, 1,674 GWh and 1,674 GWh in 2020, 2025 and 2030 respectively. Electricity generation from incineration of municipal solid waste is also considered to be started in 2015 with 50 MW (360 GWh) following waste to energy project of Addis Ababa. Waste to energy plants will be expanded among other major cities. In this scenario, Mekele, Bahir Dar, and Diredawa are assumed to have 25 MW (180 GWh) waste to energy plant each by 2015, 2020, 2025 and 2030. Thus, the total electricity generation from municipal solid waste will reach to 550 GWh, 720 GWh and 900 GWh respectively.
- A shift from using traditional wood stove to improved wood stoves (IWS) or fuel shift stoves (FSS) (i.e. electric and bioethanol and biogas stoves) is considered annually to save on average 2.2 tons of CO_2e per household. Furthermore, the shift from using traditional wood stoves to IWS and FSS is also considered annually to save 3 tons and 4.8 tons of wood per household respectively. This is applied for all scenarios.
- The complete combustion of agricultural residues can produce 100 Kg of CO_2 per gigajoule while the combustion of coal, furnace oil and petroleum coke can emit 77.4 Kg, 94.6 Kg and 97.5 KG of CO_2 per gigajoule respectively (see annex 1). Taking CO_2 emitted during combustion of agricultural residues is part of the cycle in which CO_2 is absorbed from the atmosphere while growing of the plants. Therefore, the net emission of agricultural residues can be considered as zero; and considering zero net CO_2 emission, on average 89.8 Kg of CO_2 per gigajoule on can be saved from using agricultural residues as a substitution of the above fossil fuels. This is also applied for high shift scenario.
- To evaluate the amount of foreign currency saving from reduction of gasoline and diesel importing, the average prices of gasoline (i.e. 1,093 USD per ton or 25 USD per gigajoule) and diesel (i.e. 951 USD per ton or 22 USD per gigajoule) are taken from EPSE. Since the price of oil is unpredictably fluctuating, these prices are taken as stable price. And this is common for high shift scenario and baseline scenario.
- Similarly, to evaluate the amount of the foreign currency saving from reduction of fossil fuels (i.e. coal, furnace oil and petroleum coke) importing for cement industries, the average price (i.e. 416

USD per ton or 12 USD per gigajoule) are taken. Since the price of fossil fuels is also unpredictably fluctuating, this price taken as stable price. And this is also applied for high shift scenario.

- In this scenario, the productivity of jatropha and castor is considered to be 2 and 1 tons per hectare respectively.

The summary of the parameters/targets for the moderate scenario are presented below (see table 6.10).

Table 6.10: Summary of parameters for the moderate shift scenario

Description	2030			
Population	120,000,000			
GDP (Constant 2000 USD)	117.3 Billion			
Distribution of Urban Households by Cooking Stove (%)				
Cooking Stove	**2015**	**2020**	**2025**	**2030**
Traditional Wood Stove	55.71	46.52	37.73	26.55
Improved Wood Stove	0.94	1.88	2.82	3.75
Traditional Charcoal Stove	15	10	5	0
Improved Charcoal Stove	9	15	20	25
Electric Stove	9.9	19.8	29.7	39.7
Kerosene Stove	3.5	2	0.5	0
LPG Stove	0.7	0.3	0	0
Biogas Stove	0	0	0	0
Bioethanol Stove	0.75	1.5	2.25	3
Others	2.5	1	0	0
Distribution of Rural Households by Cooking Stove (%)				
Cooking Stove	**2015**	**2020**	**2025**	**2030**
Traditional Wood Stove	75.64	60.83	45.96	31.05
Improved Wood Stove	15	30	45	60
Traditional Charcoal Stove	0.2	0.15	0.1	0.05
Improved Charcoal Stove	0.1	0.2	0.3	0.4
Electric Stove	0.94	1.88	2.82	3.75
Kerosene Stove	0.15	0.05	0	0
LPG Stove	0.03	0.01	0	0
Biogas Stove	0.94	1.88	2.82	3.75
Bioethanol Stove	0	0	0	0
Others	6	4	2	0
Biofuels Blending (%)				
Biofuels	**2015**	**2020**	**2025**	**2030**
Bioethanol by Volume	10	15	15	20
Bioethanol by Energy	7	10.4	10.4	14
Biodiesel by Volume	0	2	5	7
Biodiesel by Energy	0	1.8	4.6	6.5
Substitution of Fossil Fuels in Cement Industries (%)				
Resource Type	**2015**	**2020**	**2025**	**2030**
Agricultural Residues	2	5	10	15
Electricity Generation (GWh)				
Resource Type	**2015**	**2020**	**2025**	**2030**
Bagasse	558	1,116	1,674	1,674

Share (%)	61	67	69	64
Municipal Solid Waste	360	540	760	940
Share (%)	39	33	31	36
Total	**918**	**1,656**	**2,434**	**2,614**

6.2.3 High Shift Scenario

Unlike moderate scenario, this scenario is more optimistic. It considers high penetration in the use efficient cooking stoves as per cooking investment plan of the country; and it also considers high penetration in the efficient and modern use of bioenergy by household, transport, industry and for electricity generation. High productivity of biofuels crops is also one of the considerations of this scenario. The details of the parameters/targets which are established for this scenario are described as follow.

- The GDP of the country is estimated to reach 138 Billion USD considering annual GDP growth of 11% which is the targeted growth rate of the green economy plan of the country **[44]**.
- In this scenario, 80% of the total rural households are expected to use improved wood stoves by 2030 **[48]**; and considering evenly distribution for each GTP, the percentage distribution of rural households that use improved wood stove will be 20%, 40% and 60% in 2015, 2020 and 2025 respectively. On the other hand, 5% of the total urban households are expected to use improved wood stove by 2030; and the percentage distribution of urban households that use improved wood stoves by 2015, 2020 and 2025 will be 1.25%, 2.5% and 4.75% respectively.
- The percentage distribution of urban households that will use improved charcoal stove is considered to be 12% by 2015 and increase to 20% and 25% by 2020 and 2025 2030 respectively then decrease to 20% by 2030; and the percentage distribution of rural households that will improved charcoal stove is also considered to increase to 0.15%, 0.3%, 0.45% and 0.6% by 2015, 2020, 2025 and 2030 respectively. Due to the implementation of improved charcoal stoves, the number of households that use traditional charcoal stoves will decrease. In this scenario, the percentage of distribution of urban households that use traditional charcoal stoves will decrease to 12.5%, 5%, 0% and 0% by 2015, 2020, 2025 and 2030 respectively; and the percentage distribution of rural households will also decrease to 0.16%, 0.06%, 0% and 0% by 2015, 2020, 2025 and 2030 respectively.
- 53% of the total urban households are expected to use electric stoves by 2030 **[48]**; and about 13.25%, 26.5% and 39.75% of the urban households by 2015, 2020 and 2025 respectively. Whereas, 5% of the total rural households would use electric stoves by 2030; and about 1.25%, 2.5% and 3.75% of rural households by 2015, 2020 and 2025 respectively.
- 1%, 2%, 3% and 4% of the total urban households are assumed to use bioethanol stoves by 2015, 2020, 2025 and 2030 respectively.
- 5% of the total rural households are expected to use biogas stoves by 2030; and the percentage distribution of rural households that use biogas stoves by 2015, 2020 and 2025 will be 1.25%, 2.5% and 3.75% respectively.
- The percentage distribution of urban households that will use kerosene stoves is considered to be 3% by 2015 and decreases to 1.5% by 2020 and 0% since 2025; and the percentage distribution of rural households that will use kerosene stoves is also assumed to decrease from 0.1% by 2015 to 0% since 2020.
- In this scenario, it is assumed that there will not be households that use LPG stoves after 2015. The percentage distribution of urban households that use LPG stoves will be 0.5% by 2015; and the percentage distribution of rural households that use LPG stoves will 0.02% by 2015.

- ☞ The urban households that will use other traditional stoves is assumed to decrease from 2% by 2015 to 0% since; and the percentage distribution of rural households that will use kerosene stoves is also considered to decrease from 5% by 2015 to 2% by 2020 and 0% since 2025.
- ☞ Considering 2% of the urban household and 1% rural households are to be non-cook. 52.25%, 40.5%, 26.5% and 16% of the urban households will use traditional wood stove by 2015, 2020, 2025 and 2030 respectively; and the percentage distribution of rural households that use traditional wood stoves will be 71.07%, 51.64%, 31.05% and 8.4% by 2015, 2020, 2025 and 2030 respectively.
- ☞ In this scenario, 10% bioethanol blend with gasoline by volume (i.e. 7% by energy content) is considered for Addis Ababa and its surroundings by 2015; and 20% (i.e. 10.4% by energy content), 20% (i.e. 14% by energy content) and 25% (i.e. 18% by energy content) for the whole country by 2020, 2025 and 2030. Biodiesel blend with diesel is assumed to be started in 2017 with B5 (i.e. 5% biodiesel blend with diesel by volume or 4.6% by energy content); and the blend by 2025, and 2030 is considered to reach 7% and 10% by volume which means 6.5% and 9.3% by energy content respectively.
- ☞ 5%, 10%, 15% and 20% of fossil fuels consumption of cement industries is assumed to be replaced with agricultural residues by 2015, 2020, 2025 and 2030 respectively.
- ☞ Excess electricity generation from cogeneration of bagasse for the national grid is considered at 558 GWh by 2015 and assumed to be increased by this amount by 2020, 2025 and 2030 (i.e. 1,116 GWh, 1,674 GWh and 2,232 GWh respectively). Electricity generation from incineration of municipal solid waste is also considered to be 360 GWh by 2015. Waste to energy plants will be expanded among other major cities. In this scenario, Mekele and Bahir Dar, Diredawa and Awassa, and Adama and Jimma are assumed to have 25 MW (180 GWh) waste to energy plant each by 2020, 2025 and 2030 respectively. Thus, the total electricity generation from municipal solid waste will reach to 720 GWh, 1080 GWh and 1440 GWh by 2015, 2020 and 2030 respectively.
- ☞ In this scenario, considering productivity improvement measures would be taken, the productivity of jatropha and castor would increased to 3.5 and 1.2 tons per hectare respectively.

The summary of the parameters/targets for high shift scenario are presented below (see table 6.11).

Table 6.11: Summary of parameters for the high shift scenario

Description	2030			
Population	120,000,000			
GDP (Constant 2000 USD)	138 Billion			
Distribution of Urban Households by Cooking Stove (%)				
Cooking Stove	**2015**	**2020**	**2025**	**2030**
Traditional Wood Stove	52.25	40.5	26.5	16
Improved Wood Stove	1.25	2.5	3.75	5
Traditional Charcoal Stove	12.5	5	0	0
Improved Charcoal Stove	12	20	25	20
Electric Stove	13.25	26.5	39.75	53
Kerosene Stove	3	1.5	0	0
LPG Stove	0.5	0	0	0
Biogas Stove	0	0	0	0
Bioethanol Stove	1	2	3	4
Others	2	0	0	0
Distribution of Rural Households by Cooking Stove (%)				
Cooking Stove	**2015**	**2020**	**2025**	**2030**

Traditional Wood Stove	71.07	51.64	31.05	8.4
Improved Wood Stove	20	40	60	80
Traditional Charcoal Stove	0.16	0.06	0	0.0
Improved Charcoal Stove	0.15	0.3	0.45	0.6
Electric Stove	1.25	2.5	3.75	5
Kerosene Stove	0.1	0	0	0
LPG Stove	0.02	0	0	0
Biogas Stove	1.25	2.5	3.75	5
Bioethanol Stove	0	0	0	0
Others	5	2	0	0
Biofuel Blending (%)				
Biofuels	**2015**	**2020**	**2025**	**2030**
Bioethanol by Volume	10	15	20	25
Bioethanol by Energy	7	10.4	14	18
Biodiesel by Volume	0	5	7	10
Biodiesel by Energy	0	4.6	6.5	9.3
Substitution of Fossil Fuels in Cement Industries (%)				
Resource Type	**2015**	**2020**	**2025**	**2030**
Agricultural Residues	2	10	15	20
Electricity Generation Targets (GWh)				
Resource Type	**2015**	**2020**	**2025**	**2030**
Bagasse	558	1,116	1,754	2,234
Share (%)	57	59	61	61
Municipal Solid Waste	360	760	1,080	1,440
Share (%)	43	041	39	39
Total	**918**	**1,876**	**2,754**	**3,672**

6.3 LEAP Branch Structure of the Model

The LEAP branch structure is the detail framework of the model which is developed to analyze the scenarios. It has five main branches namely, key assumptions, demand, transformation, resources and indicators. Each main branch has several sub-branches (see figure 6.1).

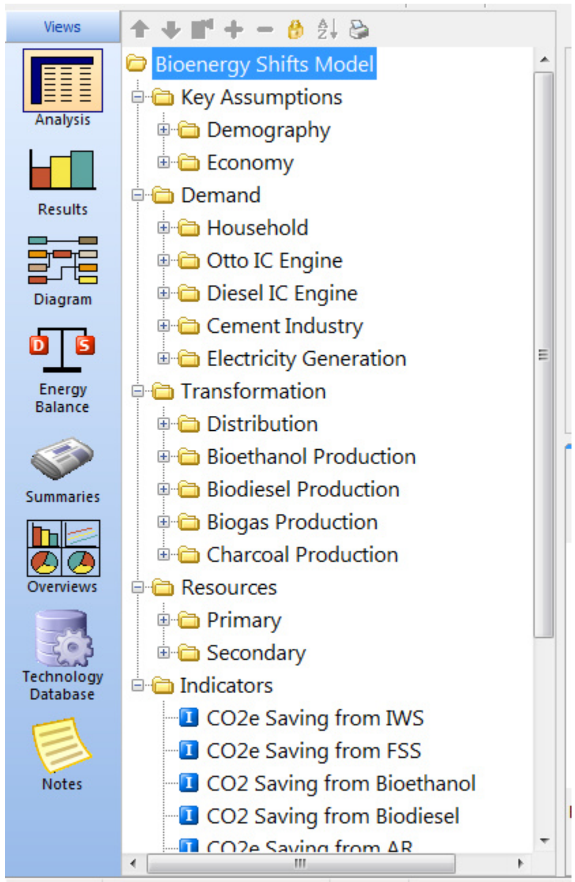


Figure 6.1: LEAP branch structure of the model

The relation diagrams created in the LEAP for demand to resource modeling and analysis is shown below (see figure 6.2).

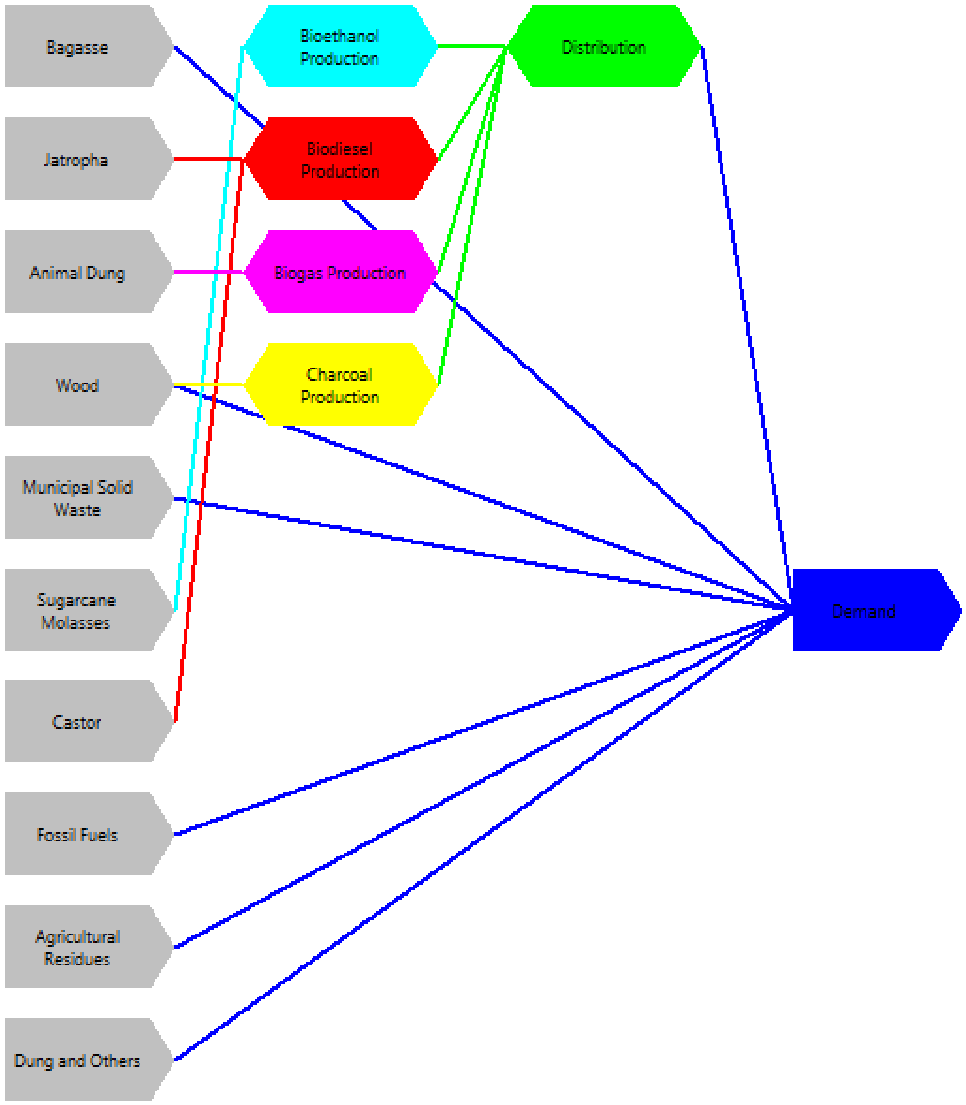


Figure 6.2: Demand to resource relationship diagram

It is seen that wood and animal dung are used directly for cooking as well as further processed to produce charcoal and biogas respectively. Bagasse, municipal solid waste, agricultural residues and others (i.e. crop residues, sawdust and other residues) are directly delivered to the demand side. Sugarcane molasses is processed to produce bioethanol while jatropha and castor to produce biodiesel.

7 Chapter Seven: Results

In this section, the results obtained from the analysis such as energy demand, production, primary resources requirement, and indicators are presented.

7.1 Energy Demand

Generally, the total energy demand by all sectors will increase in baseline scenario. However, the final energy demand by household (i.e. final energy demand for cooking) tends to decrease in the both moderate and high shift scenarios.

7.1.1 Sector

The energy demand would reach to 1,406.32, 1,265.48 and 1,212.82 million gigajoules by 2015 in the baseline, moderate shift and high shift scenarios respectively; and household sector would account for 94.3%, 92.6% and 92.2% of the total energy demand respectively (see figure 7.1 and table 7.1).

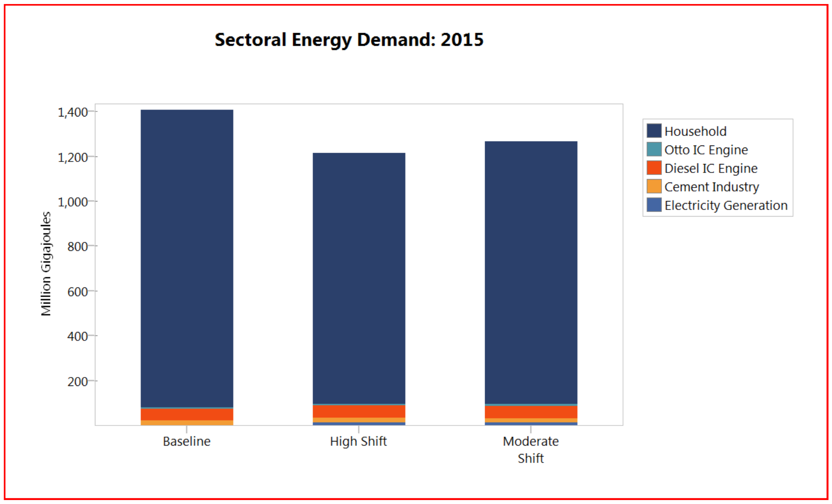


Figure 7.1: Energy demand of sectors by 2015

The energy demand would increase to 2,096.36 million gigajoules by 2030 in the baseline scenario whereas it would decrease to 1,191.78 and 984.15 million gigajoules in the moderate shift and high shift scenarios respectively of which, the household sector would account for 89.4%, 74.7% and 64.9% respectively (see figure 7.2 and table 7.1).

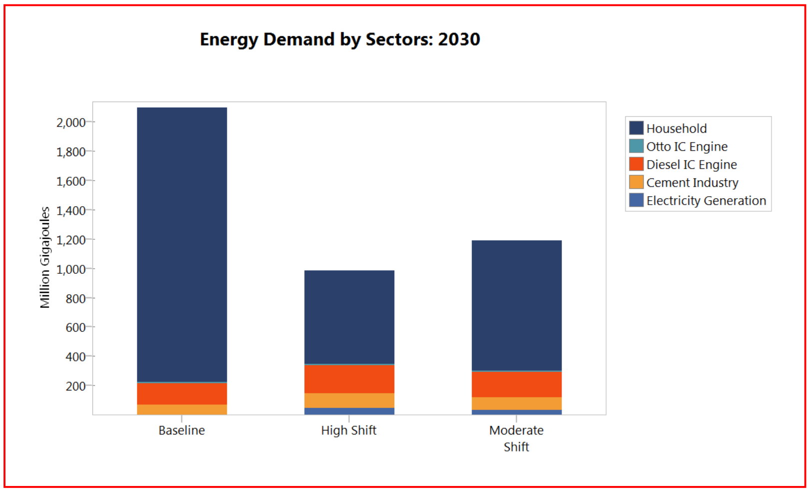


Figure 7.2: Energy demand of sectors by 2030

Table 7.1: Energy demand of sectors by 2015 and 2030

Energy Demand (Million Gigajoules)						
Description	**2015**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Household	1,326.38	1,171.78	1,117.68	1,874.60	890.51	638.39
Otto IC Engine	6.63	6.72	6.82	7.69	8.41	9.19
Diesel IC Engine	53.42	54.93	55.7	147.38	174.25	189.36
Cement Industry	19.89	20.78	21.35	66.69	86.81	102.17
Electricity Generation	0	11.26	11.26	0	31.8	45.06

7.1.2 Household

In the baseline, moderate shift and high shift scenarios, the energy demand for cooking by urban households would be 227.04, 221.77 and 208.85 million gigajoules by 2015 respectively; and wood demand would account for 75.1%, 75.3% and 75.5% of the total energy demand respectively (see figure 7.3 and table 7.2).

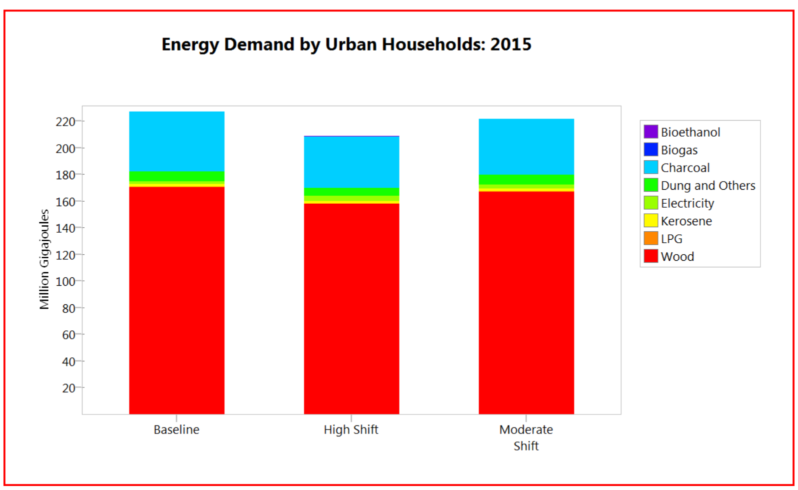


Figure 7.3: Energy demand for cooking by urban households by 2015

The energy demand for cooking by urban households would reach to 306.18 million gigajoules by 2030 in the baseline scenario but it would reduce to 178.15 and 132.69 million gigajoules in the moderate shift and high shift scenarios respectively of which, wood demand would account for 72.2%, 70.1% and 59.9% respectively (see figure 7.4 and table 7.2).

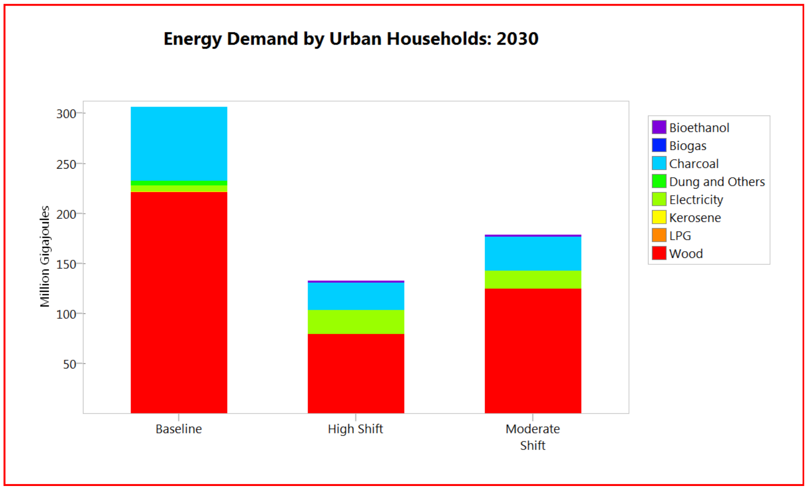


Figure 7.4: Energy demand for cooking by urban households by 2030

The energy demand for cooking by rural households would be 1,099.34, 950.01 and 908.84 gigajoules by 2015 in the baseline, moderate shift and high shift scenarios respectively of which, wood demand using traditional wood stoves would account for 92.9%, 92.6% and 93.4% respectively (see figure 7.5 and table 7.2).

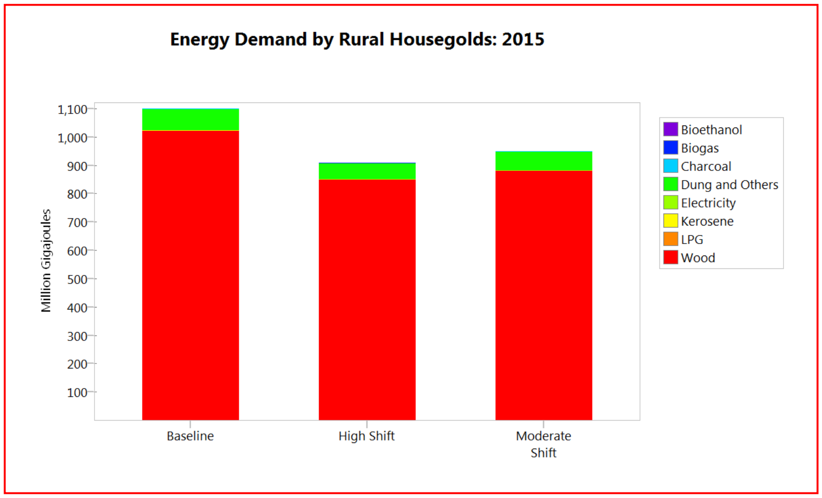


Figure 7.5: Energy demand for cooking by rural households by 2015

In the baseline scenario, the energy demand for cooking by rural households would reach to 1,568.42 million gigajoules by 2030. However, it would decrease to 712.36 and 505.7 million gigajoules in the moderate shift and high shift scenarios respectively; and wood demand would account for 96.8%, 98% and 96.4% of the total primary energy demand respectively (see figure 7.6 and table 7.2).

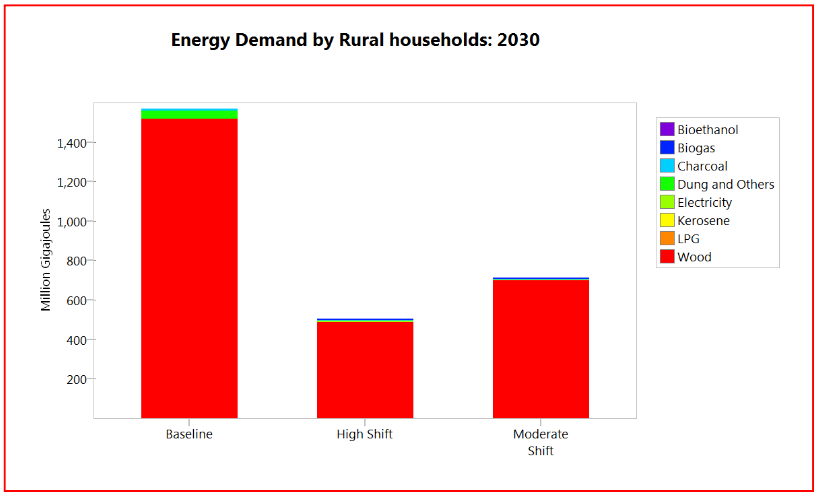


Figure 7.6: Energy demand for cooking by rural households by 2030

Table 7.2: Energy demand for cooking by 2015 and 2030

Energy Demand by Urban Households (Million Gigajoules)						
Cooking Fuel	2015			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
Wood	170.52	167.02	157.77	221.15	124.85	79.51
Charcoal	44.66	41.56	38.65	74	33.6	26.88
Electricity	2.39	2.96	3.96	6.15	17.86	23.85
Kerosene	1.89	2.23	1.92	0.65	0	0
LPG	0.23	0.24	0.17	0.08	0	0
Bioethanol	0	0.31	0.41	0	1.84	2.45
Biogas	0	0	0	0	0	0
Others	7.34	7.45	5.96	4.14	0	0
Energy Demand by Rural Households (Million Gigajoules)						
Cooking Fuel	**2015**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Wood	1,021.84	879.94	849.15	1,517.74	698.3	487.35
Charcoal	2.39	1.96	1.79	8.16	2.12	2.42
Electricity	0.01	1.03	1.37	0.02	5.06	6.75
Kerosene	0.37	0.35	0.23	0.33	0	0
LPG	0.04	0.04	0.03	0.02	0	0
Bioethanol	0	0	0	0	0	0
Biogas	0	1.4	1.86	0	6.88	9.18
Others	74.7	65.29	54.41	42.14	0	0

7.1.3 Otto IC Engine Vehicles

The energy demand of Otto IC engine vehicles would reach to 6.63, 6.72 and 6.82 million gigajoules by 2015 in the baseline, moderate shift and high shift scenarios respectively; and bioethanol would account for 4.9% of the total energy demand in all scenarios. On the other hand, the primary energy demand by Otto IC engine vehicles in the baseline, moderate shift and high shift scenarios would increase to 7.69, 8.41 and 9.19 million gigajoules by 2030 respectively of which, bioethanol would account for 4.9%, 14% and 18% respectively.

7.1.4 Diesel IC Engine Vehicles

The energy demand of diesel IC engine vehicles would be 61.16, 64.07 and 65.67 million gigajoules by 2017 in the baseline, moderate shift and high shift scenarios respectively; and biodiesel would account for 1.8% and 4.6% of the total energy demand in the moderate shift and high shift scenarios respectively. Whereas, the energy demand of diesel IC engine vehicles would reach to 147.38, 174.25 and 189.36 million gigajoules by 2030 in the baseline, moderate shift and high shift scenarios respectively of which, biodiesel would account for 6.5% and 9.3% in the moderate shift and high shift scenarios respectively.

7.1.5 Cement Industry

The energy demand of cement industries would reach to 19.89, 20.78 and 21.35 million gigajoules by 2015 in the baseline moderate shift and high shift scenarios respectively; and agricultural residues would account for 2% of the total energy demand in both the moderate shift and high shift scenarios. While, the energy demand of cement industries in the baseline, moderate shift and high shift scenarios would increase to 66.69, 86.81 and 102.17 million gigajoules by 2013 respectively of which, agriculture residues would cover 2%, 15% and 20% of the total energy demand respectively.

7.1.6 Electricity Generation

The energy demand for electricity generation would be 11.26 million gigajoules by 2015 for both moderate and high shift scenarios of which, 45.8% would be covered by municipal solid waste. On the other hand, the energy demand for electricity generation would reach to 31.8 and 45.06 million gigajoules by 2030 in the moderate shift and high shift scenarios respectively; and municipal solid waste would account for 42.6% and 45.8% of the total primary energy demand respectively.

7.2 Production

The production of bioethanol for both household sector and Otto engine vehicles would reach to 0.33, 0.65 and 0.76 million gigajoules by 2015 in the baseline, moderate and high shift scenarios respectively; and it would increase to 0.39, 3.08 and 4.19 million gigajoules by 2030 respectively. There would no biodiesel production in the baseline scenario. On the other hand, the production of biodiesel for diesel engine vehicles would be 1.18 and 3.08 million gigajoules by 2017 for the moderate and high shift scenarios respectively; and it would reach to 11.56 and 17.97 million gigajoules by 2030 respectively. There would also no biogas production in the baseline scenario. Whereas, biogas production for households would reach to 1.43 and 1.9 million gigajoules by 2015 in the moderate and high shift scenarios respectively; and it would increase to 7.03 and 9.37 million gigajoules by 2030 respectively. Charcoal production for households would be 49.52, 45.81 and 42.58 million gigajoules by 2015 in the baseline, moderate and high shift scenarios respectively; and it would reach to 86.49, 37.6 and 30.84 million gigajoules million gigajoules by 2030 respectively (see table 7.3).

Table 7.3: Production by 2015/17 and 2030

Production (Million Gigajoules)						
Description	2015			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
Bioethanol	0.33	0.65	0.76	0.39	3.08	4.19

Biogas	0	1.43	1.9	0	7.03	9.37
Charcoal	49.42	45.81	42.58	86.49	37.6	30.84

Description	2017			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
Biodiesel	0	1.18	3.08	0	11.56	17.97

7.3 Primary Resources Requirement

The primary resources requirement is automatically calculated by LEAP using bottom-up approach across the supply chain (i.e. demand to distribution loss to production to conversion process efficiency to primary resources requirement). It would reach to 1,501.43, 1,364.52 and 1,306.6 million gigajoules by 2015 in the baseline, moderate shift and high shift scenarios respectively; and wood requirement for cooking and charcoal production would account for 93.2%, 90.7% and 90.7% of the total primary resources requirement respectively (see figure 7.7 and table 7.4).

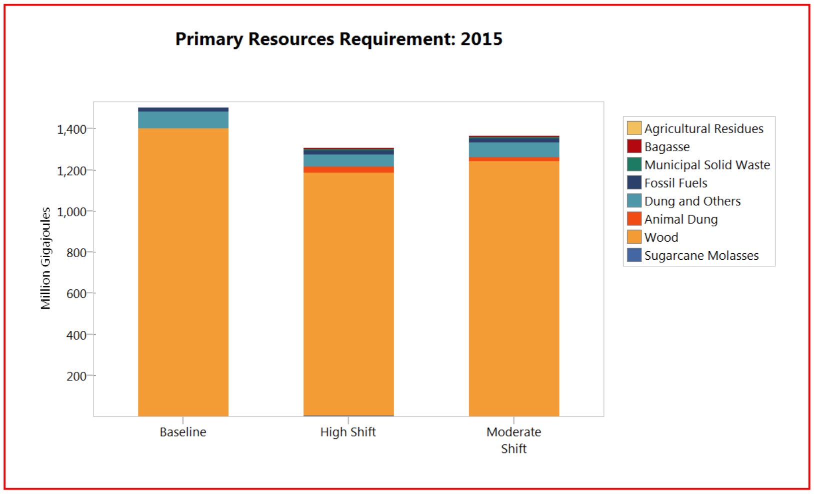


Figure 7.7: Primary resources requirement by 2015

The primary resources requirement would shift to 2,213.14, 1,241.13 and 1,040.85 million gigajoules by 2030 in the baseline, moderate shift and high shift scenarios respectively of which, wood requirement for cooking and charcoal production would account for 94.9%, 78.9% and 66.8% respectively (see figure 7.8 and table 7.4).

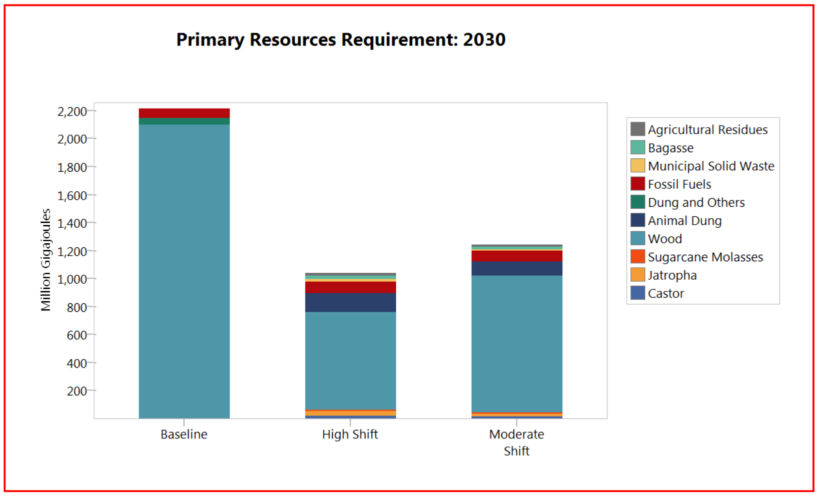


Figure 7.8: Primary resources requirement by 2030

Table 7.4: Primary resources requirement by 2015/17 and 2030

Primary Resources Requirement (Million Gigajoules)						
Description	**2015**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Wood	1,382.45	1,222.79	1,170.35	2,099.25	979.8	695.36
Agricultural Residues	0	0.42	0.43	0	13.02	20.43
Animal Dung	0	20.36	27.08	0	100.36	133.82
Bagasse	0	6.11	6.11	0	18.25	24.44
Municipal Solid Waste	0	5.16	5.16	0	13.55	20.62
Sugarcane Molasses	0.79	1.55	1.8	0.92	7.34	9.98
Dung and Others	82.04	72.74	60.37	46.29	0	0
Description	**2017**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Jatropha	0	2.32	6.06	0	22.76	35.39
Castor	0	1.25	3.26	0	12.26	19.06

7.4 Indicators

7.4.1 GHG Emissions Saving

Taking the assumptions of emissions saving in the moderate shift and baseline scenarios sections above, the use of improved wood stoves would save 4.89 and 6.52 million tons of CO_2e by 2015 in the moderate and high shift scenarios respectively; and the saving would reach to 24.25 and 32.34 million tons of CO_2e by 2030 respectively. On the other hand, the use of fuel switch stoves could save 0.705, 1.54 and 2.05 million tons of CO_2e by 2015 in the baseline, moderate shift and high shift scenarios respectively; and the saving could reach to 1.81, 8.61 and 11.48 million tons of CO_2e by 2030 respectively. By using bioethanol as transport fuel, 22.5, 22.84 and 23.17 thousand tons of CO_2 would be reduced by 2015 in the baseline, moderate shift and high shift scenarios respectively; and the reduction would increase to 26.12, 81.57 and 114.57 thousand tons of CO_2 by 2030 respectively. The use of biodiesel for transport would reduce 85.46 and 223.5 thousand tons of CO_2 by 2017 in the baseline, moderate shift and high shift scenarios respectively; and the reduction would reach to 839.27 and 1,304.91 thousand tons of CO_2 by 2030 respectively. By using agricultural residues as a fuel for cement production, 37.32 and 38.35 thousand tons of CO_2 would be reduced by 2015 in the moderate shift and high shift scenario respectively; and the reduction would increase to 1,169.35 and 1,834.97 thousand tons of CO_2 by 2030 respectively (see table 7.5).

Table 7.5: GHG emissions saving by 2015/17 and 2030

GHG Emissions Saving (Million Tons)						
Description	2015			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
CO_2e Saving from IWS	0	4.89	6.52	0	24.25	32.34
CO_2e Saving from FSS	0.705	1.54	2.05	1.81	8.61	11.48
CO_2 Saving from Bioethanol	0.023	0.023	0.023	0.026	0.82	0.11
CO_2 Saving from AR	0	0.037	0.038	0	1.17	1.83
Description	2017			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
CO_2 Saving from Biodiesel	0	0.085	0.233	0	0.84	1.3

7.4.2 Wood Saving

Taking the justification of wood saving in the moderate shift scenario section above, the shift from traditional wood stoves to IWS and FSS is also considered annually to save 3 tons and 4.8 tons of wood per household respectively. The use of improved wood stoves would also save 6.67 and 8.89 million tons of wood by 2015 in the moderate and high shift scenarios respectively; and the saving would reach to 33.08 and 44.1 million tons of wood by 2030 respectively. While, the use of fuel switch stoves could save 1.54, 3.35 and 4.48 million tons of wood by 2015 in the baseline, moderate shift and high shift scenarios respectively; and the saving could reach to 3.95, 18.78 and 25.06 million tons of wood by 2030 respectively (see table 7.6).

Table 7.6: Wood saving by 2015 and 2030

Land Use (Thousand Hectares)						
Description	2015			2030		
	Baseline	Moderate Shift	High Shift	Baseline	Moderate Shift	High Shift
Wood Saving from IWS	0	6.67	8.89	0	33.08	44.1
Wood Saving from FSS	1.54	3.35	4.48	3.95	18.78	25.06

7.4.3 Foreign Currency Saving

In baseline, moderate shift and high shift scenarios, 8.12, 8.24 and 8.36 million USD would be saved from using bioethanol as transport fuel (i.e. from reducing gasoline import) by 2015 respectively; and the saving would reach to 9.42, 29.43 and 41.33 million USD by 2030 respectively. While, biodiesel would save 25.37 and 66.35 million USD from reducing diesel import by 2017 in the moderate and high shift scenarios respectively; and the saving would increase to 249.18 and 387.72 million USD by 2030 respectively. In moderate shift and high shift scenarios, 4.99 and 5.12 million USD would be saved from using agricultural residues in cement industries (i.e. reducing fossils fuel import) by 2015 respectively; and the saving would reach to 156.26 and 245.21 million USD by 2030 respectively (see table 7.7).

Table 7.7: Foreign currency saving by 2015/17 and 2030

Foreign Currency Saving (Million USD)						
Description	**2015**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Currency Saving from Bioethanol	8.12	8.24	8.36	9.42	29.43	41.33
Currency Saving from AR	0	4.99	5.12	0	156.26	245.21
Description	**2017**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Currency Saving from Biodiesel	0	25.37	66.35	0	249.18	387.42

7.4.4 Land Use

The land required for jatropha cultivation would be 46.27 and 69.28 thousand hectares by 2017 in the moderate shift and high shift scenarios; and it would reach to 454.45 and 404.51 thousand hectares by 2030 respectively. In moderate shift and high shift scenarios, 49.93 and 108.81 thousand hectares of land would be required by for castor cultivation respectively by 2017; and it would reach to 490.31 and 635.28 thousand hectares by 2030 respectively (see table 7.8).

Table 7.8: Land Use by 2017 and 2030

Land Use (Thousand Hectares)						
Description	**2017**			**2030**		
	Baseline	**Moderate Shift**	**High Shift**	**Baseline**	**Moderate Shift**	**High Shift**
Land for Jatropha	0	46.27	69.28	0	454.45	404.51
Land for Castor	0	49.93	108.81	0	490.31	635.28

Note that, bioethanol is not directly produced from sugarcane rather it is produced from molasses. The main product of the sugar industries is sugar. Moreover, not all the molasses is used for bioethanol production. For these reasons, calculating the land use for sugarcane cultivation directly from bioethanol using bottom-up approach does not indicate the real figure.

8 Chapter Eight: Discussion and Conclusion

8.1 Discussion

Wood

Wood demand in baseline scenario for both cooking and charcoal making would increase. However, it would decrease in moderate shit and high shift scenarios due to energy efficiency improvement using improved wood stoves and fuel switch stoves (see table 8.1). Wood would continue as a largest energy source for the households. Its demand for cooking in the baseline scenario would increase from 1,192.36 to 1,738.89 million gigajoules. This corresponds to 89.9% and 92.8% of the total energy demand for cooking by 2015 and 2030 respectively. The rural households' wood demand would account for 85.7% and 88.7% of the total wood demand for cooking by 2015 and 2030 respectively. In the moderate shift scenario, wood demand would decrease from 1,046.96 to 823.15 million gigajoules by 2015 and 2030 respectively of which, 84.05% and 84.8% would be consumed by rural households by 2015 and 2030 respectively. On the other hand, wood demand in high shift scenario would decrease from 1,006.92 to 566.86 million gigajoules by 2015 and 2030 respectively of which, the rural households' demand accounted for 84.3% and 85.97% respectively. The use of improved wood stoves in the moderate shift scenario would save 6.67 and 33.08 million tons of wood by 2015 and 2030; the corresponding CO_2e saving would reach to 4.89 and 24.25 million tons; and the revenue from carbon trading schemes would be 24.45 and 121.25 million USD respectively. While, the use of improved wood stoves in the high shift scenario would save 8.89 and 44.1 million tons of wood by 2015 and 2030; the corresponding CO_2e saving would be 6.52 and 32.34 million tons; and the revenue from carbon trading schemes would reach to 32.6 and 161.7 million USD respectively. In addition, the use of fuel switch stoves in the moderate shift scenario could save 3.35 and 18.78 million tons of wood by 2015 and 2030; the corresponding CO_2e saving could be 1.54 and 8.61 million tons; and the revenue from carbon trading schemes could reach to 7.7 and 43.05 million USD respectively. On the other hand, the use of fuel switch stoves in the high shift scenario would save 4.48 and 25.06 million tons of wood by 2015 and 2030; the corresponding CO_2e saving could reach to 2.05 and 11.48 million tons; and the revenue from carbon trading schemes could be 10.25 and 57.4 million USD respectively.

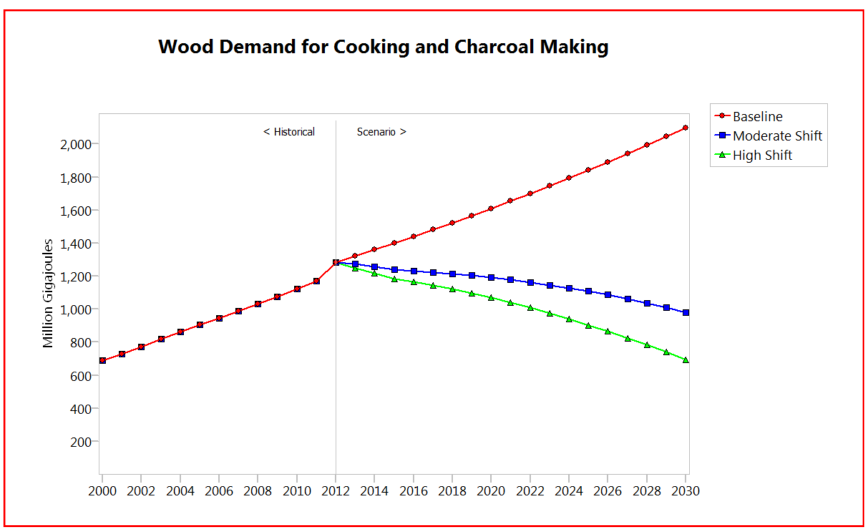


Figure 8.1: Trends of wood demand for cooking and charcoal making

Charcoal

Charcoal demand would also increase in the baseline scenario. Whereas, it would decrease in moderate shift and high shift scenarios due to efficiency improvement using improved charcoal stoves (see table 8.2). In the baseline scenario, charcoal demand would increase from 47.05 to 82.16 million gigajoules by 2015 and 2030 respectively of which, the urban households' charcoal demand would be 94.9% and 90.07%; and the corresponding wood demand for making this charcoal would be 206.35 and 360.36 million gigajoules respectively. Charcoal demand in the moderate shift scenario would decrease from 43.52 to 35.72 million gigajoules by 2015 and 2030 respectively; the urban households' charcoal demand would account for 95.5% and 94.06% of the total charcoal demand; and the corresponding would wood demand for charcoal making would be 190.87 and 156.65 million gigajoules respectively. In the high shift scenario, the charcoal demand would decline from 40.45 to 29.3 million gigajoules by 2015 and 2030 respectively from which, the urban households' charcoal demand would be 95.6% and 91.7%; and the corresponding would wood required for charcoal making would be 177.41 and 128.5 million gigajoules respectively.

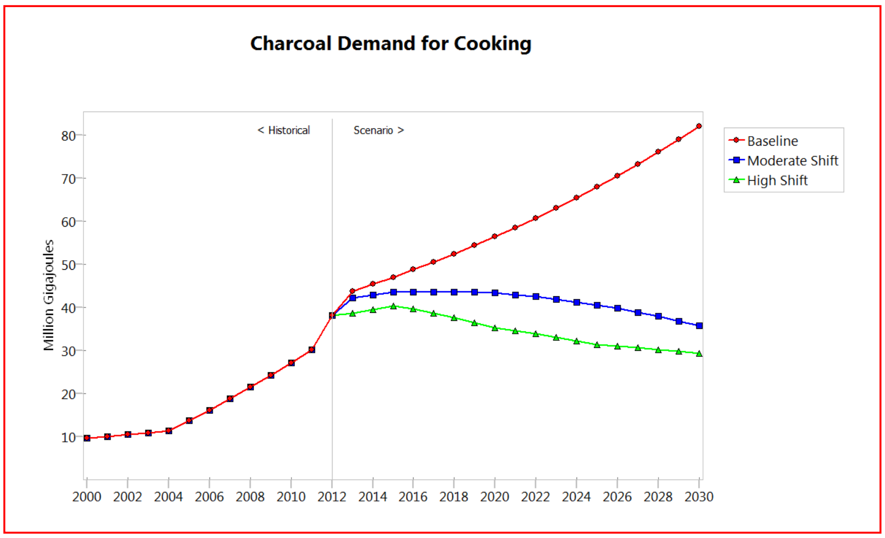


Figure 8.2: Trends of charcoal demand for cooking

Bioethanol

Bioethanol demand for both transport and cooking would grow in all scenarios (see table 8.3). In the baseline scenario, only for transport, bioethanol demand would increase from 0.32 to 0.38 million gigajoules by 2015 and 2030 respectively. The corresponding foreign currency saving from using this bioethanol in the transport sector (i.e. reducing gasoline import) would be 8.12 and 9.42 million USD respectively. Moreover, 22.5 and 26.12 thousand tons of CO_2 would be reduced by 2015 and 2030; the revenue from carbon trading schemes could reach to 112.5 and 132.5 thousand USD; and the sugarcane molasses required for the production of this bioethanol would reach to 0.79 and 0.92 million gigajoules respectively. On the other hand, bioethanol demand in the moderate shift scenario would increase from 0.63 to 3.01 million gigajoules by 2015 and 2030 respectively from which, bioethanol demand for transport sector would account for 51.9% and 39.1%; and the corresponding foreign currency saving would reach to 8.24 and 29.43 million USD respectively. In addition, 22.84 and 81.57 thousand tons of CO_2 would be reduced by 2015 and 2030; the revenue from carbon trading schemes could reach to 114.2 and 407.85 thousand USD; and the sugarcane molasses required for production would reach to 1.55 and 7.34 million gigajoules respectively. In the high shift scenario, bioethanol demand would increase from

0.74 to 4.1 million gigajoules by 2015 and 2030 respectively of which, bioethanol demand for transport sector would account for 45.1% and 40.3%; and the corresponding foreign currency saving would be 8.36 and 41.33 million USD respectively. Furthermore, 23.17 and 114.57 thousand tons of CO_2 would be reduced by 2015 and 2030; the revenue from carbon trading schemes could reach to 115.85 and 572.85 thousand USD; and the sugarcane molasses required for production would reach to 1.8 and 9.98 million gigajoules respectively.

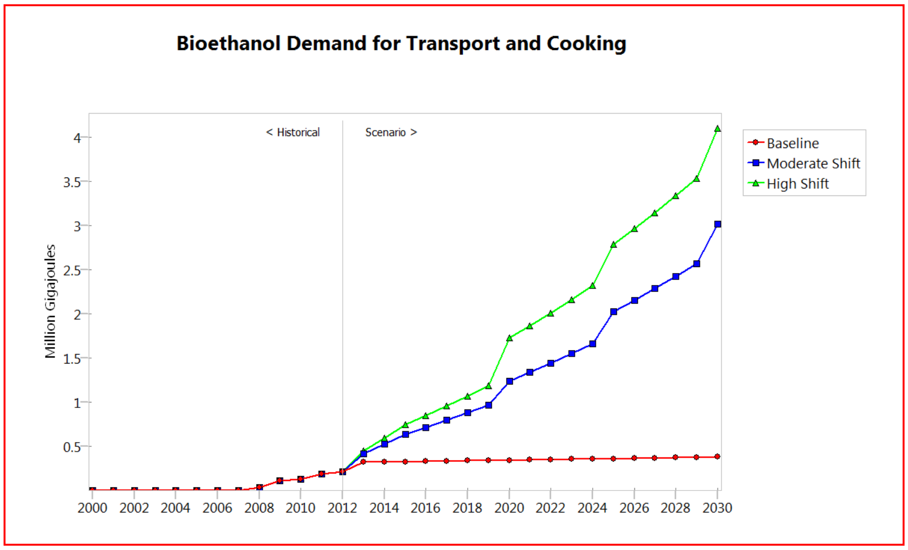


Figure 8.3: Trends of bioethanol demand for transport and cooking

Biodiesel

In both moderate shift and high shift scenarios, biodiesel demand would increase (see table 8.4). Biodiesel demand in the moderate shift scenario would grow from 1.15 to 11.33 million gigajoules by 2017 and 2030 respectively. The corresponding foreign currency saving from using this biodiesel in the transport sector (i.e. reducing diesel import) would reach to 25.37 and 249.18 million USD respectively. Moreover, 85.46 and 839.27 thousand tons of CO_2 would be reduced by 2015 and 2030; the revenue from carbon trading schemes could reach to 0.43 and 4.2 million USD; and Jatropha/castor required for the production of this biodiesel would reach to 2.32/1.25 and 22.76/12.26 million gigajoules by 2017 and 2030 respectively; and the corresponding land use for the cultivation of this jatropha/castor would be 46.27/49.93 and 454.55/490.31 thousand hectares respectively. In the high shift scenario, biodiesel demand would increase from 3.02 to 17.61 million gigajoules by 2017 and 2030 respectively. The corresponding foreign currency saving would be 66.35 and 387.42 million USD respectively. In addition, 223.5 and 1,304.91 thousand tons of CO_2 would be reduced by 2015 and 2030; the revenue from carbon trading schemes could reach to 1.12 and 6.52 million USD; jatropha/castor required for production would reach to 6.06/3.26 and 35.39/19.06 million gigajoules; and the corresponding land use for cultivation would be 68.28/108.81 and 404.51/635.28 thousand hectares respectively.

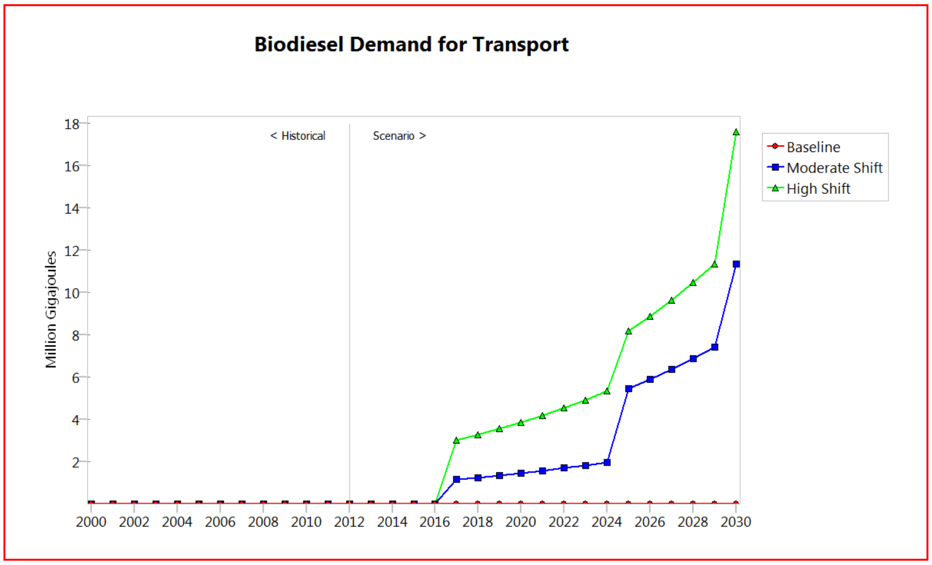


Figure 8.4: Trends of biodiesel demand for transport

Biogas

Biogas demand would grow in both moderate shift and high shift scenarios (see table 8.5). In the moderate shift scenario, biogas demand would increase from 1.4 to 6.88 million gigajoules by 2015 and 2030 respectively. The corresponding animal dung consumption for biogas production would reach to 20.36 and 100.36 million gigajoules respectively. While, biogas demand in high shift scenario would increase from 1.86 to 9.18 million gigajoules by 2015 and 2030 respectively. The corresponding animal dung demand for production would be 27.08 and 133.82 million gigajoules respectively.

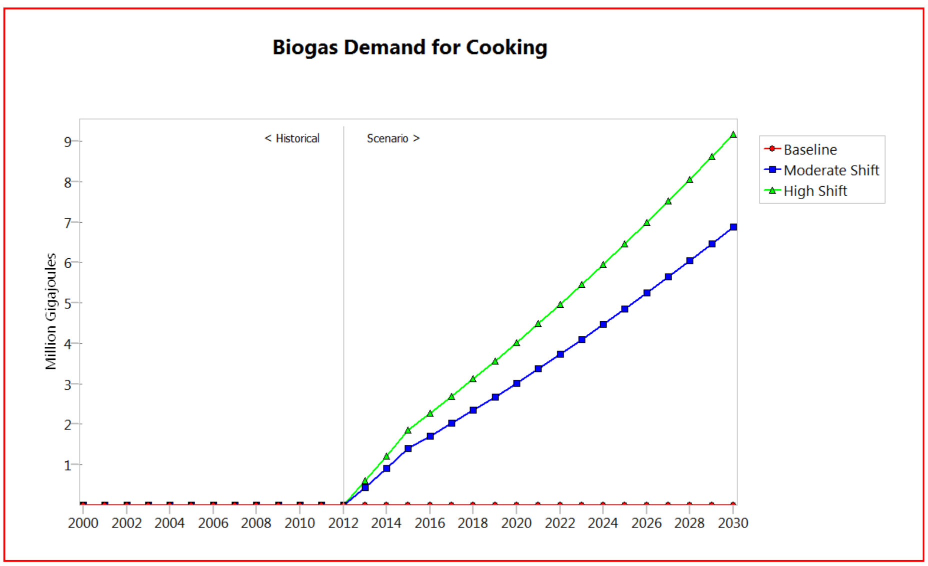


Figure 8.5: Trends of biogas demand for cooking

Agricultural Residues

In both moderate shift and high shift scenarios, agricultural residues demand would grow (see table 8.6). Agricultural residues demand in the moderate shift scenario would increase from 0.42 to 13.02 million gigajoules by 2015 and 2030 respectively. The corresponding foreign currency saving of from using this amount of agricultural residues in cement industries (i.e. reducing fossil fuels such as furnace oil, coal and petroleum coke) would reach to 4.99 and 156.56 million USD respectively. Furthermore, 37.32 and 1,169.35 thousand tons of CO_2 would be reduced by 2015 and 2030; and the revenue from carbon trading schemes could reach to 0.186 and 5.85 million USD respectively. In the high shift scenario, agricultural residues demand would increase from 0.43 to 20.43 million gigajoules by 2015 and 2030 respectively. The corresponding foreign currency saving would be 5.12 and 245.21 million USD respectively. Moreover, 38.35 and 1,834.97 thousand tons of CO_2 would be reduced by 2015 and 2030; and the revenue from carbon trading schemes could reach to 0.191 and 9.17 million USD respectively.

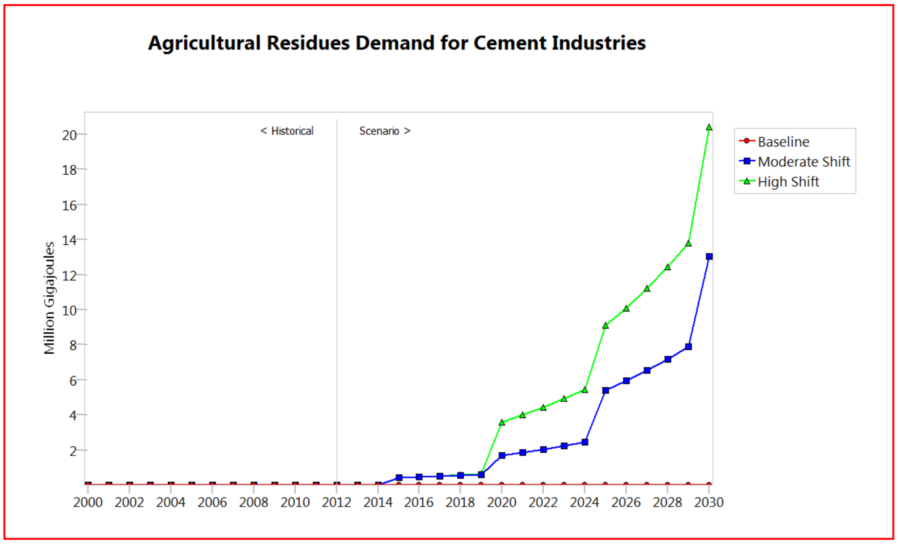


Figure 8.6: Trends of agricultural residues demand for cement industries

Bagasse

In the moderate shift scenario, the bagasse demand for excess electricity generation to the national grid would reach to 6.11 and 18.25 million gigajoules by 2015 and 2030 respectively. While the bagasse demand in the high shift scenario would be 6.11 and 24.44 million gigajoules.

Municipal Solid Waste

The municipal solid waste demand for electricity generation would be 5.16 and 13.55 million gigajoules by 2015 and 2030 respectively. In the high shift scenario, the municipal solid waste demand would reach to 5.16 and 20.62 million gigajoules.

Electricity

Electricity is one of the alternative energy sources of cooking and its demand would grow in all scenarios (see table 8.7). The electricity demand in baseline scenario would increase from 2.4 to 6.17 million gigajoules by 2015 and 2030 respectively of which, the urban households' electricity demand for cooking would account for 99.5% and 99.7% respectively. In the moderate shift scenario, electricity demand would increase from 3.99 to 22.93 million gigajoules by 2015 and 2030 respectively from which, the urban households' electricity demand for cooking would account for 74.3% and 77.9% respectively. Electricity demand in the high shift scenario would grow from 5.33 to 30.6 million gigajoules by 2015 and 2030 respectively from which, the urban households' electricity demand for cooking would account for 74.4% and 77.9% respectively.

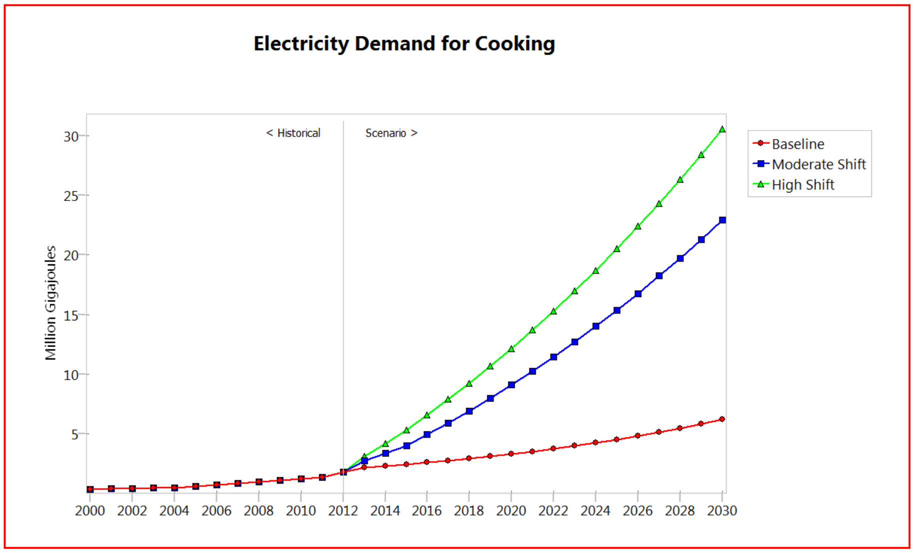


Figure 8.7: Trends of electricity demand for cooking

8.2 Conclusion

It is seen that the long-term shifts in the use of bioenergy have great opportunity for sustainable development of Ethiopia by saving wood, reducing GHG emissions, saving foreign currency, generating revenue and bioelectricity generation. Taking the high scenario case by 2030, about 65 million tons of wood could be saved; the foreign currency saving would reach to 674 million USD; the GHG emissions reduction would be 46 million tons of CO_2e which is equivalent to 18.4% of the CO_2e abatement target of the country for 2030; the corresponding revenue from carbon trading schemes would reach to 231 million USD; and electricity generation from bagasse and municipal solid waste would be 3,672 GWh which is about 3.7% of the total electricity generation for 2030.

The shift from traditional use of biomass to efficient and modern has significant benefits in terms of wood saving to its economic and ecosystem services, greenhouse gas emissions saving, generating revenue from carbon trading schemes and improving access to fuel wood. Moreover, the indoor climate pollution from using traditional cooking stoves would significantly be reduced and so does health problem to women and children. In addition, women and children would not go long distance to collect fuel wood. As a result, women can have more time to do other economic activities instead of collecting fuel wood and children can also have more time to learn. .

Wood would continue as a dominant energy source for the household sector. However, its consumption would decrease due to energy efficiency improvement. As a result, deforestation and forest degradation for fuel wood can significantly be reduced. Compared to baseline scenario, wood demand for cooking would decrease by 52.7% and 67.4% by 2030 in moderate shift and high shift scenarios respectively. The use of improved wood stoves would save 33 and 44 million tons of wood by 2030 in the moderate shift and high shift scenarios; and the CO_2e saving would reach to 24 and 32 million tons respectively. On the other hand, the use of fuel switch stoves could save 19 and 25 million tons of wood by 2030 in the moderate and high shift scenarios, and the CO_2e saving could reach to 9 and 11 million tons; and the revenue generated from carbon trading schemes of the CO_2e saving could reach to 165 and 215 million USD by 2030 in moderate shift and high shift scenarios respectively.

The deployment of biofuels in the transport sector can play important role on foreign currency saving and GHG emissions reduction. By using bioethanol, it is possible to save up to 29 and 41 million USD by 2030 in the moderate shift and high shift scenarios; and up to 82 and 115 thousand tons of CO_2 reduction respectively. On the other hand, the use of biodiesel can save up to 249 and 387 million USD by 2030 in the moderate shift and high shift scenarios; up to 839 and 1,305 thousand tons of CO_2 reduction; and about 5 and 7 million USD can be generating from carbon trading schemes of the CO_2 reduction of both biofuels respectively.

By using agricultural residues as a fuel for cement production, the cement industries can reduce their fossil fuels consumption as well as GHG emissions. The foreign currency saving from using agricultural residues would reach to 156 and 245 million USD by 2030 in the moderate shift and high shift scenario; CO_2 reduction up to 1,169 and 1,835 thousand tons; and the revenue generated from carbon trading schemes of the CO_2e reduction would be 6 and 9 million USD respectively.

Electricity generation from bagasse and municipal solid waste would reach to 2,614 and 3,672 GWh by 2030 in the moderate shift and high shift scenarios which is equivalent to 2.6% and 3.7% of the total electricity generation target for 2030 respectively.

9 Chapter Nine: Recommendation and Future Work

9.1 Recommendation

The analysis of the study shows that it is essential for the existing energy practices of Ethiopia to evolve towards more efficient and modern use of bioenergy as a substitute of traditional use of biomass and fossil fuels to achieve sustainable development. This can be effectively achieved if all the stakeholders including the civil society play their own supportive role using effective policies and strategies through the following pillars: awareness creation and capacity building, implementing effective incentives schemes, infrastructure development, establishing decentralized institutions, improving access to energy and implementing energy management system.

Awareness creation and capacity building: Awareness creation is crucial to increase the adoption rate of new technologies and practices. Energy efficiency improvement in the household sector depends on the awareness level of individual household about the benefit of using new technology. To do an effective job at creating awareness, it is necessary to choose the right awareness creation strategy. Door to door awareness creation strategy is important to reach majority of the households who do not have access to television and other digital media. It is obvious that when more households shift from using traditional cooking stoves to improved cooking stoves/fuel switch stoves, the demand for these stoves would increase. To balance demand and supply of the cooking stoves, it is necessary to increase the capacity of existing small-scale cooking stoves manufacturing enterprises, expand the number of new enterprises, and build their operational, financial and marketing capabilities. Capacity building of both the existing and future biofuels manufacturing industries is also important for increasing production to meet the growing demand of biofuels.

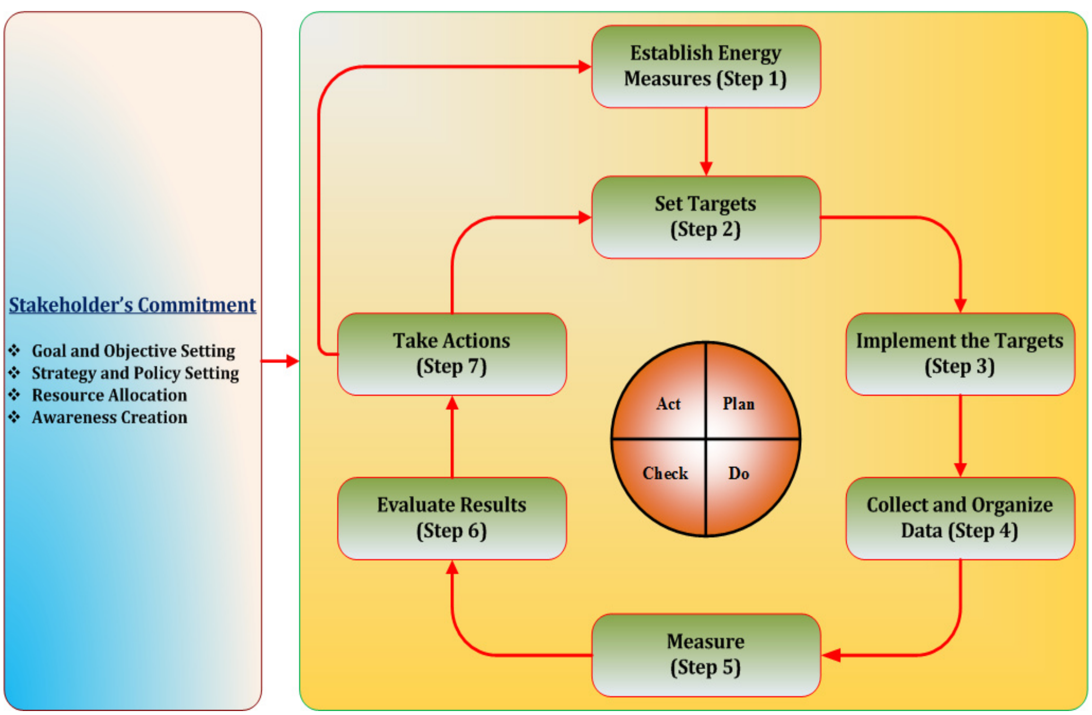
Implementing effective incentive schemes: Incentive schemes encourage commitment to accomplish a certain task in the most effective and productive way. More households would adopt new cooking technologies when they are benefited from incentives such as subsidies, loan and carbon trading schemes. In other words, provision of subsidies, loan and carbon trading scheme would attract more households for using new cooking technologies. Moreover, provision of land for free, loan for initial investment and reasonable tax holiday would attract new small-scale cooking stoves manufacturing enterprises to enter into the market and motivate the existing enterprises to expand their capacity. Incentives such as land for free, loan for initial investment, reasonable tax holiday and carbon trading schemes would also attract new biofuels manufacturing industries to enter into the market and encourage the existing industries. More cement industries would also be motivated by carbon trading schemes to introduce agriculture residues as a fuel for cement production.

Infrastructure development: One of the characteristics of bioenergy is its long supply chain from the source to end-use. Effective supply chain management improves accessibility and price competitiveness of bioenergy for the end-users. Infrastructure is the key factor for successful supply chain management of bioenergy. Development of networked infrastructures such as roads, storage areas and distribution centers such as bioethanol and biodiesel blending stations is necessary for effective logistics of bioenergy that minimizes waste, time, distance and cost.

Establishing decentralized institutions: The problems associated with traditional use of biomass and fossil fuels consumption are many and diversified. However, they can be met and solved by eastabilshing decentralized institutions which are responsible for policy and strategy formulation, research and development, and coordination of energy related activities. Expanding energy institutions from federal to district level is essential to undergo energy activities effectively from the ground. In addition, launching of energy dedicated departments in the education system of universities is crucial for human resource development (i.e. educating more energy professionals) as well as doing research and development that support the energy sector of the country.

Improving access to energy: Tree plantation at household level and on degraded lands can improve access to fuel wood as well as reduces deforestation of natural forest. Implementing sustainable tree plantation programs that vary from household to country level is required for sustainable fuel wood supply. Accessibility and price are the basic parameters that determine the preference of cooking fuels by the households. Improving accessibility and price competitiveness of bioethanol would encourage more households to use bioethanol cooking stoves. Animal dung is the promising biomass resources for biogas production in rural areas at household level. Treating this abundant biomass resource for biogas production would increase access to biogas and more rural households could use biogas cooking stoves. The existing charcoal making process from wood is very traditionally and has low conversion efficiency that leads to high amount of wood consumption. Introducing alternative biomass resources such as agricultural residues for charcoal production would be crucial to minimize wood consumption, deforestation and land degradation, and greenhouse emissions while improving access to charcoal at competitive prices. It is also crucial to do an effective job for increasing electrification rate so that more households can switch to electricity cooking stoves. Besides the use of agriculture residues, cement industries are recommended to start tree plantation on their own land and old quarries so that they can also use wood as an alternative fuel for cement production.

Implementing energy management system: Management inefficiency is the constraint that affects implementation of policies and strategies. Implementing energy management system is useful for continually improving energy performance. The following seven steps[1] are recommended for effective implementation of energy management system (see figure below).



[1] The steps are adopted from author's previous study: "*Design of Productivity Improvement Method for Ethiopian Garment Industries*", Master Thesis, Addis Ababa University, 2011. It can be accessed in the form of book with ISBN: 978-3848416219 from online book stores including *www.amazon.com*.

Finally, the analysis suggests that achieving the high shift scenario through effective policies and strategies would provide enormous social, environmental and economical benefits. Achievements between moderate shift and high shift scenarios are also welcomed. The long-term shifts in household energy sector have more significant outcomes which can lead enormous sustainable development of the country than other sectors. Therefore, household energy should be prioritized and given more attention.

9.2 Future Work

There are a number of unaddressed uncertainties in this study such as adoption rate of new technologies and practices especially by households, management efficiency in implementing policies and strategies, and supply chain management of bioenergy. Such uncertainties could affect the practical implementation of the long-term shifts in bioenergy use. Therefore, future work can take these uncertainties into account as an extension of the study.

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Annexes

Annex 1: Net Calorific Value and CO_2 Emission Factor *(Source: [24], [34], [62], [71])*

Net Calorific Value and CO_2 Emission		
Fuel	**Net Calorific Value (GJ/Ton)**	**CO_2 Emission Factor (Kg/GJ)**
Wood	15.6	112
Charcoal	29.5	112
Agricultural Residues	14.5	100
Animal Dung	12	100
Bagasse	16	100
Municipal Solid Waste	11.6	100
Bioethanol	26.8	79.6
Biodiesel	37.5	70.8
Biogas	20	54.6
Sugarcane Molasses	12.7	-
Jatropha Seed	25	-
Kerosene	43.8	71.9
LPG	47.3	63.1
Gasoline	43.4	69.3
Diesel	42.4	74.1
Residual Fuel Oil	40.4	77.4
Coking Coal	28.2	94.6
Petroleum Coke	32.5	97.5

Note that, most of the above data are taken from reference 24, reference 34 is for net calorific value of bioethanol and biodiesel, reference 62 for net calorific value of sugarcane molasses, and reference 71 for net calorific value of jatropha.

Annex 2: Percentage Distribution of Households by Cooking Fuel in Ethiopia (Source: [37], [38], [39], [40], [41])

Percentage Distribution of Urban Households by Cooking Fuel					
Cooking Fuel	**1996**	**1998**	**2000**	**2004**	**2011**
Wood	61.7	62.9	57.9	65.33	63.31
Charcoal	4.3	5	8.3	7.65	17.54
Electricity	2.7	3.8	2.2	2.36	6.18
Kerosene	18.9	17.2	21.5	13.84	4.93
LPG	1	2.5	1.4	2.69	1.05
Biogas	-	-	-	-	-
Dung, Sawdust, Crop Residues and Others	11.4	8.5	8.7	6.1	3.4
None Cook	-	-	-	1.91	3.57
Not Stated	-	-	-	0.11	0.01
Number of Households	**1,583,823**	**1,603,869**	**1,666,208**	**2,112,957**	**3,437,158**

Percentage Distribution of Rural Households by Cooking Fuel					
Cooking Fuel	**1996**	**1998**	**2000**	**2004**	**2011**
Wood	75.5	78.2	78.8	84.45	90.85
Charcoal	0.1	0.1	0	0.16	0.23
Electricity	0	0	0	0.05	0.01
LPG	0	0.1	0.1	0.07	0.04
Kerosene	0.2	0.2	0.3	0.21	0.17
Biogas	-	-	-	-	-
Dung, Sawdust, Crop Residues and Others	24.6	21.5	20.8	14.99	8.6
None Cook	-	-	-	0.05	0.11
Not Stated	-	-	-	0.01	0.0000103
Number of Households	**8,856.288**	**9,683,035**	**9,853,558**	**11,325,052**	**12,707,493**

Annex 3: Sugar and Bioethanol Development Projects in Ethiopia *(Source: ESCo)*

Sugar and Bioethanol Development Projects				
Factory	**Annual Sugar Production Capacity (Ton)**		**Annual Bioethanol Production Capacity (Million Liters)**	**Region**
	Old	**New**		
Fincha	110,000	160,000	20	Oromia
Wonji Shoa	75,000	173,946	10.3	"
Methara	136,692	-	12.5	"
Tendaho		619,000	55.4	Afar
Kuraz (1 to 5)		278,000 (*3)	26.2 (*3)	SNNP
		556,000 (*2)	52.4 (*2)	
Beles (1 to 3)		242,000 (*3)	20.8 (*3)	Amhara
Kesem		153,000	12.5	Oromia
Wolkaiyt		242,000	20.8	Tigray

Annex 4: Land Use for Sugarcane Cultivation in Ethiopia *(Source: ESCo)*

Land Use for Sugarcane Cultivation			
Factory	**Land (Hectares)**	**Water Supply**	**Region**
Fincha	21,000	Fincha River	Oromia
Wonji Shoa	16,000	Awash River	"
Methara	10,300	Awash River	"
Tendaho	50,000	Awash River	Afar
Kuraz (1 to 5)	175,000	Omo River	SNNP
Beles	75,000	Beles River	Amhara
Kesem	20,000	Kesem River	Oromia
Wolkaiyt	45,000	Zarema River	Tigray

Annex 5: Trend of Bioethanol Blend in Ethiopia *(Source: MoWE)*

Company	Trend of Blended Bioethanol (Liters)				
	2008	2009	2010	2011	2012
Nile Petroleum	1,648,333	5,146,642	6,110,936	6,110,936	2,390,241
Oil Libya	-	-	-	2,827,372	6,489,894
Nitional Oil Company	-	-	-	-	1,248,077
Total	**1,648,333**	**5,146,642**	**6,110,936**	**8,938,308**	**10,128,212**

Annex 6: List of Investors for Biodiesel Development in Ethiopia *(Source: MoWE, [10])*

Name of PLCs	Total Allocated Land (Hectares)	Land Cultivated (Hectares)	Region
Fri-Ei Ethiopia	30,000	450	SNNP
S & P Enegy Solution	50,000	600	Benishangul Gumuz
Atrif Alternative Enegy	108	61	SNNP
Agro Peace Bio Ethiopia	49,000	2,000	Somalia
Africa Power Initative	50,000	17,000	Tigray
Save the Envoroment	-	12	Somalia
ORDA	-	6,000	Amhara
MART	-	-	Tigray
The Giving Tree Nursery	100	-	Oromia

Annex 7: List of Contacts during the Fieldwork

Name	Position	Organization
Tesfaye Alemayehu	Bioenergy Case Team Leader	MoWE
Betelihem Mekonnen	Biofuel Standards Development Senior Expert	"
Tagay Girma	Biofuel Development Follow-up Expert	"
Tesfaye Abebe	Clean Development Mechanism and Environment Senior Expert	"
Dereje Beyene	Senior Energy Analyst	"
Woldemedhin Merete	Biofuel Development Follow-up Medium Expert	"
Kiflom Gebrehiwot	Biofuel Technology Medium Expert	"
Tsige Merid	Biofuel Marketing Senior Expert	"
Nadewu Tadele	Director, Biofuel Development Coordination Directorate	"
Zewditu Negede	Executive Secretary, Biofuel Development Coordination Directorate	"
Abinet Muhummed	Electrical Engineer	EEPCo
Yilma Tibebu	Director, Communication	ESCo

	Directorate	
Dawit Dagnew	Knowledge Management Officer	GIZ Energy Coordination Office

Note that, there are other experts and officials who were contacted during the fieldwork in addition to the above list of contacts.

Annex 8: Survey Questionnaire

The survey questionnaire for the study is submitted as a separate document.