# The Current and Future States of Ethiopia's Energy Sector and Potential for Green Energy: A Comprehensive Study

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# The Current and Future States of Ethiopia's Energy Sector and Potential for Green Energy: A Comprehensive Study

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**Keywords:** Electricity access, renewable energy, rural electrification, regulatory framework, sustainable development

**Abstract.** Sub-Saharan nations are facing a lot of challenges for the planning of their future energy sector. Particularly, the rural areas of Sub-Saharan nations bear scarcity of energy access as there is a lack of grid facilities, less financial and technical support, pressure from foreign institutions, excess of energy export etc. Although Ethiopia is growing as a leader of energy sector in Sub-Saharan region, it is also facing numerous problems similar to other African nations. In this paper, authors have conducted a detailed study of Ethiopian power sector. This study includes the complete background and overview of current energy sector in Ethiopia. The key factors which affect the development of energy sector such as international energy export, policy framework, role of government and regulatory framework are also discussed. It is observed that there is a huge renewable energy potential in Ethiopia which is under utilized, and can be used as a major resource for rural energy access. The authors recommend that a new policy framework and subsidies for renewable energy generation, motivational awareness, technical training, improvement in organizational efficiency and managerial skills, arrangement of financial instruments for new projects and easy ICTs based mobile banking programme should be initiated as well as improved to achieve sustainable growth, and 100% energy access by increasing renewable energy production.

## Introduction

Mostly, the global economic changes depend on the availability of energy. For industrialization and growth in economic condition, the access to energy is a key concern, which is useful to remove poverty, enhance food production, increase clean water availability, upgrade medical facilities, boost up education standards, and develop employment opportunity for young people including women. Approximately, one in five people globally lacks access to electricity. Many people still depend on charcoal, wood, waste of crops and other solid fuels for their cooking and other day to day activities; due to this, they suffer many health related issues which reduce the life expectancy, mostly of women and children. The insufficient power access also affects the household's income, industrial production, education and health. The modern energy generation units affect the atmospheric condition as they produce greenhouse gases by the combustion of fossil fuel [1]. These atmospheric changes create water and food crises at national and universal level. Additionally, this leads to land's degradation, de-forestation, increase in sea levels, and migration of people from their houses that change the geography of the planet. Sustainable development by using sustainable energy sources provides the greatest global opportunity for large scale sustainable employments. Although there are incredible advancements in sustainable energy solutions, many limitations still exist which should be addressed as fast as possible for large scale sustainable development. Additionally, for sustainable energy development a lot of advancements are required in technology, finance policy, business models, regulatory and governance structures. As a global perspective, the rate of sustainable development is very low in African countries due to poor energy production and access. Especially for Sub-Saharan Africa (shown in Figure 1(a)), there are following main energy issues: unavailability of power production, inadequate energy access and climate change. These challenges should be addressed in such a way that 100% access to electricity can be attained through sustainable energy generation system, to mitigate climate change impacts. The per capita energy consumption is shown in Figure 1(b).

Figure 1(a): Sub-Saharan African Countries [2]

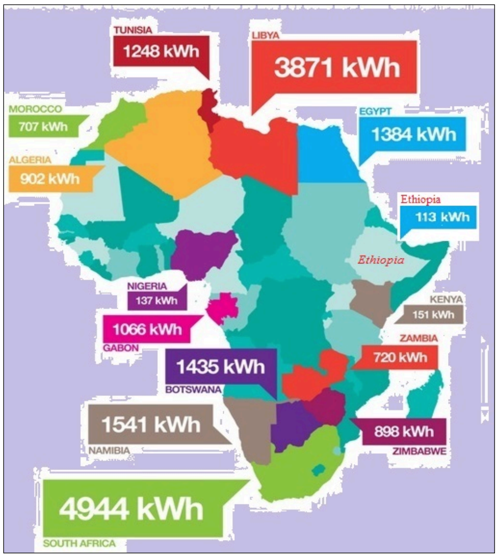


Figure 1(b):Per capita energy consumption [3]

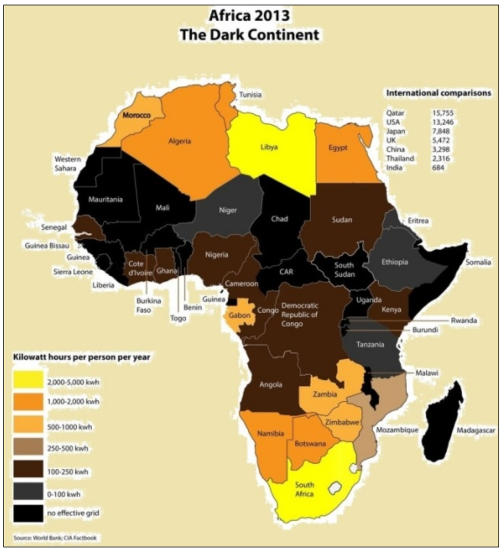


Figure 2(a): Energy Access in 2013 [4]

Figure 2(b): Predicted Energy Access in 2020 [4]

More than 600 million People in Sub-Saharan region have the least energy access as they are dependent on unreliable energy grid, which doesn't satisfy their day to day energy requirement. The average energy access, in most of the countries in this region, is below 20%. The details of energy access in 2013 and predicted energy access in 2020 is shown in Figures 2(a) and 2(b) [4], respectively. From 2000 to 2012, the electricity demand in sub-Saharan Africa increased by around 45% and it will keep on increasing at the rate of 4% per year until 2040 [5]. To supply the fast growing demand, an incredible expansion in generation capacity and transmission grid should be required in the region. More than half a billion people are predicted to live without electricity access till 2040 due to the present rate of generation and grid expansion as well as population growth [6]. Consequently the target of 100% electrification in the sub-Saharan region can only be achieved by 2080 [7]. This reflects that the sub-Saharan African region has a complex and continual electricity gap. The rural electricity percentage, the population without electricity access in millions, the national electrification and urban electrification percentage of African countries are given in Figures 3(a) to 3(d) respectively.

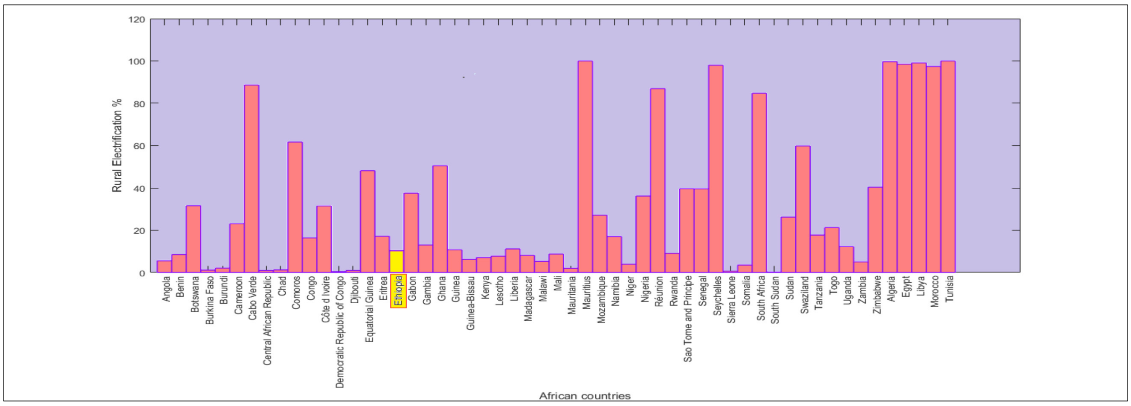



**Figure 3(a): African continent rural electrification (%) [6]**

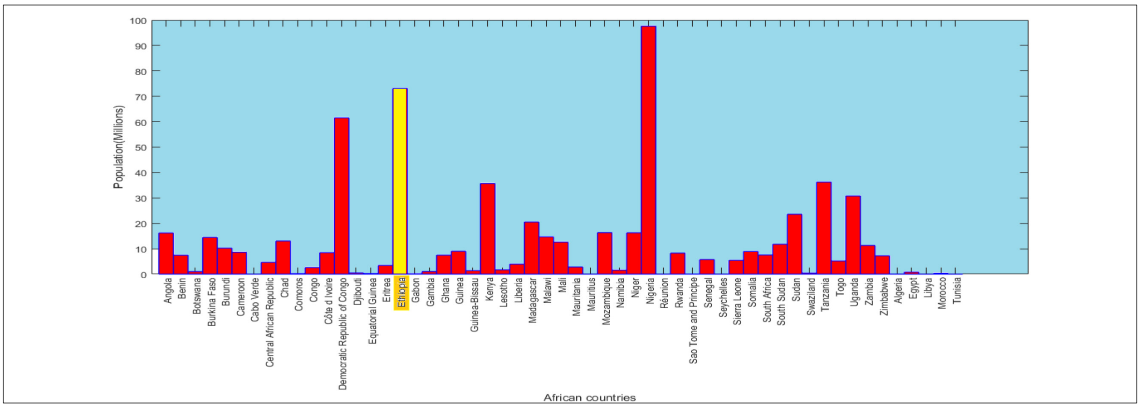



**Figure 3(b):African continent population without electricity access (in millions) [6]**

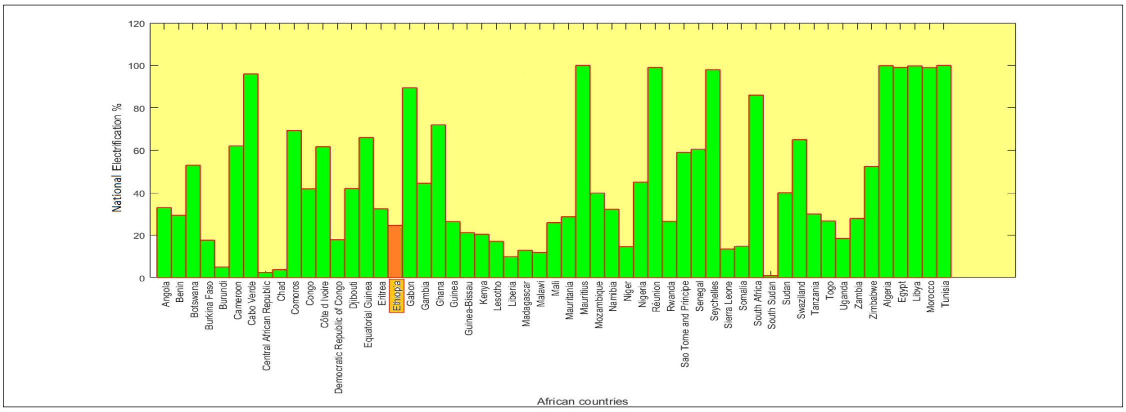



**Figure 3(c): African continent national electrification (%) [6]**

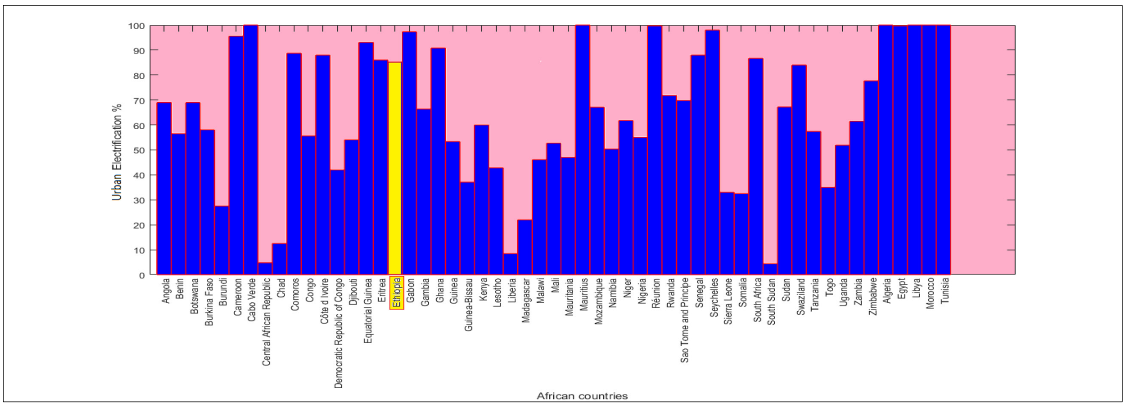



**Figure 3(d): African continent urban electrification (%) [6]**

Ethiopia is a country which is located in the horn of Africa. Ethiopia is Africa's oldest independent country and apart from a five-year occupation by Mussolini's Italy, it has never been colonised. The current population of Ethiopia is more than 90 million and it is the second largest in terms of population. The political map of Ethiopia is shown in Figure 4.

The government of Ethiopia is firmly determined to increase the production and availability of electricity for each and every citizen. Different international bodies are contributing to different projects of generation and electrification (Bank of Arab for Economic Development in Africa (BADEA), World Bank (WB), the Kuwait Fund, African Development Bank (AFDB)) [8]. In the context of the interest of rural electrification, deep and exhaustive study is required to find the effect of those on the different levels of poverty. There are different evidences available on the poverty impacts on Asian countries but proper empirical analyses are less available for African countries [8]. Hence in this work authors present a comprehensive study and valuable recommendations for the improvement and development of the Ethiopian power sector.


**Figure 4: Political map of Ethiopia [9]**

The structure of the paper is as follows. The next section provides the background of Ethiopian power sector. Section 3 discussed international energy trades of Ethiopia. Different energy policy frameworks are presented in Section 4. In section 5, the role of government in energy sector development is described. Section 6 discussed regulatory framework for energy sector followed by the conclusion and recommendations.

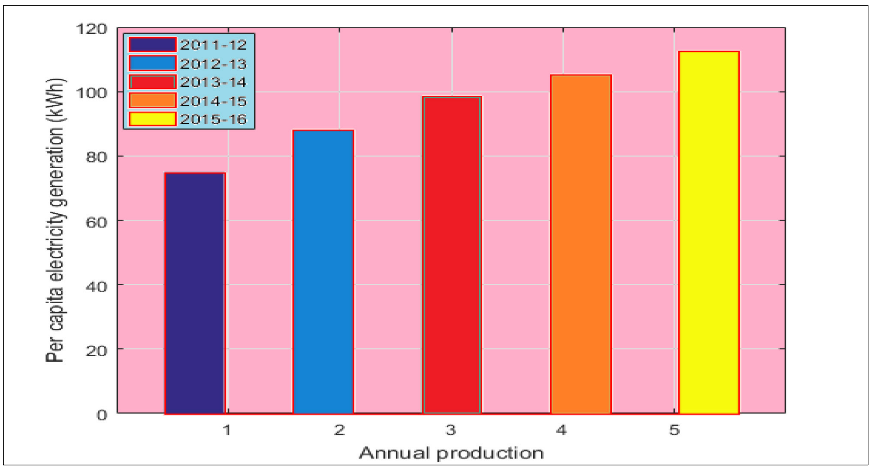



**Figure 5: Per capita electricity generation in Ethiopia (kWh) [1]**

## Background of Ethiopian Energy Sector

In the north of Africa, Ethiopia is a country which is located in the horn of Africa. The current population of the Ethiopia is more than 90 million; i.e. with respect to area, the population density of Ethiopia is one of the highest in the continent. It is the country where the major population is residing in the rural areas and involved in subsistence farming and other agriculture based works. Ethiopia is rich in natural resources and its main exports are coffee, live stock products (i.e. leather, live animals and meat), oil seeds, pulses, fruits, flowers, natural gum, spices, textile and mineral products, among others. The current GDP per capita ($1.63K) is not a big amount compared to those of other countries, even then the country has a substantial growth rate of 8-11 %. Ethiopia is one of the fastest growing economies in the African sub continent and capable of stabilizing and rehabilitating the economy of the country. The government has focused on the development of the country using the framework which is based on the good governance and leap forging [10]. There is a significant progress registered in the area of education, gender equality and health. The main international achievements of the Ethiopian government are in the field of aid coordination,

**Table 1: Energy production in Ethiopia (GWh) [1]**

| | Financial Year | | | | |
|---|---|---|---|---|---|
| **Source of energy** | **2011-12** | **2012-13** | **2013-14** | **2014-15** | **2015-16** |
| **Hydro** | 6239.29 | 7384.01 | 8336.41 | 9014.01 | 9674.16 |
| **Diesel** | 0 | 0.04 | 0 | 3.36 | 1.01 |
| **Geothermal** | 7.98 | 0 | 9.27 | 0 | 0 |
| **Wind** | 29.4 | 191.78 | 356.04 | 497.69 | 785.51 |
| **Total** | 6276.67 | 7575.83 | 8701.71 | 9515.06 | 10460.68 |

infrastructure development and harmonization [11]. Like other sub-Saharan countries, Ethiopia lacks adequate electricity production and equal energy access. Urban populations have major access to electricity, while the large populations residing in rural areas have less access to electricity. Figure 3 presents the electrification access in Ethiopia. The electricity consumption

**Table 2: Installed capacity (MW) of ICS in Ethiopia [1]**

| | | Installed capacity (MW) | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Power Plant** | **Hydro** | **Diesel** | **Geothermal** | **Wind** | **Total** | **In-service date** |
| **1** | **Adama I** | | | | 51 | 51 | 2012 |
| **2** | **Adama II** | | | | 153 | 153 | 2014 |
| **3** | **Adwa** | | 3 | | | 3 | 1998 |
| **4** | **Aluto Langano** | | | 7.3 | | 7.3 | 1999 |
| **5** | **Amerti Neshie** | 95 | | | | 95 | 2011 |
| **6** | **Ashegoda** | | | | 120 | 120 | 2012 |
| **7** | **Awash 7 Killo** | | 35 | | | 35 | 2004 |
| **8** | **Awash II** | 32 | 0.1 | | | 32.1 | 1966 |
| **9** | **Awash III** | 32 | | | | 32 | 1971 |
| **10** | **Axum** | | 3.15 | | | 3.15 | 1975/1992 |
| **11** | **Beles** | 460 | | | | 460 | 2010 |
| **12** | **Dire Dawa** | | 40 | | | 40 | 2004 |
| **13** | **Dire Dawa (Mu)** | | 3.6 | | | 3.6 | 1965 |
| **14** | **Finchaa** | 134 | 0.2 | | | 134.2 | 1973/2003 |
| **15** | **Gilgel Gibe I** | 184 | | | | 184 | 2004 |
| **16** | **Gilgel Gibe II** | 420 | | | | 420 | 2010 |
| **17** | **Gilgel Gibe III** | 1870 | | | | 1870 | 2015 |
| **18** | **Kaliti** | | 14 | | | 14 | 2004 |
| **19** | **Koka** | 43.2 | 0.12 | | | 43.32 | 1960 |
| **20** | **Meleka Wakena** | 153 | | | | 153 | 1988 |
| **21** | **Tekeze** | 300 | | | | 300 | 2009 |
| **22** | **Tis Aby I** | 11.4 | | | | 11.4 | 1964 |
| **23** | **Tis Aby II** | 73 | | | | 73 | 2001 |
| | **ICS Sub-total** | **3807.6** | **99.17** | **7.3** | **324** | **4238.07** | |

in Ethiopia is one of the lowest in the world and a major share is consumed by the few main cities (e.g. Addis Ababa, Hawassa, Mekele, Bahirdar, etc.). In the initial days, the country had low power production: for example before 1992, less than four hydro power plants existed with insufficient capacities for the future demands. Additionally, the geographical situation (i.e. hilly and landlocked) makes it difficult and expensive to provide the supply of energy. The government is focused on tackling the persistent problem of poor energy supply in rural areas and increasing the access to gird electricity. Consequently, a number of efforts are being made in cooperation with the international communities. From 1998, the rural electricity access program has been continually financed by the government of Ethiopia, BADEA, WB, KF, and AFDB; the objective considered was to achieve national electrification up to 90%. Apart from the traditional power generation, the latest non-conventional energy generation units (PV, wind, Geothermal, etc.) have been constructed and commissioned [10].

**Overview of the energy situation in Ethiopia.** The government of Ethiopia is targeting to increase the electricity access from 26% (2014) to 60% by 2040. Additionally, the enhancement in the efficiency of existing energy sources is another target. To fulfil these ambitious plans, the government of Ethiopia continuously organise new financial resources from China along with the conventional resources from the World Bank. The Universal Electricity Access Program (UEAP) has been developed to provide electricity access for most of the rural areas. The total cost associated with the UEAP is approximately US $ 920 million. An integrated plan has been developed by the Ethiopian electric power corporation (EEPCo) for achieving these goals [12]. The per capita energy generation in different financial years in Ethiopia is given in the Figure 5.
Ethiopia is having large Interconnected Power System (ICS). This ICS consist of 13 hydro, 6 diesel standby, 1 geothermal and 3 wind farms. The energy production by various sources for different financial years is depicted in Table 1. Currently, 23 power plants are operating in Ethiopia, and generating energy using hydropower, wind energy, geothermal and diesel sources. The name of the plants along with their generating capacities, resource type and in-service year is shown in Table 2. The energy production estimated in the financial year 2015-16 is around 10311807 MWh [1]. The details of production of the plants and total production are shown in the table 3.

**Table 3: Ethiopian energy production in 2015-16 [1]**

| | | Energy Production (MWh) | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Power Plant** | **Hydro** | **Diesel** | **Geothermal** | **Wind** | **Total** | **Share of energy by the plant** |
| 1 | **Adama I** | | | | 174375 | 174375 | 1.69 |
| 2 | **Adama II** | | | | 378194 | 378194 | 3.67 |
| 3 | **Amerti Neshie** | 128360 | | | | 128360 | 1.24 |
| 4 | **Ashegoda** | | | | 226585 | 226585 | 2.20 |
| 5 | **Awash II** | 66185 | | | | 66185 | 0.64 |
| 6 | **Awash III** | 65493 | | | | 65493 | 0.64 |
| 7 | **Dire Dawa (Mu)** | | 1110 | | | 1110 | 0.01 |
| 8 | **Finchaa** | 819188 | | | | 819188 | 7.94 |
| 9 | **Gilgel Gibe I** | 891941 | | | | 891941 | 8.65 |
| 10 | **Gilgel Gibe II** | 1955551 | | | | 1955551 | 18.96 |
| 11 | **Gilgel Gibe III** | 1709491 | | | | 1709491 | 16.58 |
| 12 | **Tana Beles** | 2925792 | | | | 2925792 | 28.37 |
| 13 | **Koka** | 45267 | | | | 45267 | 0.44 |
| 14 | **Meleka Wakena** | 273383 | | | | 273383 | 2.65 |
| 15 | **Tekeze** | 619542 | | | | 619542 | 6.01 |
| 16 | **Tis Aby II** | 27036 | | | | 27036 | 0.26 |
| **ICS Sub-total** | | **9527229** | **1110** | | **779154** | **10307493** | **99.96** |
| **SCS Sub-total** | | | **4314** | | | **4314** | **0.04** |
| **Grand-total** | | **9527229** | **5424** | | **779154** | **10311807** | **100.00** |

**Energy Resource Potential in Ethiopia.** Presently, Ethiopia has a total installed power generation capacity of around 4238 MW. About 90% (3807 MW) is generated by hydroelectric power plants. Additionally, 324 MW (7.65%), 7.3 MW (0.17%) and 99.17 MW (2.34%) are produced by the wind, geothermal and diesel power plants, respectively [1]. The percent division of production by different sources is shown in Figure 6.

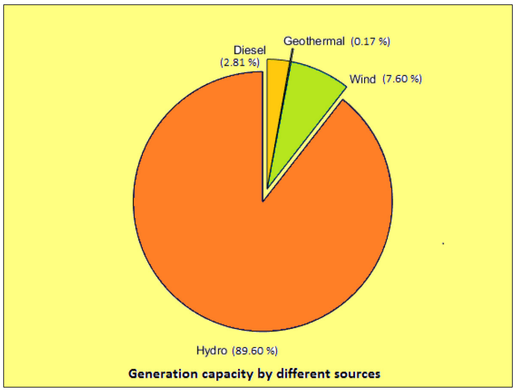



**Figure 6: Ethiopian energy generation by different sources (%) [1]**

Ethiopia is blessed with a great amount of renewable energy sources such as hydroelectric potential, wind, solar and geothermal as well as diesel. Although there is a great possibility of renewable energy generation, only a small amount of renewal energy is generated due to less financial sources and other considerable factors. Still Ethiopia is on the verge of a renewable energy revolution. To utilize such a huge potential, it requires considerable support in the fields of wind, geothermal, solar and biomass. These sources can be used as long-term energy potentials both for local industries and international energy trade. For that purpose, the Ethiopian Electric Power Corporation has developed various plans to achieve 75% energy access till the end of the decade. Figure 7 describes the availability of Wind, Solar PV and CSP resource in the Africa Continent [12].

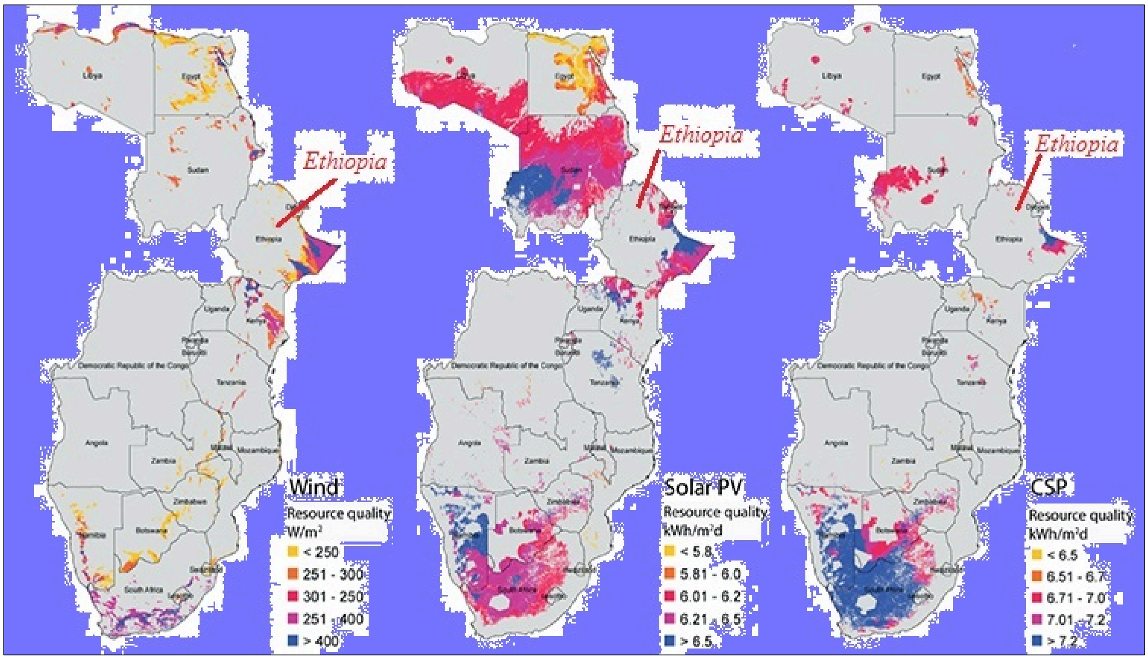



**Figure 7: Wind, Solar PV and CSP resource availability in Africa Continent [13]**

Like other sub-Saharan countries, Ethiopia lacks adequate electricity production and equal energy access. Urban populations have major access of electricity, while the large populations residing in the rural areas have less access to electricity. Figure 8 presents the electrification access in Ethiopia.

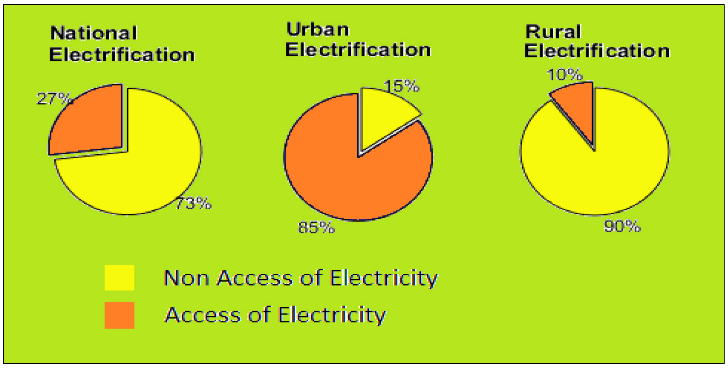



**Figure 8: Electricity access in Ethiopia [6]**

Ethiopia like other Sub-Saharan countries faces various problems, which rank Ethiopia low in terms of progress in electrification. In recent years, Ethiopia has made huge contributions in electrification of towns and villages but still the Pico-hydro power, wind and solar potential are under-used. From the climate change point of view, the energy mix is highly vulnerable and affects the lowest section of the society. The power generation in Ethiopia is mainly dependent on hydro power; this reduces the green house emission (less than 3% of the total emission). The energy production of Ethiopia has been enhanced greatly by more than 250% between 2008 and 2016, with new hydroelectric and wind power projects such as Tekeze (2009, hydroelectric, 300 MW), Gibe II (2010, hydroelectric, 420 MW), Tana Beles (2010, hydroelectric, 460 MW), Amerti Nesha (2011, hydroelectric, 97 MW), Gibe III (2015, hydroelectric, 1870MW), Ashegoda (2012, wind, 30 MW), Adama I (2012, wind, 51 MW), Ashegoda expansion(2012, wind, 90 MW), and Adama II (2014, wind, 153 MW). Additionally, one more project, the Grand Ethiopian Renaissance Dam is under construction with planned capacity of 6000 MW. The increased power generation is not efficiently utilized due to inadequate electricity grid. The projects initiated for the enhancement in the electricity production in Ethiopia are as follows [12]:

***(a) Wind power generation plants.*** The wind velocities in Ethiopia are in the range of 7 to 9 m/s which is very good for wind energy generation. The total predicted wind energy in Ethiopia is around 10000 MW [12]. In 1971, the Ethiopian National Meteorological Services Agency (NMSA) started to collect the wind data from 39 different locations. On the basis of the collected wind data from the existing wind measurement stations, two important points are concluded [11]:

- There is considerable potential of wind energy generation in Ethiopia
- Due to different topographies in Ethiopia, the generation of wind energy varies considerably for different locations. For example, the eastern half of the country has high wind velocities up to 10m/s, along with the western escarpment of the rift valley

In October 2013, Africa's largest wind farm started production in Ethiopia. This added diversity to the electricity production and made Ethiopia a major regional energy exporter. Different wind power plants projects in Ethiopia are as follows:

**Figure 9(a): Adama-I wind plant [14]**

**Figure 9(b): Adama-II wind plant [15]**

The Adama I wind power project (shown in Figure 9(a)) has an installed generation capacity of 51 MW. Adama II with total installed capacity of 153 MW (shown in Figure 9(a)) will be able to supply 480,000,000 KWh per year.

**Figure 10(a): Ashegoda wind farm [1]**

**Figure 10(b): Ashegoda Expansion wind farm [16]**

The Ashegoda wind farms (shown in Figures 10(a) and 10(b)) supply 120 MW of electricity for more than 3 million Ethiopians.

***(b) World class grand hydro-power plants.*** There is incredible hydropower potential in Ethiopia. The total predicted hydropower in Ethiopia is around 45000 MW per annum, out of which only around 8.5% capacity is utilized. The following are the various hydro power projects in Ethiopia.

**Figure 11(a): Gilgel Gibe I Dam [17]**

**Figure 11(b): Gilgel Gibe II Dam [18]**

The Gilgel Gibe I dam (Figure 11(a)) is a rock-filled embankment dam with an installed capacity of 183 MW on the Gilgel Gibe River in Ethiopia. The Gibe II hydropower project (Figure 11(b)) is the second of the three plants. It has 420 MW installed power producing 1650 GWh annually. Further the Gilgel Gibe III dam (Figure 12(a)) has1870 MW installed capacity.

**Figure 12(a): Gibe III hydro power plant [19]**

**Figure 12(b): Beles hydro power plant [20]**

Figure 12(c): Tekeze hydro power plant [21]

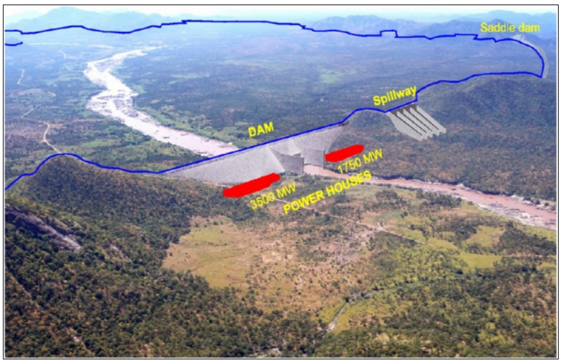



Figure 12(d): Grand Rehenaisance power plant [22]

The Beles hydroelectric power plant (Figure 12(b)) is a run-of-the-river hydroelectric power plant. The plant has an installed capacity of 460 MW. The Tekeze hydro power plant (Figure 12(c)) has a total generating capacity of 300 MW. The Grand Rehenaisance dam (Figure 12(d)) was first designed to generate 5,250 MW. However, due to expansion of the power plant, its installed capacity increased to 6,000 MW from 5,250 MW, and six years later, the design has been modified to add another 450 MW.

***(c) Geothermal Power Plants.*** The estimated potential of geothermal energy in Ethiopia is around 5000 Megawatts electric (MWe). Till now, only at two different places (Aluto-Langano (1982 to 1985) as shown in Figure 13(a) and Tendaho-Dubti (1993 to 1998) as shown in Figure 13(b)) has exploratory drilling taken place. Additionally, Corbetti, Abaya, Dofan Fantale and Tulu Moye areas are surface explored for future geothermal prospects [23].

A pilot project of 7.3 MWe based on geothermal has been installed at Aluto. Further, with the help of Japanese Overseas Development Assistance, feasibility study for the expansion of the Aluto Langano Geothermal power has been done. The Ethiopian government is currently working on the enhancement of the Aluto-Langano geothermal field up to 70 MWe. There are other geothermal areas in the Ethiopian Rift Valley (Teo, Danab, Kone and others) which can be explored for future energy production.

Figure 13(a): Aluto-Langano geothermal plant [24]

Figure 13(b): Tendaho-Dubti geothermal plant [25]

***(d) Biomass & biogas.*** Ethiopia has considerable amount of biomass energy resources. The estimated amount of national woody biomass stock (excluding branches/leaves/twigs (BLT), dead wood and homestead tree yields) was 1,149 million tons with annual output of 50 million tons in the year 2000, as was predicted by Woody Biomass Inventory and Strategic Planning Project (WBISPP). Due to higher rate of population growth, Ethiopia's biomass energy resources are exhausted rapidly.

As far as regional distribution of biomass is concerned, the northern highlands and eastern low lands have lesser biomass resources. The following areas have severe deficit of woody biomass resources:

- Eastern Tigray
- East and West Harerghe
- East Shewa and East Wellega Zones of Oromiya
- Jigjiga Zone of Somali Region

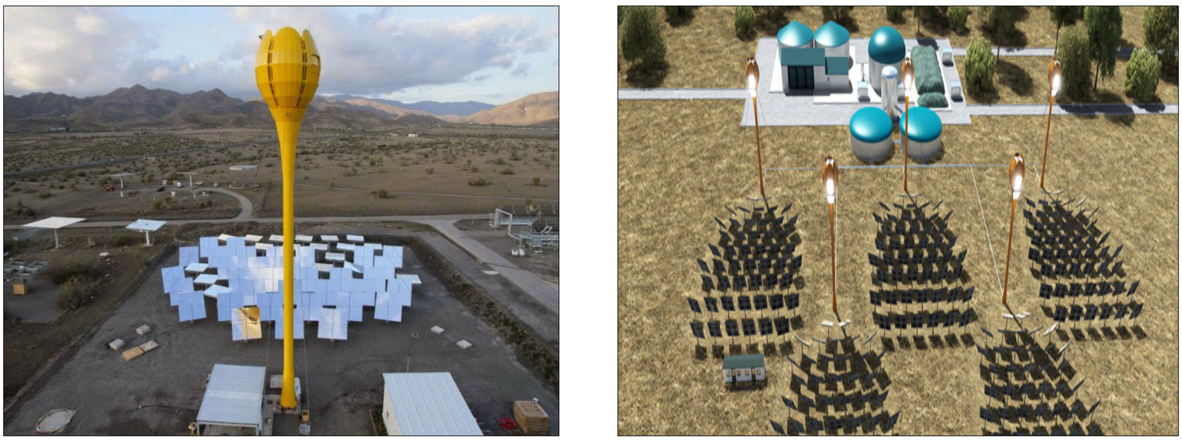
Amhara region has a moderate deficit of biomass energy sources except some districts, which have severe shortage of biomass energy sources. By products from agro processing industries (processing sugar cane bagasse, cotton stalk, coffee hull and oil seed shells) can be used as biomass energy resource [12]. Till now, grid connected biomass power plants don't exist. Additionally, sugar cane bagasses are also used for generation of electricity. Bio-fuels and municipal waste can also be used as energy sources.

There is no prediction for energy produced by municipal waste but predicted energy generation potential of landfill gases is around 24 MW. Figure 14 (a) and 14 (b) provide the process and implementation of the biomass plant.

**Figure 14 (a): Biogas Plant construction [26]**

**Figure 14 (b): Biogas Plant operation [27]**

***(e) Solar.*** The solar irradiation obtained in Ethiopia, according to region and season, is in the range of 5–7 kWh/m²/day. Thus, it has great solar energy potential. The average value of solar irradiance in Ethiopia is around 5.2 kWh/$m^2$/day, which is approximately uniform. Seasonally, the value of average solar irradiance is varying in the range of 4.55-5.55 kWh/$m^2$/day, while with respect to area it varies from 4.25 kWh/$m^2$/day in the extreme western low lands to 6.25 kWh/$m^2$/day in Adigrat area [13]. Figure 15 shows the AORA states first off-grid solar-biogas hybrid electricity plant in Ethiopia.

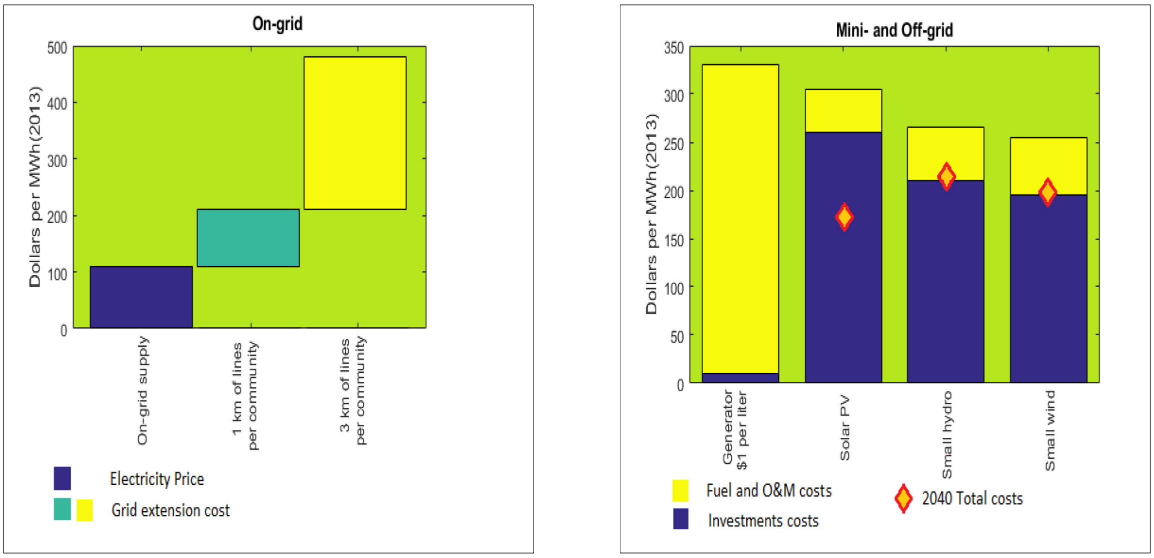


**(a) (b)**

**Figure 15: AORA off-grid solar-biogas hybrid electricity plant of Ethiopia [28, 29]**

**Transmission and substation network.** The pace of electrification process in Ethiopia is very fast, but still a broad area of rural population is without access to electricity. Only one third of the Ethiopian population has access to electricity. The challenges of electrification in rural areas are huge in Ethiopia because it has the world's second largest rural pupation without access to electricity (about 70 million). The rural electrification expansion strategies vary over time as income and demand pattern change. Additionally, a range of factors such as population density, electricity tariffs, mini and off grid technology cost and diesel cost greatly affects the generation of various options such as grid , mini-gird or off grid generation.

The overall population density of Ethiopia is significantly lower and a considerable percentage of the Ethiopian population are living in those areas which can be best connected through the grid.




**(a): On grid** **(b): Mini or Off grid**

**Figure 16: Indicative costs of electricity for on-grid, mini-grid and off-grid technologies [5]**

Hence solutions like mini and off grid can play an important role in the electrification process. In Ethiopia, the rate of electrification will increase from 26% in 2014 to around 60% by 2040. The cost of electricity, accessed from the extensions of gird is well below that of the electricity supplied by the mini or off grid systems [5].

In the context of Ethiopia, diesel generators mainly come under the category of mini or off grid systems. To supply small electrical load by off grid system, solar technologies are suitable option, while for supplying large electric loads, diesel generators are the best option as mini grid. Figures 16 (a) and (b) presents the Indicative costs of electricity for on-grid, mini-grid and off-grid technologies.

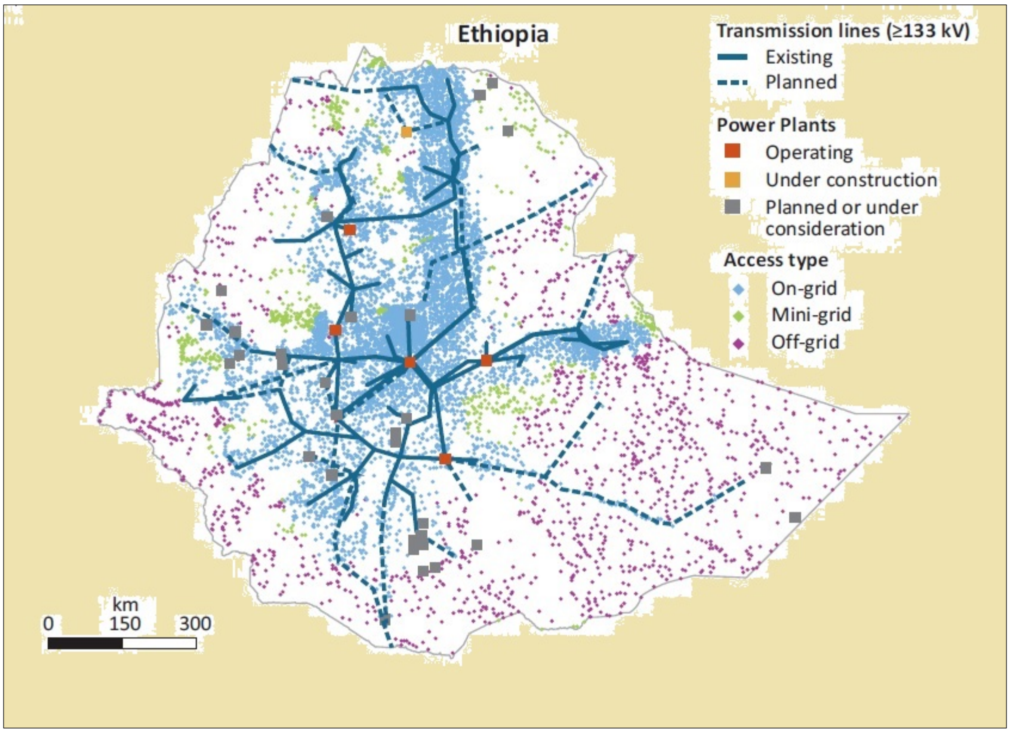



**Figure 17: Electricity Grid of Ethiopia [5]**

Figure 17 shows the complete network of Ethiopian gird. Presently Ethiopia has the hightest transmission level of 400kV. Further 500 kV transmission level is already in planning stage. Figure 17 also shows the different power plants in operation, under construction or planned. Additionally, different access types for gird (on grid, mini grid, off grid) are also presented. Table 4 presents the total length of transmission lines (km) based on their voltage levels in Ethiopia. It also presents the development of the transmission sector, year wise. Total number of transmission substations based on their voltage levels is presented by table 5. It shows yearly progress in the erection of a number of substations [5].

**Table 4: Total length of transmission lines in Ethiopia [1]**

| | Transmission network distance (km) by voltage level | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **500 kV** | **400 kV** | **230 kV** | **132 kV** | **66 kV** | **45 kV** | **Total** |
| **2011-12** | 0 | 875 | 2869 | 4871 | 1969 | 252 | 10836 |
| **2012-13** | 0 | 908 | 3597 | 4871 | 1969 | 252 | 11597 |
| **2013-14** | 0 | 908 | 4020 | 4871 | 1969 | 252 | 12020 |
| **2014-15** | 0 | 1511 | 5161 | 5048 | 1969 | 252 | 13941 |
| **2015-16** | 1240 | 1109 | 6740 | 5548 | 1969 | 452 | 17058 |

**Table 5: Number of substations [1]**

| | Number of substations by voltage level | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **500 kV** | **400 kV** | **230 kV** | **132 kV** | **66 kV** | **45 kV** | **Total** |
| **2011-12** | 0 | 7 | 19 | 56 | 30 | 13 | 125 |
| **2012-13** | 0 | 8 | 22 | 59 | 30 | 13 | 132 |
| **2013-14** | 0 | 8 | 27 | 60 | 30 | 13 | 138 |
| **2014-15** | 1 | 11 | 30 | 64 | 30 | 13 | 149 |
| **2015-16** | 3 | 12 | 41 | 64 | 30 | 13 | 163 |

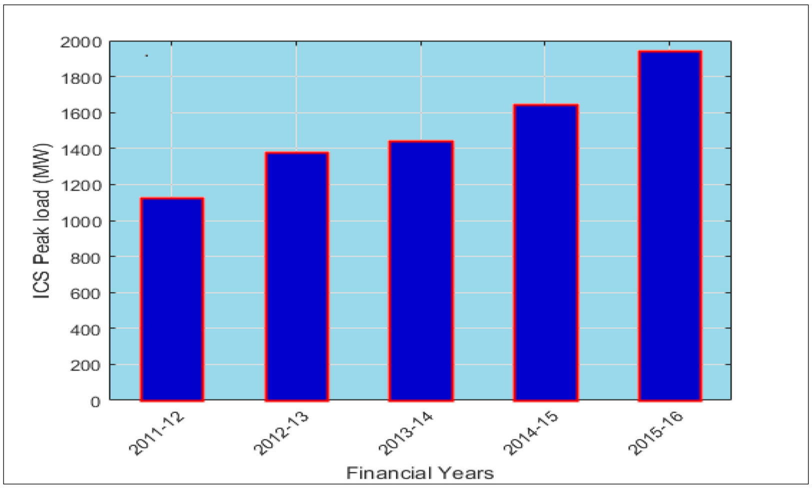



**Figure 18: Ethiopian ICS peak load in different financial years [1]**

**Electricity demand in Ethiopia.** Figure 18 presents the total interconnected system peak load of Ethiopian power system. This figure shows that there is continuous increment in system peak load from 2011-12 to 2015-16.

**Key challenges in Ethiopian energy sector.** There are unique challenges confronting the electricity sector of Ethiopia. The contribution of Sub-Saharan region to green house gases emission is least, globally. But it is the most affected region to climate change impacts such as droughts, floods, reduced crop production etc [30]. Factors such as unpredictable rainfall patterns and prolonged droughts severally affect the capacity of hydroelectric power plant and increase forced outages [31]. For Ethiopian electricity sector reform, the following challenges should be addressed with the aim of sustainable and affordable energy access.

**(a) Scarcity of System Capacity.** The economic growth of any nation is severally affected by the scarcity of generation capacity. It also prevents it from achieving the goals of health and education development. Various causes for the scarcity are as follows:

1. Shortage of generation capacity in connected regions.
2. Unavailability of adequate transmission infrastructure to transmit generated power.
3. Lack of maintenance of generating plants.
4. Lack of regulatory framework affects the steady flow of revenue for investing in new generation capacity.
5. Population dispersion in remote areas.

These factors severally affect the power sector's systematic planning, which results in higher transmission and distribution losses (around 18%, [6]). In addition to this, these factors also increase the dependence on large hydro and very expensive diesel plants.

**(b) Improper Management of Power Sector.** To improve the operational efficiency and encourage regional cooperation, restructuring and deregulation of the energy utility are of great importance; it will lead to minimize the energy deficiency. A big amount of money is spent in the regions to reduce the system losses and provide subsidies, which don't support the development of the power sector [7]. These subsidies create negative impact on system development and discourage private invertors. Thus, mostly investment in the energy sector is restricted to energy production for export purpose, for which revenue is surely guaranteed.

**(c) Excess System Losses.** Ethiopia has approximately double power system losses [6] as compared to the world average. They include technical and commercial losses due to mismanagement of transmission and distribution networks and poor revenue collection, respectively. To supply these losses, extra generation capacity is required, which makes the whole system uneconomical.

**(d) Reliance on Large Hydro Projects.** In the perspective of climate change impacts such as seasonal variations and prolonged droughts, dependency of Ethiopia on large hydro projects develops unreliable power system, which increases the social and financial risks. These risks can be calculated when these dams are in operating condition. In addition to this, the construction costs of these dams are too huge to get profit of the investment [32].

**(e) Dependency on Fossil Fuels.** The dependency on fossil fuels such as diesel, greatly affect the economics of power generation because the price of fuels vary according to the situation in the international market. Currently, 99.17 MW (2.34%) electricity is produced by diesel generator in Ethiopia, which is mainly off grid generation. Hence, the electricity non-accessed areas are greatly affected by the dependency on diesel fuel [12].

**Solutions to the key problems.** There are two mechanisms by which the electricity gap of Ethiopia can be minimized. The first mechanism is associated with increasing the electricity supply of the region and finding out whether the extra generating capacity should be from renewable or fossil fuel sources. The second mechanism associates with satisfying the electrical load and deciding the responsibility of regulated and deregulated electricity grids for increasing electricity access to people. Although, the two mechanisms are interlinked, these can be made complementary to each other by using a strategic framework [33].

**Path to Increase Supply from Renewables.** Different issues associated with the use of renewables for the expansion of electricity supply are as follows:

(a) The risk of climate change that will hamper hydropower. As Ethiopia has a great potential of electricity generation from the affordable and clean hydropower, several studies provide the high risk of climate change impact on the performance of hydro power dams. The technical performance of large hydro plants is greatly affected by the environmental constraints such as droughts, floods, variability in rainfalls etc. Furthermore, social and ecological risk factors are posed to large dams. Various measures are available that can be used to mitigate the detrimental impacts of large dams. For that purpose effective policies and management is required [34].

(b) Intermittent and variable nature of wind and solar. The renewable energy sources such as wind and solar are intermittent and variable in nature. They can be forecasted up to certain levels. The main issue with the gird system is that they are developed to operate on controllable generators instead of intermittent renewable sources. By using international standard's designs and technologies, Ethiopia is on the road of removing the barriers associated with the intermittent renewable energy sources [34].

(c) The risk of over-generation and curtailment. Normally, peak demands occur during evening hours, whereas solar generation peaks at midafternoon. Hence there is a mismatch in peak demand and peak generation by renewables which raises the risk of generating extra energy than the demand during off peak hours (over-generation) and generation of energy would subsequently be cut off (curtailment).

**Cost of renewable energy.** The high economic cost is no longer the main constraint for deployment of renewals. Now the main aim is to achieve efficient gird operation with renewables. For large scaled utility plants, the weighted average cost is reduced from $5 per watt (in 2009) to around $2 per watt (in 2015), globally. There has been an incredible reduction in the cost of solar PV modules. In 2009, it was around $0.52, which has dropped to $0.27 per watt in 2015.
Presently, an average cost of $0.03 per kWh is reported for 800 MW solar plant situated at United Arab Emirates [35], which is considerably low as compared to large scale hydropower plant ($0.08 per kWh), geothermal ($0.10 per kWh) and natural gas power plant ($0.14 per kWh) [5]. For achieving 100% renewable energy generation in Ethiopia, the following are the necessities:

1. Policy framework, to incentivize renewable energy installation and discourage new fossil fuel projects.

2. Novel financing instruments to provide decentralized solutions and be incorporated for future expansion of grid.
3. A supporting framework to private investors in energy sector that develops trained manpower by authorizing local entrepreneurs.
4. An enhanced organizational measures and adequate sector management that allows operating power pools to share power and reduce cost.
5. Strategic framework that supports decentralized renewable energy systems and enables 100% access to reliable and affordable power.
6. Strategies related to transmission of power that prioritizes the generation system's diversity for example dispatchable renewables and storage, which minimize the necessity of fossil fuels and provide secure supply.

**Flexibility of Power System.** There are various system states in different time horizons which should be adapted and responded to by the power system structures and operators. Two different types of flexibilities can be incorporated into the system i.e. short term and long term. The former is concerned with meeting the demand with respect to supply over minutes and hours of a day, while the later is related to the change in generation and transmission capacity over years of investment. In the perspective of high energy penetration levels from renewables, flexibility of power system is a critical issue for reliable operation of the power system. Various resources for improving system flexibility are as follows [36]:

1. Increased transmission link capacity
2. Dispachtable generation
3. Regional grid cooperation
4. Large balancing regions
5. Demand side management techniques
6. Supply side management techniques
7. Energy storage devices

There is an inherent level of flexibility in every power system. The main problem with the flexibility of power system is the storage of excess power during no load or light load conditions. Once the electricity is generated, it can not be stopped from flowing on the transmission lines. Additionally, the generated energy should always equal to the available demand in the system at all times. Because there is a huge and rapid variation in the demand (both predicted and unpredicted), power system are designed to be flexible enough to supply this variable demand. There should be enough reserve capacity (also known as operation or spinning reserve) for the robustness of the generating system [37].

Generally the power systems, which depend on hydropower, are more flexible as compared to the systems with coal and nuclear generation. The ramping time for coal and thermal power are very high, hence require more time to reach their rated capacity as compare to reservoir dam. Typically, forecasted demands are available with gird operator one day ahead, which is updated in the hour ahead and finally in the minutes ahead of the service. The planning of supply to match with demand is very difficult with wind and solar as their outputs incredibly vary over short time durations. Furthermore, dispatchability is not available in their outputs. Consequently, more flexibility is required for transitioning to high penetration level of variable renewable generation. For improving the flexibility of system under such scenario, reserve capacity generators can be used. But for each renewable energy generator, reserve is not required because the gird system also supports the variable demands [36].

In Ethiopia, for transitioning to high penetrated renewable power system, regulators and system operators can select the various options from the available suit presented in Figure 19. These options provide different strategies which are as follows:

1. Physical strategies: Battery storage, Chemical storage.
2. Operational strategies: Hydro ramping, Improved forecasting.
3. Institutional strategies: Integration of demand response, new market designs .

As compared to the gird connected battery energy storage system, pumped hydro storage is a cheaper source for improving flexibility. Additionally, the presented options for improving flexibility and their respective costs are system specific factors.

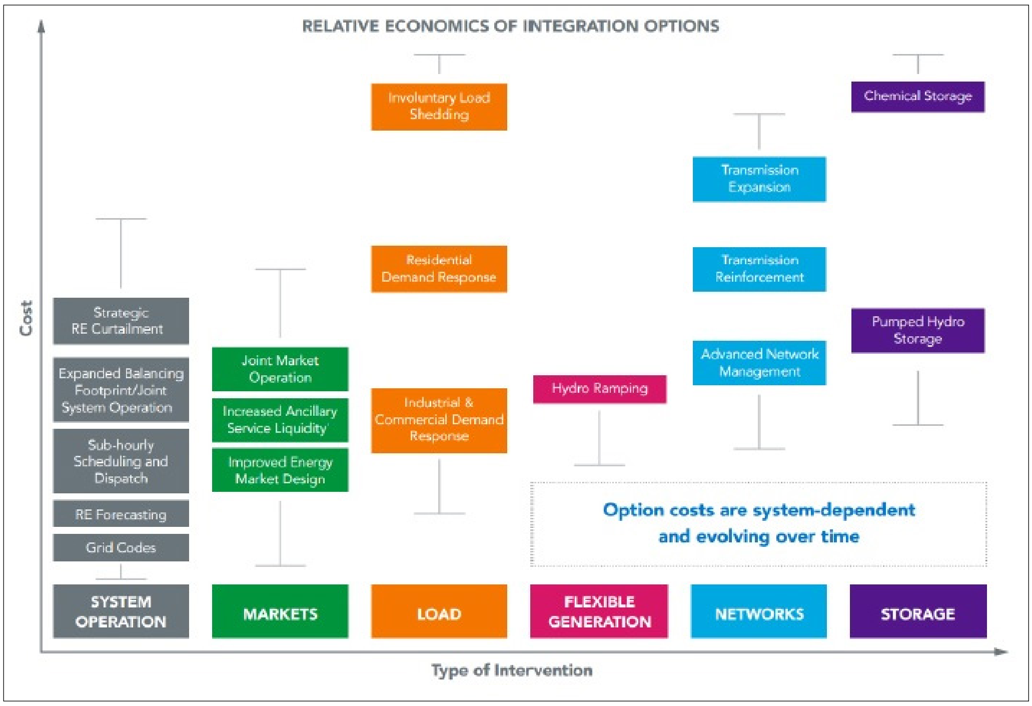



**Figure 19: Strategies for flexibility enhancement [36]**

The following are the various issues which can be prevented by improving system flexibility [36]:

**(a) Volatility of energy price.** Due to the poor flexibility, generators are not able to reduce their generation during light load period. This extra generation of energy can cause prices to drop considerably, leading to the system being in financial risks. In addition to this, during peak load hours, due to low flexibility, generators are not able to increase their outputs to supply peak demands. This leads to very high energy prices for consumers to bear.

**(b) Curtailment of Energy.** During the period of high generation and low demand, inflexible and non dispachtable systems must be shut off (curtailed).

**(c) Load shedding.** By maintaining the supply demand balance, quality power can be supplied to the consumers. In the case of inflexible power plants, load shedding is used to match the supply demand balance during periods of high demand and low generation.

**Facilitation by Power Pools.** Power pool and cross border energy supply as a regional support, which will help to decrease the electrification gap in Sub-Saharan Africa. The cooperation can help the countries to maintain the energy cost. By pooling their resources, the average cost of energy production of the countries can be restricted to a certain level. This pooling can help to protect them from price changeability, which is due to the dependency on the fuel or climate in case of hydro-power.

Pooling decreases the import of fossil and shares the renewable resources. South Africa which is generating energy from coal can get support from the geothermal resources of Kenya. Pooling of the resources is affected by the political issues and challenges [33]. To have effective power pool cooperation, member countries should come to a common agreement. Additionally, the member countries should work on a common effective energy production framework accepted legally and technically.

**The Eastern Africa Power Pool (EAPP).** In 2005, countries from east Africa established a power cooperating group as EAPP. The seven member countries of EAPP are Ethiopia, Egypt, Burundi, DRC, Kenya, Sudan and Rwanda. Later on three more countries Tanzania, Uganda and Libya joined the power pool EAPP. Common Market for Eastern and Southern Africa (COMESA) has adopted it as a dedicated association to promote energy system interconnectivity. EAPP has laid the master plans to study and cooperate in the regional power generation systems. The EAPP has been fully operational for a number of years.

**Distributed energy resources.** To close the electricity gap in sub-Saharan Africa, the use of off-grid and distributed system plays a major role. The off grid systems are not only powered by the diesel generators but also by the renewable resources. The modern distributed system are a combination of renewable sources (solar and wind) and/or small scale hydro-power. The awareness regarding renewable and distribution system management ease the use of distributed energy resources (DERs) such as rooftop, battery and solar PV systems.

**The potential of distributed energy resources (DERs).** There are different advantages of DERs over centralized grid system, such as power loss reduction, scaled design and appropriateness to use renewable resources. It helps to balance the inequality between rural and urban electrification. The grids supply the electricity to economically sound communities, capable of paying the connection fees, whereas low income rural communities are left with less electrification options. DERs are capable to supply the electricity to areas left without grid access and need less monitoring efforts for operation. The smart grid technologies make feasible the attachment of micro-grid to grid to reduce the load of the centralized power generation. ICTs play a significant role in the success of DERs as they help in distant announcement of maintenance, recuperation, effortless data analysis and smart metering. For increasing electric power in Ethiopia, a balanced combination of grid and micro-grid is required. Micro-grid can be considered as a temporary situation of the main grid and they are required to be integrated to the main grid to increase their reliability. The private micro-grid organizations should be motivated and financially supported by the different government and non-government agencies.

## Comparison of Decentralized Energy Technologies

**(a) Solar lanterns.** A solar lantern unit is a combination of a photovoltaic (PV) panel with lighting equipment or a PV panel with a set of lights which can be charged in day time and used in dim light for lighting. The standalone solar lanterns are easily available in Ethiopia. The cost of solar PV lightening is less and quality is high with respect to kerosene lamps and candles. The variable cost related with kerosene and other lighting energy resources is reduced as the fuel cost for solar PV is nil.

Some associations such as Global Off-Grid Lighting Association (GOGLA), produces and motivates high quality products to improve the business of solar companies. Although, a lots of efforts are made for better quality lantern, instead, inexpensive low quality ones reach consumers and they have a small life time, poor lightning and fewer options for repair.

**(b) Pico-solar and solar home systems.** Small solar PV systems Pico-solar or pico-PV having power generation capacity of 1W to 10W, are mostly used for lightning and low load applications such as phone charging. In the last few years, the developments in the technologies of solar panels have reduced the manufacturing cost and materials cost for PV panels; this has increased the use of solar panels in different rural areas as well. The solar power generations are beneficial because of the light-emitting diodes (LED) technology as well as innovations in payment systems based on mobile phone banking and others.

The M-Kopa organization, which is acing in the east of Africa, is installing the pico-solar systems with some lightning and appliances for entertainment. Consumers can buy such systems in onetime payment or on easy monthly installments which can be paid by using mobile banking. Such options have made it easy to access solar systems for the rural areas and low income zones also. Solar systems of M-Kopa with capacity of 8W are available with several LED lights, a charable radio and mobile charger. To date, more than 300000 houses are connected with M-Kopa units (PwC, 2016). Solar unit production organization Mobisol has the largest system with sufficient power generation capacity to charge laptops, a DC refrigerator and a television for long duration of time. The company has established a large number of solar home systems in East Africa.

**(c) Micro-grids.** A micro-grid is a small energy production and distribution unit capable of supplying electricity to a few buildings in rural areas. In sub-Saharan Africa, micro-grids are owned by the private sectors and the funding is from different sources such as donors, bank loan, equity investors or government support. Micro-grid is capable to supply the electricity to remote sites. It is less expensive and takes less time to construct. Diesel cost is variable. Further, its transportation cost to rural areas increase the energy cost from micro-grid, but diesel is easy to store. Although the tariffs of energy from renewable sources are high, renewable sources are more the tradition in micro-grid as its fuel cost is nil, decreasing price of solar panels and wind technologies as well as improved battery storage technology.

## International energy trade

Ethiopia has developed the energy sector and starts production on massive scale. It is one of the rising energy production zones in the east Africa. It has sufficient capacity and production to wholesale the energy at international level. Currently, Ethiopia is selling the energy to three of its neighbouring countries Djibouti, Kenya and Sudan. The exports of energy in different Ethiopian financial years are depicted in Figure 20.

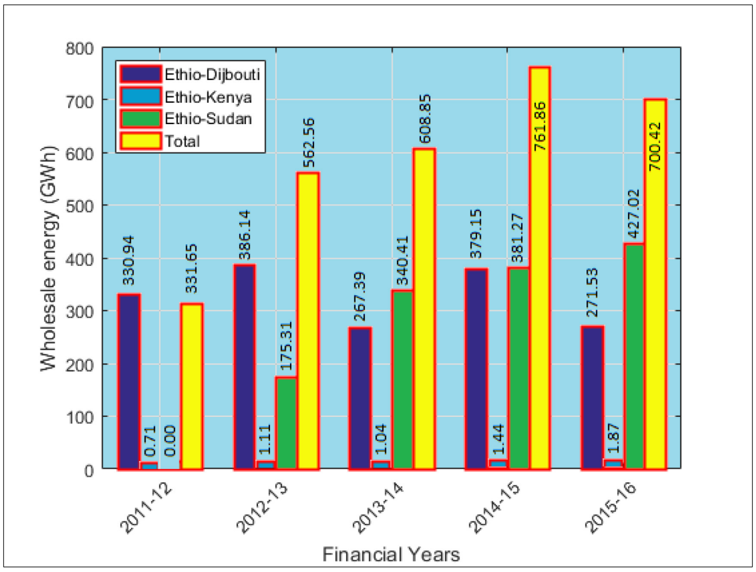



**Figure 20: Ethiopian energy export in different financial years [1]**

## Energy policy framework

In the last two decades, the Ethiopian government has taken a lot of initiatives under different policies pertaining to energy production, transmission, distribution and electrification. There is a major emphasis on the hydropower resources and considerably fewer policies are available for renewable energy resources and development. Some of the frameworks of policies are generated for renewable energy; for example the 1994 National Energy Policy describes the problem of household energy and promotes agro forestry, energy efficiency in biomass fuels and use of modern renewable sources. In doing so, it motivates the private sector to participate in energy production by different means.

A national Growth Transformation Plan (GTP) (2011-2015), has a motive to generate sustainable energy by promoting Green Development Strategy. This plan encourages the development of hydropower expansion plan including the Blue Nile dam which is adequate enough not only to satisfy the national demand but also for export. The policy also considers the expansion of wind, bio-fuel and solar energy sources [40].

The objective of enhancing renewable energy production for regional and domestic markets is considered in Climate Resilience and Green Economy (CRGE) strategy. To increase the reliability and decrease the dependability on the weather conditions, a strategy Electricity Feed-in-Tariff Law (2012) motivates the inclusion of mix power in the national grid. Alternative Energy Development and Promotion programme focus on the development and rehabilitation of abundant renewable energy resources by using advanced technologies.
Ethiopia developed a proposal and submitted it to CIF partner countries forum in Washington D.C. to enhance the Renewable Energy Program (SREP) in coordination with African Development Bank (AfDB), World Bank Group (IBRD, IFC) and other partners including Ethiopian stakeholders. The plan was approved and a financial support was provided for one wind project (Assela, 120 MW) and one geothermal project (Aluto Langano, 200 MW). The long term plan of EEPCo was to attain the zero carbon emission by 2015 with the support of the private public partnership [38].

**National Biogas Programme (NBP) of Ethiopia.** For selected areas of Ethiopia, NBP started working in 2007 along with EREDPC to encourage the use of domestic biogas. The program had financial support from different investors and donors. This program is operating in more than 37 districts, and more than 1200 plants have already been constructed as an output of it [40]. This program has become a base for the national level investment and improvement in cooking with stoves.

**GiZ Energy Coordination Office (ECO).** In coordination with Ministry of Water and Energy (MWE), ECO has been promoting the production and use of renewable energy since 2010 in Ethiopia. The outcome of the effort is installation of photovoltaic solar systems in more than 100 off-grid remote public health centres and four community centres. Additionally, Selam Vocational Training Centre in Addis Ababa has started a first training center for solar technology. Four micro-hydropower plants having the capacity of 125 KW have been constructed with the support of Ethiopian Alternative Energy Promotion and Development Centre (EAEPDC) in three villages of SNNPR. More than 650 energy-efficient cooking stove units have been established in 310 districts.

**Role of Government**

**Ministry of Water and Energy (MWE).** MWE is an organization established by the government of Ethiopia and dedicated with the responsibility to plan, develop and manage the energy resources. In 2010, the government restructured the energy organizations and all responsibilities and duties of the Promotion Directorate (AEDPD), Rural Energy Development and Promotion Centre (REDPC) and Alternative Energy Development were transferred to a newly merged department of MWE. The responsibilities of the MWE were extended by inclusion of accountability to create various policies, strategies and programs. Further, it is responsible to implement the policies, strategies, law and regulation generated [40]. Additionally, it provides technological help to regional energy departments and offices. It has the right to sign the agreement with international agencies. A specific fund named as Rural Electrification Fund has been allotted to MWE so that it can provide loan to some of the small-scale energy initiatives (including renewable energy initiatives) in rural areas. MWE contributed to the improvement of the off grid rural electrification plan using the renewable energy technologies. There are different government organizations which make contributions to the energy sector using different means, such as the Ministry of Finance and Economic Development (MoFED), the Ministry of Trade, the Ministry of Mines and Environment Protection Agency [1].

**Government agencies.** There are number of government agencies which are working for the harnessing renewable energy, enhancement of electrification access, awareness and training about benefits of renewable energy. Government agencies such as Rural Electrification Executive Secretariat (REES), Regional Energy Agencies, Ethiopian Rural Energy Development and Promotion Centre (EREDPC) and Ethiopian Electric Power Corporation (EEPCo) are currently working for the establishment and enhancement of energy sector.

REES is responsible to ensure and motivate the off-grid rural electrification projects with the help of private sector operators and cooperatives involved in energy production exterior to the national grid [40]. REES is responsible for the management of Rural Electrification Fund (REF) and works under the command of AEDPD. The government bureaus act as regional energy agencies and they are responsible to encourage and assist the awareness and training programs to communicate the advantages of the use of modern energy technologies. EREDPC is responsible for laying the policies and resolve the issues pertaining to the rural energy development, distribution and electrification through the extension of national grid. There is a great possibility of involvement of EREDPC in the expansion of small scale off grid renewable energy production but a small contribution is observed [40].
In 1956, the Ethiopian Electric Light and Power Authority (EELPA) was established to look after the issues of energy power generation and distribution, but later it was restructured and reorganised with a new name Ethiopia electric power corporation (EEPCo). To enhance the working capability of the power sector, EEPCo was divided into two organizations i.e. Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) [39]. In 2013, EEP was created by regulation number 302/2013 which was formed by the council of ministers. EEP is made accountable for production, transmission and trade of electricity nationwide and internationally to the neighbouring countries. EEP has a large workforce with different education standard, age group and gender ratios as shown in Figures 21(a) to 21(c) [1]. EEP is devoted to increase the education standard and achieve a balanced ratio of gender by different promotional programs and supports [1].

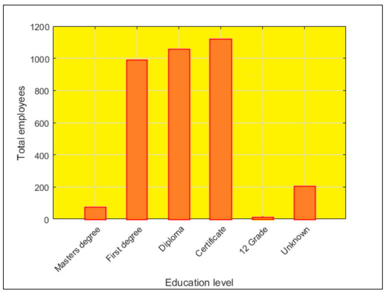


Figure 21(a): Educational level of employees in EEP

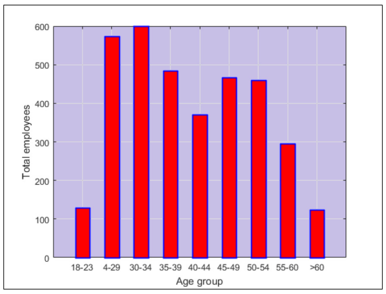


Figure 21(b): Employees of EEP by age groups

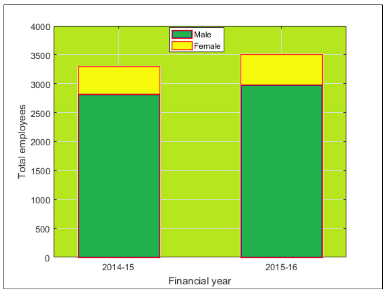


Figure 21(c): Gender ratio of employees in EEP

## Regulatory Framework

The private sector is motivated to invest in the energy sector through the Ethiopian Electric Power Corporation (EEPCo) and to accomplish this, related declarations were made in 2005 and 2007. EEPCo has settled different Private sector power purchase agreements (PPAs). On the basis of guidelines laid out in the Electricity Operations Regulations (49/1999), the investment proclamation (280/2004) and the letter of power sector policy (2003). Independent power producers (IPPs) are motivated to make initiation in the energy production by different means. With the consent of the Ethiopian government, developers involved in the geothermal energy production have the chance to buy the geothermal exploration licenses on the basis of the regulation laid by the government [40]. A separate legislation (feed-in tariff legislation) for IPPs has been laid by MWE to settle the unit cost for selling electricity to national grid. The legislation has undergone different changes till date.

**Regulatory roles.** The Ethiopian government has laid out several regulations and rules to govern the rising energy generation and access. The regulations are used to maintain the quality and standard of electric supply as well as installation. It is also used to identify and certify the qualitative suppliers and contractors in the field of energy. As per the guidelines of the regulations (such as Electricity Proclamation No. 86/1997), the decision to issue or retract the permit and supervision of the transmission, production, allocation and trade of electricity are accomplished [39]. The decision of the settlement of tariff value and its collection is accomplished as per the guidelines of the regulations. Additionally, to enhance the technical skills of the staff and others, cooperation is provided from different institution by means of various training programmes.

**Energy regulation role.** The EEA is making a lot of efforts to accomplish the maximum expansion of qualitative low cost energy production and evenly distribute it. Different efforts are made by the Ministry of Infrastructure, EEA and the Council of Ministers, through different directives and regulations, such as Regulation Number 49/1999, to enhance swift socioeconomic development of the nation [40].

## Conclusion and Recommendations

Currently, Ethiopia is a leading nation in the energy sector development. The energy policy and regulatory frameworks are key factors, which will have a long-term effect on the development of energy production and the socioeconomic condition of the country. The future outcomes are highly dependent on the current decisions. To take the appropriate decisions, detailed study is required for specific fields. Hence the paper presents a comprehensive report on the Ethiopian power sector, which will be helpful for taking long term structural decisions. This paper explains in details the pros and cons involved in the development of the energy sector of Ethiopia. The current electricity access in Ethiopia is 27%, which is very low compared to international standards; it can increase up to 75% by 2040 using the renewable energy potential of the country. The present study observed that out of the various renewable energy sources, geothermal and solar are less utilized (around 0.2%), which could be the key source for rural electrification. In the off gird area, diesel generators are used for electricity access, which can be replaced by solar or wind sources. However, energy production using renewable energy sources is increasing day by day in Ethiopia. The Ethiopian government should come out with encouraging energy policy and regulations framework. The futuristic extension of the current study will be a detailed investigation of the integration of large capacity renewable energy sources and their impact on gird flexibility. On the basis of the current study, the following recommendations are made:

- The taxes and import duty on energy generation equipment should be reduced
- Loans should be provided with low interest rate to motivate the establishment of renewable energy sources
- Foreign investment should be motivated by ensuring easy acquisition of license for energy generation
- Local equipment production units should be established as a prosperous business
- Different institutions should be motivated and trained to use the renewable resources
- Motivational awareness programs should be conducted for the use of renewable resources
- In rural areas, bio gas plants should be established as a substitute for grid supply for cooking
- Technical training programs should be offered to teach the operation and maintenance of the energy sector
- ICT based banking services should be motivated for easy transaction of money
- The work of regulatory bodies should be audited and scaled, to motivate and control them
- New regulations should be structured to motivate investors from different sectors
- The use of pico-solar systems should be encouraged for lightning the houses in rural areas
- To increase the flexibility of systems with high levels of renewable energy penetration, physical (storage), operational (hydro ramping) and institutional strategies (Integration of demand response) can be used
- By using international design standards and technologies, the barriers related to the intermittent renewable energy sources can be removed
- The risk of climate change that will hamper hydropower can be mitigated by using different studies and measures
- Policy framework, to incentivize renewable energy installation and discourage new fossil fuel projects can be formulated

- Novel financing instruments to provide decentralized solutions can be incorporated for future expansion of grid
- A supporting framework for private investors in the energy sector can be developed to train manpower by authorizing local entrepreneurs
- An enhanced organizational measure and adequate sector management should be implemented to allow operating power pools to share power and reduce cost
- Strategic framework that supports decentralized renewable energy systems and enables 100% access to reliable and affordable power should be improved

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