Geothermal Power Potential in Ethiopia

Fiseha M. Guangul and Girma T. Chala

Abstract Ethiopia is endowed with various types of renewable energy resources. The country has significant amount of geothermal energy source that can be developed to produce more than 10,000 MW electric power. The unique location of Ethiopia where The Great Rift Valley extending 1000 km from the Afar depression at Red Sea–Gulf of Aden junction north-west to Turkana depression on the south enables the country to share the abundant geothermal energy of the rift valley. Currently the total electric energy produced from geothermal source is not more than 8 MW. The disparity between the power demand and supply gap available in the country and the need to diversify the hydroelectric energy to other renewable sources enhance the development geothermal energy source in the country. High initial investment cost for geothermal energy development as opposed to hydropower energy, lack of technical competence and low tariff regime of electric power are some of the challenges faced by the country to develop geothermal energy. In this chapter, the opportunities and challenges of developing geothermal energy in Ethiopia are discussed. In addition, some recommendations to overcome the challenges are highlighted.

1 Introduction

Currently fossil fuel takes the major share in the global energy supply. Nevertheless, due to the adverse effect of fossil fuels on the environment and the limited supply, the focus of many countries has been shifted to renewable energy sources [1–6]. Ethiopia is the second most populated nation in Africa next to Nigeria with 108 million people

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as of 2018, and one of the fastest growing economy in the world. Yet, the country is still regarded among the poorest countries in the world with annual per capita income of $953. It was projected that the country would reach to lower–middle–income status by transforming the agriculture sector into manufacturing sector by 2025 [7]. However, energy supply remains as one of the bottlenecks to achieve the targeted growth. In the Growth and Transformation Plan I (GTP I), which covered between 2011 and 2015, the government planned to increase the power supply from 2000 to 8000 MW. Although the power generation was grown by more than one fold to 4180 MW, the targeted plant was not achieved [8].

In the second Growth and Transformation Plan (GTP II), which is planned to be implemented between 2016 and 2020, The government has targeted to enhance the electric power supply to 17,208 MW from 4180 MW, of which 13,817 MW is expected from hydropower, 1224 MW from wind power, 300 MW from solar power, 577 MW from geothermal power, 509 MW from reserve fuel (gas turbine), 50 MW from wastes, 474 MW from sugar bagasse and 257 MW from biomass [8].

Currently hydropower provides 90% of the country electric power supply. Ethiopia has a potential to generate 45,000 MW electric power from hydropower; however, the country has only used not more than 10% of the resource to generate power. Though the country depends almost entirely on hydropower energy to cover its demands, this energy source is currently facing a challenge with rainfall fluctuation as a result of the world climate change resulting in shortage of water [9]. Hence, the government has intended to diversify the renewable energy source and as a result geothermal energy was set to be considered as the second priority.

The Ethiopian Rift extends from the Ethiopia–Kenya border to the Red Sea in a NNE direction for over 1000 km within Ethiopia and covers an area of 150,000 km^2. The geothermal locations of Ethiopia are shown in Figs. 1 and 2 [10, 11]. The exploration of geothermal energy in Ethiopia was started in 1969 with a regional

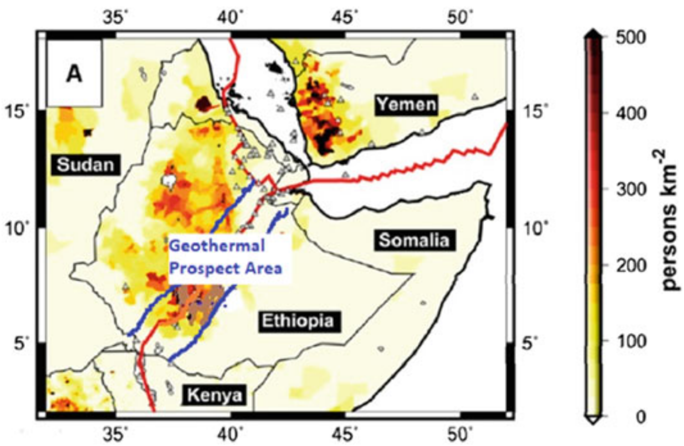

Fig. 1 Geothermal prospect areas in Ethiopia [10]

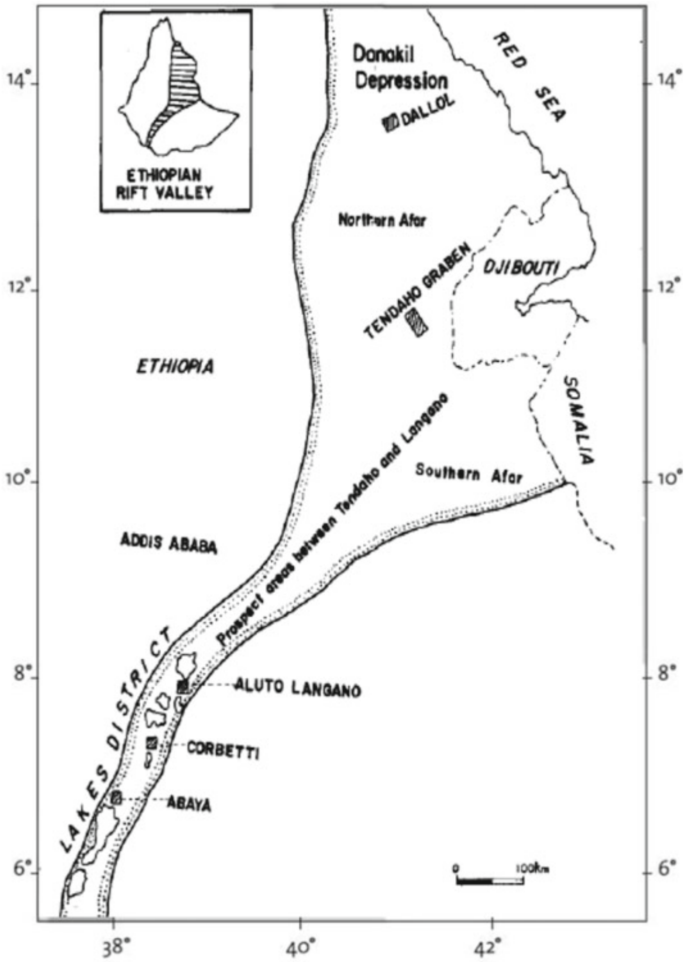

Fig. 2 Geothermal resource locations in Ethiopian Rift Valley [11]

geological–volcanological mapping and hydrothermal manifestation inventory in most of the Ethiopian Rift. Even though the inventory work is not completed in all parts of the country, especially in the highland areas, the rift valley areas are well covered, and about 120 locations are found to have independent heating and circulation system. Among these locations, above two dozen were identified to have high enthalpy resources for potential application of electric power generation. Previous studies showed that an electric power ranging between 4200 and 10,800 MW could be generated from the sites [12, 13]. The objective of this chapter is, therefore, to discuss the opportunities and challenges of developing geothermal energy in Ethiopia.

1.1 Geothermal Resource

Geothermal energy is obtained from the Earth natural heat, primarily due to natural decay of radioactive isotopes of uranium, thorium and potassium. The temperature of the earth increases with depth measured from the surface to the interior. On average, the increment on temperature reaches 20–30 °C/km. The temperature at the base of the continental crust ranges from 200 to 1000 °C, whereas it could reach 3500–4500 °C at the Earth's centre. Because of the heat gradient, the flow of heat takes place from the interior to the surface depending on the geothermal gradient and thermal conductivity of the rock. The amount of heat flow at the surface to the atmosphere ranges between 40 and 90 mW/m^2, and the total global output could reach over 4×10^{13} W. Currently, the total global energy consumption is about 10^{13} W, and this is a quarter of the energy that dissipates from the surface of the earth. Hence, the thermal energy of the Earth is immense; however, only a fraction can be utilized. Most geothermal exploration and use occur at the higher temperature gradient and where drilling is shallower and less costly. Currently the utilization of geothermal energy is limited to areas where heat transfer can be achieved from deep hot zone to the surface or near the surface by using heat carrier, i.e. liquid water or vapour [14, 15].

Economical geothermal energy development is achieved at a higher temperature gradient along the depth and higher temperature can be obtained in shallower depth. The shallow depth geothermal energy can be obtained when: (1) a great quality of heat is brought up by intrusion of molten magma from deep surface to the shallow surface; (2) the heat flow is high as a result of thin crust and high temperature gradient; (3) the groundwater is able to circulate to depth of several kilometres and heat transfer occurs as a result of normal temperature gradient; (4) the thermal conductivity is low due to the thermal blanket shale formation in the deep rock; and (5) the radioactive elements which may be intensified by thermal blanketing create heat in the shallow rock [16].

Geothermal resources that are used in large-scale power generation are hydrothermal, geopressured brines, hot dry rock and magma. Commonly, hydrothermal resources are used in commercial scale plants. Water heated by descending to shallow depth from few hundred to 3000 m and escaped as steam or hot water is utilized in binary power plant for electric power generation. The resource is classified into three main groups based on the temperature of the water or steam obtained: high for temperature above 200 °C, medium for temperature range between 100 and 200 °C, and low for temperature below 100 °C. The geothermal resource below 100 °C is not suitable for commercial power generation. The geothermal resource with high water content has low efficiency when compared to that of conventional steam power plant since the heat in the water is not convertible to electric energy [17].

Geopressured brains are hot pressurized waters with temperate range between 149 and 204 °C containing methane and found at 3000–6000 m below the surface of the earth. Three types of energy can be produced from geopressured brines: thermal energy produced from high temperature fluid, hydraulic energy produced from high pressure and chemical energy produced from burning of the dissolved methane gas. The geopressured brains become unusable from economic point of view once enough quantity of water is removed, and the pressure and the brine are dropped.

Dry rocks that are commonly found at depths of 4000 m and below are exceptionally hot. Two wells need to be drilled to access the hot rocks. The preexisting fractured rocks between the wells would help water to be pumped into the dry hot rock at high pressure. The water pumped is then heated and converted into steam and drawn up with the other two wells. By using a binary of flash power plant, the thermal energy of the steam is converted to electric power [17].

1.2 Types of Geothermal Power Plants

Geothermal plants operate over a temperature range of 50 and 250 °C, which is lower than the conventional fossil fuels or nuclear plants (usually at 550 °C). Geothermal power plant can be classified into three types: flash, binary and dry steam plants.

Dry steam plant

Dry steam plant is the oldest and simplest geothermal plant. The turbine operates with the steam coming directly from the production well. After using the steam and operating the turbine, the exiting steam or water is cooled and pumped back to the injection well [18].

Flash steam plant

Currently flash steam geothermal power plant is commonly used type power plant. The power plant uses water above 180 °C that flows upwards from a high-pressure reservoir well. As the water ascends to the surface, the pressure drops and the hot water partially converted into steam. The steam is sent to the turbine to drive after separating the water from the steam using steam separator. The condensed steam that exits the turbine and the unused water are pumped to the injection well as depicted in Fig. 3 [19].

Binary steam plant

Binary power plant is recently developed. In this plant, the water is used to heat another organic fluid that has lower boiling temperature. Hence, the organic fluid is converted into gas and used to drive the turbine instead of the hot water or steam. The advantage of this power plant is the possibility of electricity generation from a low water reservoir temperature of below 150 °C. The power plant uses heat exchanger to transfer the heat from the water to the secondary working fluid. The water is allowed to cool further in a condenser and injected to the well, as shown in Fig. 4 [19].

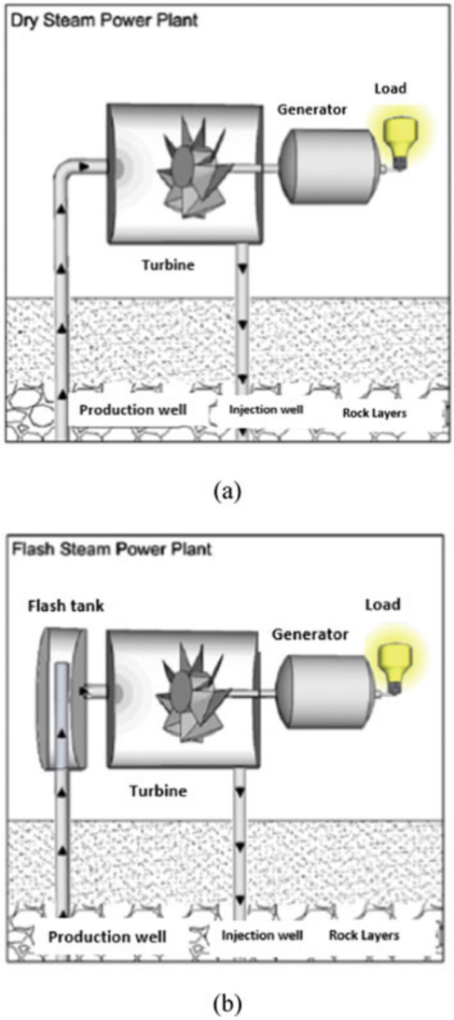

Fig. 3 Geothermal power plant: **a** dry steam and **b** flash steam [19]

1.3 Geothermal as a Source of Electrical Energy

The global utilization of geothermal energy in the current electric power generation is not more than 0.3% of the total electric production. The contribution of geothermal energy for electric power generation did not also exceed 1.5%. Figures 5, 6 and 7 show the geothermal energy contribution to generate electricity and its application in various areas [20].

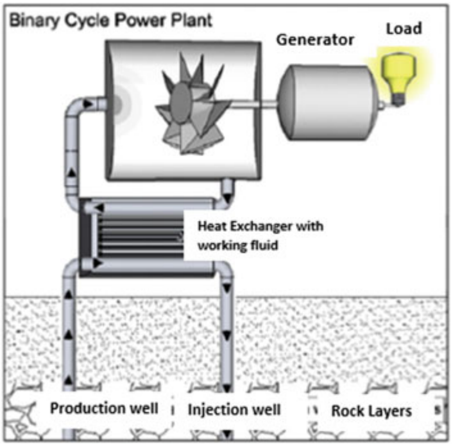

Fig. 4 Binary cycle geothermal power plant [19]

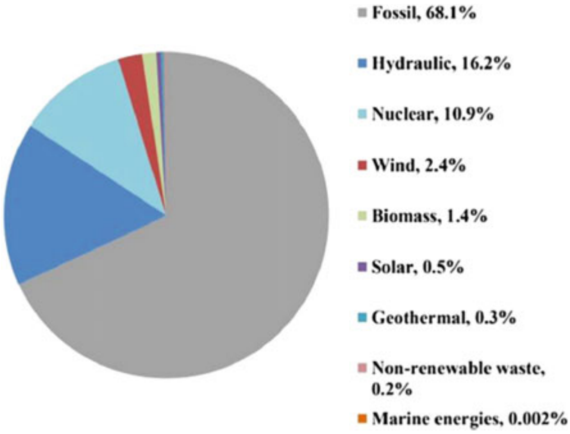

Fig. 5 World electric production from renewable and non-renewable sources in 2012

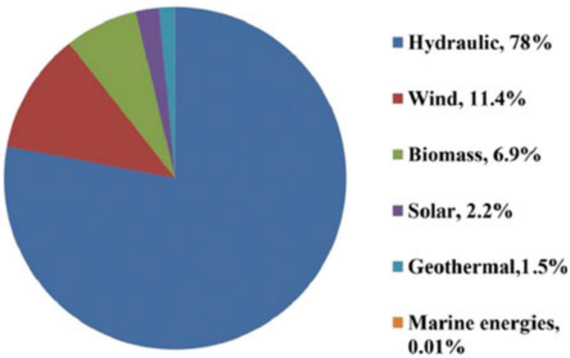

Fig. 6 World electric production from renewable source in 2012

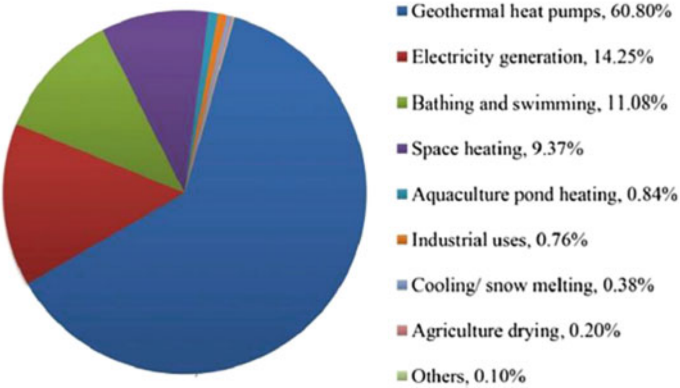

Fig. 7 Worldwide geothermal energy applications in 2014

1.4 Global Geothermal Development and Ethiopia's Position

The contribution of geothermal energy to the world's primary energy is small in proportion. In 2015, the new installed capacity of geothermal energy was about 315 MW and the total capacity reached 13.2 GW by the end of the same year. Half of the new installed capacity was added by Turkey followed by the USA, Mexico, Kenya, Japan and Germany. The countries benefited from geothermal energy are not many. For instance, countries like China, Iceland, Turkey, Hungary, Japan, USA and New Zealand comprise 70% of the total in utilizing direct geothermal energy for different applications in 2015.

The earth has an estimated stored thermal energy of 43×10^6 EJ within the continental crust in 3 km depth. This energy is higher than the world's total primary energy consumption. A significant percentage reaching 43% out of the total installed generation capacity resides in island countries. This geothermal source provides not only electric power but also heating and heat storage over a wide spectrum of conditions [21].

Iceland geothermal development is a good model and can be considered as a benchmark for Ethiopia geothermal development plan as both countries have similar geological features [9]. A report in 2013 indicated that 69.2% of the primary energy source in Iceland was obtained from geothermal energy. In 2012, about 5210 MW of electric power accounting 30% of the total demand was generated from geothermal energy. The history of using geothermal energy started late 1918 when the coldest winter hit the country, and coal price escalated due to the Second World War. During the same year, two-third of the population were affected by flue as a result of severe weather condition. By 1926, the Government of Iceland initiated to increase the usage of geothermal energy for district cooling. Geothermal energy was not applied to generate electric power until 1944. In 1944, a small turbine was used to generate electricity from a geothermal hotspot. The first commercial power plant that generated 3 MW was established in 1969 after the establishment of National Energy

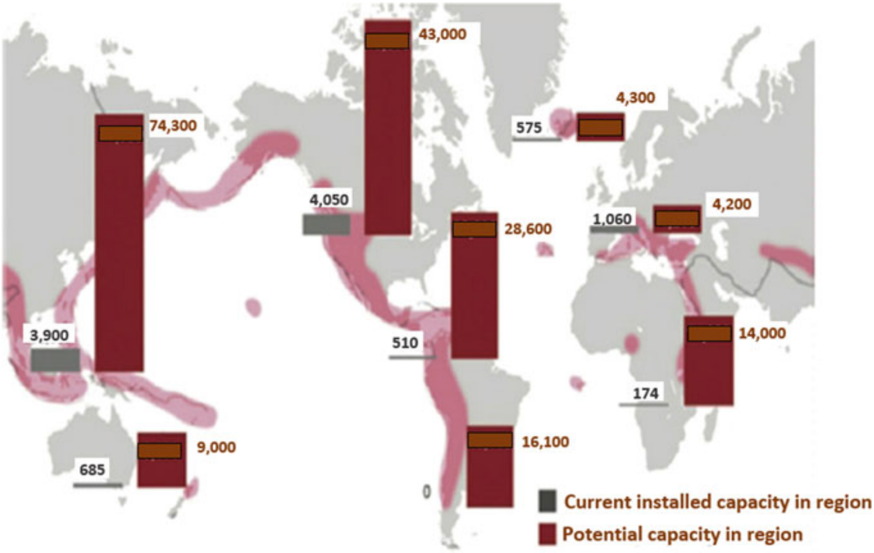

Fig. 8 Global potential and installed geothermal power in MW [22]

Authority. The country has able to generate 5210 GWh, which is 30% of the total electrical power produced, from geothermal source after the government took several steps to improve various initiatives and legal frameworks in 2012. Studies indicated that Iceland and Ethiopia have similar geological profile and Ethiopia can benefit from Iceland experience in developing geothermal energy [9].

Ethiopia is among countries that have been endowed with high potential of geothermal energy. As shown in Fig. 8, the potential of geothermal energy of the globe is much higher than the installed capacities and geothermal projects under installation. Ethiopia's geothermal energy is estimated to reach 10,000 MW, and this is higher than the available geothermal potential even to some of the continents.

1.5 Geothermal Exploration and Development in Ethiopia

Ethiopia is located in the horn of Africa that lies between 3 °N and 15 °N latitude, and 33 °E and 48 °E longitude. The country has approximately 1.14 million km^2 area [12]. Currently, the population is estimated to reach up to 110 million. The country is known as one of the least developed country (LDC) in sub-Saharan Africa. Nevertheless, during the last decade, the country has recorded more than 10% GDP growth per annum and became one of the fastest growing economies in the world [23]. In the two Growth and Transformation Plans of the country, i.e. GTP I & GTP II, the Government of Ethiopia had planned to transform the economy from agricultural lead to manufacturing lead economy. In achieving the transformation plan, power has

Table 1 Exploitable and exploited energy source [24]

Resource	Unit	Exploitable reserve	Exploited percent (%)
Hydropower	MW	45,000	<5
Solar/day	kWh/m^2	4–6	<1
Wind: Power	GW	100	<1
Speed	m/s	>7	
Geothermal	MW	10,000	<1
Wood	Million tons	1120	50
Agricultural waste	Million tons	15–20	30
Natural gas	Billion m^3	113	0
Coal	Million tons	300	0
Oil shale	Million tons	253	0

remained as one of the challenges for the government. The energy source in Ethiopia can be classified into two major categories: traditional source (biomass) and modern source (electricity and petroleum). The traditional energy source is the principal source of energy as more than 80% of the population are living in the rural area and engaged in the small-scale agricultural sector [12]. To address the energy shortage of the country in the rural areas and newly flourishing industrial areas, the government is investing huge amount of money to generate electric power from various renewable sources. Ethiopia has abundant unexploited renewable energy sources. The electric power generated from hydro and geothermal alone exceeds 55,000 MW. The potential of various energy sources and their utilization percentage are shown in Table 1. Ethiopia can generate and cover the future power from renewable sources at low cost. As shown in Table 1, from hydropower 45,000 MW and from geothermal 10,000 MW, electricity can be generated. The country can also generate huge electric power from solar and wind energies.

Currently, the total electric power generation capacity is 4180 MW. As per the GTP II, the government has planned to generate 7579 MW power from hydropower. In the last several years, the country has faced seasonal electric power supply fluctuation when the amount of rainfall fluctuated as a result of climate change. To ensure a reliable and climate resilient power supply, the Government of Ethiopia is striving to diversify the renewable energy sources to generate power from solar, geothermal, wind, biomass, etc. The government has agreed with two companies to generate 1000 MW electricity power from geothermal energy on two sites (Corbetti & Tulu Moye) [25, 26]. Currently the country produces 324 WM electric power from wind energy and by the end of 2020 this would reach 5200 MW. There is also an ambitious plan to install 5200 MW solar energy conversion plants on different sites [26]. The implementation plans for the solar energy and wind energy development do not seem achievable as only one year is left for GTP II to be concluded.

In the last four decades, substantial geothermal exploration has been carried out and promising and feasible results were obtained. Since 1970 geoscientific surveys that comprise geology, geochemistry and geophysics were carried out covering from south to north areas, which included Abaya, Corbetti, Aluto–Langano, Tulu Moye and Tendaho. From early to 1985, eight exploration drilling operations were carried out and five of them were proved to be productive. After continuing the exploration work until 1998, the pilot plant with 7.2 MW became operational. During this exploration period, three deep wells up to 2100 m and three shallow wells up to 500 m were drilled, and the temperature was found to be above 250 °C. In the preliminary operation test, from shallow wells, a steam that can produce up to 5 MW electricity was obtained, and in the deep wells, a steam that can produce up to 20 MW electricity was obtained [12, 27].

2 Opportunities of Geothermal Energy in Ethiopia

2.1 The Unique Geographical Location

The Great Rift Valley crosses Ethiopia and extends more than 1000 km in the N-S direction starting from the Afar depression at Red Sea–Gulf of Aden junction outwards to the Turkana depression. The typical rift morphology is developed in the main Ethiopian Rift covering a length of 500 km [9, 28]. The Rift Valley of Africa is known by its tremendous geothermal energy. The utilization of this resource for electricity generation and other applications are at the infant stage with the notable exception of Kenya. With the current production technologies, more than 15,000 MW electric power can be generated from East African countries geothermal resource (Fig. 9) [29, 30]. Exploration studies show that Ethiopia, Djibouti, Uganda, Kenya and Tanzania have enormous geothermal resources to generate electric power [30].

Currently Ethiopia generates 4180 MW of electricity and only 27% of the population have access to electricity grid. Hence, the geothermal resource available in the country could be one feasible source to address the power shortage of the country.

2.2 Government Policy and Trend

The Ethiopian National Energy policy which was first drafted by the Transitional Government of Ethiopia in 1996 sets two main goals. The first goal was to provide electric power at affordable price to support the agricultural led industrial development. The second goal was to ensure an electric power supply to the community and shift the traditional energy source to a sustainable, modern and renewable energy source with the aim of achieving comprehensive rural energy development [9]. With special emphasis on renewable energy, the government has introduced feed-in tariffs

Fig. 9 Potential geothermal sites in East Africa [31]

to promote investment to generate electric energy from renewable sources. The electricity feed-in tariff law would attract investors to involve in diversified renewable energy sources with financial and economic benefits as the competitiveness of some of the renewable energy technologies are not comparable with other non-renewable sources [29].

2.3 Transformation to Modern and Renewable Energy Source

Over 80% of the population in Ethiopia are residing in the rural area and use traditional energy sources such as wood, dung and agricultural residue. In sub-Saharan Africa, Ethiopia has the largest population with high level of dependence on traditional solid fuels for cooking purpose. The biomass fuels have, however, increasingly become challenging to get in abundance as the population increases and free land becomes scarce. In addition, overutilization of these resources will adversely affect the soil moisture, recycling of soil nutrients and conservation of water, soil and wildlife. Henceforth, the Government of Ethiopia has promoted diversification of the energy portfolio giving more focus on renewable energy. Although the utilization of biomass as a source of energy has an adverse effect on the environment, substitution of this resource with other renewable energy source remains slow-moving. The utilization of the renewable energy is insignificant compared to the available potential. For instance, the utilization of hydropower energy is below 10% and the utilization of geothermal energy is almost negligible [9].

Successful development of renewable energy utilization in Ethiopia is imperative for the following reasons:

1. Renewable energy is suitable for decentralized applications.
2. Ethiopia is endowed with renewable energy sources such as hydropower energy, geothermal energy, wind energy, solar energy and biomass. These sources can be used depending on their availability in a specific location.
3. It can save the hard currency spent to import the fossil fuels.
4. Utilization of renewable energy fosters environmental security [9].

2.4 Power Demand Growth

Currently the energy sector is characterized by the extraordinary demand growth which has huge disparity with the supply growth. According to the Ministry of Water and Energy, the target scenario would have a growth by 32% from 2011 to 2015. This huge demand growth rate is attributed to number of factors. Some of the factors were the fast GDP growth of the country amounting to above 10% for the last 10 years, steep population growth, expansion of the national grid to the rural areas, manufacturing boost and construction sectors [9, 32]. Considering two scenarios, i.e. CENT, where the demand is supplied only from the centralized grid and SPLIT where the demand is supplied both from the central grid and off-grid sources. Longa et al. 2018 have projected the electric generation capacity until 2050 in Ethiopia. In the projection, the amount of electric generation in 2050 will reach up to 200 TWh as shown in Fig. 10 [33].

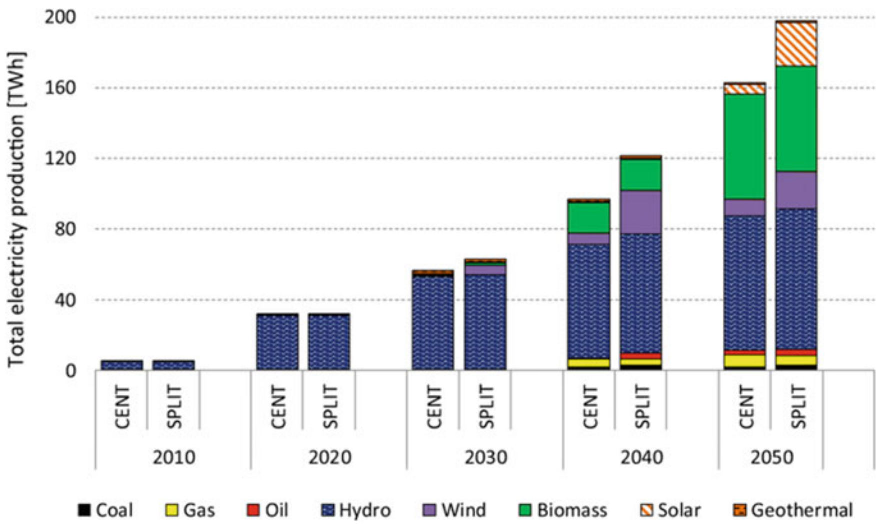

Fig. 10 Total electricity production projection in the SPLIT and CENT scenarios [33]

To address the unprecedented demand, growth in the energy sector of the country developing the geothermal energy source is one crucial option to complement other sources.

2.5 Issues with High Dependency on Hydroelectric Power

Ethiopia's electric power generation is heavily dependent on hydroelectric power. However, there is apparent threat on the heavily reliance on hydroelectric power due to a continuous variation in rainfall amount from year to year. The climate change poses a considerable uncertainty on the energy production in the country. Particularly the effect of climate change on hydropower energy sector would become more severe in the long run. To overcome the effect of climate change, Ethiopia should plan to use other renewable energy sources in the future. Geothermal energy has high capacity, longevity and stability as opposed to wind and solar energy resources, which are seasonal/intermittent and thus require storage facilities encoring additional costs [34].

3 Challenges of Using Geothermal Energy in Ethiopia

3.1 High Capital Cost

The development of geothermal energy requires high initial cost. Currently the main source of electricity in Ethiopia is hydropower. Based on the recent project costs, for instance, Gibe III and Ethiopian Grand Renaissance Dam cost around $1000 per installed kW, whereas taking in to consideration the estimated development of Corbetti and Tulu Moye geothermal power plants, the cost of electric power generation reaches $4000 per installed kW [9]. Hence, the initial investment cost of geothermal power per kW is four folds of the hydroelectric power generation. In addition, the maintenance and operation cost of hydropower plant is very little compared to geothermal power plant.

The 'levelized cost of energy' (LCOE) which is the break-even cost of generating power helps measure the competitiveness of renewable energy. This cost considers the initial investment costs, interest rates, annual operating costs and devaluation rates of power generation. The levelized cost of energy is defined as lifecycle cost of the power plant per lifecycle power generated and is given as:

$$\text{LCOE} = \text{Life cycle cost/life cycle energy} \tag{10.1}$$

Table 2 shows the annual present capital cost, capital subsidy, LCOE and the LCOE difference of other renewable electric generation sources with hydroelectric generation [34]. The LCOE value of concentrated solar power is the highest in the current context (US$ 0.189/kWh). Biomass and wind are the most expensive energy sources for electrical power generation after solar with LCOE of US$ 0.122/kWh and US$ 0.102/kWh, respectively. Hydro and geothermal sources have lower LCOE of US$ 0.051/kWh and US$ 0.080/kWh, respectively.

As the difference in capital cost and LCOE for alternative renewable sources such as solar, geothermal, wind, biomass has remained high compared to hydropower

Table 2 Required estimated capital subsidies and the difference in LCOE (US$/kW) if hydropower is substituted with other renewable energy sources [34]

Energy source	Annual present capital cost US$/kW	Capital subsidy (US$/kW)	LCOE US$/kWh	LCOE difference over hydroelectric
Wind energy	131.4	114.7	0.10	0.05
Solar energy	280.0	263.3	0.19	0.14
Hydroelectric energy	16.7	0.0	0.05	–
Geothermal energy	134.8	118.1	0.08	0.03
Biomass	137.1	120.4	0.11	0.07

source, it has become a barrier to alternative energy diversification in Ethiopia. To provide energy for communities located in remote areas, Ethiopia should have an optimal strategy to support the investment on other alternative renewable resources and provide incentives to private, household or cooperative associations to harness the required energy. Related policies such as capital subsidies should target reducing upfront capital investment costs to make alternative renewable resources competitive with hydroelectric power [34]. The capital subsidy indicated in the table for wind, solar, geothermal and biomass refers the subsidy provided by the government to make the resources competitive and attract the private investors, household or cooperative associations. To make solar energy competitive with hydroelectric energy, the Ethiopian Government must provide a capital subsidy of US$ 263/kW, followed by geothermal with US$ 118/kW, biomass with US$ 120/kW and wind with US$ 115/kW.

3.2 Lack of Technical Competence

Geothermal resources development requires a multidisciplinary professionals and institutions with different technical background and experience. The major technical competences or disciplines that are required for geothermal development include geology, geochemistry, geophysics, reservoir engineering, environmental science and geothermal engineering [30, 35]. Generally, in East Africa, studies show that the geothermal energy development is dependent mainly on the foreign institutions and personnel. Ethiopia's case is also not different. Lack of technical capacity in design, development, operation, maintenance, consultancy and provision for electrical equipment as well as appliances are some of the technical challenges of the country [36]. As geothermal energy development is at infant stage in the country lack of experience in the field will compel the country to depend on foreign companies and spend high foreign currency.

In the short run, outsourcing and contracting projects partly to experienced foreign companies could be inevitable. However, defining the requirement of core institutional and organizational capabilities and creating an action plan for developing business skills and execution capacity in domestic institutions are an ultimate solution to exploit the resource adequately [36].

3.3 Low Prevailing Tariff Regime

Broadly speaking, tariffs must be high enough to allow the utilities to cover their costs and finance new investment, but not so high as to frustrate demand and deny access to poor households that consume small amounts of electricity (subsistence consumers) [37]. Ethiopians have been enjoying low electricity tariffs for over a decade compared to their neighbouring countries in the east African region. Current

Table 3 Comparison of electric tariff between Ethiopia and other countries [39]

Countries	Price ($/kWh)	Difference (%)
Ethiopia	0.02	
Burkina Faso	0.032	60
Brazil	0.222	1010
Costa Rica	0.044	120
Swaziland	0.572	2760
Egypt	0.032	60
Madagascar	0.064	220

electricity tariffs in Ethiopia seem to be too low to guarantee continued interest of foreign investors to invest into electricity generation projects [38]. Table 3 compares the tariff of other African Countries with that of Ethiopia.

The price for electricity (per 1 kWh) in Ethiopia is 2760% lower than the electricity price in Swaziland. The existing cost of electricity, which is below the break-even, is currently hampering investment in the sector. Subsequently, the negotiation power of the Ethiopian Government with multinational companies is adversely affected [38].

The low prevailing electricity tariffs have also an effect on swelling of the country debts, threatening the credit worthiness of government-owned power companies and dragging down the national budget. The government is considering revision on the tariff structure in order to cover the electric production cost and attract the private sectors in the power market. The tariff reform is planned to be implemented step by step in three-year time instead of doing it at a time with abrupt change. The tariff increment would also consider the amount of electric consumptions and consumer type. The change in tariff for households would be lesser than that of enterprises. Block rate tariff which will have a progressive increment based on the consumption increment would be implemented. Complementary policy measures are also being considered to encourage households and enterprises to engage in energy efficiency and conservation activities [40]. In addition, incentives such as waiver of import duties, grant of tax holidays on dividends and interest incomes could also be considered to attract private investors. These measures will contribute in making tariff affordable to consumers as a result of lowering electric production cost.

4 Summary

Ethiopia is endowed with various natural resources that can enable the country to develop sustainable and renewable energy. The country can produce more than 10,000 MW electric power from geothermal energy. The Great Rift Valley of Africa crosses the country starting from the Afar depression, at Red Sea–Gulf of Aden junction north-west to Turkana desperation on the south covering about 1000 km. As the Great Rift Valley of Africa is the source of tremendous geothermal energy, Ethiopia shares significant areas of this region and can tap the resource for the development of electric power. The low level of electrification of the country is another factor for Ethiopia to focus and develop the geothermal source to fill the gap. From the 100 million estimated population of the country, 80% of the population are living in the rural areas and use biomass sources as a fuel. However, obtaining the biomass resource in sufficient amount has increasingly become difficult due to a surge in population. This prevailing condition of the country pushes the government to develop a strategy to use renewable energy sources such as geothermal energy. The other pushing factor to develop geothermal energy source is the over-dependence on hydroelectric power plants. More than 90% of the electric power is generated from hydroelectric power which, in many instances, is affected by unsustainable rainfall due to seasonal fluctuation of the weather condition. Consequently, in the past decade, the country has experienced unsteady electric power supply. In conjunction with the urban growth and above 10% GDP growth of the country in the past 12 years, the annual power demand growth has also reached to 30%. To cope up with the power demand growth, diversifying the energy source and developing geothermal energy source would be one strategy.

Despite the many opportunities to develop geothermal energy in the country, there are still challenges hampering the development. The development of geothermal energy requires high capital cost when compared with that of the hydropower energy. For instance, the initial investment cost of Corbetti geothermal power plant was more than four folds per kilowatt of Grand Renaissance Dam. The other significant challenge in the development of geothermal energy is the lack of institution and expertise. Developing geothermal energy is a new phenomenal compared to hydropower energy in the country which has more than 80 years of history with Aba Samuel hydropower plant commenced operation in 1932 with an installed capacity of 6.6 MW. The low electric power tariff rate of the country is also another challenge to involve private sector in the development of the sector.

To overcome the aforementioned challenges, the Government of Ethiopia should have a strategy in short run and long run. In the short run, involving experienced foreign companies in the development of the resource could be of a solution. However, defining the requirement of core institutional and organizational capabilities and creating an action plan for developing business skills and execution capacity in domestic institutions are an ultimate target to exploit the resource adequately. The government has to conclude the revision of the tariff structure and implement it to solve the low tariff rate problem, which is a hindrance in generating adequate amount of income from the service to cover the initial capital cost and running cost of geothermal power plant for the private sector. Considering incentives to private investors in the field, such as waiver of import duties, grant of tax holidays on dividends and interest incomes could also be considered. These measures will contribute to make tariff affordable to consumers as a result of lowering the electric production cost. Complementary policy measures which have already been started to encourage households and enterprises to engage in energy efficiency and conservation activities have to be strengthened and continued.

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