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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 and has a population of over 120 million, with an agricultural led economy. The current total installed electrical capacity from all sources has reached 5,274.7 MW (mainly from hydro), with geothermal only contributing 8.5 MW.

The East African Rift System cuts Ethiopia from northeast to southwest forming a topographic depression known as the Ethiopian Rift system. The rift system is tectonically active with emplacement of various young volcanos along its axis. Because of the favorable geological conditions, Ethiopia is endowed with large geothermal potential. So far 26 prospect areas of high to medium enthalpy geothermal resources have been identified with an estimated electrical potential of over 10,000 MW.

Ethiopia started geothermal exploration in 1969, within the Ethiopian sector of the East African Rift System. Since then, 20 prospects have been covered with detailed surface exploration and 6 areas are at a level of reconnaissance stage. In three areas deep drilling has been conducted, including the Tendaho and Aluto prospects, which are public, and Tulu Moye prospect which is owned by private entities. The results of the drillings indicate high temperatures, but some permeability problems have been encountered in some of the wells. Recent drillings at Aluto prospect secured sufficient steam for a 30 MW electrical production.

The utilization of geothermal resources for electric power is so far limited to the only pilot plant of 8.5 MW, which was installed at Aluto Langano in 1998. Installation of a well head turbine of 5 MW has been completed at Aluto and is awaiting commissioning. Direct use applications in Ethiopia are limited to bathing and swimming, but modern direct use developments are expected to be implemented in the near future.

A total of 980 MW electricity has been planned to be developed from geothermal by 2030 from three committed projects and six candidate projects with public and private sector funds.

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 120 million (CSE, 2020). 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 twelve regional states.

1.2 Status of electricity production

The total installed electrical capacity has reached 5,274.7 MW. From these, over 91.3**%** is from hydro (Table 1).

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

No	Source of generation	Installed capacity (MW)	%
1	Hydropower	4,818	91.3
2	Wind	324	6.1
3	Geothermal	8.5	0.2
4	Thermal	99.2	2
5	Waste to energy	25	0.47
	Total	**5274.7**	100

The national level of electricity access in Ethiopia was 51.9% by 2022. Grid-connected installed electricity capacity trends in Ethiopia by source from 2010 to 2021 is shown in Figure 1. Since 2017, the installed capacity of electricity has increased rapidly, mostly due to hydropower build-up and renewable energy sources. Conversely, the installed capacity of fossil fuel-derived thermal power has been declining since around 2015. Ethiopia's geothermal power plant with operational experience at Aluto-Langano (8.5 MW), is the only geothermal power installed capacity. However, the government plans to fast-track development of geothermal resources though both public and private investments.

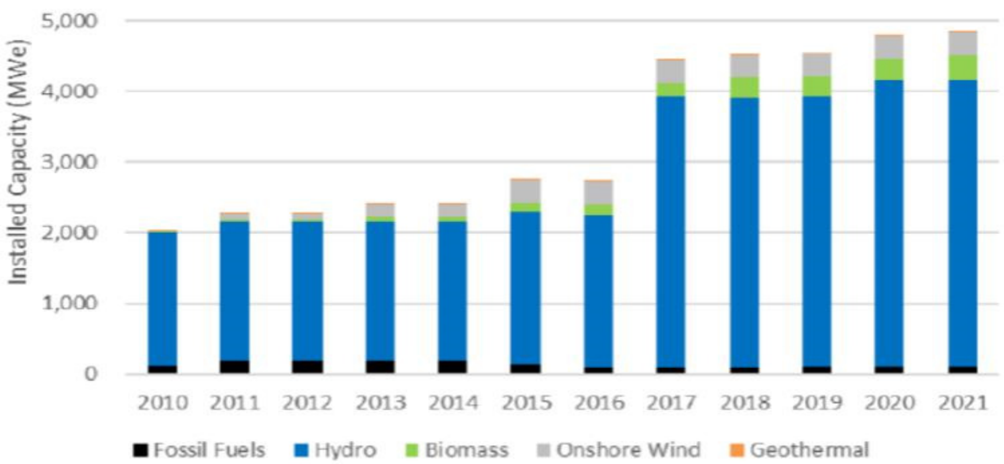

FIGURE 1: Electricity capacity trends by source

This paper mainly highlights: the status of geothermal resources exploration, utilization and future geothermal development plans in Ethiopia.

2. GEOTHERMAL RESOURCES EXPLORATION

2.1 Geology background

The East African Rift System (EARS) cuts Ethiopia from northeast to southwest forming a topographic depression known as the Ethiopian Rift system (Figure 2). The Ethiopian Rift system is divided into the Main Ethiopian Rift (MER) and the Afar Depression. The MER extends in NNE-SSW trend, dominated by silicic volcanoes. The latest tectonic activity in the MER has been related to a fault system known as the Wonji Fault Belt. This system has a swarm of dextral en-echelon displacements with Quaternary volcanoes located along its axis (Figure 2).

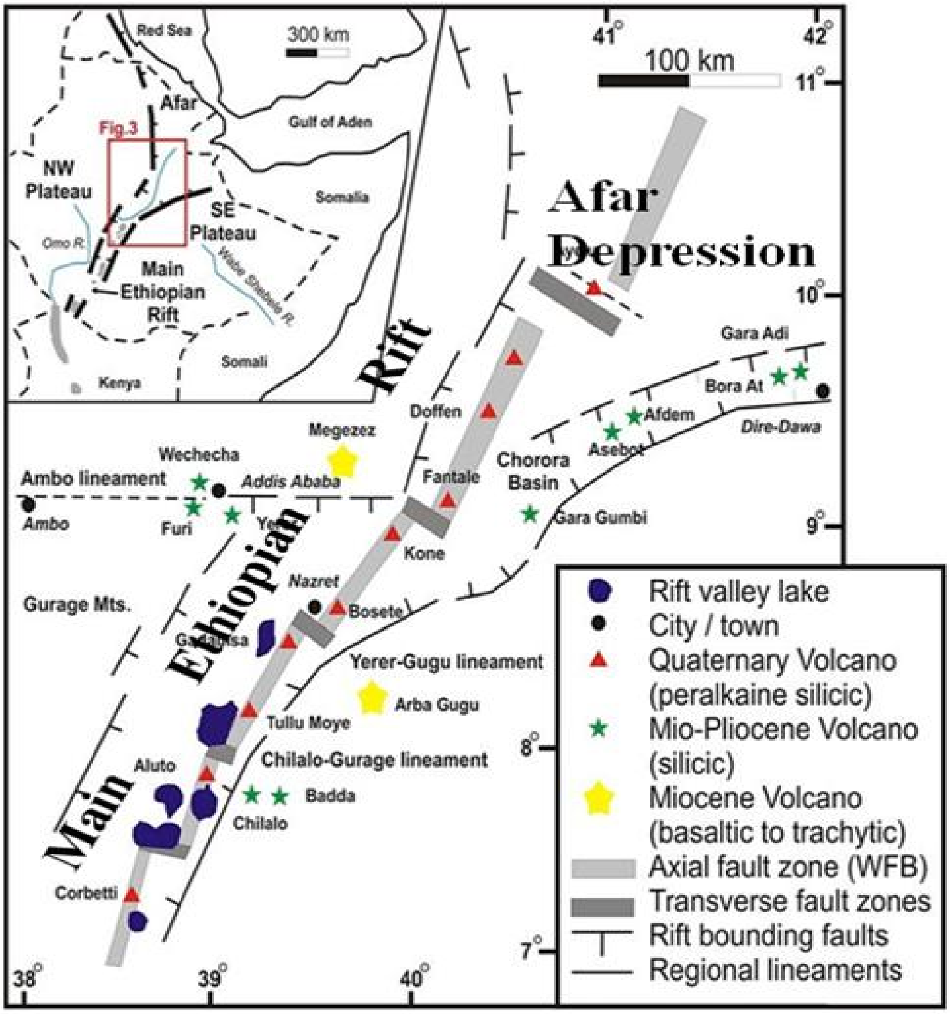

FIGURE 2: Geological set up of geothermal prospects in Ethiopia

On the other hand, volcanism in the Afar depression has been related mainly to northwest-southeast trending fissured structural systems with some eruptive centers. The composition of the lavas produced ranges from mainly basalt dominated to siliceous types. The lower elevations of the Rift floor are mainly filled with young sediments of Quaternary age. These include: Conglomerate, sand, clay and lacustrine sediments. The crust inside the Rift is thinning due to divergence of the continental crust. There is an upper mantle intrusion beneath the thinned crust forming a regional temperature gradient anomaly. Furthermore, recent volcanic activities, commonly with residual magmatic chambers underneath form areas of high heat flow anomalies and good geothermal potential within the sectors of the Ethiopian Rift.

The Ethiopian geothermal resources could be categorized mainly into magmatic geothermal play types with most of the reservoirs controlled by fault structures. However, few of the resources are typical of deep circulation in which the fluid leaks from the fault into a permeable concealed layer. In turn, fluids can move from a permeable layer into the fault zone and from there to the surface.

2.2 Exploration background

Ethiopia started geothermal exploration in 1969, within the Ethiopian sector of the EARS The initial level of exploration had been reconnaissance, covering the whole rift system. Under this survey about 120 localities within the rift system were believed to have independent heating and circulation geothermal systems and from these, about two dozen were judged to have potential for high to medium enthalpy resource development, including for electricity generation. A much larger number have been considered as low enthalpy, suitable for direct utilizations (UNDP, 1973). The geothermal sites are geographically distributed from the southwestern part of the Ethiopian Rift up to the northeastern part (Figure 3).

Since the late 1970s, geo-scientific surveys mostly comprising geology, geo-chemistry, and geophysics, were carried out at the southern-central part of the Ethiopian Rift and at Tendaho prospect in Afar to the north. In addition, a semi-detailed surface exploration of ten sites in the central and southern Afar was carried out in 1986.

Exploration work by deep test well drilling started during the early to mid-1980s 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. A power plant of 8.5 MW was installed in 1998 using the productive wells.

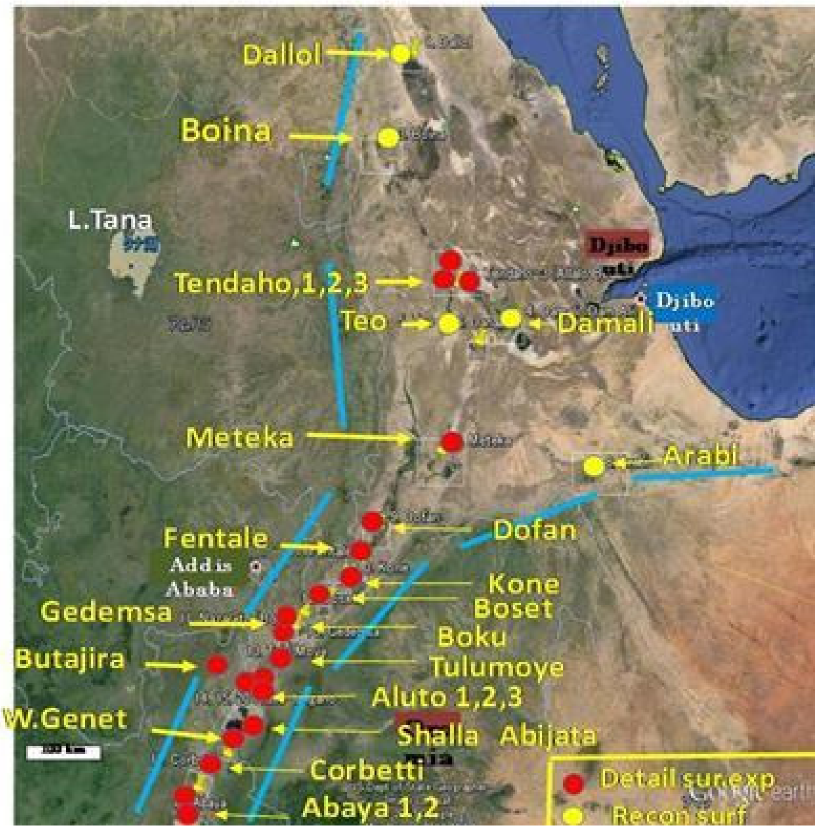

FIGURE 3: Location map of geothermal prospects in Ethiopia

2.3 Recent exploration and development

Recent exploration and development activities in the country are being carried out by both the public and the private sector.

2.3.1 Activities carried out by the public sector

A geothermal master plan study project was completed in 2015. The project conducted geo-scientific, social and economic surveys in 22 prospects for potential estimation and prioritization for development. The results of the study showed that the total geothermal electrical potential of the 22 prospects range from 4,200 MW to 10,800 MW. Ranking of the prospects for development has also been made on the bases of geothermal knowledge, potential, economics, and site-specific factors, (GSE and JICA, 2015).

Geo-scientific surface investigations including geology, geochemistry, geophysics (MT/TEM, gravity and micro-seismics) have been carried out at Aluto Langano prospect for the expansion of the field. The results have indicated that there is an additional upflow center east of the previously drilled productive wells in an area locally known as Bobesa. A conceptual model has been developed for this new area, which indicates an additional potential of 35 MWe, totaling the Aluto capacity to 70 MWe, (ELC, 2016a).

Detailed surface exploration in the southwestern part of Tendaho area known as Allalobeda prospect was also completed in 2015. The exploration works included geophysical exploration (MT, gravity and micro-seismics) and other subordinate geo-scientific methods. The purpose of the exploration was to have a conceptual model of the geothermal system for subsequent well site selections. Developed conceptual model of the field has indicated three target areas in order of priority and a total potential of about 125 MWe. According to the conceptual model, the main features of the hypothesized reservoir, with reference to the first priority zone has 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 in 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, the 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).

Other prospects with detailed surface studies included Shalla-Abiata, Butajira and Meteka prospects. In 2016, geological, geochemical and geophysical surveys were conducted in these areas. The preliminary results of the survey in Shalla-Abiata and Butajira prospects have indicated that geothermal reservoirs with temperature in excess of 200°C may likely exist at depth. Similar geo-scientific data collection and interpretation was carried out at Meteka in 2017/18.

The drilling of two appraisal wells for reservoir modelling and subsequent selection of production wells was carried out in 2013 and 2014. The wells, LA-9 D and LA-10 D, were planned to be drilled to about 2500 m depth, but due to the rig technical problems, each have been completed prematurely to depths of 1920 m and 1951 m respectively. However, 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.

Reservoir simulation has been conducted using data from the newly drilled wells at Aluto, including data from previous wells. The results of 5 cases (25 MW, 35 MW, 45 MW, 55 MW and 65 MW) in generation capacity of forecasting simulation were considered and analyzed. Based on these results, it is indicated that the power output could not be sustained for 30 years in cases of 55 MW and above but it could be sustained in cases of 45 MW and below. Therefore, this result indicates that the resource potential of the drilled and known part of Aluto Langano field is around 45 MW. However, a 35 MW development option is preferred in a first phase to lower the number of wells required for steam field development (West Jec, 2015).

Currently deep production drilling is being carried out in the previously discovered production area at Aluto Langano and exploratory drillings are also being carried out in the newly proposed target area, Bobesa. 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 and using its newly purchased two deep drilling rigs, operating in parallel. From end of May 2021 to May 2023 nine directional production wells and one exploratory well have been completed in Aluto. Production tests have been conducted in most of the completed wells and the results have indicated that the drilled wells could sustain a power output of 30 MW in total with reservoir temperatures as high as 346°C (EEP, 2023).

2.3.2 Activities carried out by the private sector

Currently five private companies have concessions in various prospects. Most of them have completed surface exploration and have selected target areas of drilling and one of them has conducted deep exploratory drilling at Tulu Moye prospect. In this prospect, the drilling of five exploratory wells has been completed so far and the wells are currently under testing. Preparatory works to start deep drilling at Corbetti prospect are almost completed by an IPP and drilling is also expected to start soon in this prospect.

3. GEOTHERMAL UTILIZATION

The utilization of geothermal resources for electric power is so far limited to the only pilot plant of 8.5 MW that has been installed at Aluto Langano in 1998. The plant has been intermittently functioning due to technical problems and has been using steam from two of its highest temperature wells to run a steam turbine and two of its lower temperature wells to heat a working fluid known as iso-pentane. The plant is currently not operating and a general overhaul of the plant is planned. Installation of a well head turbine of 5 MW has been completed at Aluto for early power generation, using the steam discovered in the two wells drilled in 2013/2014.

Direct use applications in Ethiopia are limited to bathing and swimming. A number of resorts, hotels and parks have been utilizing hot water and steam for bathing, in swimming pools and for balneological purposes. The energy used for these direct utilizations has not been yet determined, as there is lack of data on flow rates and in and out temperatures differences. With the assistance of UN Climate Technology Center and Network (UN CTCN) studies on direct use have been conducted recently, 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 (Dubti, 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 economic viabilities of these applications have been assessed in each selected area and some of them were indicated to be viable (UN CTCN, 2021).

4. FUTURE GEOTHERMAL DEVELOPMENT PLAN

According to recent Ethiopian power system expansion plan study, a generation planning has been established for the period up to 2045. It is based on demand forecast which has indicated both annual energy and peak demand to increase by over three times the 2020 level by 2030 and over eight times the 2020 level by 2045 (USAID, 2021).

Ethiopia is a country with high hydropower potential and aims to be a powerhouse of Africa exporting electricity to its neighbors. Approximately 91% of generated energy in Ethiopia is in the form of hydropower; however, this makes the system vulnerable to low hydrological conditions, sometimes leading to load shedding. Therefore, the country is keen to increase resilience to drought and therefore wishes to reduce its dependence on hydropower and is aiming for less than or equal to 75% hydro generation by 2030. Accordingly geothermal, being base load and one of the indigenous renewable resources of the country, is assigned a development of 980 MW by 2030 in the energy mix (Eshetu, 2019). This geothermal development is expected to be achieved by developing already committed projects and candidate projects by public and private companies in various phases (Table 2).

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

Name	Status	Ownership	N° units	$P_{inst.}$ (MW)	Expected commissioning date
Aluto Langano I (Rehabilitation)	Committed	EEP	2	9.5	2023
Aluto Langano II	Committed	EEP	2	70	2026
Corbetti I	Committed	IPP	1	50	2024
Corbetti II	Committed	IPP	2	100	2026
Tulu Moye I	Committed	IPP	1	50	2023
Tulu Moye II	Committed	IPP	2	100	2025
Total committed capacity				**380**	
Shashemene Geothermal	Candidate	IPP	2	150	2026
Dugna Fango Geothermal	Candidate	IPP	2	100	2027
Tendaho-Alalobad Geothermal	Candidate	IPP	2	100	2027
Boku Geothermal	Candidate	IPP	2	100	2027
Dofan Geothermal	Candidate	IPP	2	100	2027
Fentale Geothermal	Candidate	IPP	1	50	2027
Shashemene Geothermal	Candidate	IPP	2	150	2027
Total committed and candidate capacity				**980**	

However, the actual implementation of the planned geothermal development is lagging far behind schedule. As a result, the government opts to revise the plan and develop a new strategy. Accordingly, a short-term strategy of the public sector is to participate in de-risking of selected prospects of high priority by drilling at least three exploratory wells in each area, so that the private sector can fast track the next phases of development. To this end, two areas at Tendaho prospect and one new target area at Aluto are selected for exploratory drillings in the coming couple of years by Ethiopian Electric Power (S317 Consulting, 2023).

5. CONCLUSION

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

980 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; (iv) create appropriate enabling environments for private sector investment; and (v) the public should participate in de-risking of the prospects licensed to private developers through use of its drilling rigs and other equipment.

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 megawatts of geothermal power to the grid within the next ten years.

With the introduction of feasibility studies for geothermal direct uses in the agricultural sector, modern direct use developments are also expected to be implemented in Ethiopia in the near future.

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