UNITED NATIONS UNIVERSITY
UNU-GTP
Geothermal Training Programme

Orkustofnun, Grensasvegur 9,
IS-108 Reykjavik, Iceland

Reports 2018
Number 31

# STRENGTHENING OF THE GEOTHERMAL SECTOR IN ETHIOPIA

**Biniam Zerihun Amanu**
Ethiopian Electric Power
Aluto Geothermal Project
P.O. Box 1233
Addis Ababa
ETHIOPIA
*biniamzeri@gmail.com*

## ABSTRACT

The goal of this study is to analyse the current status of geothermal development in Ethiopia and explore a way to strengthen it. The objective is to study how to improve the electricity generation mix in Ethiopia with geothermal power and to analyse how substantial amounts of stable baseload power will increase the electricity sector's reliability. Ethiopia has experienced strong economic growth over the past decade and is with an averaged- of around 10% growth per year the fastest growing economy in Africa. Today about 20.6% of the population lives in urban centres, with the great majority of them living in Addis Ababa. Access to electricity in urban areas is 85.4% and 26.5% in rural areas. It has been estimated that Ethiopia has a geothermal power generation potential of up to 10,000 MW. The estimated potential is found in different places in the Ethiopian rift valley. A recent geothermal master plan study was conducted including 22 potential geothermal areas. Of these prospected areas the government of Ethiopia prioritizes 7 sites for the development of a geothermal project.

Geothermal energy could reduce Ethiopian dependency on hydro power alternatives, helping to provide stable electricity and increase the energy security of the country. The government of Ethiopia recognizes that engagement with the private sector as Independent Power Producers (IPP) for power generation is crucial to meet the country's needs and enabling the country to develop. Ethiopia has increased its electric generation capacity during the last two decades from 380 MW in 1991 to around 4355.8 MW in 2018. The actual consumption of electricity energy has been increasing at an annual average rate of about 25-30%. Hence, the government of Ethiopia has planned to increase the electric generation capacity of the country to about 25,000 MW by 2030, utilizing hydro, wind, geothermal and solar energy to address and satisfy domestic demand and export the surplus neighbouring countries. The government needs to explore all options to increase the energy availability in the country including PPP and IPP to radically improve the energy sector in the country and enhance service delivery to their people. Geothermal development business models allow the government to share risks and responsibilities with private firms while ultimately retaining control of assets what will improve services while avoiding some of the pitfalls of privatisation such as unemployment, higher energy prices and corruption.

## 1. SCOPE OF THE STUDY

The goal of this study is to analyse the current status of geothermal development in Ethiopia and the way to strengthen it. It is very important for Ethiopia to provide stable electricity supply and to increase the energy security of the country to meet the long-term goal of becoming a middle-income country by 2025 to ensure clean, modern energy and good access to it for rapid social and economic growth.

The objective is to study how to improve the electricity generation mix in Ethiopia by adding geothermal power and to analyse how substantial amounts of stable baseload power will increase the electricity sector's reliability. Existing electricity consumers will benefit from this increased reliability. Geothermal development will also increase Ethiopia's overall electricity generation potential, and thus strengthen the Government of Ethiopia electricity access agenda.

Ethiopia has started to export electricity to its neighbouring countries, who will also benefit from the electricity sector's increased reliability and the substantial increase in baseload electricity generation. To ensure that the country's geothermal resources are developed in an orderly, sustainable and environmentally friendly way, to ensure security of tenure for all investors in respect of geothermal resources development operations and to encourage a sustainable, carbon-neutral economy in Ethiopia, it is an important step for the country. Different types of geothermal development models can be considered to attract private developers in this field.

## 2. COUNTRY OVERVIEW

Ethiopia is a country of many nations, nationalities, and people. Ethiopia is located in the Horn of Africa, it shares borders with Eritrea to the north and northeast, Djibouti and Somalia to the east, Sudan and South Sudan to the west and Kenya to the south (Figure 1). It is land-locked with an area of 1.1 million $km^2$. The population growth rate is 2.46% per year. Ethiopia's biophysical environment includes a variety of contrasting ecosystems with significant differences in climate, soil properties, vegetation


FIGURE 1: Map of Ethiopia (africaguide.com, 2018)

types, agricultural potential, biodiversity, and water resources. The current population of Ethiopia is 107,500,000 (2018), based on the latest United Nations estimates. Today about 20.6% of the population lives in urban centres, with the great majority of them living in Addis Ababa. Access to electricity in urban areas is 85.4% and 26.5% in rural areas (Worldometers, 2018; IECONOMICS, 2018).

Ethiopia has experienced strong economic growth over the past decade and has had an average growth rate of around 10%, the fastest growing economy in Africa. This growth is driven by many factors such as agricultural modernization, the development of new export sectors, strong global commodity demand and government-led development investments. The Government of Ethiopia is currently implementing an ambitious Growth and Transformation Plan (GTP), which sets the long-term goal of becoming a middle-income country by 2025. To achieve the GTP goals, the Government of Ethiopia has followed a "developmental state" model where the government plays a strong role in many aspects of the economy. It has prioritized key sectors such as industry and agriculture as drivers of sustained economic growth and job creation.

Ethiopia is opening its door to the world with an unprecedented privatization plan. The country plans to sell stakes in some of the most-prized public assets through a full- or semi-privatization to boost the private sector and make it competitive. This is intended to bring in hard currency to allow payments of outstanding debt and import basic goods of high demand. The aim of the government is to supply and issue a regulatory framework that empowers rather than restrains freedom of movement of social and financial capital.

The country is now paving the way for a historical reunion with Eritrea. The two countries are breaking a deadlock of 20 years in bilateral relations. It raises unprecedented prospects of reconciliation for enhanced regional cooperation and stability in the Horn of Africa. The two countries have now signed an agreement ending a long war and restoring good relations between them. The landlocked country Ethiopia intends to start again using the ports of the neighbouring country Eritrea.

## 3. GEOTHERMAL POTENTIAL IN EAST AFRICA RIFT VALLEYS

The East African Rift System has become a new source of hope to enable Africa to meet its energy needs in the future. Geothermal energy potential in the valley is now attracting the attention of major investors to tap in to an energy source that has large potential, is renewable and largely environmentally friendly.

The East African Rift System stretches about 6500 km, from the Middle East (Dead Sea-Jordan Valley) in the north to Mozambique in the south (Figure 2). It passes through Eritrea, Djibouti, Ethiopia, Kenya, Tanzania, Uganda, Rwanda, the Democratic Republic of Congo (DRC), Zambia, Malawi, Mozambique and Madagascar. It contains vast geothermal energy potential estimated to be much more than 15,000 MW in total. However, the high upfront capital cost and risk in resource exploration, long lead times and the nature of technical expertise required make it a less attractive option for investment compared to some other renewable energy resources. In Africa, only Kenya has successfully utilized this power source with more than 50% of its electric generation coming from geothermal energy. The Kenyan success story has now opened the mind of investors and lenders to geothermal power in Africa and although geothermal energy has its complications it is predicted that there will be a take-off in development in countries such as Ethiopia, Djibouti, Kenya, and Tanzania to name a few.

Kenya has pushed hard to harness its geothermal capabilities. The first geothermal power plant in Africa was online in 1981, soon generating 45 MW of power from geothermal energy. Kenya has now an installed capacity of about 680 MW (Atwa, 2018) and is pushing to expand in the near future. This explosive growth has made geothermal power a promising source of renewable energy for a country of 44 million people that is expected to nearly double in population by 2050.

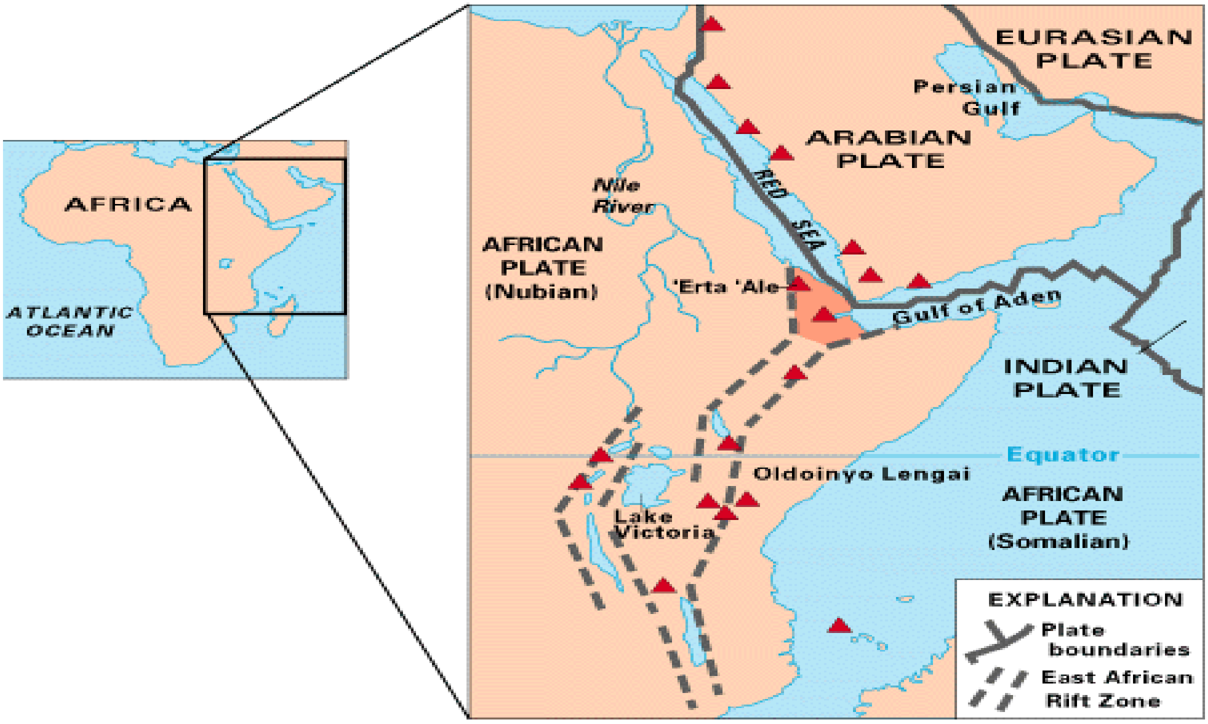


FIGURE 2: The East African Rift System (Kebede, 2016)

## 4. GEOTHERMAL RESOURCE IN ETHIOPIA

It has been estimated that Ethiopia has a geothermal power generation potential of up to 10,000 MW. The estimated potential is found in different places in the Ethiopian rift valley (Figure 3). The rift valley runs through Ethiopia from the Red Sea to Lake Turkana on the Kenyan border in a NNE-SSW trending direction for over 1,000 km and covers an area of 150,000 $km^2$. The more advanced prospective areas are the Aluto-Langano geothermal field and the Tendaho geothermal field.

The Aluto-Langano geothermal site is located in the Oromia regional state. It lies about 200 km southeast of Addis Ababa, the capital of Ethiopia, and is conveniently located in between Lake Ziway and Lake Langano. In Aluto-Langano, detailed geological, geochemical and geophysical surveys were done in the late 1970's and early 1980's, and a small geothermal pilot power plant built in the late 1990's.

The Tendaho geothermal site is located in Dubti Woreda, Afar regional state. It lies in the north-eastern part of Ethiopia and is about 600 km away from Addis Ababa. The first exploration studies in the Tendaho geothermal field were also carried out in 1970's and 1980's.

In Ethiopia lies the largest section of the East African Rift System. In recent study of a geothermal master plan, geoscientific, social and economic surveys were conducted in 22 potential prospects areas. Of these prospect areas the government of Ethiopia prioritises 7 sites for the development of a geothermal project. These are Corbetti, Abaya, Tulu Moye, Dofan, Fentale, Aluto-Langano and Tendaho. Along with the two advanced geothermal projects which are being developed with implementation by EEP, the Ethiopian government recently signed an agreement and a 25 years power purchase agreement with two foreign private investor groups to develop geothermal power in Corbetti and Tulu Moye. It is planned that the two projects will each provide up to 520 MW, or more than 1000 MW together, of renewable baseload power to the Ethiopian national grid through development during the next 10 years.

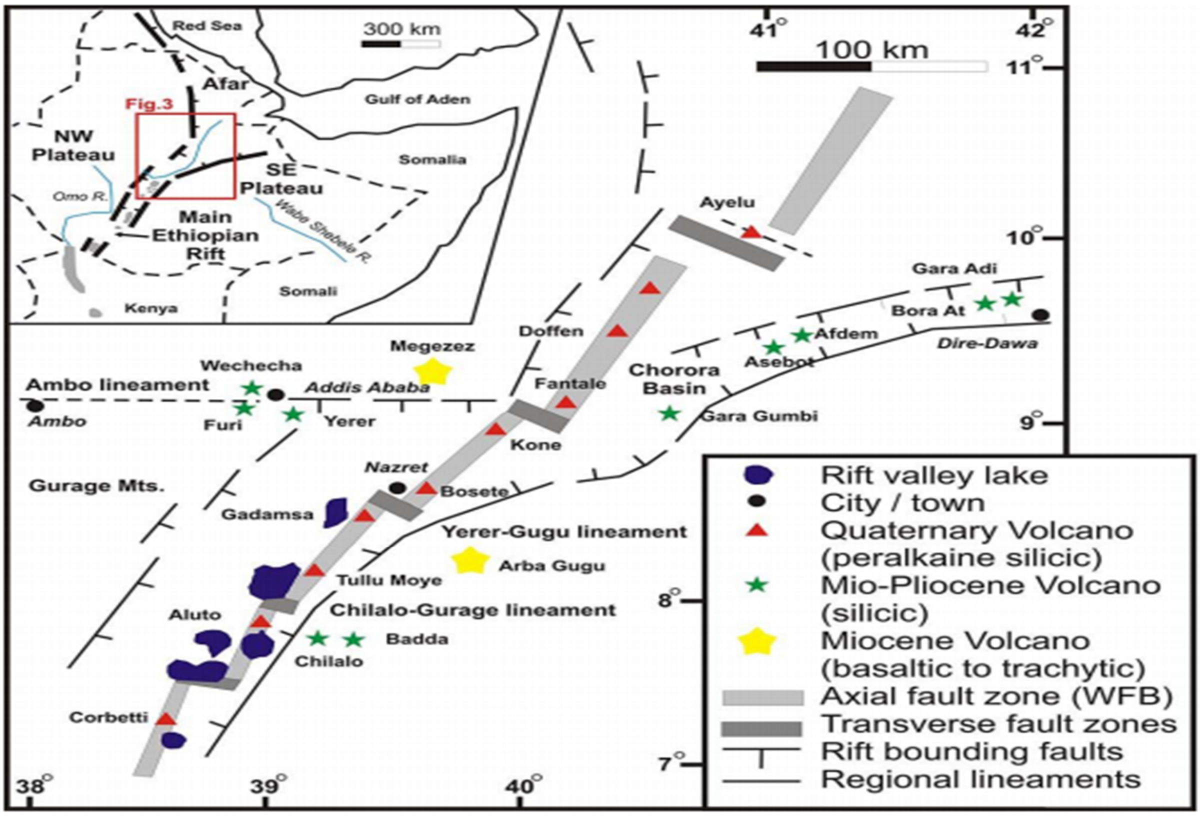


FIGURE 3: Map of some of the geothermal resources in Ethiopia (Kebede, 2016)

## 5. ADVANTAGE OF GEOTHERMAL ENERGY

### 5.1 Eco-friendly

Geothermal energy is good for the environment, extracted from the earth's crust without burning fossil fuels. It is an environmentally friendly energy source when compared with fossil fuel alternatives such as coal, oil, and gas. The production of electricity from geothermal energy has a much lower impact on the environment than these alternatives. Thus, using geothermal energy reduces emission of greenhouse gases coming from power production (cleanenergyideas, 2018)

### 5.2 Renewable and constant power source

Geothermal energy is in principle a renewable energy resource suitable for electrical baseload production. It has its origin deep in the earth' crust and is therefore not dependent on the sun, wind or rain. It is a relatively constant source of energy which is available all the year. Geothermal energy can be utilized for electricity generation and for various other types of direct use applications, e.g. district heating purposes, fish farming, bathing etc. Unlike other renewable energy technologies (such as solar and wind power), geothermal power can provide a constant, uninterrupted supply of electricity. Solar panels can only produce electricity during the day and wind turbines only produce power when there is enough wind.

The benefit of constant supply makes geothermal energy a far more predictable means for generating electricity when compared to its renewable energy rivals. No power plant operates at 100% capacity factor. For hydro power plants, reasons like drought and maintenance of power plant reduces production, solar plants are down at night and cloud cover and maintenance of power plant reduce efficiency; and intermittent blowing of wind as well as maintenance reduces production through wind energy. In a geothermal power plant, steam draw down in the reservoir as well as maintenance of power plant reduce production.

To better understand the importance of baseload power it is good to look at some definitions and do some calculations.

*Rated capacity:*
The rated capacity is defined as the maximum power in MW that the unit is designed to provide to the grid at any given time.

*Energy produced:*
The amount of electricity put on the grid over time is called energy and is determined by the unit's actual operating level multiplied by the amount of time the unit is running. This quantity is typically stated in MWh. For example: If a 500 MW unit is run at 300 MW for 1 year (365×24 = 8760 h) it will have an output of 300 MW × 8760 h = 2,628,000 MWh.

*Capacity factor:*
The capacity factor is defined as the ratio of the total energy produced or supplied over a definite period to the energy that would have been produced if the plant (generating unit) had operated continuously at the maximum rating, or:

$$Capacity\ factor = \frac{Actual\ energy\ produced\ in\ time\ T}{Maximum\ plant\ rating\ \times\ T}$$

The capacity factor indicates the extent of use of the generation station. If the power generation unit is always running at its rated capacity, then its capacity factor is 100% or 1.

*Example:* The output of a 500 MW unit was 2,628,000 MWh over 1 year. The unit has a capacity factor of 2,628,000 MWh divided by 500 MW × 8760 h or 4,380,000 MWh, which is its maximum output. The capacity factor of the unit for those 8760 hours was 60%. The capacity factor is used to determine how fully a unit's capacity is utilized. It is interesting to compare different capacity factors between different renewable energy options. Table 1 shows some typical values for capacity factors over a year for four renewable energy power plants.

TABLE 1: Capacity factor (Shahan, 2012)

| Type of power plant | Minimum | Medium | Maximum |
|---|---|---|---|
| Hydropower | 35% | 50% | 93.2% |
| Geothermal | 80% | 90% | 95% |
| Solar | 16% | 21% | 28% |
| Wind | 27% | 43% | 54% |

The table shows that the capacity of geothermal power plants is usually high compared with other renewable energy power plants. This directly relates to the payback period of investments because having a higher capacity factor means that more electricity can be sold and therefore higher investments yield higher returns

Table 2 shows the energy produced over a year by different renewable energy power plants using the medium capacity factor given in Table 1.

TABLE 2: Energy produced in power plants

| Type of power plant | Capacity (MW) | Load factor medium | Energy produced (MWh) |
|---|---|---|---|
| Hydropower | 500 | 50 | 2,190,000 |
| Geothermal | 500 | 90 | 3,942,000 |
| Solar | 500 | 21 | 919,800 |
| Wind | 500 | 43 | 1,883,400 |

The table shows how big a difference a geothermal power plant can make on the energy mix in a country. Although the rated capacity is the same for all types of plants, the geothermal plant is producing far the highest amount of energy. But this table does not take another significant factor into consideration which is the unpredictability of some of the renewable resources. The capacity factor for a given plant can vary considerably in time.

### 5.3 Space conservation

Compared with other renewable energy power plants such as hydro, wind or solar power plants, geothermal power plants require a relatively small amount of space. Although a geothermal power plant reaches depths where a sufficient level of geothermal energy is stored, its land footprint is rather small. Geothermal power is considered to have one of the smallest surface land footprints per kilowatt (kW) of all the renewable power plant technologies in use today. The well fields of geothermal power plants are often integrated into farming communities once the geothermal power plant and associated pipelines are completed the land can be used for livestock grazing or other agricultural purposes as illustrated in Figure 4.

FIGURE 4: Aluto geothermal power plant site (courtesy of Reykjavik Geothermal)

### 5.4 Stable energy

Introducing a more stable energy environment in Ethiopia will have a big impact on all businesses and households. As is, every business needs to have diesel generators installed to be able to have electricity available at all time. As an example, the energy stability in Addis is very poor and power shortages are frequent. Installing, operating and maintaining such equipment is very costly and inefficient. Better stability and availability of energy will reduce the import of diesel fuel and cut down cost for the benefits of the country, business and people. Introducing geothermal energy to the mix will help creating this.

### 5.5 Job creation

Geothermal energy not only provides a source of clean and renewable electricity, it can also provide numerous benefits to the economy of a particular country through aspects such as job creation. The construction and maintenance of geothermal power plants has the potential to create employment. This does not only include direct job creation in the plant itself, but also indirect jobs created in the service sector. However, most jobs will be created due to the increased availability of energy in Ethiopia. Energy is the fundamental source for creating well paid job. It helps to build up industries, manufacturing, modern agricultural industries and other small businesses in the rural and urban areas. The people will have the opportunity to open various kinds of small businesses in their home towns or rural areas.

## 6. DISADVANTAGES OF GEOTHERMAL ENERGY

### 6.1 Geographical limitations

The most active geothermal resources are usually found along major tectonic plate boundaries where most volcanoes are located. Geothermal activity is often greatest along tectonic fault lines within the earth's crust and it is in these areas where geothermal power plants are considered to be the most effective and yield high electric production (cleanenergyideas, 2018)

### 6.2 Large investments needed

The upfront investment that is needed for a geothermal power plant is quite high when compared to the investment required for some other power plants that produce electricity from other resources. A large proportion of this cost is associated with the exploration, drilling and plant installation while operation and maintenance are low. Additionally, in new potential geothermal prospects a large investment is needed before the resource is proven to be big enough for economic exploitation. This is one of the main reasons why development of geothermal power plants has been slow compared to some other renewable resources like wind and solar. However, it is quite safe to say that the total cost of fossil fuel extraction is much higher and geothermal power would be considered one of the cheaper options. Compared to other renewable power options geothermal is also considered to be cost competitive when successfully developed, specially taking into consideration its base load nature.

In rural or undeveloped areas in Ethiopia with no connection to the power grid, the first choice for electricity generation is usually diesel. Diesel usage is characterized by low first cost but very high operation and maintenance cost. The system is often in a remote location and the difficulties of purchasing imported spare parts and fuel have often made the diesel power unreliable on top of being very costly. One of the goals of the government of Ethiopia is to make power much more available for urban areas and where currently only 26.5% of the population have access to power. But to do so, much more power is needed to be installed and the system needs to be stabilized. In Table 3 capital expenditure (CAPEX) cost for a 50 MW geothermal power plant is presented.

TABLE 3: Cost of a 50 MW geothermal power plant (Gehringer and Loksha, 2012)

| Phase / activity | | Low estimate | Medium estimate | High estimate |
|---|---|---|---|---|
| 1 | Preliminary survey, permits market analysis | 1 | 2 | 5 |
| 2 | Exploration | 2 | 3 | 4 |
| 3 | Test drillings, well testing, reservoir evaluation | 11 | 18 | 30 |
| 4 | Feasibility study, project planning, funding, contracts, insurances etc. | 5 | 7 | 10 |
| 5 | Drillings (20 boreholes) | 45 | 70 | 100 |
| 6 | Construction (power plant, cooling, infrastructure, etc.) | 65 | 75 | 95 |
| | Steam gathering system and substation, connection to grid (transmission) | 10 | 16 | 22 |
| 7 | Start-up and commissioning | 3 | 5 | 8 |
| | **Total** | **142** | **196** | **274** |
| | In million USD / MW installed | 2.8 | 3.9 | 5.5 |

### 6.3 Environmental impact

When looking at the disadvantages of geothermal energy, there are various environmental impacts that should be noted. Below the earth's surface lies an abundance of gases that can be harmful to the environment and our atmosphere. During the production of geothermal power, gases can be released into the atmosphere. These gases include hydrogen-sulphide ($H_2S$), hydrogen ($H_2$), carbon dioxide ($CO_2$), ammonia ($NH_3$), methane ($CH_4$), and boron (B), some of which can contribute to global warming. When developing, building and operating a geothermal power plant such gases need to be taken into consideration and their negative impact eliminated or at least controlled. Water quality also needs to be taken into consideration as a potential environment impact of geothermal energy. That said, a proper operation of a geothermal plant can minimize any such environmental impact.

### 6.4 Sustainability concerns

A quick payback of investment cost is usually a main objective. Sometimes a resource is put into production just to meet an economic goal. Although geothermal energy itself is considered highly sustainable, there exist sustainability concerns associated with how it is used. Studies show that without careful management of geothermal reservoirs, they can become depleted, rendering a geothermal power plant useless until the reservoir recovers. With the advancement of geothermal energy technologies, this sustainability concern is becoming less of an issue. Efforts are now made to inject geothermal fluids back into reservoirs as soon as the thermal energy has been utilized, thus reducing the chance of a well becoming depleted. Today, every geothermal plant operator has developed a reservoir model to better understand the reservoir and to be able to better manage the resource.

## 7. GEOTHERMAL ENERGY AS PART OF THE ETHIOPIAN ENERGY MIX

Geothermal energy could cut down Ethiopian dependency on hydro power, helping to provide stable electricity and to increase the energy security in the country. Geothermal energy is a viable means of generating electricity and a significant proportion of that country's energy demands can be met by the use of geothermal technologies. This reduces the need to obtain electricity or natural resources from other countries, thus helping to increase energy security.

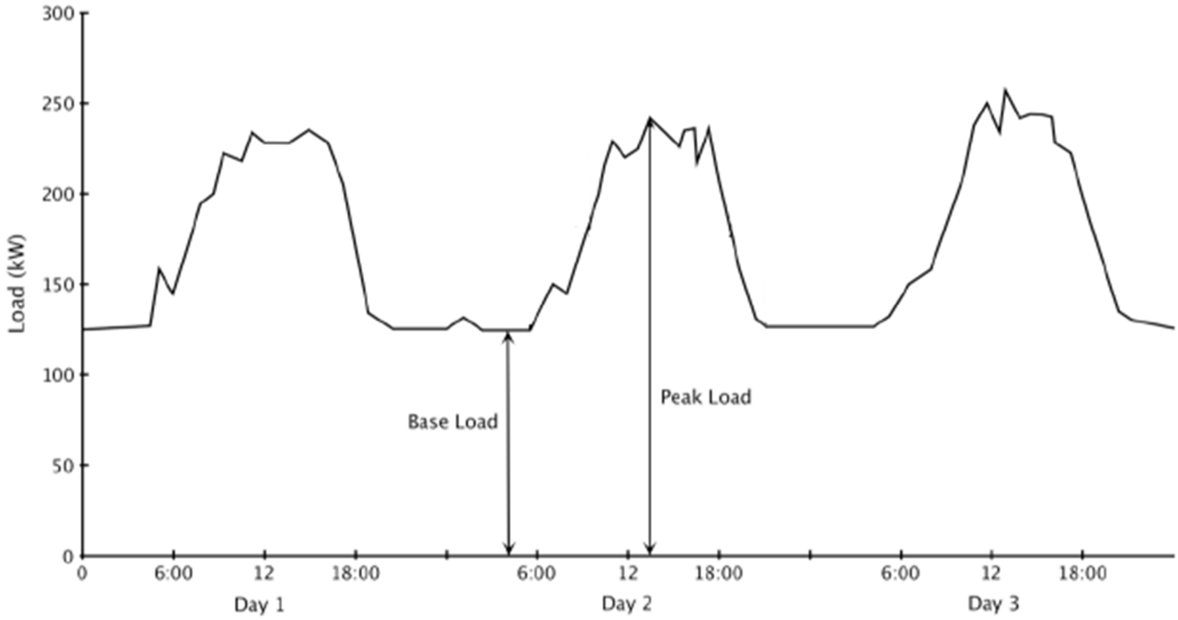


FIGURE 5: Base load curve (Hyde, 2015)

As shown in Figure 5, electric demand rises and falls during the course of a typical day. Less power is used in the morning than in the afternoon. In Ethiopia today, most of this power, both peak power and base load power, comes from hydro power plants. Utilizing hydro power in that way while taking into consideration a typical capacity factor for hydro power (Table 1) is not a good way of running a power system in a country. Hydro power with low capacity factor is not the best way of supplying base load power. It is very likely that at some point the hydro dams will be low in water creating shortage of energy. Both solar and wind power can help reduce the dependence on hydro power. But that is not enough, more is needed and geothermal power is ideal to fill the gap. Geothermal power could provide the day-to-day baseload power and peaking power is what can be actuated when more is need. Geothermal energy is not well suited to be turned on and off due to steam-field operation. So constant steam flow from geothermal resources to the turbines is the best way of operating a geothermal power plant. Hydro power on the other hand can be a peak power source, as ramping up power production from a hydroelectric dam is generally a matter of letting a bit more water in through the turbines. Combining hydro and geothermal power sources should be a very good basis for running a stable power system and will give the system operators a way of utilizing the hydro power plant in the most effective way.

## 8. INSTITUTIONAL FRAMEWORKS AND ENERGY PLOICY

### 8.1 Institutional framework and regulatory framework

*The Ministry of Water, Irrigation and Energy* (MoWIE, 2016) is the leading institution for the energy sector. It supervises three main institutions:

*Ethiopian Electric Power (EEP)* – responsible for generation, transmission construction and operation, universal electric access programme and power export.
*Ethiopian Electric Utility (EEU*) – responsible for distribution and sales.
*Ethiopian Energy Authority (EEA)* – a regulatory body for electricity and energy efficiency.

Figure 6 summarises the institutional and regulatory framework.

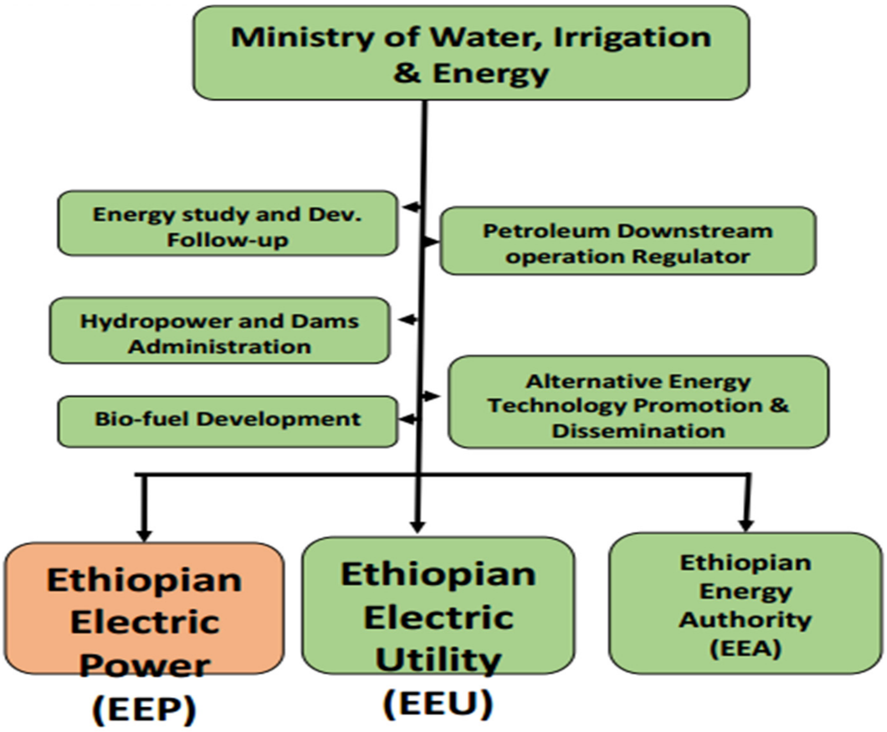


FIGURE 6: Institutional and regulatory framework (Asnake, 2015)

### 8.2 Energy policy

Ethiopia has enormous potential for energy production. Many of these resources have not yet been utilized (Table 4 shows the estimated potential in Ethiopia). Most of the country's energy demand today is met by traditional energy sources like fuel wood, charcoal, branches and dung cakes which are used for cooking and lighting. Energy consumption is dominated by the domestic sector. The energy system is characterised by traditional use of biomass fuels which constitutes to 80% of the total national energy consumption while the remaining 20% are non-biomass fuels such as petroleum (Kebede, 2012).

TABLE 4: Indigenous energy resources (Lemma, 2014)

| Resource | Unit | Exploitable reserve | Exploited |
|---|---|---|---|
| Hydropower | MW | 45,000 | < 5% |
| Solar/day | kWh/$m^2$ | Avg. 5.5 | < 1% |
| Wind: Power | GW | 1,350 | < 1% |
| Speed | m/s | >6.5 | |
| Geothermal | MW | 7000 | < 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% |

The Government of Ethiopia (GoE) recognizes that engagement with the private sector as Independent Power Producers (IPPs) for power generation is crucial to meet the country's needs and enabling it to develop. To ensure that Ethiopia reaches its development goals it is essential that IPPs are established in the country. Therefore, the GoE has reached out to Power Africa who has been assisting EEP to produce IPP tender documents and the legal and regulatory IPP framework. The Power Africa Initiative was launched by President Barack Obama in Tanzania in July 2013. The initiative aims at supporting economic growth and development by increasing access to reliable, affordable, and sustainable power in Africa. Ethiopia is drafting its feed-in tariff bill which should offer IPPs the option to sell renewable energy power to the national grid at specified rates.

## 9. THE ELECTRICITY SECTOR

Ethiopia has increased its electric generation capacity considerably during the last 2-3 decades. Electric generation has increased from 380 MW in 1991 to around 4356 MW today. The installed generation capacity by the government is mostly hydro power based or approximately 87% of the total production. The remaining capacity is from diesel, wind and thermal sources (Table 5). It should be mentioned here that these capacity figures do not include any private generating facilities which are mostly diesel generators. Today there are possibly hundreds if not thousands of MW installed in diesel generators in Addis Ababa alone.

TABLE 5: Installed generation capacity (Wikipedia 2018)

| Unit | Hydro | Diesel | Thermal | Wind | Total |
|---|---|---|---|---|---|
| MW | 3814 | 98.8 | 119 | 324 | 4355.8 |
| % | 0.87 | 0.026 | 0.027 | 0.074 | 1 |

### 9.1 Transmission and substations

Ethiopia has constructed transmission, substation and distribution lines to meet power demand across some parts of the country. Table 6 shows the main facts.

TABLE 6: Transmission, substation and distribution lines (Asnake, 2015)

| Type | Number/length |
|---|---|
| Substation | 145 |
| Distribution line (km) | 189,000 |
| Transmission line (km) | 12,825 |

### 9.2 Hydro power

Ethiopia gets 87% of its electric energy from hydro power., The hydro power potential is estimated to be up to 45,000 MW which is why Ethiopia is usually referred as the power house of Africa. However, not more than 8.4% of this potential has been utilized so far. Hydro power is entirely dependent on rainfall. Rainfall is seasonal in Ethiopia with the peak rainfall occurring between July and August.

The first hydro power station in Ethiopia was built in 1936 at the Akaki river to generate and supply electricity to small factories in Addis Ababa. It started production in 1941 with a capacity of 3.3 MW. The operation was stopped in the 1970s because of lack of maintenance. It is now under rehabilitation with the restart generation being upgraded to a capacity of 6.6 MW. The total installed hydro power capacity in Ethiopia is now 3814 MW from 14 existing power plant (Table 7). Two plants are currently under construction and when the committed construction is completed, the installed capacity will rise to 10,610 MW. The government plans to construct twenty-eight new power plants in the future. Some of the future plants are at the stage of inception or reconnaissance, but for most of them a pre-feasibility or feasibility study is available.

TABLE 7: Existing and under construction hydro plants (Brinckerhoff, 2013)

| Power plant | Capacity (MW) | In-service date (G.C) |
|---|---|---|
| Koka | 43 | 1960 |
| Awash II | 32 | 1966 |
| Awash III | 32 | 1971 |
| Fincha | 134 | 1973/2003 |
| Melka Wakana | 153 | 1988/2004 |
| Tis Abay I | 11.4 | 1964/2000 |
| Tis Abay II | 73 | 2001 |
| Gilgel Gibe | 184 | 2004 |
| Tekeze | 300 | 2009 |
| Gilgel Gibe II | 420 | 2010 |
| Beles | 460 | 2010 |
| Finca Amerti Neshi | 95 | 2013 |
| Gibe III | 1870 | 2015 |
| Aba-Samuel | 6.6 | 2016 |
| *Genale 3* | *254* | *Under construction* |
| *Grand renaissance* | *6000* | *Under construction* |

### 9.3 Wind

Ethiopia plans to install 800 MW of wind power. As the dry season is also the windy season, wind power is a good complement to hydro power. The first wind installation in the country was the 51 MW Adama I wind farm, built in 2011. The 120 MW Ashegoda wind farm opened in October 2013 and was the largest wind farm in Africa at that time. The larger 153 MW Adama II wind farm went online in May 2015, bringing Ethiopia's installed wind capacity to a total of 324 MW.

Two plants are currently under construction. Ayisha I and Ayisha II, which are expected to each generate 120 MW. When the committed construction is completed the installed capacity is expected to rise to 564 MW.

### 9.4 Solar

Ethiopia is also called the land of thirteen months of sunshine, referring to its sunny climate and its unique calendar. Ethiopia has always been a major place for solar power. Solar energy is an environmentally friendly renewable energy source that does not emit carbon to the atmosphere that affects global warming. Many analysts agree that Ethiopia has a huge solar power potential, especially in the north-western and eastern lowlands, where the solar radiation is strongest. With all its potential, the Ethiopian solar market is still at an early development stage. Demand for solar power comes mostly from off-grid areas. Utility scale solar power as part of its generation mix has yet to be developed in Ethiopia, but it has a huge potential for the country’s energy sector. Over the last decade, lots of progress has been made in solar technology, making it cheaper, reliable and more efficient.

Solar photovoltaics are being promoted to replace fuel-based lighting and off-grid electrical needs. Estimates say that about 5 MW of off-grid solar power are installed in Ethiopia. Most of the current solar power is used for telecommunications. Other uses include village well pumps, health care and school lighting. A current government initiative plans to bring solar power to 150,000 households by 2020. A solar panel assembly plant opened in Addis Ababa in early 2013 capable of producing panels equivalent to 20 MW/year.

## 9.5 Geothermal development in Ethiopia

### 9.5.1 Current development areas

In Ethiopia, geothermal resource potential for power generation is estimated to be about 10,000 MW. So far, exploratory drilling has taken place in Aluto-Langano (1982-1985 and in 2013-2015) and Tendaho-Dubti (including Alalobad) (1993-1998) geothermal fields. Detailed surface exploration has been completed in five other geothermal prospect areas (Corbetti, Abaya, Dofan, Fentale and Tulu Moye) and deep exploration will commence soon in some of them (Teklemariam et al., 2000; Teklemariam and Beyene, 2005).

Recently, various development partners including international development cooperation agencies and private developers have been and are participating in geothermal energy development in Ethiopia.

### 9.5.2 Aluto-Langano and Alalobad geothermal prospects

The Aluto-Langano geothermal field is located in Oromia regional state. The project site is located about 200 km southeast of Addis Ababa and is conveniently located in between Lake Ziway and Lake Langano. A study for geothermal development in Aluto Langano was launched in the 1970s. A total of 8 geothermal wells were drilled by the Ethiopian government, and a pilot binary plant with a 7.3 MW production started operation in June 1998. However, the plant operation has been stopped for long periods due to maintenance problems.

The government of Ethiopia launched the project "Study on the geothermal power development in the Aluto-Langano field" in 2010 and conducted an exploration survey, including an extensive MT survey. Two new appraisal wells were drilled in the Aluto-Langano prospect in 2013-2015 and well production tests were undertaken in May 2016. The Geological Survey of Ethiopia (GSE) carried out the drilling and the well tests.

The government is now working on expanding the Aluto-Langano geothermal field to a capacity of 70 MW. The expansion is expected to be financed by the World Bank, Government of Iceland (GoI), Government of Japan (GoJ) and Government of Ethiopia (GoE).

The 'Geothermal Sector Development Project' consists of four components. The first component is development of the Aluto-Langano geothermal site. This component comprises the financing of goods, including drilling consumables and associated materials, services, including drilling contractors, the supervision engineer, reservoir engineering, and management, drilling and testing of about 22 wells, and the design and construction of a steam-gathering system connecting the producing and injection wells.

The second component is the Alalobad geothermal site development. The Alalobad geothermal site is located in the Dubti Woreda, Afar regional state. The project site is in the north-eastern part of Ethiopia, about 600 km from Addis Ababa. The Alalobad project area is situated within the Tendaho Graben, which is spread over approximately 100 $km^2$, potentially containing several distinct geothermal reservoirs. This component will finance goods, including drilling consumables and associated materials, services, including drilling contractors and the supervision engineer. and drilling and testing of about four wells. Financing from International Development Association (IDA) will be used for production drilling and testing activities in order to establish the economic viability of the geothermal resource and finalize a feasibility study of the Alalobad geothermal site.

The third component contains the drilling rigs, associated accessories, and spare parts. This component will finance goods, in particular two full-size modern diesel electric drilling rigs with all associated equipment, accessories for directional drilling and both overpressure and under-pressure drilling, and a complete inventory of spare parts.

Finally, the fourth component is the legal, institutional, and regulatory framework development.

In the second phase of the project, the steam resources that were developed and identified in the first phase will be used to generate electricity. The Aluto site is expected to generate about 70 MW of electricity. In Alalobad, based on the results of the four exploration wells, well-head generators will be installed and 12 MW of electricity production is expected. The GoE is now in discussion with IDA, the GoJ, and other development partners to fund the second part.

Detailed breakdown of the project components and their financing sources is provided in Table 8.

TABLE 8: Detailed project cost and financing breakdown (World Bank, 2014)

| **Project scope** | **Amount (M USD)** | **Proposed financing (Million USD)** |
|---|---|---|
| *Aluto* | | |
| Exploration, well siting | 1.5 | GoI |
| Full-service drilling contractor | 23.2 | WB |
| Supervision engineering | 4.5 | WB |
| Drilling consumables | 24.5 | SREP |
| | 35.5 | WB |
| Steam-gathering system | 29.0 | WB |
| Project management | 8.0 | GoE |
| Total for Aluto | 126.2 | |
| *Alalobad* | | |
| Reconnaissance and exploration | 2.0 | GoI |
| Drill rig mobilization, site prep | 1.5 | WB |
| Full-service drilling contractor | 4.3 | WB |
| Drilling consumables | 13.0 | WB |
| Supervision engineer | 1.0 | WB |
| Project management | 4.0 | GoE |
| Total for Alalobad | 25.8 | |
| *Rigs and accessories* | | |
| Drilling rigs with accessories and spare parts inventory | 63.5 | WB |
| Total for drilling rig and accessories | 63.5 | |
| *Technical assistance* | | |
| Capacity building | 1.0 | WB |
| Legal, institutional, and regulatory framework development | 2.0 | WB |
| Total for technical assistance | 3.0 | |
| **Total project cost** | **218.5** | |

### 9.5.3 Tendaho Dubti

The French Development Agency provided grant aid for the "Consultancy services for Tendaho geothermal resources development feasibility study" that was completed in October 2013. This study consisted of a geoscientific review on the existing data and information and the proposal of a basic project component and feasibility study. Environmental and social impact assessment were also included. The counterpart organization was the Geological Survey of Ethiopia.

### 9.5.4 Corbetti and Tulu Moye

In October 2013, Ethiopia signed a preliminary agreement with a US-Icelandic firm for a $4 billion private sector investment intended to tap its vast geothermal power resources and produce about 1,000 MW from steam. Since then the 1000 MW project has been split into two projects, one in *Corbetti* and the other in *Tulu Moye*, at 500 MW each. The location of Corbetti is in the southern district in the central main Ethiopian rift valley within two federal states Oromia and the Southern Nation's nationalities people's regional state. It is located in a populated area with good road access and near the national grid. Tulu Moye is situated in the Main Ethiopian Rift, northwest of Assela, close to the eastern margin of the rift. It is a wide zone where tectonic and volcanic activities are concentrated and is located about 100 km southeast of Addis Ababa with Lake Koka to the north and Lake Ziway to the south. It is close to the Koka hydro power station and the national grid system.

Since 2013 extended negotiation has been taking place with the GoE and EEP for both projects. Projects sponsors have secured equity for the first phase of the projects which is in the range of 50 MW each. Civil work has started and ESIA work is completed. In December 2017, an Implementation Agreement (IA) was signed with the GoE and a power purchasing Agreement (PPA) with EEP for both projects. But before projects sponsors are able to start the exploration drilling phase the IA needs to be rectified by the Ethiopian parliament. The rectification will happen soon and the drilling should start in 2019.

The power purchase agreement with the developer of the two 500 MW geothermal projects in Corbetti and Tulu Moye contains provision that both geothermal projects will be transferred to the government after 25 years and that the finalization of the construction in eight years requires a total investment of USD 4 billion. According to the geothermal proclamation, there is a transfer obligation to the GoE after the term of the PPA which is equivalent to both projects being public-private partnerships (PPPs) projects.

This pioneering geothermal power project is intended to deliver based load renewable power to the Ethiopian national grid. It is the major step in the development of privately developed and financed power in Ethiopia. It is the first independent power project to sign a power purchase agreement and the first large scale project using a geothermal resource.

### 9.5.5 Dofan and Fentale and other geothermal prospects

Surface reconnaissance surveys have been carried out at both the Dofan and Fentale geothermal fields. Both fields are fairly close east of Addis Ababa and are promising for further development. Table 9 shows geothermal prospects under development.

Other geothermal prospect areas in the Ethiopian Rift valley that are at reconnaissance stage of exploration include Teo, Danab and Kone.

TABLE 9: Geothermal fields and expected development plan (Kebede, 2012, Reykjavik Geothermal, pers. comm.)

| Prospect area | Expected output (MW) |
|---|---|
| Aluto Langano | 75 |
| Tendaho | 100 |
| Corbetti | 520 |
| Abaya | 100 |
| Tulu Moya | 520 |
| Dofan | 30 |
| Fentale | 30 |
| **Total** | **1,375** |

## 10. BUSINESS MODELS FOR GEOTHERMAL DEVELOPMENT

There are two principal business models that can be used by the government to attract private investors into specific sectors like the energy sector. That is using Public Private Partnership (PPP) or a fully private approach. In the energy sector the Private model is named Independent Power Producer (IPP).

The PPP is defined as a long-term contract between a private party and a government entity for providing service in which the private party bears significant risk and management responsibility. How much the private party receives for its participation typically depends on performance. Most PPP projects have a contractual term between 20 and 30 years, others have shorter terms and few last longer than 30 years.

The project functions transferred to the private party, such as design, construction, financing, operations, and maintenance, may vary from contract to contract but in all cases the private party is accountable for project performance and bears significant risk and management responsibility. PPP contracts typically allocate each risk to the party that can best manage and handle it. Risk transfer to the private party is not a goal but instrumental for full transfer of management responsibility and for the alignment of private interests with public interest.

A PPP sometimes includes a long-term commitment to provide infrastructure services. This implies the design and construction of infrastructure or the renewal of existing assets, and the provision of long-term asset-maintenance. Most PPPs contain additional services, including the full operation of the infrastructure when the private operator is able to commit to service quality and performance and the procuring authority is able to define that same quality and performance. These additional services should also take place over long term.

PPPs have been used in a wide range of sectors to procure different kinds of assets and services. In all cases, the PPP project constitutes or contributes to the provision of public assets or services and it involves long-life assets. Public service is any service that the government considers its responsibility to provide or ensure is provided. The focus on long-term assets highlights the long-term nature of a PPP contract. PPPs generally involve fixed assets but projects may also include related long-life assets that are purpose or site-specific. The types of assets and services that can be procured by PPPs are listed in Table 10.

TABLE 10: Public-Private Partnership (PPPs) by sectors

| Sector | Project types |
|---|---|
| Transport | Roads, tunnels, bridges<br>Rail<br>Mass transit system<br>Ports<br>Airports |
| Water and waste | Bulk water treatment<br>Water distribution and sewerage system<br>Solid waste management service |
| Power | Generation assets<br>Distribution systems |
| Social and governmental infrastructure | Education-school facilities and service<br>Health-hospitals and health facilities and service<br>Prisons<br>Urban regeneration and social housing projects |

*Public-private partnerships offer several benefits:*

- They provide better infrastructure solutions than an initiative that is wholly public or wholly private. Each participant does what it does best.
- They result in faster project completions and reduced delays on infrastructure projects by including time-to-completion as a measure of performance and therefore of profit.
- A public-private partnership's return on investment (ROI) might be greater than traditional, entirely private or government methods. Innovative design and financing approaches become available when the two entities work together.
- Risks are fully appraised early on to determine project feasibility. In this sense, the private partner can offer a break on unrealistic government promises or expectations.
- The operational and project execution risks are transferred from the government to the private participant, which usually has more experience in cost containment.
- Public-private partnerships may include early completion bonuses that further increase efficiency.
- By increasing the efficiency of the government's investment, it allows government funds to be redirected to other important socioeconomic areas. The greater efficiency of PPPs reduces government budgets and budget deficits.
- High-quality standards are better obtained and maintained throughout the life cycle of the project.

*PPPs also have some drawbacks:*

- Every public-private partnership involves risks for the private participant, which reasonably expects to be compensated for accepting those risks. This can increase government costs.
- When there are only a limited number of private entities that can perform these tasks, the limited number of private participants that are big enough to take on these tasks might limit the competitiveness required for cost-effective partnering.
- Profits of the projects can vary depending on the assumed risk, competitive level, complexity, and the volume of the project being performed. If the expertise in the partnership lies heavily on the private side, the government is at an inherent disadvantage. For example, it might be unable to accurately assess the proposed costs.

*Power sector business model*
Investment in renewables is growing rapidly, generally power generation projects fall into one of three categories:

1. *Baseload:* baseload generators operate on a continuous basis.
2. *Peak:* peak generators operate only where demand exceeds the output of the baseload generation facilities. Peak generators are commonly either hydropower, or combined-cycle or open-cycle natural gas generators, due to the need for quick start-ups to meet intermittent peaks.
3. *Mid-merit:* mid-merit generators fill requirements somewhere between those of the baseload and peak generators. A mid-merit generator will be used as a base generator during the day, or during periods of high demand, and will then be used as a peak generator at night or in times of lesser demand. Mid-merit generators are often older and more expensive than baseload plants.

To meet the growing demand for electricity, additional capacity needs to be built and/or existing generation facilities must be updated. Public-private partnerships can be used to overhaul old facilities and construct new ones. The most frequently used forms of PPP transactions for geothermal development are listed in Figure 7. These models range from fully private, in which the project relies on an independent private developer (Model A), to fully public, where only a national company is involved (Model F). Public-Private Partnerships, which can be developed between these two parties, refers to a financing scheme that integrates commitment of resources from public and private participants to establish an investment project. PPPs can have different structures, ranging from a public authority offering full or partial financing of each phase (Models B, C and D) to an equal partnership through all phases (Model E).

| | identification | Screening | Assessment | Selection | Pre-develop. | Development | Execution | Operation | |
|---|---|---|---|---|---|---|---|---|---|
| Model A | Public / Private | Private | Private | Private | Private | Private | Private | Private | Fully private |
| Model B | Public | Public | Public | Private | Private | Private | Private | Private | PPP |
| Model C | Public | Public | Public | Public | Public | Private | Private | Private | PPP |
| Model D | Public | Public | Public | Public | Public | Public / Private | Public / Private | Private | PPP |
| Model E | Public / Private | Public / Private | Public / Private | Public / Private | Public / Private | Public / Private | Public / Private | Public / Private | PPP |
| Model F | Public | Public | Public | Public | Public | Public | Public | Public | Fully public |

FIGURE 7: Applicable project business models for geothermal development (IRENA, 2018)

Model A is almost entirely private. The public party contributes only to the identification of the geothermal field (e.g. information on an appropriate geothermal site). In Models C and D, in which the public authorities are doing the exploration drilling and possibly all of the subsequent drilling as well, their strategy is to "de-risk" the project in its riskiest phases and then tender out plant construction and operation, sometimes also involving production drilling. The idea is to generate more interest for private investors by decreasing the project risk. In Model D, a public company would be formed to manage the geothermal resource and sell steam to the power plant.

Some typical project financing models are:

*Design-Build (DB):* When applying this model, an owner typically hires a single entity, the design/builder, to perform the entire power plant design and construction under a single contract. Portions or the complete design and construction may be performed by the entity or subcontracted to other companies. DB is characterized by high levels of collaboration between the design and construction disciplines, input from multiple trades into the design, and a single entity bearing the project risk. Typically, the general contractor is responsible by contract in this delivery mode.

*Operation and Maintenance contract (OM):* The main common features are that the awarding authority engages the contractor to manage a range of activities for a relatively short time period (2-5 years), while the power plant remains under the ownership of the public-sector partner. Management contracts tend to be task specific and input rather than output focused. Operation and maintenance agreements may have more outputs or performance requirements.

*Design-Build-Finance-Operate (DBFO):* This model contains a contract with a private partner to design, build, operate and finance a power plant for a defined period, after which government takes over. The power plant is owned by the private partner for the contract period and covers cost through public subvention. Key drives are the utilisation of the private finance and transfer of design, construction and operation risk. This could be a possibility in Models B, C and D.

*Build-Own-Operate (BOO):* This is a model in which a private organization builds, owns and operates some power plant structure with some degree of encouragement from the government. Although the government does not provide direct funding in this model, it may offer other financial incentives such as tax-exempt status. The developer owns and operates the power plant independently. This could be a possibility for Model E or F.

*Build-Own-Operate-Transfer (BOOT):* This model of project financing involves a single component, who designs, builds, funds, owns and operates the power plant for a defined period of time and then transfers the power plant ownership to an agreed party. This approach is comparable to Models B, C, D and F.

*Buy-Build-Operate (BBO):* This model is a form of asset sale for a specified period that includes a rehabilitation or expansion of a power plant. The government sells the power plant to the private sector entity, which then makes the improvements necessary to operate the facility in a profitable manner. This is a possibility for Model E.

*Build-Lease-Operate-Transfer (BLOT):* The private sector designs, finances and constructs a new facility on public land in long term lease and operates the facility during the term of the lease. The private owner transfers the new facility to the public sector at the end of the lease term. This is a possibility for Model E.

*Finance Only (FO):* This model describes the process by which the private sector, a financial representation of some type, covers all costs associated with the development, with a given security. This is another possibility for Model E.

None of these models is superior and probably all them could be used in a country like Ethiopia with its size and vast opportunities. The GoE has put a BOOT model into the Geothermal Proclamation as a preferred way to cooperate with private investors in the geothermal industry. Both contracts for the Tulu Moye and Corbetti are based on the BOOT model.

## 11. CONCLUSION AND RECOMMENDATIONS

Sustainable energy is a fundamental requirement for:

- Economic development;
- Poverty reduction;
- Enhancing gender equality;
- Job creation;
- Ensuring environmental sustainability;
- High social returns; and
- Welfare.

Governments are ultimately responsible for the provision of public services and the infrastructure required for the energy development. Energy investment is often part of the social connection between a government and its citizens. Inadequate energy is a constraint on the growth and negatively impacts the quality of life.

Ethiopia has realised the potential of its renewable energy resources. Hydro, solar, wind and geothermal energy resources are all contributing to changing its economic fortune and that of its people. Acknowledging these clean and sustainable, abundant and feasible alternatives, the nation has engaged in the development of these energy resources. The available renewable energy resources, if developed, could not only help meet the local energy demand, but also bring additional revenue from energy exports to countries in the region.

Ethiopia needs energy to provide and increase the energy security to meet the long term goal of becoming a middle-income country by 2025. The country has experienced strong economic growth over the past decade. To maintain this growth and meet the long term goal, the country should also explore other means of energy sources. Ethiopia generates electricity mostly from hydro power (87% of electricity). The remaining electricity is generated from diesel, wind and thermal sources. The newly estimated geothermal potential in Ethiopia is about 10, 000 MW in different geothermal prospects in the Ethiopian rift valley. So far only a very minor fraction of the potential has been harnessed. Geothermal energy can reduce Ethiopian's dependency on hydro power and a significant portion of the country's energy demand can be met by the use of geothermal technology.

The government needs to explore all options to increase the energy availability in the country including PPP and IPP to radically improve the energy sector in the country and enhance service delivery to its people. This review of PPPs suggests that, above all, governments must fundamentally improve their approach in dealing with the private sector to realise the efficiency and effectiveness gains that these partnerships promise.

To attract private investors interested in developing or financing geothermal projects the country must have a transparent legal and regulatory framework in place which addresses issues such as geothermal resource rights, licensing and concessions, and is properly enforced. There also needs to be a clear policy framework which ensures an attractive and robust set for tariff and pricing arrangements to reassure investors that they will be paid a fair return for their investments.

## REFERENCES

Africaguide, 2018: *Map of Ethiopia*. AfricaGuide, website: *www.africaguide.com/country/ethiopia/*

Asnake, A., 2015: *The Ethiopian energy sector investment opportunities, UK-Ethiopian trade and investment forum, London.* Developing Markets, website: developingmarkets.com/site/default/file.ppt

Atwa, V.O., 2018: Analysis of stuck pipe and fishing operations: case study of Olkaria geothermal field in Kenya. Report 8 in: *Geothermal training in Iceland 2018*. UNU-GTP, Iceland, 1-32 pp.

Brinckerhoff, P., 2013: *Ethiopian power system expansion master plan study.* Ethiopian Electric Power Corp. interim report, generation planning, vol. 3.

Cleanenergyideas, 2018: *Advantage and disadvantage of geothermal energy-clean*. CleanEnergyIdeas, website: *www.clean-energy-ideas.com*

Gehringer, M, and Loksha. V, 2012: *Geothermal handbook: Planning and financing power generation.* Energy Sector Management Assistance Program (ESMAP), The World Bank, Technical Report 002/12, 10+150 pp.

Hyde, H., 2015: *South Africa's base load addiction*. Hans' World Travels 2.0 & Beyond, website: *hansworldtravels.com/on-energy/hans-on-energy-article-excerpts/.*

IECONOMICS, 2018: *Ethiopian access to electricity urban percent of urban population*. IECONMICS, website: *www.ieconomics.com*.

IRENA, 2018: *Geothermal development*. International Renewable Energy Agency (IRENA) website: *www.irena.org*.

Kebede, S., 2012: Geothermal exploration and development in Ethiopia: Status and future plan. *Paper presented at "Short Course VII on Exploration for Geothermal Resources", organized by UNU-GTP, KenGen and GDC, in Naivasha, Kenya,* 16 pp.

Kebede, S., 2016: Status of geothermal exploration and development in Ethiopia. *Presentation from the ARGeo-C6 Conference, Addis Ababa, Ethiopia,* 24 pp.

Lemma, M., 2014: *Power Africa geothermal roadshow.* Ethiopian Electric Power, Presentation, 24 pp.

MoWIE, 2016: Ethiopian geothermal policy, legal and regulatory framework. *Presentation by the Ministry of Water, Irrigation and Electricity at the ARGeo C6 conference, Addis Ababa,* 21 pp, website: *theargeo.org/presentations/Ethiopian%20geothermal%20policy.pdf*

Shahan, Z. 2012: *Wind turbine net capacity factor- 50% the new normal*. Clean Technica, website: cleantechnica.com/2012/07/27/wind-turbine-net-capacity-factor-50-the-new-normal/

Teklemariam, M., Beyene, K., Amdeberhan, Y., and Gebregziabher, Z., 2000: Geothermal development in Ethiopia. *Proceeding of the World Geothermal Congress 2000, Kyushu-Tohoku Japan,* 475-480.

Teklemariam, M., and Beyene, K., 2005: Geothermal exploration and development in Ethiopia. *Proceedings of the World Geothermal Congress 2005, Antalya Turkey,* 9 pp.

Wikipedia, 2018: *List of power stations in Ethiopia.* Wikipedia, website*: en.wikipedia.org.*

World Bank, 2014: *International development association project appraisal document.* World Bank, report to the Federal Democratic Republic of Ethiopia, for the geothermal sector development project, report no. 83994-ET.

Worldometers, 2018: *World population/Ethiopian population.* Worldometers, website: *www.worldometers.info.*