Presented at SDG Short Course II on Exploration and Development of Geothermal Resources,
organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya, Nov. 9-29, 2017.

STATUS OF GEOTHERMAL EXPLORATION 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 4,200 MW and the country has to develop over 25,000 MWe by 2030, due to a rapidly rising demand in the last decade which has been forecasted to the future. 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 24 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.

Various geothermal activities are being carried out in Ethiopia by the public and the private sector, since recent years. The public sector activities included: (i) geothermal master plan study, (ii) surface exploration, deep drilling and testing at Aluto Langano prospect, (iii) surface exploration and feasibility study at Tendaho geothermal prospect, (iv) surface exploration at Shala - Abijata and Butajira prospects and (v) emplacement of new geothermal law and regulations to speed up private sector participations. Seven private sector investors have concessions in various prospects and most of them have completed surface explorations and are preparing to conduct deep drillings.

The medium term geothermal development plan of the country envisages to develop 675 MWe from various prospects and the long term plan has set a goal of developing 5000 MWe by 2037.

1. INTRODUCTION

1.1 Location and economy

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 90 million (CSE,2013). The Ethiopian economy, which is non- oil-driven economy, has grown on average rate of 10.2 % for the last 10 consecutive years. The economy is agricultural led economy with major exports of coffee, oil seeds, animal skin and horticultural products.

1.2 Energy and electricity sector

The energy sector in Ethiopia can be generally categorized in to two major components: (i) traditional (biomass), and (ii) modern (such as electricity and petroleum). As more than 80% of the country's population is engaged in small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of energy in Ethiopia.

The continuous economic growth has undoubtedly influenced the growth of energy demand. The current total installed electricity generation capacity has reached over 4,200 MW. To fulfill the high growth rate of electricity demand which is recently 20 % / yr, it is planned to increase the generation capacity to over 25,000 MW by 2030. The aim is to address both domestic demands while exporting surplus power to neighboring countries and beyond. The need to expand the transmission and distribution system is also emphasized in order to deliver the energy generated to the consumer in an efficient and reliable manner. The growth plan further envisages increasing the customer base of the power utility from the current level of 2 million to 4 million and the universal electricity access rate from 45% to 75% (Lemma, 2012).

Hydropower generates more than 90% of electricity in Ethiopia. However, as the rainfall in Ethiopia varies considerably from year to year, the need to diversify the country's energy sources to ensure a stable supply is desired. It also implies that overdependence on hydropower makes energy supply unstable, resulting in heavy strains on the pace of growth in every sector and thus more stable geothermal power is considered essential.

1.3 Energy policy

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 in 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 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 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 as a project developer but also as a critical stakeholder that can bring financing to the table under the right circumstances.

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 Rift up to the North eastern part (Figure 1).

Ethiopia has started geothermal exploration in 1969, within the Ethiopian sector of the East African Rift system. 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 enthalpy resource development, including for electricity generation. A much larger number have been considered as low enthalpy, suitable for direct utilizations (UNDP, 1973).

Since the late 1970's, geo scientific 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 the central and southern Afar has been carried out by the Geological Survey of Ethiopia (GSE) and Electroconsult (ELC) in 1986.

Exploration work has 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 five of these proving productive.

Resource utilization at Aluto was delayed until 1998. In 1998 a 7.2 MWe net capacity pilot plant has been installed at Aluto.

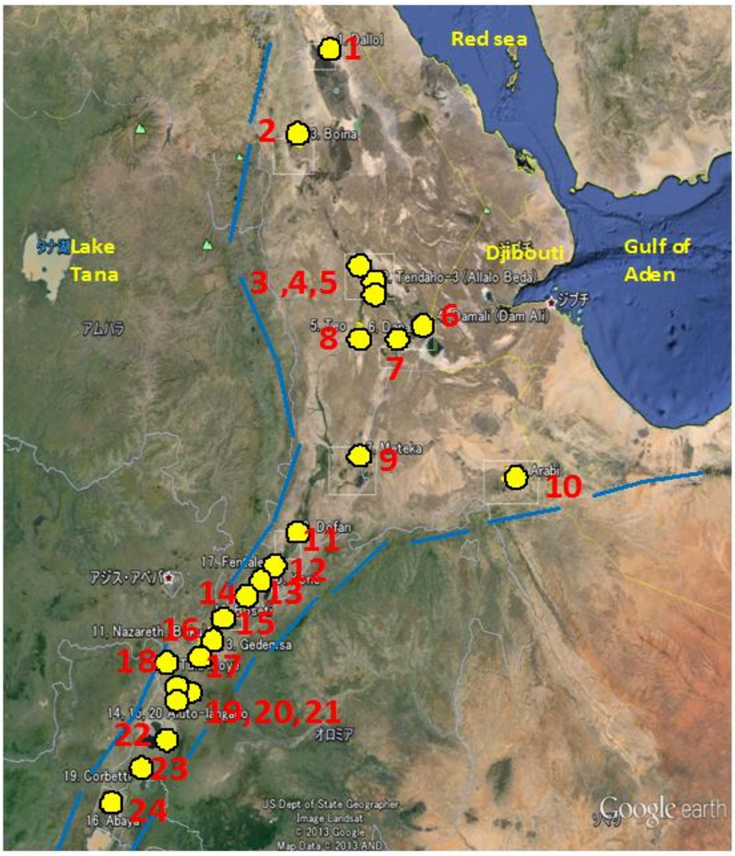

FIGURE 1: Location of geothermal prospects in Ethiopia. 1 Dallol, 2 Boina, 3,4,5 Tendaho (Arobera, Doubti, Allalobad), 6 Damali, 7 Danab, 8 Teo, 9 Meteka, 10 Arabi, 11 Dofan, 12 Fentale, 13 Kone, 14 Boseti, 15 Boku, 16 Gedemsa, 17 Tulu Moye, 18 Butajira, 19,20,21 Aluto (west, center, east (Bobesa), 22 Abiata-Shalla, 23 Corbetti, 24 Abaya

The other better explored area including by drilling is the Tendaho geothermal prospect in Northern Afar. The geothermal exploration have been carried out in the Tendaho area with economic and technical support from Italy between 1979 and 1980. Between 1993 and 1998, three deep (about 2,100m) and three shallow exploratory wells (about 500m) were drilled 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 and techno-economic study indicated that the drilled shallow productive wells could supply enough steam to operate a pilot power plant of about 5 MWe and the potential of the deep reservoir was estimated to be about 20 MWe. But recent estimations put a much larger potential.

During the four decades that geothermal resource exploration work was carried out in Ethiopia, a good information base and a good degree of exploration capacity, in human, institutional and infrastructure terms, has accumulated, ensuring that selected prospects can be advanced to the resource development phase much more rapidly than before.

The exploration work to date has been carried out by GSE in collaboration with EEP but has benefited from a number of technical cooperation programs. The most recent technical assistances are from Icelandic International Development Agency (ICEIDA), United Nations Environmental Programm

(UNEP), French Development Agency (Afd), World Bank and Japan International Cooperation Agency (JICA).

3. RECENT GEOTHERMAL EXPLORATION AND DEVELOPMENT ACTIVITIES

Recently various geothermal activities are being carried out in Ethiopia by the public and the private sector participation. These activities included: surface explorations, deep drillings and testing's and work on regulatory issues.

3.1 Activities carried out by the public sector

3.1.1 Geothermal master plan study in the Ethiopian Rift Valley

A geothermal master plan study has been completed recently with JICA technical assistance. The project has conducted geo scientific, social and economic surveys in 22 prospects for potential estimation and to prioritize them. The results of the study has showed that a minimum geothermal potential of 4200 MWe and a maximum of 10,800 MWe for Ethiopia. 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).

3.1.2 Deep drilling and surface exploration at Aluto Langano geothermal field

The drilling of two appraisal wells for reservoir modeling and subsequent selection of production wells has been carried out in 2013. The wells, LA-9D and LA-10-D, have been planned to be drilled to about 2500 m depth but due to rig technical problems each have been completed prematurely to depths of 1920 m and 1951 m respectively. Both wells are productive with bottom hole temperatures of over 300°C, however permeability is not sufficient enough for maximized production. 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 results of 5 cases (25 MW, 35 MW, 45 MW, 55 MW and 65 MW) in generation capacity of forecasting simulation are shown in Figure 2. The number of production and reinjection wells required in the simulation is shown in Table 1. 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 known Aluto Langano field is around 45 MW. However the total number of required production and reinjection wells is 36 in case of 45 MW (Table 1) and this number seems to be too many to drill (West Jec, 2015). Therefore, the preferable option may be 35 MW.

Contemporary with the drilling of the initial two wells at Aluto Langano, geo scientific surface investigations including, geology, geochemistry, geophysics (MT/TEM, gravity and microseismics) have been carried out with technical assistance of ICEIDA. The results have indicated that the Aluto geothermal anomaly occurs not only along a fault zone located along the current productive wells but also east of the current productive wells close to the eastern margin of Aluto caldera, known as Bobesa. A conceptual model has been developed for this new area, which have indicated a potential of 35 MWe, totaling the Aluto capacity to 70 MWe (ELC, 2016).

Further drilling of about 20 deep wells is planned at Aluto on the bases of the surface exploration. This deep drilling project is to be financed by World Bank and to be implemented by the Ethiopian Electric Power (EEP). Drilling contractors and the purchase of new rigs are being considered to implement the project.

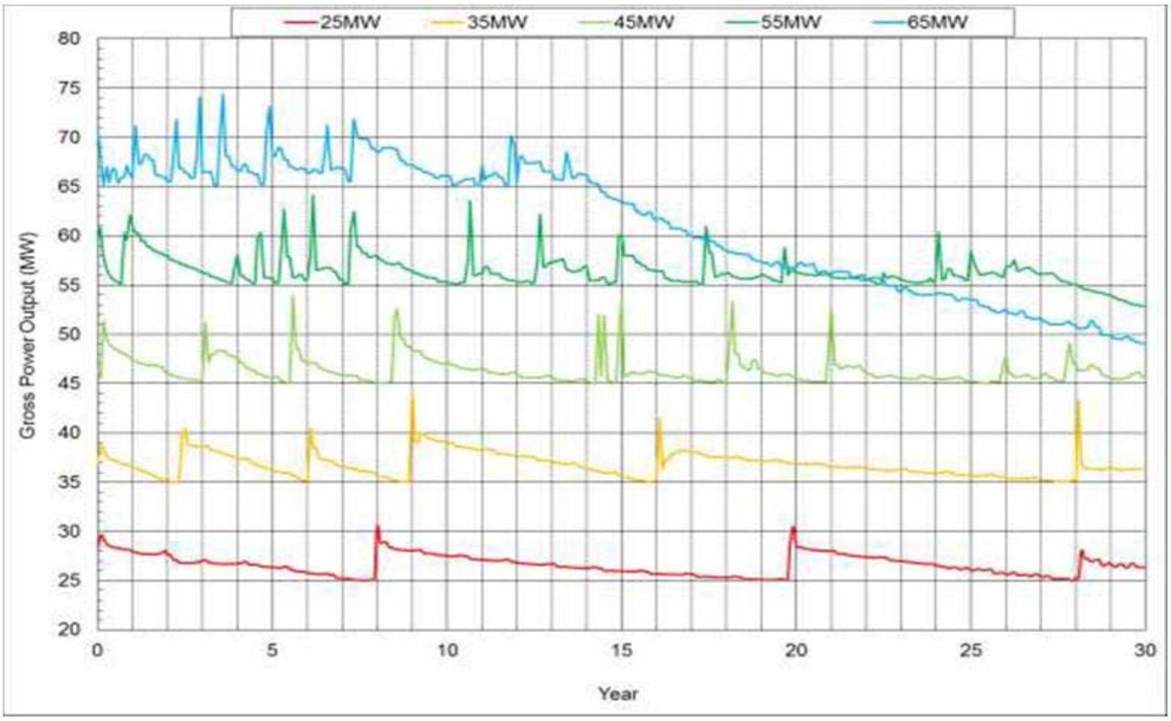

FIGURE 2: Result of study on appropriate development scale in simulation (West Jec,2015)

TABLE 1: Number of required drilling wells in forecasting simulations (West Jec, 2015; ELC, 1986)

Power output (MW)	Production well			Reinjection well			Grand total
	Start-up	Make-up	Total	Start-up	Make-up	Total	
25	7	3	10	4	0	4	14
35	9	5	14	4	2	6	20
45	11	11	22	8	6	14	36
55	14	> 17	> 31	10	> 10	> 20	> 51
65	16	> 15	> 31	13	> 7	> 20	> 51

3.1.3 Surface explorations and feasibility study at Tendaho geothermal prospect

The Tendaho prospect involves three target areas, named as, Doubti, Allalobeda and Ayrobera (Figure 3).

Surface exploration in target areas of Tendaho Doubti has been finalized under the framework of ARGeo project. The purpose of the survey has been to develop a conceptual model and site deep wells in target areas**.** A review of all the available geoscientific data for the Tendaho area, development of a new 3D model of temperature in the area, and definition of areas of interest for further exploration and development have been made. The new conceptual model developed for the Doubti area is largely consistent with previous assessments.

Geologic and geophysical data and interpreted geo-referenced images were imported to Leapfrog Geothermal Software, and integrated to develop a temperature model of the Doubti region. This model has relied on available well temperature data and interpreted “updoming” of the bottom of a widespread shallow conductive layer as indicating conversion of low-temperature smectite clay to higher temperature minerals in areas of known thermal manifestations. Example wells were defined that would test and validate the new model for Doubti area.

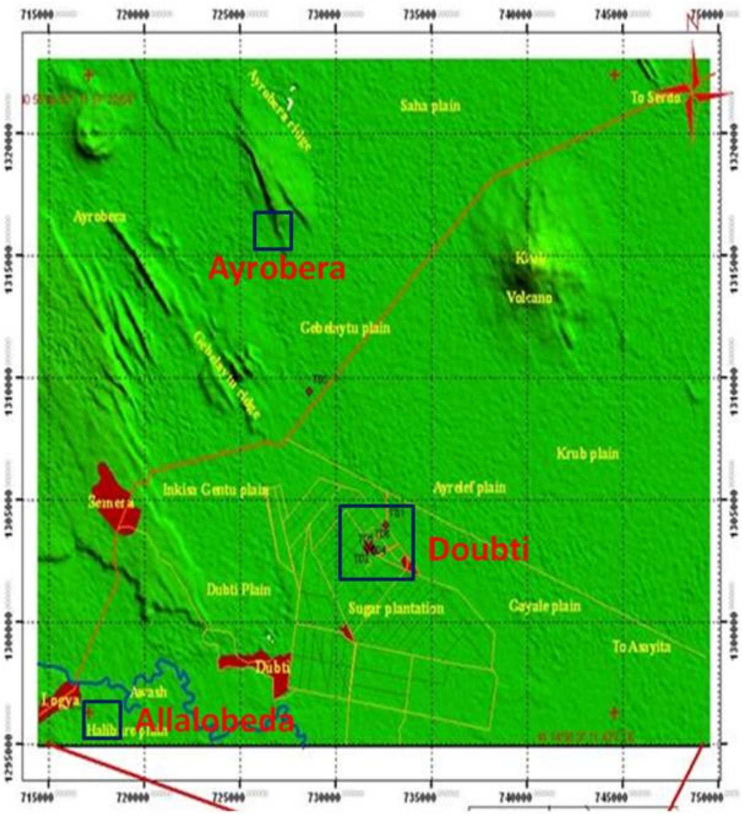

FIGURE 3: Location of three prospects in Tendaho area

A feasibility study for shallow resource development at Doubti has also been conducted with AFD assistance. The purpose of the study was to assess the feasibility of development and exploitation of the Tendaho Doubti geothermal resources on the basis of the various studies conducted in the past, including the drilling of six exploratory wells. The study recommended, the immediate exploitation of the proven resource pertaining to the shallow reservoir, through a power plant of capacity of up to 12 MWe, by drilling of additional six, 600 m deep wells (ElC, 2014).

Currently preparatory works to commence the drilling are being conducted, including hiring of a geothermal consultant and a drilling service company.

JICA assisted detail surface exploration for well siting, including geophysical (MT/TEM, gravity and micro seismic) and environmental studies have been conducted in 2015. 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 in Allalobeda target area of Tendaho prospect has been completed in 2015, with technical assistance from ICEIDA. The exploration work included geophysical exploration (MT, Gravity and Microseismics) and subordinate other 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 have indicated three target areas in order of priority and a total potential of about 125 MWe

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) tthermodynamic 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 SO4, are rather diluted (TDS around 1,400 ppm) and may exhibit some calcite and silica scaling tendency (ELC, 2016).

3.1.4 Surface exploration at Shalla–Abiata and Butajira

Shalla-Abiata and Butajira are prospects in the central part of the rift (Figure 1), which are recently considered as high temperature fields. In 2016 geological, geochemical and geophysical surveys including MT surveys have been conducted in both areas by the GSE. The preliminary results of the survey indicate that geothermal reservoirs with temperature in excess of 200 ° C do likely exist in these areas.

3.1.5 New geothermal law and regulation

A new geothermal law for operation of geothermal activities in both the public and private sector has been approved. A Proclamation cited as the "Geothermal Resources Development Proclamation" has been put in to 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) .

Private developers could apply to a licensing authority that may grant the following geothermal operation licenses: (i) reconnaissance license; (ii) exploration license; and (iii) geothermal well field development and use license.

The government may conduct geothermal operations, either by itself or in partnership with private-sector investors, based on a determination that such action will be in the best interest of the people of Ethiopia and the country's economic and social development. The Government may also undertake geothermal resource exploration and development activities to the degree where the licensing authority gets sufficient data to grant a well field development and use license on a competitive basis.

A new geothermal regulation has also been drafted to facilitate the implementation of the geothermal law. The draft regulation is expected to be approved by the council of ministers soon.

3.2 Private sector activities

Currently about seven private companies have concessions in various prospects. Most of them have completed surface exploration for well siting with satisfactory results. The most progressed private company in exploration activities is Corbetti geothermal Plc. Hot and detailed power purchase agreement for Corbetti geothermal development has been signed with the government. The agreement considers development of the Corbetti prospect to 500 MWe with estimated investment cost of 2 billion US$. Currently additional negotiations with the government are being conducted and mobilization works to commence test well drilling are expected soon.

4. FUTURE GEOTHERMAL DEVELOPMENT PLANS

On the bases of the country's energy development plan a medium term and long term geothermal development goal has been established. According to the medium term plan, a total of 675 MW geothermal power is to be developed from six selected prospects and in the long term 5000 MWe is planned by 2037. The development is expected to be achieved with the participation of both the public and the private sector.

The Aluto Langano and Tendaho geothermal fields are at the forfront in public sector projects and activities are underway for drilling of deep wells to be seceded by power plants construction. Corbetti and Tulu Moye prospects are on the way for development by the private sector with the commencement of drilling activities soon.

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 unfavorable periods of severe droughts, geothermal development in Ethiopia has been given more attention, since recent years.
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Currently geothermal is: (i) 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 Mega Watts of geothermal power in to the grid in the short term.

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