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GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

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ABSTRACT

Surface exploration for geothermal resources in Ethiopia began over four decades ago. The geothermal exploration so far have identified over 22 areas that have geothermal resources suitable for electricity generation, with a total potential of over 10,000 MW. These resources are considered to have high quality in terms of temperature and chemistry.

Despite the countries long term geothermal exploration and huge potential, the progress of development of geothermal resources has been slow. Deep drilling has been conducted only in two prospects and only a 7.2 MW pilot plant has been installed so far. However, since recent years the country has adopted, a renewable energy mix policy, geared towards the advancement of various renewable resources development, including geothermal energy resources. Accordingly both the public and private sector geothermal projects are being implemented at larger scale than before.

The public sector has focused in developing, the two most explored prospects in the country, the Aluto Langano and Tendaho geothermal fields. In these prospects detail surface exploration, test well drillings and feasibility studies are being conducted.

The private sector has concessions in about seven prospects and is being actively engaged in exploration, including in green fields.

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 country's geothermal development plan considers the development of 675 MW geothermal power in the medium term and 5000 MW by 2037. There are challenges to achieve the plan that may include: (i) high upfront capital costs required and availability of sufficient finance, (ii) risks associated with the drilling phase, and (iii) limitations in local human resource capacity

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. The Ethiopian economy, which is non-oil-driven economy, has grown on average rate of 10.2% for the last 10 consecutive years. The growth and transformation plan GTP envisions a major leap in terms of not only economic structure and income levels but also the level of social indicators.

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 the 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. The delivery of an adequate electricity service is essential. 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%.

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.

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’s Energy policy is an integral part of its overall development policy. 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, 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. GEOTHERMAL EXPLORATION AND DEVELOPMENT IN THE PAST

Ethiopia started long-term geothermal exploration in 1969. Over the years, an inventory of the possible resource areas within the Ethiopian sector of the East African Rift system, as reflected in surface hydrothermal manifestations has been built up. The inventory work in the highland regions of the country is not complete but the rift system has been well covered. Of the about 120 localities within the rift system that are believed to have independent heating and circulation systems, about two dozen are judged to have potential for high enthalpy resource development, including for electricity generation. A much larger number are capable of being developed for non-electricity generation applications such as in horticulture, animal breeding, aquaculture, agro-industry, health and recreation, mineral water bottling, mineral extraction, space cooling and heating, etc. (UNDP, 1973).

Since the late 1970's, geoscientific surveys mostly comprising geology, geochemistry, and geophysics, were carried out at, from south to north, the Abaya, Corbetti, Aluto-Langano, Tulu Moye and Tendaho prospects. In addition, a reconnaissance survey 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. Some of these exploration have been followed up by more detailed surface investigation. The prospects and fields discussed here are shown in Figure 1.

Due to various factors that determined where the first geothermal power plant would best be located, detailed exploration work was decided to commence in the Lakes area of the rift system during the 1970's, where the National grid was located. The best prospect areas from the technical point of view were located in the Afar but the area has been poorly endowed with essential infrastructure and local load demand to support power development. The present circumstances however favor resource development also in the Afar region.

FIGURE 1: Location of geothermal prospects in Ethiopia

Exploration work peaked during the early to mid 1980's when exploration drilling was carried out at Aluto. Eight exploratory wells were drilled with five of these proving productive. During 1993-98, exploration drilling was also carried out at Tendaho. Three deep and three shallow wells were drilled and geothermal fluids were encountered in the 200-600m depth range.

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

The other better explored area is the Tendaho Geothermal field. Geothermal exploration was carried out in the Tendaho area with economic and technical support from Italy between 1979 and 1980.

Between 1993 and 1998, three deep (about 2,100 m) 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 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 have been carried out in Ethiopia by the public and the private sector participation. These activities include: surface exploration, deep drillings and work on regulatory issues.

3.1 Public sector activities

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, in the Ethiopian Rift Valley. Ranking of the prospects for development was made on the bases of geothermal knowledge and 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 testing, reservoir modeling and subsequent selection of production wells has been carried out. The wells (LA-9D and LA-10D) have been drilled to depth of 1920 mt and 1951 mt respectively. Both wells are productive with bottom hole temperatures of over 300ºC. Currently testing is being carried out to determine the output of each well. Preliminary testing's 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.

Contemporary with the drilling of the initial two wells, geo scientific surface investigations including, geology, geochemistry, geophysics (MT/TEM, gravity and microseismics) have been carried out with technical assistance of ICEIDA. Initial results have indicated that the Aluto geothermal anomaly occurs not only along a fault zone located along the current productive wells but also has extension both to the east, west and north. Accordingly, a third well, to be drilled soon (LA-11D) was sited north of a current production well (LA-6) . The results of the surface exploration have come up with conceptual model that would also enable the siting of several wells for subsequent drilling.

Three potential areas have been identified and in order of their ranking are the Aluto proper, Bobesa area and Adonshe area. The Aluto proper field definitely stands out as the first priority

prospect, not only due to the fact that it corresponds to an already proven resource, but also for the specific features recognized in the course of the present project

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.

3.1.3 Surface exploration at Tendaho geothermal prospect

The Tendaho prospect involves three target areas, named as, Doubti, Allalobeda and Ayrobera (Figure 2).

Surface exploration at Doubti and Ayrobera

Surface exploration in two target areas of Tendaho (Doubti and Ayrobera) 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. The Ayrobera area has less data and further exploration was recommended.

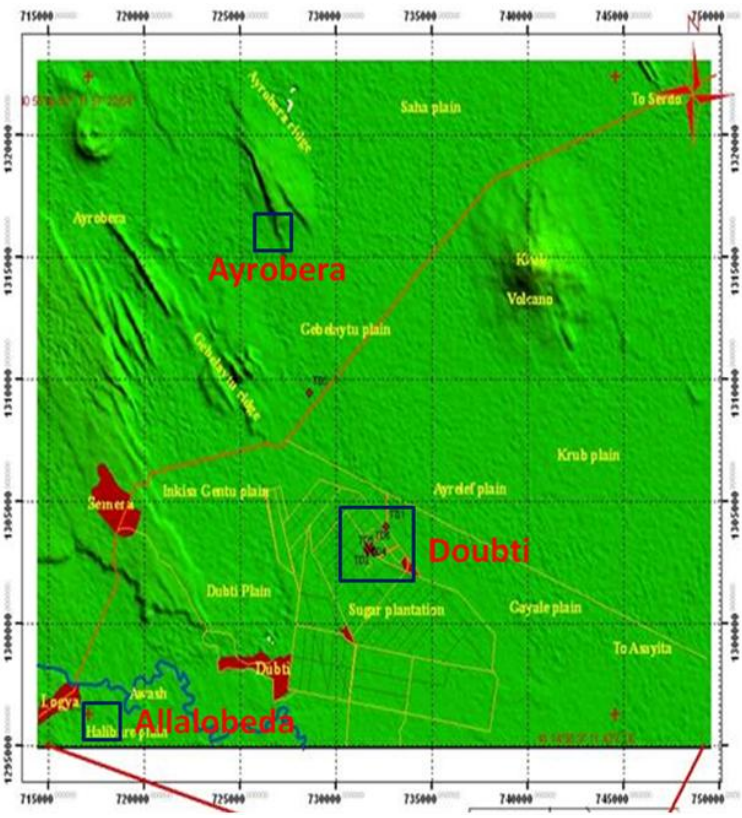

FIGURE 2: Location of three prospects in Tendaho area

Geologic and geophysical data and interpreted geo-referenced images were imported to Leapfrog Geo-thermal 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.

Feasibility study at Doubti

Feasibility study for shallow resource development at Doubti has 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 installed capacity of up to 12 MWe, by drilling of additional six (600 mt) wells.

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

Detail surface study at Tendaho (Ayrobera)

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 at Tendaho (Alallobeda)

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 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. Developed conceptual model of the field have indicated three target areas in order of priority.

The most promising sector, which can be classified as First Priority Zone or "probable area", has been identified taking into account several factors, that is:

- Its occurrence at the intersection between the Red Sea and the Ethiopian Rift tectonic trends.
- The presence of very conspicuous emergences of hot water
- The existence of a thick moderately conductive unit, attributable to the cap-rock of the geothermal system
- The existence in part of the zone of a positive gravimetric anomaly
- The almost perfect coincidence with the anomaly of high density and shallow depth of the seismic events
- The main features of the hypothesized reservoir, with reference to the first priority zone, are estimated as follows:
    - Areal extent: The first priority area covers a surface of 8 km^2, being delimited at all sides by geoelectrical lateral discontinuities.
    - 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., that is at an elevation of -600 m a.s.l. By analogy with other geothermal fields and considering that no lithological variations are expected to occur downwards, the thickness is assumed to be in the order of 1,000-1,200 m.
    - 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 SO4, are rather diluted (TDS around 1,400 ppm) and may exhibit some calcite and silica scaling tendency. Nothing can be said at this stage on their possible content of NCG

Volumetric approach has indicated a potential of about 125 MWe for Alalobeda prospect

3.1.4 New geothermal law

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.

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 lLicense on a competitive basis.

3.2 Private sector activities

Currently about seven private companies have concessions in various prospects. Most of them have started surface exploration for well siting. The most advanced 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 mobilization works are being conducted by the company to commence test well drilling.

4. FUTURE GEOTHERMAL DEVELOPMENT PLANS

Since recent times, the country has shifted its policy of relying in a single source of electric power (hydro) to secure energy in the country and thus geothermal sector development is receiving support. As a result a medium term and long term geothermal development plan 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 MW is planned by 2037.

One of the major challenges in Ethiopia's geothermal sector development program is financing. In order to achieve the countries medium to long term plan in geothermal development both the public sector financing, development partners input and the private sector participations are essential.

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 is 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, and (iii) the private sector is being encouraged to participate in geothermal development projects and as a result activities by the private sector in selected prospects have started.

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