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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 between 3.5° and 14°N and 33° and 48°E. Energy consumption in Ethiopia is still: (a) low in per capita terms, and (b) under developed by structure. The energy consumption comprises: (i) less than 2% from electricity, (ii) about 5.4% from hydrocarbon fuels, and (iii) the balance from traditional biomass fuels. The electrical energy demand growth in recent years has been very significant and an annual growth rate of 25% is expected at the end of 2010. The current generation capacity is 2000 MW from hydro, thermal and geothermal. The generation expansion plan envisages a total installment of 16,000MW from mainly hydro and complimentary from geothermal and wind.

The sector policy and regulatory framework supports IPP development. Subsequent to the National Economic Policy (NEP) of 1991 that encouraged private sector participation in the economic development of the country, a number of Proclamations and reforms have been made, aimed at enabling private participation within the electricity sector. Development of renewable energy resources for power generation is now being encouraged through the establishment of feed-in-tariffs (FIT) for such sources. A draft law and regulations supporting FIT is soon to be passed into law.

Ethiopia started long-term geothermal exploration in 1969. About 120 localities within the rift system are believed to have independent heating and circulation systems. From these localities about two dozen are judged to have potential for high enthalpy resource development, including for electricity generation. Only two prospect areas have been subjected to exploration drilling to date. Currently geothermal exploration and resource assessment is being carried out in strategically selected prospect areas in the Ethiopian Rift Valley.

The strategic plan for future exploration and development of geothermal resources considers the development of the most explored geothermal localities (Aluto Langano and Tendaho) to be followed by other geothermal prospect areas (such as Corbetti, Abaya, Tulu Moye, Fentale and Dofan) that are only at the level of detailed surface investigations. The completion of the works proposed in the strategic plan is expected to have significant impact on energy supply including improvement of the generation mix and thus diversification away from over-reliance on hydropower.

1. BACKGROUND INFORMATION

1.1 Physiography and Climate

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 1.14million km^2 made up of a broad plateau and low lands along its periphery. The highlands rise up to 4600m altitude while the most depressed lowlands reach 120m below sea level. The Ethiopian sector of the Great East African Rift bisects the plateau from the northeast to the southwest of the country (Figure 1). The rift in Ethiopia has created a conducive environment for the exisistence of geothermal resources and covers an area of about 150,000 km^2 that is close to 12% of the total land area.

Several rivers drain the plateau flowing, radially outwards, into the peripheral lowlands and onwards into the neighboring countries. The average annual rainfall in the highlands is 1200mm in the northern half of the country and 1800mm in the southwest. The lowlands annually receive below 600mm of rainfall. About 70-80% of the rain falls during mid-June to mid-September. In the highlands, the maximum monthly average temperature ranges between 23 and 27°C and the minimum between 10 and 13°C. In the lowlands, these temperatures range much higher.

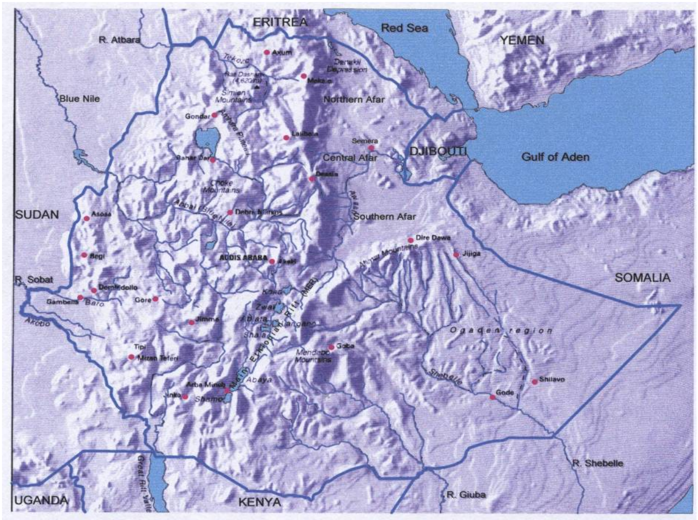

FIGURE 1: Physiography of Ethiopia.

1.2 Energy Situation

Energy consumption in Ethiopia is still (a) low in per capita terms, and (b) underdeveloped by structure. The energy consumption comprises: (i) less than 2% from electricity, (ii) about 5.4% from hydrocarbon fuels, and (iii) the balance from traditional biomass fuels. Most of the hydrocarbon fuels are consumed in the transport sector. Household energy comprises primarily traditional biomass fuels. Specifically, about (a) 40 million tons of fuel wood, and (b) 8 million tons of agri-residue is consumed annually. In addition, an important source of rural fuel supply is animal droppings.

1.2.1 The Electricity Sector

According to the official statistics (CSE, 2009), the current electrification status could be summarized as follows:

- No. of electrified towns are only 3967 from a total of about 7000 rural towns/villages;
- Generation capacity is 2000 MW from Hydro, Thermal and Geothermal;
- No. of customers are about 2 million;
- Access to electricity is about 41 %;
- Per-capita energy consumption is about 100 kwh/year (500-1000 Kwh/yr is considered the average minimum level of consumption per- capita for reasonable quality of life) ;
- The annual new customer's connection in the past was limited to a maximum of 40000; and
- After undertaking a wide spread reform program, the current annual new connection rate has grown to an average of 350,000.

The electrical energy demand growth in recent years has been very significant and an annual growth rate of 25% is expected at the end of 2010. In some months of the past year a growth rate of 21% has been registered. The average annual energy demand growth in 2002 to 2005 has been only 13% .The most notable factors that played a major role for the attainment of such a remarkable growths in recent years are: (i) GDP growth of more than 10% for the last five consecutive years, (ii) population growth, (iii) aggressive expansion of the National grid to rural towns and villages, and (iv) implementation of customer service reform programme.

Power demand forecasts indicated a total of 70,000GWH energy is required by 2030 from the existing 8000GWH in 2010. In compliance with prescribed reliability and system reserve criteria, an updated schedule for implementation of new generating plants and transmission additions is designed, to meet the projected demand. The generation development plan consists mainly of hydro projects. Generation from wind and geothermal power plants are foreseen to compliment the hydro. The generation expansion plan envisages a total installation of over 16,000 MW, mainly from hydro and complimentary from geothermal and wind by 2030.

1.2.2 Energy Policy

The sector policy and regulatory framework supports IPP development. Subsequent to the National Economic Policy (NEP) of 1991 that encouraged private sector participation in the economic development of the country, a number of Proclamations and reforms have been made, aimed at enabling private participation within the electricity sector. Development of renewable energy resources for power generation is now being encouraged through the establishment of feed-in-tariffs (FIT) for such sources. A draft law and regulations supporting FIT is soon to be passed into law.

The rapid increase in demand for energy and through the poverty eradication programme, the government devotes a lot of energy and resources to rural development for the purpose of enabling the large rural population to emerge out of subsistence production and become integrated within the national economy as surplus producers for trade and as a market for goods and services. The emphasis on agriculture aims at achieving food security, increased rural income, surplus generation and production for the agro-industry for export.

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.

2. GEOTHERMAL EXPLORATIONS AND DEVELOPMENT IN ETHIOPIA IN THE PAST

2.1 General

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 (Teklemariam and Beyene, 2005). In addition, a reconnaissance survey of ten sites in the central and southern Afar has been carried out, some of these being followed up by more detailed surface investigation. The prospects and fields discussed here are shown in Figure 2.

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. The ICS was already being extended into this region of load growth. The best prospect areas from the technical point of view were located in the Afar which had then 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.

Exploration work peaked during the early to mid 1980's when exploration drilling was carried out at Alutu. 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.

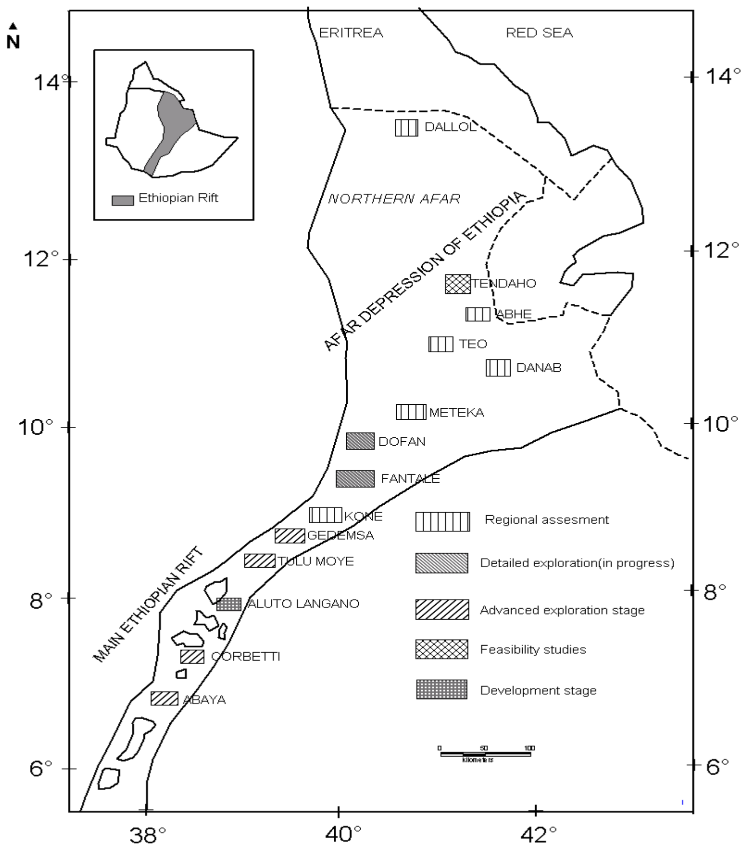

FIGURE 2: Location of geothermal prospects in Ethiopia

Resource utilization was delayed until 1999. A 7.3 MWe net capacity pilot plant installed at Aluto has faced operational difficulties that are essentially due to the lack of the appropriate field and plant management and operation skills. In 2007 activities related to problem identification and putting the plant back into have been carried out at the Aluto-Langano geothermal field. The plant is partially rehabilitated and has been put back into an operation of about 5 MWe.

During the three 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 the Geological Survey of Ethiopia (GSE) but has benefited from a number of technical cooperation programs. The most consistent over the long term had been support by UNDP, which also helped in creating other technical capacities of the GSE. The European Development Fund financed the overseas cost of the exploration-drilling project that resulted in the discovery of the Alutu resource. The development cooperation program of the Italian Ministry of Foreign Affairs provided the funding for the offshore costs of the surface and drilling exploration of the Tendaho prospect. The reconnaissance survey of the Afar was spawned by the Petroleum Exploration Promotion project financed by IDA during the 1980's. The IAEA is assisting the GSE in the isotope geochemical study of hydrothermal fluids and in the process is providing training and experience in the application of the technique in geothermal investigations. IAEA also provided technical advice and equipment. The German Geological Survey (BGR) assisted in geophysical investigations (MT) of the Tendaho deep geothermal reservoir during 2006-07. The specialized geothermal science and technology training programs in Japan, Italy, New Zealand, Iceland and Kenya (in cooperation with United Nations University- Geothermal Training Programme of Iceland) contributed in human resource training and development.

The explored prospects in the country are at various stages of exploration and include: (i) more advanced prospects where exploration drilling has been conducted (Aluto Langano and Tendaho), (ii) prospects where surface exploration is relatively at higher level (Abaya, Corbetti, Tulu Moye and Fentale and Dofan), and (iii) prospects where surface exploration is at lower level and warrant further exploration in the future (Kone, Meteka, Teo, Danab, L. Abe and Dallol).

2.2 The More Advanced Prospects

2.2.1 The Aluto-Langano Geothermal Field

Detailed geological, geochemical and geophysical surveys were carried out in the Langano area during the late 1970's and early 1980's. Results showed the existence of an underground fluid at high temperature with evidence of long time residence in zones occupied by high temperature rocks (ELC, 1986). The objective then was to locate an economically exploitable geothermal reservoir.

Two wells (LA3 and LA6) drilled on the Aluto volcano produced 36 and 45 t.p.h. geothermal fluid at greater than 300^{O}C along a fault zone oriented in the NNE-SSW direction. Two wells drilled as offsets to the west (LA4) and east (LA8) of this zone respectively produced 100 and 50 t.p.h. fluid with a lower temperature. LA5, drilled in the far SE of the earlier two wells was abandoned at 1,867m depth due to a fishing problem but however later showed a rise in temperature over an extended period of time. LA7 was drilled in the SW but could discharge only under stimulation, being subject to cold-water inflow at shallow depth. The earliest wells drilled in the prospect were drilled outside the present limits of the reservoir area, to the south (LA1) and west (LA2) of the area drilled later.

A 7.3 MWe pilot geothermal plant was installed in 1999 utilizing the production from the above exploration wells. The plant has not been fully operational due to reasons that have to do with the lack of operational experience. But since 2007 the plant has been partially rehabilitated and put back into an operation of about 5 MWe.

2.2.2 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 2,100m) 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 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.

Based on this and further studies, the Ministry of Mines and Energy is currently working on Tendaho for progressing it towards development. The recent upgrade of a trunk highway through the Tendaho area will help facilitate such exploration and development. In addition, the Ethiopian government plans to extend the country's main 230KV transmission line to Semera, which is within ten km of the drilled wells at Dubti.

2.3 Prospects Where Surface Exploration is At Higher Level

Over the years, a number of prospects have been subjected to surface investigation: geology, geochemistry and geophysics and the shallow subsurface has been investigated by drilling at a few of the prospects. They are mostly located in the MER, especially in its most recent zones of tectonic and magmatic activity, the different sectors of the discontinuous WFB. These prospects from south to north are: Abaya, Corbetti, Tulu Moye, Fentale and Dofan.

2.3.1 The Abaya Geothermal Prospect Area

Abaya is located on the northwest shore of Lake Abaya, about 400 km south by road from Addis Ababa. The Abaya prospect exhibits a widespread thermal activity mainly characterized by hot springs, fumaroles and altered ground. Spring temperatures are as high as 96 °C with a high flow rate. Integrated geoscientific studies (geology, geochemistry, and geophysics) have identified the existence of a potential geothermal reservoir with temperature in excess of 260°C (Ayele et al., 2002). Further geophysical studies including drilling of shallow temperature gradient wells are recommended here.

The 132 KV transmission line to Arba Minch to the south starts at the Wolayta Soddo substation located about 40 km distance to the NNW of the prospect. This raises the prospect for development of the resource once it is adequately explored, including by drilling.

2.3.2 The Corbetti Geothermal Prospect Area

The Corbetti geothermal prospect area is located about 250 km south of Addis Ababa. Corbetti is a silicic volcano system within a 12 km wide caldera that contains widespread thermal activity such as fumaroles and steam vents. Detailed geological, geochemical and geophysical investigations conducted in the Corbetti area indicate the presence of potential geothermal reservoirs with temperatures exceeding 250°C. Six temperature gradient wells have been drilled to depths ranging from 93-178m (Kebede, 1986). A maximum temperature of 94°C was recorded. The data shows the probable existence of an economically exploitable deep geothermal reservoir.

A 132 KV power transmission line passes within 15 kms of the prospect and is the main trunk line to southern Ethiopia, to towns along the two branches of the highway to Kenya.

2.3.3 The Tulu Moye Geothermal Prospect Area

The area is characterized by volcanism dating from Recent (0.8 –0.08 Ma) to historical times. Volcanism involved the extrusion of per alkaline felsic lava associated with young tensional and transverse tectonic features dating from 0.1 to1.2 Ma, with abundant silicic per alkaline volcanic products (Di Paola, 1976) **.** This suggests the existence of a deep seated magma chamber with a long residence time. The area is highly affected by hydrothermal activity with the main hydrothermal manifestation being weak fumaroles, active steaming (60-80°C) and altered ground. The absence of hot springs is related to the relatively high altitude of the prospect area and the considerable depth to the ground water table. During 1998-2000, integrated geological, geochemical and geophysical studies including shallow temperature gradient surveys (150-200m) , confirmed the existence of potential geothermal reservoirs with a temperature of about 200°C (Ayele et al., 2002) and delineated target areas for further deep exploration wells.

This prospect area is located close to the koka and Awash II and III hydro-electric power stations and the associated 230 and 132 KV substations and transmission lines.

2.3.4 The Fentale Geothermal Prospect Area

The Fentale geothermal prospect is characterized by a recent summit caldera collapse, felsic lava extrusions in the caldera floor and widespread fumarolic activity, suggesting the existence of a shallow magma chamber. Active tensional tectonics form fissures up to 2m wide near the volcanic complex. Ground water discharge to the system is assured by the proximity of the area to the western escarpment. The results of an integrated interpretation of previous data suggest that the area is potentially prospective for future detailed geothermal resource investigations. Therefore, due to the presence of an impervious cap rock, the western part of the prospect particularly deserves to be investigated during a more detailed geothermal exploration programme. In this view, the Geological Survey of Ethiopia has carried out detailed geological, geochemical and geophysical investigations in order to delineate and select target areas for deep exploration wells.

2.3.5 The Dofan Geothermal Prospect Area

Geological, geochemical, and geophysical investigations in the Dofan geothermal prospect show that the area is characterized by a complex volcanic edifice that erupted a considerable volume of pantelleritic lava from numerous eruptive centers between 0.5-0.2 Ma (Cherinet and Gebreegziabhier, 1983). The presence of several hydrothermal manifestations (fumaroles and hot springs) within the graben, together with an impervious cap, needs to be regarded with high priority for further detail exploration and development (Teclu, 2002/2003).

The area is located about 40 km from the high voltage substation in the Awash town.

2.4 Prospects Where Surface Exploration is At Lower Level

During the 1980's, reconnaissance geological, geochemical and geophysical investigations have been conducted at Dallol, Kone, Meteka, Teo, Danab and L. Abe areas that are found in a zone extending between the southern and northern Afar geological provinces. Meteka and Teo hold promise for the discovery of economically exploitable geothermal resources at high temperature and warrant detailed surface investigation, to be followed by exploration drilling. The Lake Abe area warrants further investigation in a wider exploration context that encompasses areas in the eastern part of Tendaho graben and the Lake Abe prospect in Djibouti. These resource areas are not included in this proposal as their large distances from electricity load centers and the national grid accord them lower priority. With advancing economic activity in southern and central Afar as well as in the eastern part of the country, these prospect areas should prove useful for power supply both within the region and to the national grid in the longer-term.

The prospects that have been dealt with under reconnaissance stage are located to the north of 12°N latitude and comprise terrain that is at the most advanced stage of rift evolution in the eastern Africa region and holds a much greater potential for geothermal resources than any other region of equivalent size. This region should be considered as a prime target area for future exploration and development. With the improving availability of the economic development infrastructure in the region, the power-supply system in the load growth areas of northern Ethiopia would benefit from geothermal power generating facilities located in this part of the country.

From these long-term points of view, reconnaissance and preliminary surface evaluation works should commence in the not too distant future in the regions of southern and central Afar, North of 12°N latitude, in order to raise the available level of knowledge regarding the resource areas and to provide the necessary information that is required for long-term planning.

3. CURRENT GEOTHERMAL ACTIVITIES AND FUTURE STRATEGIES

3.1 Current Activities

Currently the following geothermal activities are being conducted in Ethiopia:

- A three year project entitled Strategic Geothermal Resource Assessment in the Ethiopian Rift Valley has started in 2009. The target areas of the assessment are Tendaho, Aluto Langano, Dofan, Fentale and Arabi. Geoscientific studies including: (i) geological, (ii) geochemical, (iii) geophysical (MT, TEM, Gravity and Magnetics) and (iv) Reservoir Engineering studies are being conducted in these areas. The objectives of the project are to locate and identify areas (sites) for deep drilling by acquiring data that can supplement the already available ones, and upgrade and synthesize all existing information in order to establish a geothermal exploration conceptual model for future feasibility studies. The exploratory work at Tendaho is being supported by the German Geological Survey.

- Ethiopia and Japan signed a memorandum of understanding in June 2009 to generate geoscientific and reservoir engineering data that can be used for expansion and further development of the Aluto Langano geothermal field. Under this framework, the main activities conducted in August 2009 are magneto telluric (MT) and Audio magneto telluric (AMT) survey on 40 selected stations. During this survey, while experts from Phoenix Company of Canada conducted the MT study under contract for West Jec consultants of Japan, Ethiopian geophysicists took part in the field survey with the aim of obtaining hands-on experience in MT data generation and processing. The study outlined subsequent two phases for the expansion and power development, which include: (i) the drilling of four appraisal wells and resource assessment in the next phase, and (ii) the drilling of production wells and installation of a 35MW plant in the final phase. Preparatory work for the drilling of the four wells is being conducted. Currently well pad preparation for the drilling of the appraisal wells is completed and a deep drilling rig has been transferred from Tendaho to the Project site. After the drilling consumables are delivered from over seas drilling will start in early 2012.

- Exploration license has been given to the private sector in three main geothermal prospect areas: (i) Corbetti, (ii) Abaya and (iii) Tulumoye. Currently the company named "Reykajavik Geothermal" has started MT-TEM survey at Corbetti.

3.2 Future Strategies

During the past several decades, Ethiopia has faced repeated cases of impending or actual power shortages. Reliance on hydro-power has exposed the Ethiopian power sector to the vagaries of periodic drought as it limited the power that could be generated. Consequently, it is planned to diversify the power generation mix. Specifically, this will be done through utilizing indigenous energy resources that are economically competitive, reliable and have a low environmental impact. According to worldwide experience, geothermal resources meet these criteria. Indeed, geothermal is known to be a cheaper energy source. Besides, in Ethiopia it is more intensively studied compared to other renewable resources such as wind and solar.

Currently, the desire to increase geothermal development and utilisation in Ethiopia is on account of the:

- Critical role of energy in socio-economic development of the country;
- Energy demand growth;
- Vulnerability to drought of the hydro power (currently, the main electrical energy supply) ;
- Opportunity to use Risk Mitigation Fund (RMF) of the World Bank through the ARGeo programme and the German Development Bank;

- Readily available local qualified geoscientists and engineers and equipment (Deep drilling Rigs etc..), for geothermal exploration and development; and
- Existence of identified potential geothermal prospect areas.

The current generation expansion plan in geothermal envisages the development of 450MW by 2018 from six selected geothermal prospects, namely, Aluto Langano, Tendaho, Corbetti, Abaya, Tulu Moye and Dofan and Fentale both by the public and the private sector. (Table 1).

3.2.1 Criteria for Prioritization of the Geothermal Prospect Areas

The main criteria for prioritization of various prospect areas for undertaking further exploration and development are: (i) state of advancement of exploration level (technical), (ii) the relative strategic location (proximity to the existing national grid as an economical factor), and; (iii) population density of the areas (GSE and EEPCO, 2008).

TABLE 1: Short Term Generation Development Plan in Geothermal

No	Project	Current stage	Projected capacity (MW)	Energy (GWH)	Estimated commissioning year
1	Aluto Langano geothermal	Feasibility	75	525.6	2012
2	Tendaho geothermal	Pre-feasibility	100	700.8	2018
3	Corbetti geothermal	Pre-feasibility	75	525.6	2018
4	Abaya geothermal	Pre-feasibility	100	700.8	2018
5	Tulu Moya geothermal	Pre-feasibility	40	280.32	2018
6	Dofan and Fantale geothermal	Pre-feasibility	60	420.48	2018
		Total	**450**	**3153.6**	**2018**

4. CONCLUSIONS

Despite the long history of geothermal exploration in Ethiopia and an estimated 5000 MW potential, so far only a very little fraction of the total potential is harnessed. The main constraints for development of geothermal resources in Ethiopia were largely related: (i) geothermal was not part of the National Energy Development Plan, (ii) lack of awareness in the part of energy development policy makers, (iii) large upfront cost of exploration and development and the risks associated with it, and (iii) lack of continuous and integrated work in exploration and development of the resource.

Currently geothermal is: (i) integrated in the National Energy Development Plan, (ii) participation of international financial institutions, bilateral donors and development agencies to assist geothermal development projects has grown, and (iii) the government is convinced that irrespective of future hydro developments, geothermal's contribution to energy security at times of drought is critical. Therefore a national energy mix is the solution to the drought prone region of Ethiopia and in the coming few years a significant fraction of the total potential shall be harnessed.

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