



Development of Alternative Scenario for Ethiopia's Electricity Sector by LEAP Software

By Md. Minarul Islam, Elizabeth Mosqueda & Mir Tanweer Husain

University of Flensburg, Germany

Abstract - Ethiopia, a country in Africa, is endowed with renewable energy sources such as hydro, solar and wind. These energy sources are economically exploitable and if electrical energy could be produced it could be surplus beyond the country's demand. Exporting electrical energy, Ethiopia could earn more money without disturbing environment as it is a global warming issue now-a-days. But due to lack of technology, the rich renewable resources are not utilized properly, and as a result, only 15% of the population of the country have access to electricity. In this paper, based on moderate scenario, an alternative scenario for Ethiopia's electricity sector will be developed to meet its energy demand upto the year 2030. For alternative scenario, the time range from year 2008 to 2030 was considered in LEAP software. In the alternative scenario, hydro and geothermal were judiciously selected as the source of energy. Solar energy was not selected due to its upfront cost which is unbearable by any developing countries. Wind energy was not selected because of seasonal variations in energy production around the year.

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Abstract - Ethiopia, a country in Africa, is endowed with renewable energy sources such as hydro, solar and wind. These energy sources are economically exploitable and if electrical energy could be produced it could be surplus beyond the country's demand. Exporting electrical energy, Ethiopia could earn more money without disturbing environment as it is a global warming issue now-a-days. But due to lack of technology, the rich renewable resources are not utilized properly, and as a result, only 15% of the population of the country have access to electricity. In this paper, based on moderate scenario, an alternative scenario for Ethiopia's electricity sector will be developed to meet its energy demand upto the year 2030. For alternative scenario, the time range from year 2008 to 2030 was considered in LEAP software. In the alternative scenario, hydro and geothermal were judiciously selected as the source of energy. Solar energy was not selected due to its upfront cost which is unbearable by any developing countries. Wind energy was not selected because of seasonal variations in energy production around the year.

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I. INTRODUCTION

The production of world electricity in 2008 was 20,261TWh, which was 11% of the solar energy the earth receives in one hour. Sources of electricity were fossil fuels 67%, renewable energy 18%, and nuclear power 13%. Ninety-two percent of renewable energy was hydroelectric followed by wind at 6% and geothermal at 1.8%. Solar photovoltaic was 0.06%, and solar thermal was 0.004%[1]. The share of renewables in electricity generation is around 19%, with 16% of global electricity coming from hydroelectricity and 3% from new renewables. The amount of electrical energy produced in 2008 around the world, from different fuel sources, are shown in figure 1. A global-country comparison can be seen on the table 1.

Approximately, Africa produced 9% of the world Energy. African production is dominated principally by traditional biomass and oil [1]. The average consumption per household is 47 KWh/year per capita. Around the world, 500 KWh/yr is the average minimum level of consumption for a reasonable quality of life.

Author α : Md. Minarul Islam is with the Department of Electrical and Electronic Engineering University of Flensburg, Germany.
e-mail: minarbueta@gmail.com

Author σ : Elizabeth Mosqueda is with Semarnat as a consultant, Mexico city, Mexico.

Author ρ : Mir Tanweer Husain is with LGED, Dhaka, Bangladesh.

In this paper, as an alternative scenario will be proposed for Ethiopia's electricity sector, let us look through the Ethiopia's baseline scenario. Ethiopia's energy supply is covered mostly by waste and biomass (92%). Oil (6.7%) and hydropower (0.9%) are the other two primary energy sources. The installed capacity of electrical power is about 2060 MW (88% hydro, 11% diesel and 1% thermal). This production is equal to 10% of the demand. For this reason, the country is dependent on the imports of petroleum to meet its requirements.

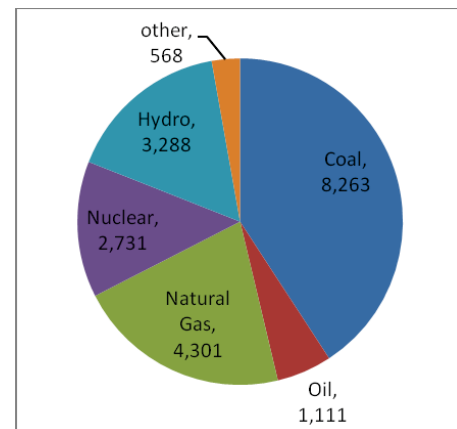


Figure 1 : Source of Electrical energy (TWh/year) around the world (2008) [1]

Table 1 : Electricity production sources global-country basis[1-2]

	World (%)	Africa (%)	Ethiopia(%)
Hydro	16%	27	94
Natural Gas	21	25	3
Coal	41	40	
Oil	5	10	

With only 15% of the population having access to electricity, there is a significant bias between electricity supply of urban and rural population: 80% of urban areas have access to electricity, whilst only 2% of rural areas habitants have access to electricity [3]. As it can be observed in the Figure 2, the average electrification rate in developing countries is 72%. Therefore, there is a gap of more than 57% to achieve the target for developing countries, specially for Ethiopia.

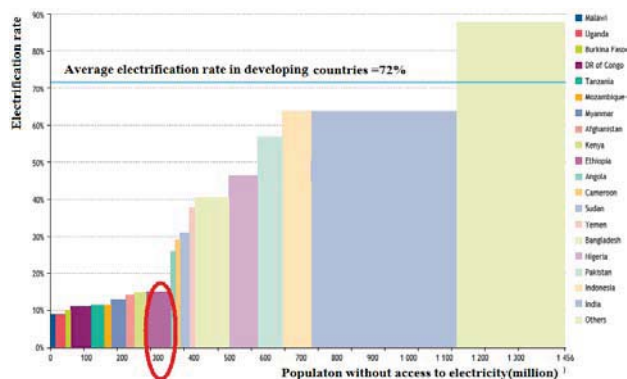


Figure 2 : Electrification rates and population without access to electricity, 2008

According to Ethiopian Electric Power Corporation (EEPCo) electricity generation in 2010 was 3,981.07 GWh. Hydropower generates 88% of the electricity and thus is the country's dominating electricity source. The other sources for EEPCo energy generation are diesel and geothermal as shown in the figure 3.

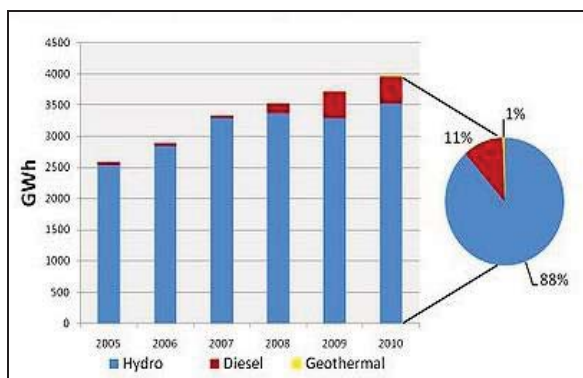


Figure 3 : Development of Energy Generation of EEPCo ICSs and SCS, Period 2005-2010 (in GWh) and share by fuel 2010

Although there are a number of private, municipal and cooperative owned small scale power producers in areas not served by the utility their combined contribution is estimated not to exceed 2% of EEPCo's capacity.

EEPCO runs two systems; the Interconnected System (ICS) and the Self Contained System (SCS). The ICS, which generates more than 98 percent of total EEPCO supply capacity, is supplied mainly from a set of large hydro systems with some thermal back up. The SCS is a much smaller system of decentralized mini-grid and off-grid systems supplied by small hydro plants and diesel generators. The technologies used by the ICS and SCS are shown in the table 2.

Table 2 : EEPCo's ICS and SCS plants[4]

	Hydro power	Geothermal	Diesel-grid Connected	Total Capacity
ICS	plants-1842 MW	1 plant-7.3 MW	15 plants-172.3 MW	2019.3 MW
SCS	3 plants-6.15 MW	-	31.34 MW	37.49 MW

The ICS is currently becoming bigger because of the interconnection of SCS to ICS. In 2010, a total of 5,163 towns were connected by EEPCo. The electricity generation increased 53% from 2005 to 2010. This results in a shortage of electricity, because of a slant between the grid extension and the load of power generated. Transmission and distribution losses are around 20%. This event causes that the users willingness to pay increases significantly in isolated systems.

Nevertheless, Ethiopia's target was to supply 20% of the population with electricity by the year 2012. This is due to the 5 year Growth and Transformation Plan, launched in 2010 which aims to quadruple or even quintuple the country's current capacity and to connect 4 million costumers by 2015. The plan includes the installation of the following new plants:

- 8 hydropower plants with 8,737 MW of total capacity.
- 7 wind plants with 866 MW of total capacity.
- 70 MW geothermal power plant of total capacity.

Keeping this plan in mind, the alternative scenario is developed. If this scenario is implemented, it will meet Ethiopia's energy demand which will improve the economic growth of the country.

II. ETHIOPIA'S ELECTRICITY GENERATION POTENTIAL

a) Hydro Potential

The total hydro potential of Ethiopia is 45,000 MW[6]. Which is the second highest potential in Africa (after Congo). Approximately 30,000 MW hydro power is economically feasible[8-9]. Current production is of only 2.5% of the potential. It is also important to mention that a vast potential is not only given for large hydropower projects, but also for small scale schemes. The potential from micro hydropower schemes is 100 MW, that could be developed on a land area of 200,000 km². Most promising sites can be found in the western part of the country since suitable constant flows are prevailing, figure 4. Though, the drying seasons has to be taken into account because of the lack of water during this period of the year. Hydropower is the main source of electric power in Ethiopia. The exploitable hydro energy potential is estimated to be about 159TWh/year. Nearly 50% of this resource is in the Abay River Basin and 22% is in the Omo-Gibe River Basin.

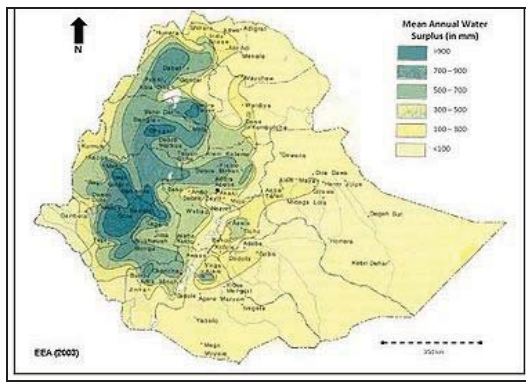


Figure 4 : Mean Annual Water Surplus in Ethiopia

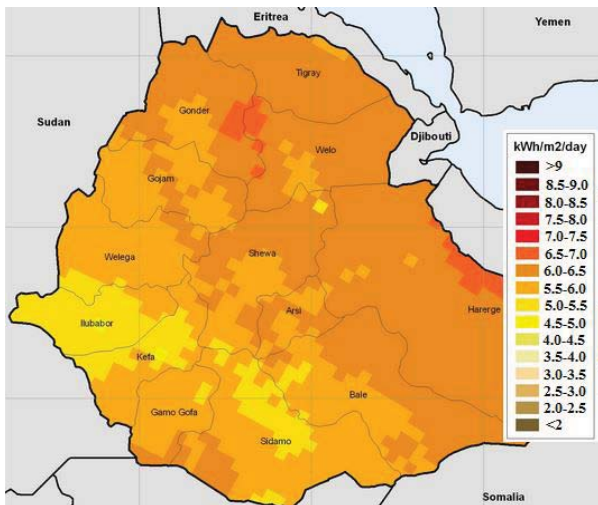


Figure 5 : Solar Irradiation in Ethiopia (in kWh/m²/day)[5]

b) Solar Potential

Ethiopia's solar potential has been shown in figure 5. The solar potential is 5 kwh/m²day[9]. Ethiopia receives a solar irradiation of 5000-7000 Wh/m² according to region and season. Although the growth rate of the solar PV market has grown (from <5% since the early 1990s to 15 – 20% in the last few years) it is still at an early stage. With an installed capacity of approximately 5MW and an estimated PV market potential of 52 MW, not even 10% is exploited.

c) Biomass

A total of 30 MW of capacity surplus could be fed in the grid by sugar factories. Power production potential of landfill gas is estimated to be 24 MW.

d) Wind

With wind resources with a velocity of 5-6(m/s), Ethiopia's wind potential is estimated to be 10,000 MW[6,9]. EEP Co is planning to develop seven wind sites that are in close proximity to the ICS by 2015. They will have a capacity between 50 and 300 MW. The installed wind power capacity would be approximately of 720 MW. In rainy seasons the hydropower potential is high

whereas low winds prevail, vice versa hydropower potential is low in the dry season whereas the wind potential is high as can be seen in the figure 6.

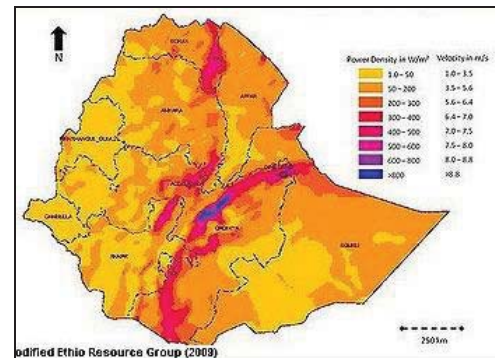
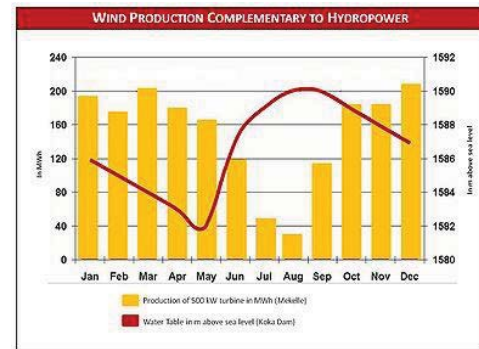


Figure 6 : Annual Mean Wind in Ethiopia and wind production compared to hydropower generation [4]

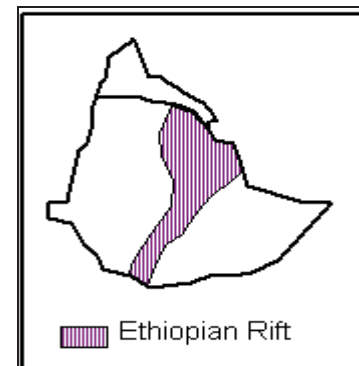


Figure 7 : Geothermal Ethiopia's energy base

e) Geothermal Energy

Ethiopia's geothermal resources are estimated to be 5 GW of which 700 MW are suitable for electric power generation [6-9]. They are primarily located in the Rift Valley, figure 7. Only one 7.3 MW geothermal has been commissioned so far but was shut down in 2002. Based on available scientific information and experiences on the Rift geothermal system both in Kenya and Ethiopia, it is plausible to assume the presence of a huge geothermal energy base in Ethiopia.

III. TECHNOLOGIES SELECTED FOR ETHIOPIA' ALTERNATIVE ENERGY SCENARIO

For the development of Ethiopia's alternative scenario to meet its energy demand, two technologies, as shown in figure 8, were selected as follows:

- Hydropower plants (microhydropower plants for the SCS system and hydropower plants for the ICS system)
- Geothermal power plants.

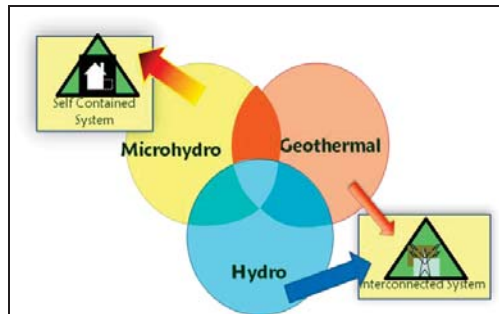


Figure 8 : Approach for alternative scenario

a) Aspects of the Selected Technologies

Hydropower Plants : The hydropower plants were chosen because of the highest potential of the country and the current low production as well as the possibility to develop large or small projects. Hydropower is the most abundant energy source of Ethiopia, it is thought to form the backbone of the country's energy sector development. Additionally, hydro is the cheapest potential amongst PV and wind. For this reason, hydro power can be selected as the best technology suitable.

Geothermal Plants : The development of the alternative scenario involves the introduction of geothermal power plants that are feasible because they are located in the Ethiopian geothermal rift.

Other technologies not considered : Despite of this, we were willing to introduce wind, but the wind availability was not sufficient in some areas to produce electricity, and in the areas where we have potential there were already transmission lines, which means that they would be suitable under ICS.

b) Description of the Elaborated Systems

Self Contained System : We choose to install 36 hydropower plants with an average capacity of 10 MW distributed along the country where no ICS is available, Figure 9. The selected areas have hydro potential. Additionally, the small projects would offer the opportunity to initially start as SCS and then get connected to the grid. We selected to put this power plants near rivers. The gap to be fulfilled for the self contained system is of around .131 GW. The vast amount of the SCS hydro power plants was located near rivers.

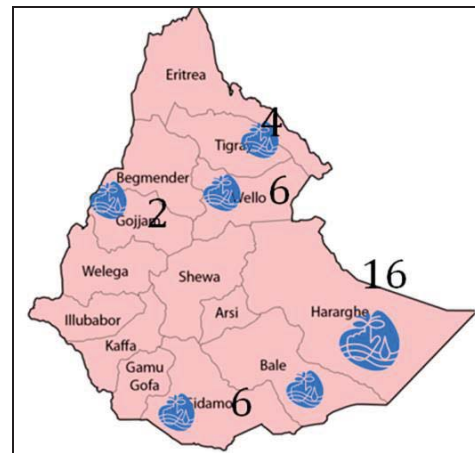


Figure 9 : Proposed SCS plants

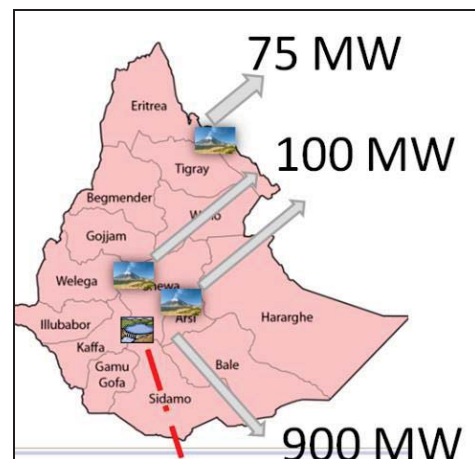


Figure 10 : Proposed ICS plants

Interconnected system : There is a deficit of around 400,000 MWh for the period 2008-2030. To fulfill the deficit we decided to construct 4 new Powerplants (3 Geothermal and 1 Hydro) figure 10. The plants that we decided to construct were:

Geothermal Power Plants : Corbetti Geothermal Power Plant. Corbetti Plant has a capacity of 75 MW. This plant was selected because it is already been considered by EEP Co and is in the Ethiopian rift to generate electricity through geothermal sources. We installed as well two other geothermal plants Tulu Moya & Dofan Geothermal Power Plants with a capacity of 100 MW. For the replacement of business as usual plant Yayu coal (capacity of 100 MW), we decided to install a 100 MW plant which will have very similar characteristics.

Hydro Plant : Additionally we add one big hydropower plant of 900 MW, Figure 10. This plant would be available in the west part of the country, because there is a very big potential for hydropower plant. Gibe IV would be of around 1472 MW. For this reason, our consideration of installing one plant of 900 MW is not by any chance out of analysis. As the new plant will be located near the line that exports electricity to Kenya, we can expect also to export electricity.

IV. COMPARISON BETWEEN MODERATE AND ALTERNATIVE SCENARIO

a) Demands in Moderate and Alternative Scenario

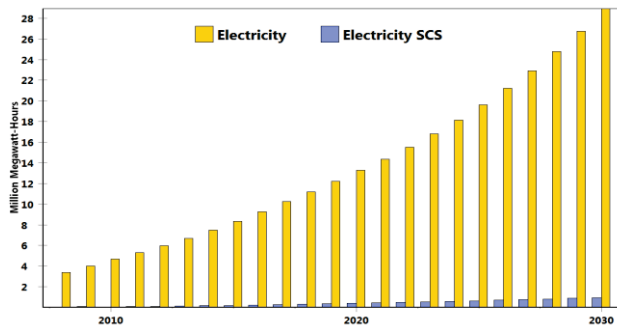


Figure 11 : Scenerio: Ethiopia moderate demand

Ethiopia's moderate scenario, figure 11, describes the electrical energy requirement for next 30 years. From figure 11, it is seen that in 2008, the total demand(ICS and SCS) is 3.46 million which is increasing exponentially and becomes 29.86 million MWh in 2030. We did not change anything in the forcasted demand of electrical energy for Ethiopia in our alternative scenario.

b) Outputs : Alternative Scenario

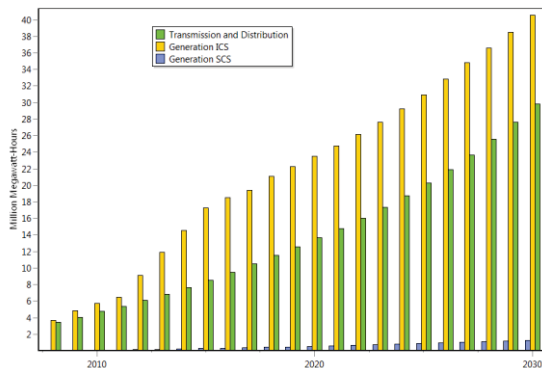


Figure 12 : Transformation:outputs; ethiopia moderate demand

The transformation: outputs result catagory displays the electrical energy produced in ICS, SCS with their losses in transmission and distribution, figure 12. From figure 12, we see that in 2008, total output is 7.21 million MWh (consist of ICS generation of 3.67 million MWh, SCS generation of 0.07 million MWh and losses in both ICS and SCS of 3.46 million MWh). In 2012, the output is 14.70 million MWh (ICS generation 8.54 million MWh, SCS generation 0.07 million MWh, transmission and distribution loss 6.08 million MWh). In 2030, the total output is 69.83 million MWh(ICS generation 39.89 million MWh, SCS generation 0.07 million MWh, transmission and distribution loss 29.86 million MWh). It is seen that the transmission and distribution losses are always very big. In this studies, no attempts were taken to reduce the losses.

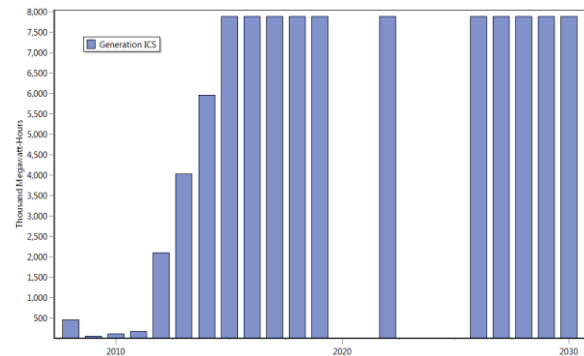


Figure 13 : Unmet requirement, ICS; Ethiopia moderate demand, Fuel: all fuels

c) Unmet Demands in ICS

The unmet requirements in ICS generation will be large from 2012 to 2019 then there will be no unmet requirements in the year of 2020, 2021 and from year of 2023 to 2025. Again, it becomes large from the year 2026 to 2030 as shown in figure 13. We ignored the unmet requirements from the year 2008 to 2011 because the unmet requirements were very small.

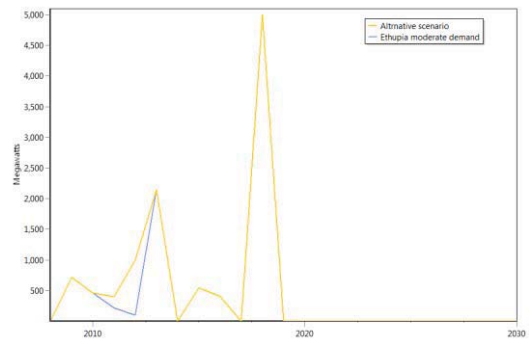


Figure 14 : Capacity added in ICS for alternative scenario, Capacity: all capacities

We attempted to reduce the unmet demands in ICS from the year of 2011. For this reason, we added two power plants named Corbetti GPP and Tulu Moya and Dofan of capacity 75 MW and 100 MW respectively. Both were geothermal power plants. Again, we added another two plants in the year of 2012 where one named as Abaya GPP(geothermal plant) of capacity 100 MW and one named as Gilgel Gibe IV(hydro power plant) of capacity 900MW. Addition of these four plants are shown in figure 14.

d) Capacity Installation in ICS

After addition of 4 power plants in ICS, we see that there are no unmet demands in ICS in the year of 2013 and from 2018 to 2026, figure 15. The limitation of the analysis here is that we installed plants in the year of 2011 and 2012 but its effect goes to unmet requirements in the year of 2013 and from the year of 2018 to 2026.

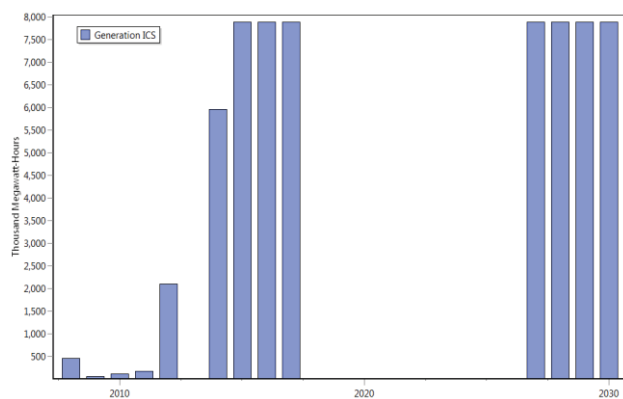


Figure 15 : Unmet demands in the alternative scenario,
Fuel: all fuels

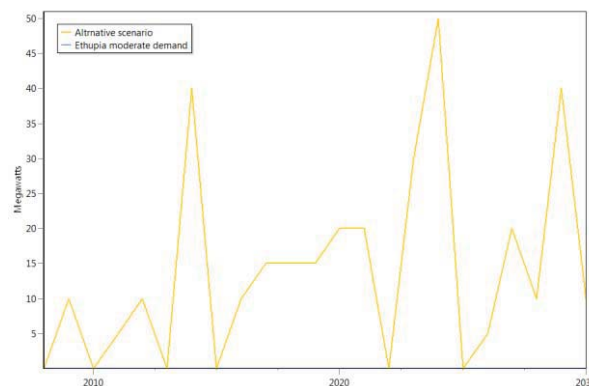


Figure 17 : Installatin of small hydro power plants in SCS
area, Capacity: all capacities

Table 3 : Capacity added to SCS area

Year	Alternative scenario(MW)	Ethiopia Moderate demand(MW)
2009	10	0
2011	5	0
2012	10	0
2014	40	0
2016	10	0
2017	15	0
2018	15	0
2019	15	0
2020	20	0
2021	20	0
2023	30	0
2024	50	0
2026	5	0
2027	20	0
2028	10	0
2029	40	0
2030	10	0

We see no change of unmet requirements in the other years. However, our target was not to reduce all the unmet demands in ICS but a little. Also due to increase export energy, we installed that plants in the ICS.

e) Unmet Demand in SCS of Ethiopia Moderate Scenario

The figure 16 shows the unmet demands in the SCS area. We see that the unmet demands in the year of 2008 and 2030 are 0.01 million MWh and 4.21 million MWh respectively where the demands are increasing almost exponentially with the year. Our target in the Ethiopia alternative scenario was to meet all the unmet demands in the SCS area.

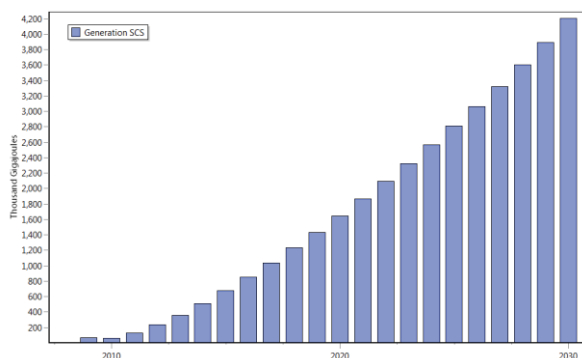


Figure 16 : Unmet demands in Ethiopia moderate
scenario, Fuel: all fuels

f) Capacity Installation in SCS

We offered 35 small hydro plants of capacity 5MW and 10MW in different years in the period of year 2008 to 2030. The figure 17 shows the installation of power plants in different years and the table 3 shows the capacity added to the SCS area in our alternative scenario in the respenctive year according to the unmet demands.

g) Unmet Demands in SCS of Ethiopia Alternative Scenario

After installing the small hydro plants in the SCS area we see that the unmet demands will be very small in few years. The figure 18 describes the unmet requirements in the Ethiopia alternative scenario. The table 4 explains the small unmet demands in some years. In our alternative scenario, we left these unmet demands, because these are small and sometimes to meet these small demands, the installation of new power plants will not be economically feasible.

Table 4 : Generation SCS

year	Unmet demands in alternative scenario(Thousands MW)
2008	9.02
2009	0.32
2011	1.87
2013	37.08
2022	8.04
2028	4.76

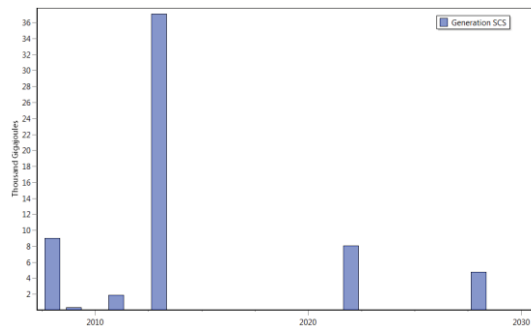


Figure 18 : Unmet demands in alternative scenario in SCS area

h) Capacity and Reserve Margin

The figure 19 describes the comparison between two scenarios for Ethiopia's electrical power capacity from the year 2008 to 2030. As we tried to reduce the unmet demands in the alternative scenario, its capacity is higher than the capacity in the moderate scenario.

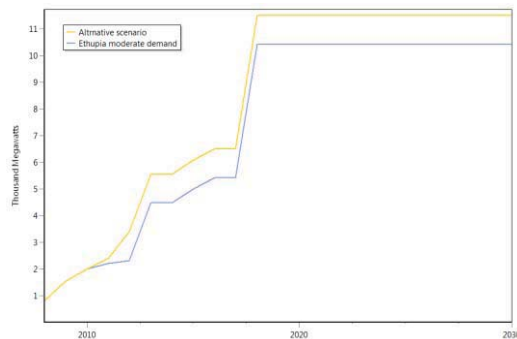


Figure 19 : Capacitis in both scenarios

The figure 20 shows the amount of reserve margin in the ICS area. This variable is generally only relevant for electricity generation modules. This variable is only reported if we have specified capacity data for the module.

Reserve margin is defined as follows:

$$\text{Reserve Margin}(\%) = \frac{100 * (\text{Module Capacity} - \text{Peak Load})}{\text{Peak Load}}$$

Where, Module Capacity = Sum(Capacity * Capacity Value) for all processes in the module.

Assuming that we have specified certain processes that will be added automatically using the Endogenous Capacity, then the actual reserve margin reported here should be greater than or equal to the planning reserve margin. This is because LEAP automatically adds new plants as needed in order to keep the reserve margin on or above the planning reserve margin. On the other hand, if plants are not being added automatically and if we have not exogenously specified sufficient capacity expansion, then it is possible that the actual reserve margin may fall below the planning reserve margin.

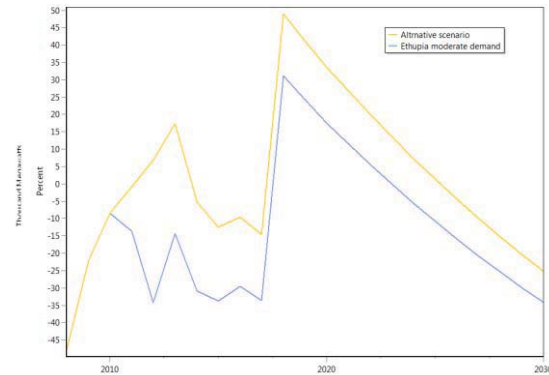


Figure 20 : Actual reserve margin in ICS are for both scenario

From the figure 20, we see that the reserve margin in alternative scenario is always greater than the reserve margin in the moderate scenario.

i) Exports

The results in figure 21 explains the exports from ICS area in both scenario. We see in the bar chart that exports in alternative scenario are greater than moderate scenario one from the year of 2012 to 2017 and 2027 to 2030, also exports are equals in both scenario from the year of 2018 to 2025.

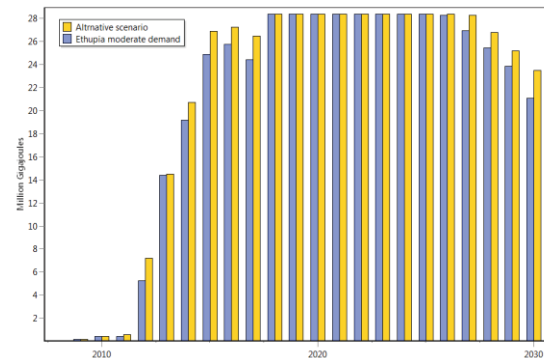


Figure 21 : Export of electricity from ICS in both scenario

j) Module Balance

The module balance in figure 22 explains domestic requirements, exports, imports, outputs and unmet demands. The unmet demands are always smaller than module outputs. We see that the exports are gradually decreasing, because in our scenario we selected domestic demands as priority that is why with the increase of domestic demands exports are decreasing.

But if we select exports as priority then the export would be constant all through the years which is shown in figure 23.

But the problem with export as priority that the unmet demands are always larger than the module outputs which may result in load shadding.

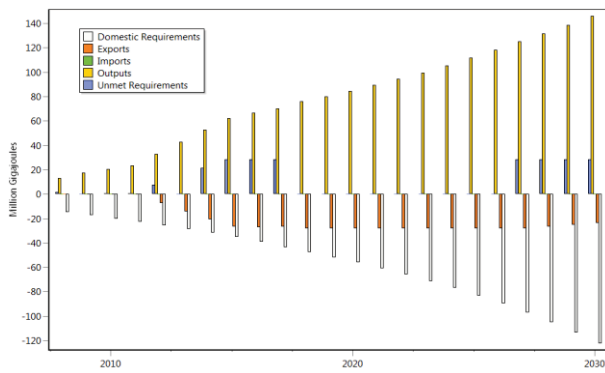


Figure 22 : Module balance with domestic demands priority in alternative scenario

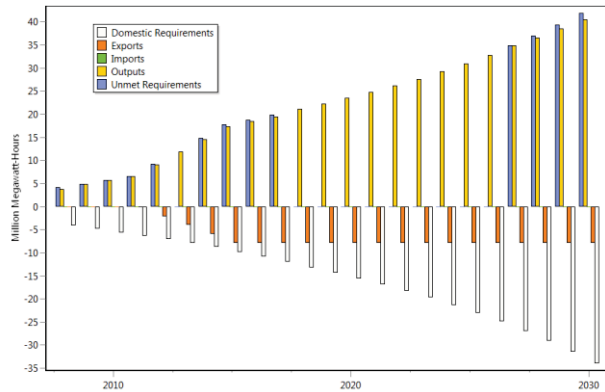


Figure 23 : Module balance with export priority

V. IMPACT ON IMPORT & EXPORT OF SECONDARY FUEL

a) Import

In the BAU scenario, Ethiopia needs to import secondary fuel namely diesel for both ICS and SCS electricity generation. In the proposed alternative scenario, new plants have been considered based on country's own renewable resources. In case of ICS, the proposed power plants' capacity is more than the existing electricity deficit.

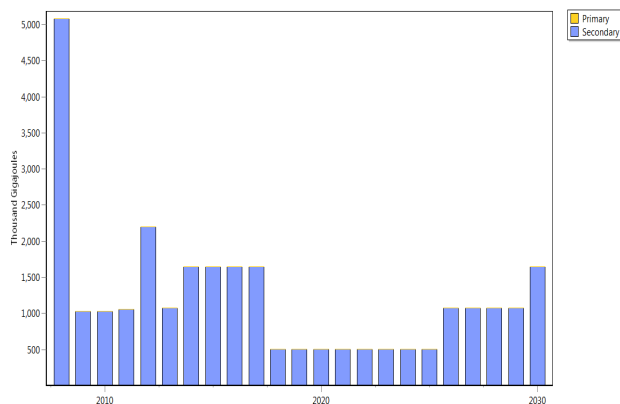


Figure 24 : Import - BAU Scenario

As a result, in some cases LEAP has chosen to use the additional electricity from the new power plants instead of diesel based power plants due to less generation cost. Consequently, there is reduction of diesel import from other countries. Diesel import in BAU scenario, figure 24, is compared to diesel import in alternative scenario, figure 25.

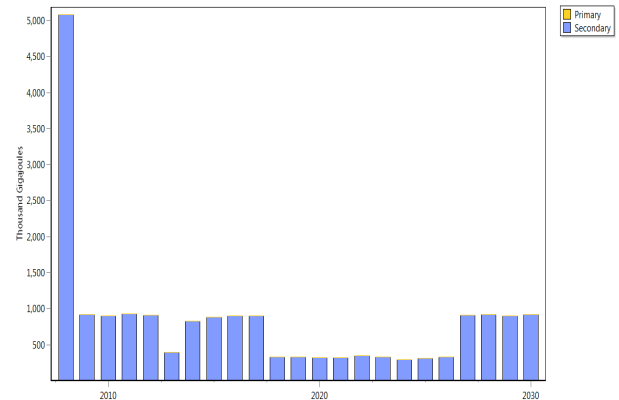


Figure 25 : Import - Alternative Scenario

b) Export

One of the objectives of the alternative scenario was to fulfill the demand of electricity for ICS. Though the focus was not to boost up electricity export, slight increase of export is also observed, comparison of figure 26 and 27.

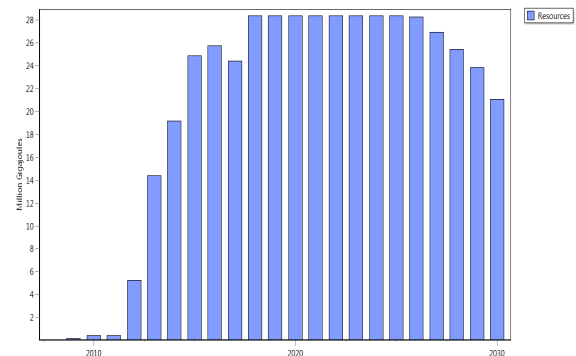


Figure 26 : Export - BAU Scenario

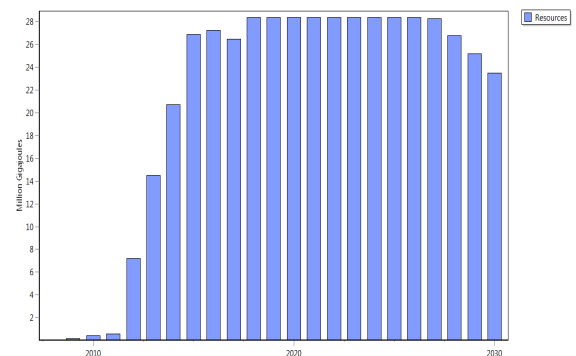


Figure 27 : Export - Alternative Scenario

Because, according to the alternative plan, the additional amount of electricity will be exported to neighbor countries after meeting the domestic demand. Here, this is to be noted that for 'Priority Use of Output' of 'Transformation- Generation ICS- Output Fuel- Electricity' we chose 'Domestic Requirement' instead of 'Export'. So our export quantity didn't remain fixed rather varied.

VI. SYNOPSIS OF ENERGY BALANCE

From 2008 to 2030, Ethiopia's Energy balance for each year reflects the changes in resources and transformations brought within the scenarios. For example, we can consider the energy balance of Ethiopia in 2012 for both the scenarios (please refer to Appendix – Table 6: Energy Balance for Ethiopia, 2012 - BAU Scenario and Table 7: Energy Balance for Ethiopia, 2012- Alternative scenario)

In the year 2012, there is considerable amount of increase of production from hydro and geothermal sources in the alternative scenario compared to BAU scenario. Subsequently, import of diesel has reduced from 379 thousand barrel of oil equivalent (BOE) to 156 thousand BOE in the proposed scenario. On the other hand, export has increased from 903 thousand BOE to 1235 thousand BOE. For SCS, electricity generation from hydro has increased and from diesel has decreased. Electricity from coal power plant has reduced from 654 thousand BOE to 0. Total transformation in BAU was 1467 thousand BOE and it has changed to 3805 thousand BOE in the alternative scenario. Total demand for electricity is 3767 thousand BOE in both cases as no change was done from the moderate scenario. In the year 2012, there was unmet demand of 40 thousand BOE in case of SCS which has been totally diminished in the alternative scenario.

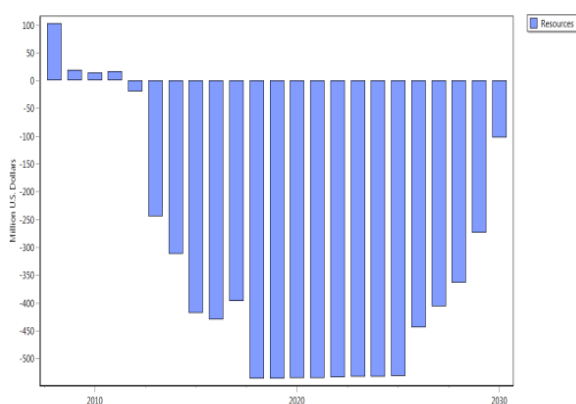


Figure 28 : All costs (domestic / foreign) – BAU

VII. FINANCIAL INVESTIGATION OF THE SCENARIOS

a) Cost & Benefit of the Scenarios

The figures 28 and 29 show the financial comparison between the moderate and alternative

scenarios. It is observed that the involved costs are less and the negative costs i.e. benefits are more in the alternative scenario. For example, in the year 2030, the benefit available in the BAU and alternative scenario is around 90 Mill US \$ and 430 Mill US \$ respectively. It means benefit would be around 5 times more than the BAU scenario.

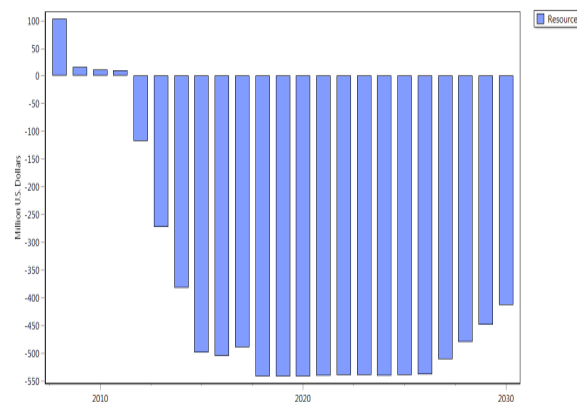


Figure 29 : All costs (domestic / foreign) - Alternative Scenario

b) Financial Investigation of the Alternative Scenario

The cumulative cost and benefit of the proposed alternative scenario from the year 2008 to 2030 compared to Ethiopia's moderate demand in Million US Dollar is given on the table 5.

Table 5 : Alternative scenario

Costs	
Demand	
Domestic	0.0
Commercial	0.0
Street Lighting	0.0
Industrial LV	0.0
Industrial HV	0.0
Rural Electrification	0.0
Transformation	
Transmission and Distribution	0.0
Generation ICS	1,688.5
Generation SCS	-2.6
Resources	
Production	-309.6
Imports	-162.6
Exports	-177.5
Unmet Requirements	0.0
Environmental Externalities	0.0
Net Present Value	1,036.2
GHG Savings (Mill. Tonnes C Eq.)	0.5
Discounted GHG Savings (Mill. Tonnes C Eq.)	0.3
Cost of Saved Carbon (U.S. Dollar/Tonne C Eq.)	3,585.1

It is observed that the cost involved in generation ICS is 1,688.5 Million US \$. Small hydro power plants were proposed for SCS generation. In the long run, there would be benefits which is equivalent to 2.6 Million US \$. As no change was brought in the demand side, there is no involvement of cost also. It is seen that the collective benefits from production, import & export of resources are 309.6, 162.6 & 177.5 Million US \$ respectively. It means though some amount would be spent for import, it will bring benefit equivalent to 162.6 Million US \$ in the long run. Overall, after considering the benefits, cumulative cost involved is 1,036.2 Million US \$ (discounted at 5% to the base year). To be mentioned here, there is no cost involved in environmental externalities for this green scenario, on the other hand, there will be considerable amount of GHG saving. According to the IPCC's 100 years' integration global warming potential factors, the total cumulative emissions of all greenhouse gases avoided by the alternative scenario are 0.5 Million Tonnes of Carbon equivalent.

VIII. ENVIRONMENTAL ASPECT OF THE SCENARIOS

There was a coal power plant called 'Yayu Coal' in the moderate or business-as-usual scenario. In the alternative scenario, because of the environmental considerations, this plant was replaced by environment friendly geothermal power plant. The impact of this decision has been clearly illustrated in Figure 30 and 31. In the year 2012, when the coal power plant would likely be installed, GHG emission would be around 380 thousand tonnes CO₂ equivalent. On the other hand, there is apparently no emission of global warming potential GHGs in the alternative scenario.

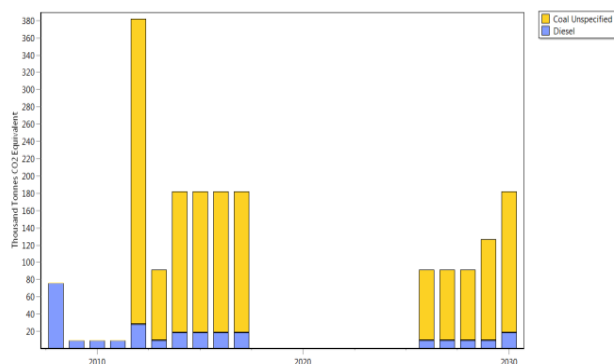


Figure 30 : Global Warming Potential - BAU Scenario

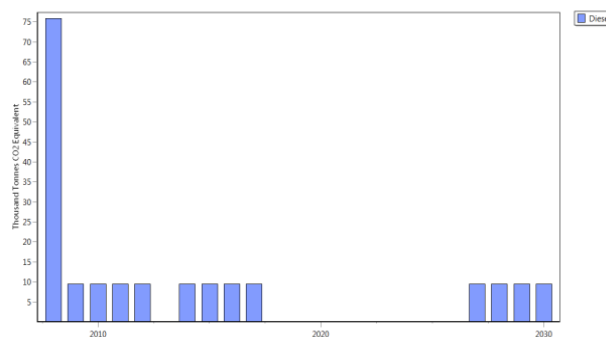


Figure 31 : Global Warming Potential - Alternative Scenario

IX. CONCLUSION

Ethiopia is endowed with renewable energy resources. The alternative scenario focused on maximum utilization of this resource as a source of clean electricity for the country. There is abundant of sunshine all through the year in the country. But solar energy was not selected due to its high upfront cost. There are some potentials of wind energy also in Ethiopia. Unfortunately, that is limited to some areas only and there are lots of seasonal variations in production around the year. However, the country has many rivers with huge potentials of hydro energy. That's why, in the proposed scenario, hydro and geothermal were judiciously selected as the source of energy. In the business-as-usual scenario, there were some unmet demands of ICS electricity. The alternative scenario has fulfilled the gap and also increased export of electricity to neighboring countries. In case of SCS, there was unmet demand at every year. These gaps have been almost fulfilled in a conservative manner as the additional production would be wasted. Besides, there was one coal based plant in the business-as-usual scenario which has been replaced by geothermal power plant. This change has turned the alternative scenario a cleaner one compared to BAU with diminishing of global warming potential GHG emissions. Thus, our proposed alternative scenario is capable enough to meet the electricity demand of Ethiopia in a more reliable and sustainable way than the business-as-usual scenario.

REFERENCES RÉFÉRENCES REFERENCIAS

1. International Energy Agency. (2010). Energy Balances for Non OECD Countries. Energy (Vol. 2010).
2. World Energy Outlook 2009. International Energy Agency.
3. Legros, G., Havet, I., Bruce, N., & Bonjour, S. (2009). A Review Focusing on the Least Developed countries and Sub-Saharan Africa.
4. Ethiopia Current Situation. https://energypedia.info/index.php/Ethiopia_Country_Situation Consulted September 2011.
5. http://www.nrel.gov/gis/images/swera/ethiopia/ethiopiaNREL_glo.jpg

6. Meseret Teklemariam, Kibret Beyene, Yiheyis AmdeBerhan, Zewde Gebregziabher, 'Geothermal Development in Ethiopia', Proceedings World Geothermal Congress 2000, Kyushu - Tohoku, Japan, May 28 - June 10, 2000
7. Bezawit Teshome, Getachew Bekele, 'Energy Conserving Electrical Design and Analysis for Commercial Building', Addis Ababa Institute of Technology, Addis Ababa, Ethiopia, http://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0331_full%20paper.pdf, March, 2013
8. Wolde-Ghiorgis Woldemariam, 'The Potential Contribution of Renewables in Ethiopia's Energy Sector: An Analysis of Geothermal and Cogeneration Technologies', Sponsored By HBF-HA, Sida/SAREC and AFREPREN/FWD, 2004, http://www.afrepren.org/drafttrpts/hbf/geo_eth.pdf, March, 2013
9. W. Wolde-Ghiorgis, 'Renewable Energy for Rural Development in Ethiopia: The Case for New Energy Policies and Institutional Reform', Renewable Energy for Rural Development in Ethiopia / Energy Policy. <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.201.191>, March, 2013

APPENDIX

Table 6 : Energy Balance for Ethiopia, 2012 - BAU Scenario

Scenario: Ethiopia moderate demand (Thousand Barrel of Oil Equivalent)							
	Electricity	Diesel	Wind	Hydro	Geothermal	Coal	Electricity Total
Production	0	0	279	4698	86	654	5717
Imports	0	379	0	0	0	0	379
Exports	-903	0	0	0	0	0	-903
From Stock Change	0	0	0	0	0	0	0
Total Primary Supply	-903	379	279	4698	86	654	5193
Generation SCS	0	-86	0	-20	0	0	-60
Generation ICS	5288	-293	-279	-4678	-86	-654	-701
Transmission and Distribution	-684	0	0	0	0	0	-706
Total Transformation	4604	-379	-279	-4698	-86	-654	-1467
Statistical Differences	0	0	0	0	0	0	0
Domestic	1144	0	0	0	0	0	1146
Commercial	900	0	0	0	0	0	902
Street Lighting	34	0	0	0	0	0	34
Industrial LV	404	0	0	0	0	0	404
Industrial HV	388	0	0	0	0	0	388
Rural Electrification	832	0	0	0	0	0	894
Total Demand	3701	0	0	0	0	0	3767
Unmet Requirements	0	0	0	0	0	0	40

Table 7 : Energy Balance for Ethiopia, 2012 – Alternative Scenario

Scenario: Alternative scenario (Thousand Barrel of Oil Equivalent)							
	Electricity	Diesel	Wind	Hydro	Geothermal	Electricity SCsS	Total
Production	0	0	279	5049	3322	0	8650
Imports	0	156	0	0	0	0	156
Exports	-1235	0	0	0	0	0	-1235
From Stock Change	0	0	0	0	0	0	0
Total Primary Supply	-1235	156	279	5049	3322	0	7572
Generation SCS	0	-58	0	-69	0	87	-41
Generation ICS	5620	-98	-279	-4980	-3322	0	-3059
Transmission and Distribution	-684	0	0	0	0	-21	-706
Total Transformation	4936	-156	-279	-5049	-3322	65	-3805
Statistical Differences	0	0	0	0	0	0	0
Domestic	1144	0	0	0	0	2	1146
Commercial	900	0	0	0	0	2	902
Street Lighting	34	0	0	0	0	0	34
Industrial LV	404	0	0	0	0	0	404
Industrial HV	388	0	0	0	0	0	388
Rural Electrification	832	0	0	0	0	61	894
Total Demand	3701	0	0	0	0	65	3767
Unmet Requirements	0	0	0	0	0	0	0