Presented at SDG Short Course V on Exploration and Development of Geothermal Resources,
organized by GRÓ GTP, KenGen and GDC, at Lake Bogoria and Lake Naivasha, Kenya, Nov. 14 – Dec. 4, 2021.

STATUS OF GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

Solomon Kebede
Ethiopian Electric Power
Addis Ababa
ETHIOPIA
kebesolo17@gmail.com

ABSTRACT

Ethiopia is located in the horn of Africa. Electricity is one of the modern energy supplies in the country. The current total installed electricity generation has reached over 4,500 MW but geothermal contributes only to a fraction of it. The government policy direction is to generate virtually all electricity from clean and renewable sources, centered on hydropower, geothermal, wind, solar and other renewable energy resources, using public and private sector funds.

Ethiopia is endowed with large geothermal potential, with 25 areas of high temperature sources and estimated geothermal electrical potential of over 10,000 MW. These resources are located in the Ethiopian Rift valley, which is part of the East African Rift system.

To date, the number of prospects identified to have high temperature resources has reached 25, out of which 20 have been explored with detailed surface exploration and three including by deep drillings. The only power plant installed in the country so far is a 7.3 MW binary plant at Aluto Langano Geothermal field.

Currently deep geothermal drilling activities are being carried out at Aluto Langano and Tulu Moye prospects by the public and the private sector respectively. A well head turbine is also being installed at Aluto Langano prospect. Assessment on the most suitable direct use applications in Ethiopia is also being carried out using climate technology center and network (CTCN) funds.

A total of 995 MW electricity is planned to be developed from geothermal by 2030 by public and private sector funds. The plan is currently under various phases of implementation.

1. INTRODUCTION

1.1 Country background

Ethiopia is located in the horn of Africa between 3.5° and 14° N and 33° and 48° E. The country has an area of 1.14 million km^2 and a population of over 100 million (CSE, 2016). The Ethiopian economy is a non-oil-driven economy, which is agricultural led with major exports of coffee, oil seeds, animal skin and horticultural products. The government setting has been federal democratic republic with eleven regional states.

1.2 Energy and electricity sector

1.2.1 Status of electricity production

The sources of energy in Ethiopia can be generally categorized into two major components: (i) traditional (biomass) and (ii) modern (such as electricity and petroleum). From the total energy consumption, 87 % is from traditional and derived biomass, 10 % is from petroleum products and coal and only 2 % is from electricity (Eshetu, 2019).

The total installed electrical capacity has reached over 4500 MW. From these, 4077 MW is from hydro, 7.3 MW is from geothermal, 349 MW is from other renewables and 89 MW is from fossil fuels (Table 1).

TABLE 1: Sources of current generation in Ethiopia and corresponding installed capacity

No	Source of generation	Installed capacity (MW)	%
1	Hydropower	4077	90.1
2	Other renewables*	349	7.7
3	Geothermal	7.3	0.2
4	Thermal	89	2
	Total	**4522.3**	100

*Other renewables include: wind, solar and waste to energy

1.2.2 Energy policy and regulation

The government policy direction is to generate virtually all of our electricity from clean and renewable sources centered on hydropower, geothermal, wind, solar and other renewable energy resources (Abayneh, 2013). It aims to facilitate the development of energy resources for economical supply to consumers. It seeks to achieve the accelerated development of indigenous energy resources and the promotion of private investment in the production and supply of energy. Electricity supply, as an element of the development infrastructure is being advanced by the government in two fronts: (i) the building up of the grid based supply system to reach all administrative and market towns, and (ii) rural electrification based on independent, privately owned supply systems in areas where the grid has not reached.

An independent power producer (IPP) may engage in power development for selling the generated electricity to the public utility, Ethiopian Electric Utility (EEU), known as the single buyer model. The single buyer model does not exclude captive geothermal power generation, i.e. generation for own use in primary economic production or service industries owned by the developer. Recently, policies on public private partnerships (PPP) options were also put into force.

A new geothermal law for operation of geothermal activities for both the public and private sector has been approved. The proclamation, cited as the "Geothermal Resources Development Proclamation" has been put into force since 2016. The objectives of this proclamation are to: (i) ensure that the country's geothermal resources are developed in an orderly, sustainable and environmentally responsible manner; (ii) support the generation and delivery of electricity from geothermal energy for local consumption and export; and (iii) promote the use of low enthalpy geothermal resources for direct uses (Federal Negarit Gazette, 2016).

1.3 Institutional set-up in geothermal

The surface exploration work to date has been carried out by the Geological Survey of Ethiopia (GSE). The Ethiopian Electric Power (EEP) is currently engaged in deep drilling and Power plant development. The EEU is responsible for electric power distribution and purchase and selling of electric power. A geothermal licensing and administration department which has recently moved from the Ministry of Water, Irrigation and Energy to the Ministry of Mines and Petroleum has a mandate of handling geothermal regulatory issues.

2. GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

2.1 Geothermal exploration and development in the past

2.1.1 Surface exploration

Ethiopia is endowed with a large geothermal potential. The geothermal resources are located in the Ethiopian Rift Valley, which is part of the East African Rift System. The geothermal sites in Ethiopia are geographically distributed from the south-western part of the Ethiopian Rift up to the north eastern part (Figure 1).

Ethiopia started geothermal exploration in 1969, within the Ethiopian sector of the East African Rift system. To date the number of prospects identified to have high temperature resources has reached 25. The initial level of exploration had been reconnaissance, which included regional infrared air born surveys, covering the whole rift system (UNDP, 1973).

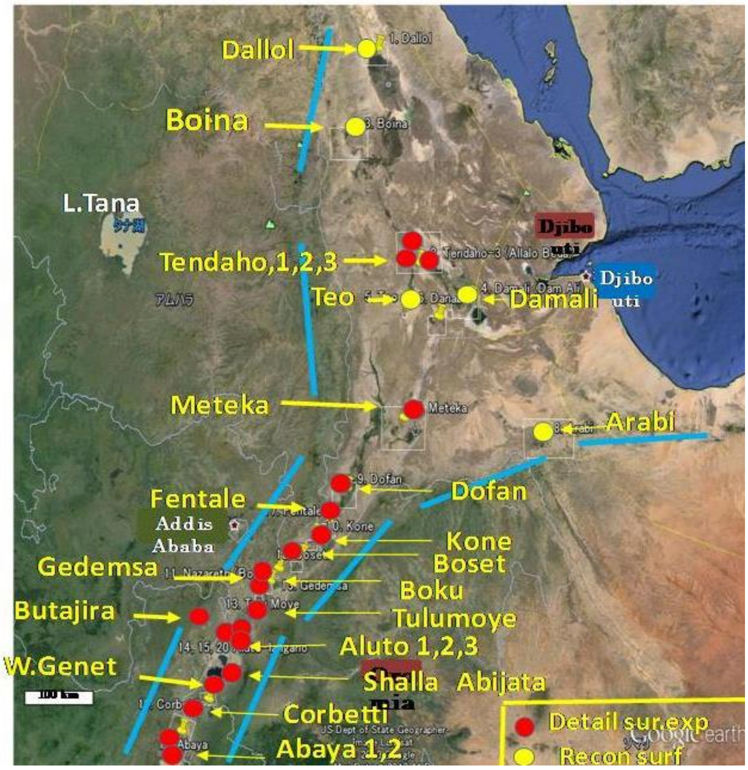

FIGURE 1: Location map of geothermal prospects in Ethiopia

Since the late 1970's, geoscientific surveys mostly comprising geology, geochemistry, and geophysics, were carried out at the southern-central part of the Ethiopian Rift and Tendaho prospect in Afar to the north. In addition, a semi-detailed surface exploration of ten sites in central and southern Afar was carried out in the mid-1980s (ELC, 1986). So far, detailed surface exploration studies have been completed in 20 of the 25 prospects (Figure 1).

Aluto Langano Prospect

One of the best explored areas is the Aluto Langano prospect. A more detailed surface exploration of the prospect was carried out during 2015-2016, by focusing on the main anomaly areas, Aluto 1, 2 and 3 (Figure 2), with the objective of identifying the most favorable sectors within the Aluto volcanic complex for the implementation of underground exploration activities.

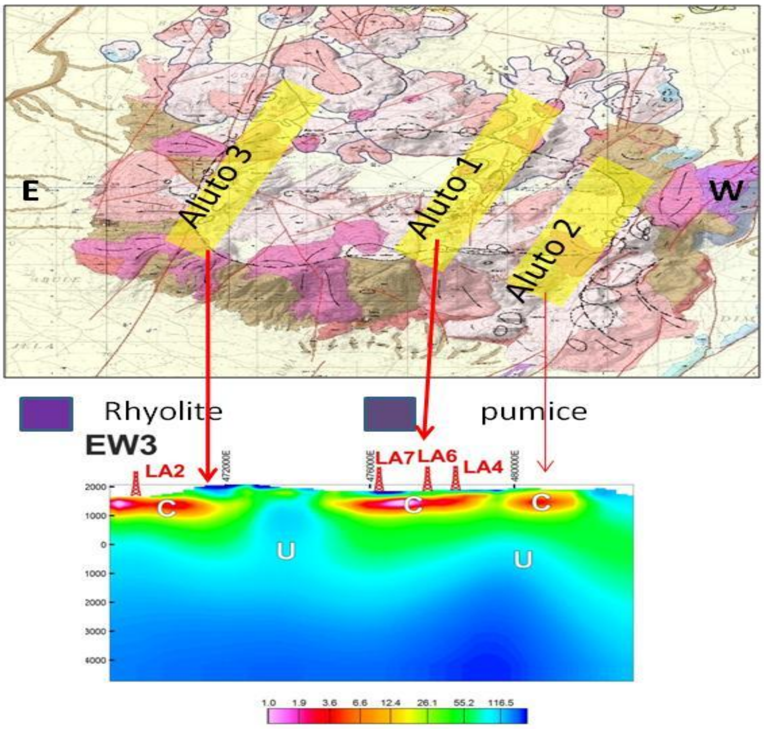

FIGURE 2: The Aluto Langano prospect and 2D resistivity profile

To achieve the objectives, geological and geochemical studies, as well as geophysical surveys (gravity, geo-electrical and micro-seismic) have been conducted. The integrated interpretation of the results of these surveys has led to the following conclusions: (i) the geo-volcanic situation may create an intense, wide and shallow thermal anomaly, (ii) the main element controlling the configuration of the geothermal system is represented by NNE-NNW trending faults, (iii) the other structural element of major importance is the Aluto caldera, elongated in a W-E direction over an extension of 8.5 x 5 km, (iv) from resistivity surveys clay caps corresponding to the top of the reservoir have been identified in the central (Aluto 1) and eastern portion of the volcano (Aluto 2) (Figure 2) and these two areas have been selected as future targets for drilling, (v) at Aluto 2, volumetric estimation has indicated, a probable power of 33 MWe and a possible power of 50 MWe, and (vi) by analogy with the Aluto 1 field, the Aluto 2 reservoir fluids are of Na-HCO3-Cl type with average total salinity of 100 meq/kg, with non-condensable gas content of 6-8% in the steam, scaling phenomena expected to be minor, and no corrosion foreseen (ELC, 2016a).

Tendaho Geothermal Prospect

The Tendaho prospect involves three target areas, named as Tendaho 1, 2 and 3 (Figure 1). Surface exploration in the target area of Tendaho 1 has been finalized under the framework of ARGeo project in 2013. The purpose of the survey was to develop a conceptual model and select deep well sites. A review of all the available geoscientific data of the Tendaho area, development of a new 3D model of subsurface temperature and definition of areas of interest for further exploration and development have been made. The new developed conceptual model is largely consistent with previous assessments. Initial exploration wells are sited to be drilled to validate the model.

At Tendaho 2, JICA assisted detailed surface exploration, including geophysical (MT/TEM, gravity and micro-seismic) and environmental studies, which were conducted in 2015 for siting of wells. The results indicated priority areas for test well drilling. Accordingly, the drilling of 2 to 3 wells is being planned with technical assistance from JICA.

Surface exploration at Tendaho 3 was completed in 2015, with technical assistance from ICEIDA. The exploration works included geophysical exploration (MT, gravity and micro-seismics) and subordinates other geo-scientific methods. The purpose of the exploration was to have a conceptual model of the geothermal system for subsequent well site selections. The developed conceptual model of the field has indicated that there may be three target areas in order of priority and a total potential of about 125 MWe.

According to the conceptual model of Tendaho 3, the main features of the hypothesized reservoir, with reference to the first priority zone have been estimated as follows: (i) areal extent: covers a surface of

8 km^2, being delimited at all sides by geo-electrical lateral discontinuities; (ii) vertical extent: in accordance with the information derived from the MT survey, the top of the reservoir occurs at an average depth of about 1,000 m b.g.l. and the thickness is assumed to be on the order of 1,000-1,200 m; and (iii) thermodynamic and chemical conditions: the reservoir is expected to be liquid dominated with a temperature of 200-220°C, fluids have Na-Cl composition with relatively high content of SO_4, are rather diluted (TDS around 1,400 ppm) and may exhibit some calcite and silica scaling tendency (ElC, 2016b).

2.1.2 Surface exploration in other areas

Surface exploration has been conducted at Shalla-Abiata and Butajira areas, in the central part of the rift in 2016. Geological, geochemical and geophysical surveys including MT have been conducted by GSE. The preliminary results of the survey in these two prospects indicated that geothermal reservoirs with temperature in excess of 200°C may likely exist at depth. Similar geoscientific data has also been collected at Meteka in 2017/18, which was used to conceptually model the geothermal system and indicated preferred areas for further investigation (ELC, 2019).

2.1.3 Surface exploration by private sector

Multiple private sector companies have been involved in surface explorations in their respective concession areas. Accordingly, detailed surface explorations and conceptual modeling have been completed in various prospects including Dofan, Fentale, Tulu Moye, Corbetti, Wendogenet and Abaya (Figure 1).

2.1.4 Exploration drilling

Exploration drilling has been conducted from the early to mid-1980s at Aluto Langano, in the southern part of the Rift. Eight exploratory wells were drilled with four of these proving productive with an average output of about 2 MWe/well.

The other well explored area, including by drilling, is the Tendaho geothermal prospect in northern Afar. Between 1993 and 1998, three deep (about 2,100m) and three shallow exploratory wells (about 500m) were drilled in Tendaho 1 area and yielded a temperature of over 250ºC. The Italian and Ethiopian governments jointly financed the drilling operation in the geothermal field. A preliminary production test has indicated that the discovered shallow reservoir at Tendaho 1 alone could generate about 25 MWe. Volumetric estimate of the total Tendaho prospect potential, however, indicates an order of several hundred MWs.

2.1.5 Appraisal drilling

The Aluto Langano prospect is the only prospect where appraisal drilling has been conducted or is being conducted. The drilling of two appraisal wells for reservoir modeling and subsequent selection of production wells has been carried out in 2013 and 2014 at Aluto 1. These wells, LA-9D and LA-10D, have been drilled to depths of 1920 m and 1951 m respectively. Both wells are productive with bottom hole temperatures of over 300ºC. Testing and reservoir engineering have indicated that the two wells together may sustain about 5 MW electricity. Reservoir simulation studies have also been conducted using data from the newly drilled two wells at Aluto, including data from previous wells. The result shows that a sustained 35 MW electcity could be generated at Aluto 1.

2.1.6 Geothermal utilization

Geothermal utilization for electrical power generation at Aluto Langano prospect started in 1988 by installing a 7.3 MWe net capacity binary pilot plant. The plant is currently under maintenance and does not produce power.

Direct utilization of the low to medium enthalpy geothermal resources has been so far limited to bathing, in spas and swimming pools.

2.1.7 Geothermal Master Plan Study

A geothermal master plan study has been completed recently with JICA technical assistance. The project included geoscientific, social and economic surveys in 22 prospects for potential estimation and prioritization. The results of the study have showed an electrical potential of over 10,000 MW. Ranking of the prospects for development has also been made on the bases of geothermal knowledge, potential, project economics, and site-specific factors (GSE and JICA, 2015).

2.2 Current geothermal exploration and development activities

Currently deep geothermal drilling activities are being carried out at Aluto Langano and Tulu Moye prospects by the public and the private sector respectively. A well head turbine is also being installed at Aluto Langano prospect. Using climate technology center and network (CTCN) funds, assessments on the most suitable direct use applications in Ethiopia are being conducted.

2.2.1 Current appraisal drilling at Aluto Langano

The present project foresees the drilling and testing of 6 full diameter appraisal wells in Aluto 1 and 2 and 2 exploratory wells in Aluto 2 (Figure 2). The drilling of the current first appraisal well (LA 11 D1) started at the end of May 2021 and was completed at 3000 m depth in early November 2021. The well is currently (as of late November 2021) under a heat-up period and maximum measured temperature measured so far has reached 312°C. The second appraisal well (LA 12 D1) is under drilling and has reached a depth of 1130 m by November 23, 2021. The drilling project is being financed by the World Bank, under the framework of Geothermal Sector Development Program (GSDP). The project is being implemented by EEP, with the role of owner, using its newly purchased two deep drilling rigs, operating in parallel.

2.2.2 Well head turbine at Aluto Langano

Following the drilling of two appraisal wells at Aluto Langano in 2013/2014 with JICA/World Bank financing and subsequent testing of the wells, the Japanese government has decided to support the installation of a 2.6 MW well head turbine using the steam from the two productive wells (LA 9 and LA10). Accordingly, the housing of the turbine and surface facilities are currently under construction.

2.2.3 Exploration drilling at Tulu Moye Prospect

A private company, called Tulu Moye Geothermal has been conducting surface exploration at Tulu Moye geothermal prospect since the last few years with conceptual modeling of the geothermal system to target test exploratory wells. Following the site selection, 3 deep wells have so far been drilled in the area and testing and resource assessment in these wells is currently ongoing.

2.2.4 Direct use studies

CTCN technical assistance on direct use has been to identify the most suitable direct use applications and technologies in low to medium temperature geothermal systems of the country. So far in three areas (Doubti, Aluto Langano and Abaya), potential direct use applications (such as fruit and vegetable drying, aquaculture and fish drying, green house heating, milk pasteurization and balneotherapy) have been identified and the technical and economical viability is under assessment.

3. GEOTHERMAL DEVELOPMENT PLANS

A total of 995 MW electricity may be developed from geothermal by 2030. The plan is currently under various phases of implementation (Table 2).

TABLE 2: Planned production of geothermal electricity in Ethiopia by 2030

No	**Locality**	**Developer**	**Current status**	**Total under implementation or planned (MWe)**
1	Aluto Langano	Public (EEP)	Under implementation	70
2	Alalobad (Tendaho 2)	Public (EEP)	Under preparatory phase	25
3	Corbetti	Private (Corbetti Geothermal)	Under implementation	150
4	Tulu Moye	Private (Tulu Moye Geothermal)	Under implementation	150
5	Shashemene (Wendo Genet)	Private (Ormat Plc)	PPA negotiation	100
6	Dofan	Private (Ormat Plc)	PPA negotiation	100
7	Boku	Private (Ormat Plc)	PPA negotiation	100
8	Dugna Fano (Abaya 2)	Private (Ormat Plc)	PPA negotiation	150
9	Fentale	Pribate (Cluff Geothermal)	PPA negotiation	150
Total				**995**

4. CONCLUSIONS

Despite the long history of geothermal exploration in Ethiopia and an estimated potential of over 10,000 MW, so far only a very little fraction of the total potential has been harnessed. In order to avert possible shortfalls and also due to the added advantage in complementing the hydro generation during unfavorable periods of severe droughts, geothermal development in Ethiopia has been given more attention in recent years.

Over 995 MWe has been planned to be developed from geothermal by 2030. However, planning alone cannot fast track the resource development. In addition to planning: (i) the government has to assign sufficient budget, build enough capacity and set appropriate institutional set-up to remove the risk barriers, (ii) facilitate PPA negotiations with private companies, (iii) establish and implement geothermal laws and regulations and (iv) create appropriate enabling environments for private sector investment.

Currently: (i) geothermal is integrated in the National Energy Development Master Plan, (ii) participation of international financial institutions, bilateral donors and development agencies, to assist geothermal development projects has grown, (iii) the public sector is implementing various geothermal projects and the private sector is being encouraged to participate in geothermal development projects. Therefore, Ethiopia is expected to connect hundreds of megwatts of geothermal power to the grid in the long term.

REFERENCES

Abayneh, G., 2013**:** Short remarks on Ethiopian energy sector development program. *Exchange training program at the Geothermal Energy Association, Geothermal Energy Expo and the Geothermal Resource Council Annual Meeting*, Las Vegas, Nevada, United States.

CSE, 2016: *Statistical abstract*. Central Statistical Agency, Addis Ababa, Ethiopia.

Electro Consult (ELC), 1986: Geothermal Exploration Project, Ethiopian Lakes District, Exploitation of Langano-Aluto Geothermal Resources, feasibility report, ELC, Milano, Italy.

ELC, 2016a: Consultancy services for Aluto Langano geothermal resources development, conceptual model report. Electro Consult, Milan, Italy.

ELC, 2016b: *Consultancy services for Tendaho geothermal resources development, conceptual model report*. Electro Consult, Milan, Italy.

ELC, 2019: *Consultancy services for Meteka geothermal resources development, conceptual model report.* Electro Consult, Milan, Italy.

Eshetu, Y., 2019: Highlights of the Ethiopian energy sector. *1st international conference on Geothermal Energy in Ethiopia, Addis Ababa*, power point presentation.

Federal Negarit Gazette, 2016: *Geothermal resources development proclamation*. The Federal Democratic Republic of Ethiopia, proclamation no 981/2016.

GSE and JICA, 2015: *The project for formulating master plan on development of geothermal energy in Ethiopia, final report*. Geological Survey of Ethiopia and Japan International Cooperation Agency.

UNDP, 1973: *Investigation of geothermal resources for power development. Geology, geochemistry and gydrogeology of hot springs of the east African Rift System within Ethiopia*. United Nations Development Programme, New York, New York, United States, technical report DP/SF/UN 116, 275 pp.