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STATUS OF GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

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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 a large geothermal potential, with 25 areas of high temperature sources and estimated 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.

Geothermal exploration in Ethiopia began in 1969. Various geothermal studies have been carried out by the public and the private sector, in recent years. The recent public sector activities include: (i) Geothermal master plan study; (ii) Surface exploration, deep drilling and testing at Aluto Langano prospect; and (iii) Surface explorations in other areas. The results of the surface explorations have all indicated favorable resource conditions for geothermal development.

Five private sector companies are operating in the country. They have completed conceptual modeling of respective geothermal fields and are moving to the next stage of drilling activity.

The geothermal development plan of the country envisages development of 1735 MWe by 2030 from 9 target areas using private and public sector funds.

1. INTRODUCTION

1.1 Background country information

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, which is a non-oil-driven economy, has grown on an average rate of 10.2% for the last 10 consecutive years. The economy is agriculturally led with major exports of coffee, oil seeds, animal skin and horticultural products.

1.2 Energy and electricity sector

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).

1.2.1 Status of Electricity Generation

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 renewable include: Wind, solar and waste to energy.

1.2.2 Energy policy and regulation

The government policy direction is to generate virtually all of Ethiopia's 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 economic 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 on two fronts: (a) The building up of the grid based supply system to reach all administrative and market towns; and (b) Rural electrification based on independent, privately owned supply systems in areas that 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 Power (EEP), 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. EPC turnkey contracts could be negotiated and signed between private companies and the public utility, in which the private sector would have the role of not just a project developer, but also as a critical stakeholder who can bring financing to the table under the right circumstances. Recently, policies on public private partnerships (PPP) options have also come 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", came into force in 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; (iii) Promote the use of low enthalpy geothermal resources for direct uses including space heating and cooling, industrial and agricultural processes, refrigeration, green housing, aquaculture and balneology; (iv) Ensure security of tenure for all investors in respect of geothermal resources development operations; and (v) Encourage a sustainable, carbon-neutral economy in Ethiopia (Federal Negarit Gazette, 2016).

1.3 Geothermal sector institutional set-up

The surface exploration work to date has been carried out by the Geological Survey of Ethiopia (GSE). There has been collaboration between GSE and EEP in carrying out some of the drilling activities. EEP is responsible for building and operating geothermal power plants. The Ethiopian Electric Utility (EEU) is responsible for electric power distribution, purchasing and selling electricity. The Ethiopian Energy Authority has a mandate of handling regulatory issues, geothermal licensing and administration.

Most of the geothermal institutions have benefited from a number of technical cooperation programs. The most recent technical assistances are from Icelandic International Development Agency (ICEIDA), United Nations Environmental Programme (UNEP), French Development Agency (Afd), World Bank, and Japan International Cooperation Agency (JICA).

2. HISTORY OF GEOTHERMAL EXPLORATION IN ETHIOPIA

Ethiopia is endowed with 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. 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 airborne surveys, covering the whole rift system (UNDP, 1973). Later studies have completed detailed surface explorations in 20 of the 25 prospects (Figure 1).

Since the late 1970's, geoscientific surveys mostly comprising geology, geochemistry, and geophysics, have been 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 by GSE and Electroconsult (ELC) in 1986.

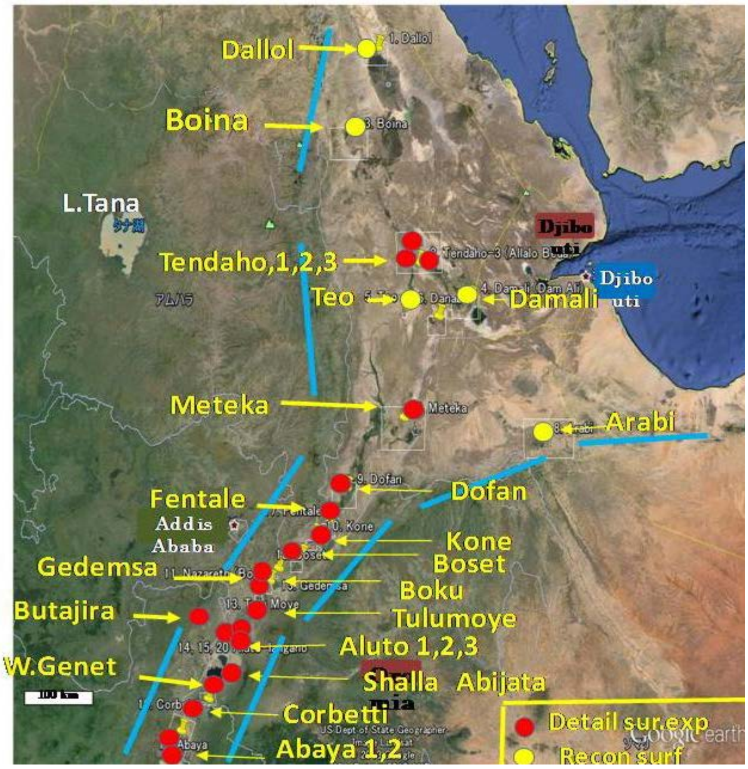

FIGURE 1: Location map of geothermal prospects in Ethiopia

Exploration work peaked during the early to mid-1980's when exploration drilling was carried out at Aluto Langano, in the southern part of the Rift. Eight exploratory wells were drilled, with four of these proving productive. Resource utilization at Aluto was delayed until 1998 when a 7.3 MWe net capacity binary pilot plant was installed.

The other well explored area, including by drilling, is the Tendaho geothermal prospect Northern Afar. It has three target areas indicated as Tendaho 1, 2 and 3. The geothermal exploration has been carried out in the Tendaho 1 area with economic and technical support from Italy between 1979 and 1980.

Between 1993 and 1998, three deep (about 2,100 m) and three shallow exploratory (about 500 m) wells have been drilled in this 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 indicated that the shallow reservoir at Tendaho 1could generate about 25 MWe. A volumetric estimate of the total Tendaho prospect potential has been put at over 1000 MW.

3. RECENT GEOTHERMAL EXPLORATION AND DEVELOPMENT ACTIVITIES

Recently various geothermal activities have been carried out in Ethiopia by public and the private sector participation. These activities include: Surface exploration, and deep drilling and testing.

3.1 Recent public sector geothermal activities

3.1.1 Geothermal master plan study

A geothermal master plan study has recently been completed with JICA technical assistance. The project has conducted 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 1000 MW. Ranking of the prospects for development has also been made on the basis of geothermal knowledge, potential, project economics, and site specific factors (GSE and JICA, 2015).

3.1.2 Deep drilling and surface exploration at Aluto Langano geothermal field

Deep drilling and testing

The Aluto Langano prospect has three anomalous target areas for further assessment and development. These areas are Aluto 1, 2 and 3 (Figure 2). The drilling of two appraisal wells for reservoir modelling and subsequent selection of production wells was 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 300°C. Testing and reservoir engineering have indicated that the two wells together may sustain about 5 MW electricity. Installation of a well head turbine on the two wells is under consideration for early power generation. Reservoir simulation has been conducted using data from the newly drilled wells at Aluto, including data from previous wells. The result shows that a sustained 35 MW electcity could be generated at Aluto 1.

Surface exploration

The Aluto Langano prospect is a wide volcanic complex. The geothermal surface exploration of the prospect was carried out in

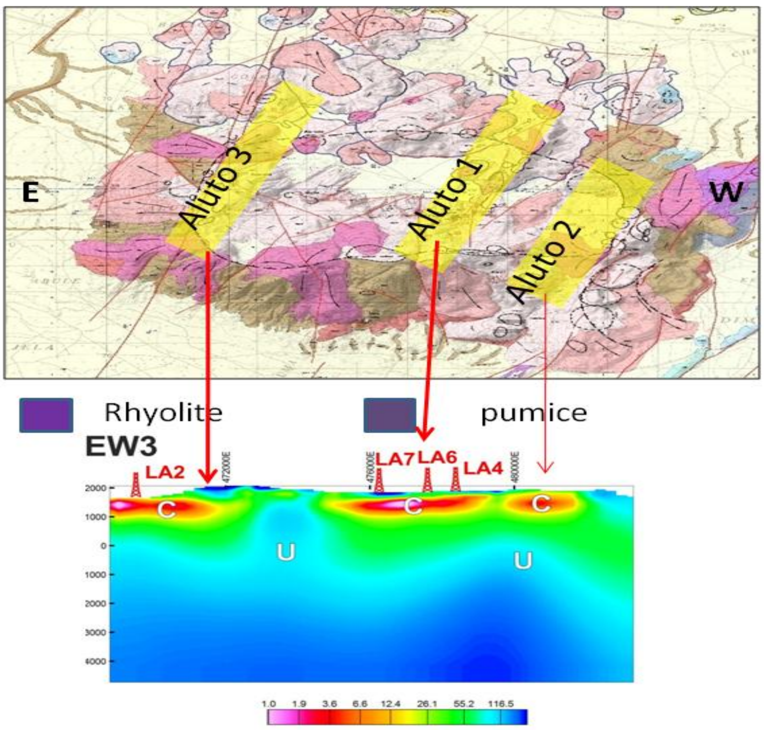

FIGURE 2: The Aluto Langano prospect and 2D resistivity profile

2015-2016, by focusing on the main anomaly areas, Aluto 1, 2 and 3, with the objective of identifying the most favourable sectors within the complex for the implementation of underground exploration activities, refinement of the conceptual model and definition of future drilling strategy.

To achieve the objectives, geological and geochemical studies and geophysical survey (gravity, geo electrical and micro seismic) have been conducted. The integrated interpretation of the results of these surveys 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 8.5x5 km, (iv) from resistivity survey clay caps corresponding to the top of reservoir are identified in the central (Aluto 1) and eastern portion of the volcano (Aluto 2) (Figure 2). These two areas are selected as future targets for drilling, (v) at Aluto 2, volumetric estimation has indicated, a probable power of 33 MWe and a possible one of 50 MWe, (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 and non-condensable gas content of 6-8 % in the steam and scaling phenomena are expected to be minor and no corrosion
is foreseen (ELC, 2016a).

3.1.3 Surface exploration at 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 an ARGeo project. 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 detail surface exploration, including geophysical (MT/TEM, gravity and micro-seismic) studies, and environmental studies were conducted in 2015 for siting of wells. The results have 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 work included geophysical exploration (MT, gravity and micro-seismics) and other geoscientific methods. The purpose of the exploration was to generate a conceptual model of the geothermal system for subsequent well site selections. The conceptual model was then used to identify three target areas in order of priority, with a total estimated potential of about 125 MWe.

According to the conceptual model, the main features of the hypothesized reservoir for Tendaho 3, with reference to the first priority zone have been estimated as follows: (i) Areal extent: Covers a surface area 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 sits 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 a Na-Cl composition with relatively high content of SO_4 and are rather diluted (TDS around 1,400 ppm), and may exhibit some calcite and silica scaling tendency (ElC, 2016b).

3.1.4 Surface exploration in other areas

Surface exploration were 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 indicate that geothermal reservoirs with temperature in excess of 200°C may likely exist at depth. Similar geoscientific data were also collected at Meteka in 2017/18, on which a conceptual model of the geothermal system was based, indicating preferred areas for further investigation (ELC, 2019).

3.2 Private sector activities

Currently five private companies (Corbetti Geothermal, Reykjavik Geothermal, Tulu Moye Geothermal, Cluff Geothermal, and Ormat Plc) have concessions in various prospects. All of them have completed surface exploration for well siting, in multiple prospects with satisfactory results. Tulu Moye Geothermal is under preparation to commence drilling in early 2020. The rest of them are under PPA negotiations before start of drilling.

4. GEOTHERMAL DEVELOPMENT PLANS

A total of 1735 MW electricity is planned to be developed from geothermal by 2030. The plan is currently under various phases of implementation (Table 1). The Aluto Langano and Alalobad geothermal fields are two of the priority areas in current public-sector projects and preparations are underway for drilling of deep wells to be followed by power plant construction. Under the framework of Geothermal Sector Development Project of the World Bank, the two geothermal prospect areas are to be drilled with a total finance of 218.5 million USD, funded by the World Bank (major financer), Government of Iceland, and Government of Ethiopia. At Aluto Langano geothermal field, it has been planned to drill up to 22 geothermal wells with the potential to develop 70 MWe in two phases. Currently procurement of two drilling rigs with the provision of drilling operation has been completed. At Alalobad area of Tendaho prospect, 4 deep test wells will be drilled to explore the site and develop potentially about 25 MW in the initial phase (EEP, 2017).

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 implementation	25
3	Corbetti	Private (Corbetti Geothermal)	PPA negotiation	520
4	Tulu Moye	Private (Tulu Moye Geothermal)	Under implementation	520
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	Private (Cluff Geothermal)	PPA negotiation	150
Total				**1735**

To fast track the development of the resources in Ethiopia, a new public sector institutional setup is under consideration. The proposed institution, under the Ministry of Water, Irrigation and Energy is to be called “Energy Development Commission” and will have geothermal development department among other renewable energy development departments. Its mission will be to complete the upstream exploration activities of geothermal and pass it over to public or private developers for power plant construction and operation. In this way, the conditions for a geothermal business model accepted in Ethiopia, where developers could join geothermal development after feasibility studies are completed will be met.

Geothermal companies from the private sector indicated in Table 1 have all completed surface exploration and are awaiting the finalization of PPA negotiation to commence drilling, except Tulu Moye Geothermal, which has started mobilization for drilling.

5. 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 their added advantage in complementing the hydro generation during unfavourable periods of severe droughts, geothermal development in Ethiopia has been given more attention in recent years.

Over 1700 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 a 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; and (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 thousands of Mega Watts of geothermal power in to the grid in the long term.

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