

Strategy for Geothermal Resource Exploration and Development in Ethiopia

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ABSTRACT

Energy consumption in Ethiopia is (a) low in per capita terms, and (b) underdeveloped by structure. It is made up of (i) less than 1% electricity, (ii) about 5.4% hydrocarbon fuels, and (iii) the balance is from traditional biomass fuels. Most of the petroleum products are consumed in the transport sector, whereas household energy comprises primarily of biomass fuels. About 40 million tons of fuel wood and 8 million tons of agri-residue are consumed annually. An important source of rural fuel supply is animal droppings.

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: The building up of the grid based supply system to reach all administrative and market towns, and rural electrification based on independent, privately owned supply systems in areas where the grid has not reached.

The present total generation capacity is 814 MW, with hydro-generation accounting for 90%. 669.9 MW from 8 hydropower stations and 113.1 MW widely distributed diesel capacity feed the Interconnected System (ICS) and 7.3 from the Aluto-Langano Geothermal Pilot Power Plant. In Fiscal year 2007, the recorded energy generation has reached 3339 GWh. Comparing the 10 month generation of the current year (under load shedding to the whole of 2005 and 2006), it is evident that rapid increase in demand has taken place in the current and the last year due to the unprecedented increased access and associated consumption in all spheres of the economy.

Presently, the most explored geothermal field is the Aluto Langano geothermal field followed by Tendaho. These two fields can be most easily and rapidly advanced to the development stage for execution of power projects in five to ten years. Other geothermal prospect areas (such as Corbetti and Abaya) that are only at the level of detailed surface investigations will be rapidly advanced to Exploration/appraisal drilling stage followed by production and development consistent with the schedule of forthcoming hydropower projects.

The long term electricity development Master Plan also concluded that geothermal exploration should define proven geothermal energy resources in other areas of Ethiopia. Accordingly, the strategic plan also focuses on surface exploration works in other prospect areas (Tulu Moye, Gedemsa, Dofan, Fantale, Teo, Danab etc.) of the Main

Ethiopian Rift and the Afar Rift. The (a) selection of, and (b) prioritization of these prospects would be considered based on economic criteria: (i) their strategic locations in close proximity to the existing grid, and (ii) to regions of high population density.

1. BACKGROUND

Ensuring integrated development of a country could not be realized without paying sufficient attention to the energy sector. Being the power source of an economy, it has a lot of benefits in enhancing investment opportunities, expanding employment, supporting the other sectors and in all of it, reinforcing the economic development of the country. To this end, the strategic development plan of Ethiopia has accorded due attention to the energy sector. This plan recognizes not only the essentiality of energy as an input for growth of the modern sector but also its important role in rural transformation through underpinning the expansion of agricultural production, irrigation, education and health sectors. It is relevant to note that to break the "vicious energy poverty circle"; a Universal Electricity Access Programme (UEAP) is being implemented in the PRSP (Poverty Reduction Strategy Programme) of Ethiopia. It targets the electrification of around 6,000 rural towns and villages, making energy available to some 24 million people, while increasing the electricity penetration to 50% by the year 2015.

Energy consumption in Ethiopia is still (a) low in per capita terms, and (b) underdeveloped by structure. The energy consumption comprises: (i) less than 1% 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.

The present total Ethiopian electricity generation capacity is 814MW, with hydro-generation accounting for 90%. This means that: (i) 669.9 MW is contributed from 8 hydropower stations, (ii) 113.1 MW contributed by widely distributed diesel capacity which feeds into the Interconnected System (ICS), and (iii) 7.3 MWe contributed by the existing Aluto-Langano Geothermal Pilot Power Plant.

1.1 Additional Energy Plans

Aside from the expansion of new small and larger hydropower projects, other generation technology alternatives are being looked so as to enhance the total generation capacity and to widen the energy mix. Geothermal power provides the second indigenous alternative energy resource in the country after hydropower. It is estimated that Ethiopia could generate more than 5,000 MWe from its geothermal energy resources. However, little has been done so far with regards to development of this

resource, since the early 70's where exploration of geothermal resources was initiated in Ethiopia jointly by the United Nations Development Programme and Ethiopian Government.

This slow progress of Exploration (including deep drilling) and development of geothermal has been due to two main reasons:

- (1) The great demands of the pressing tasks in socio-economic development in the country impose equally heavy demands for budgetary allocation such that adequate resources could not be allocated to projects of essentially long-term impact, such as in geothermal resource exploration and development. As a result, the limited annual allocations that could be made enable only limited studies, mainly restricted to surface investigations. These are however insufficient to progress even the most attractive prospect areas to the stages where they could be investigated by drilling, and so they remain at levels of knowledge that are far below the threshold levels required to embark on resource development.
- (2) During the past several decades, Ethiopia had faced repeated cases of impending or actual power shortages that could be responded to more expeditiously by resort to hydro-power development based on existing studies and rankings of known hydro-potential sites. On the other hand, no geothermal resource area has been studied to the full extent of its potential to allow consideration as an alternative means of satisfying the short-term power needs. The high cost and risk of drilling, the commonly longish project gestation period, unfamiliarity with the technology involved militate against maintaining required levels of investment over the required extended periods.

Over-reliance on hydro-power is exposing the Ethiopian power sector to the vagaries of periodic drought and the country to environmental concerns. As a result, Ethiopia now plans to (a) diversify power sources, and (b) to improve the power generation mix, and (c) to do so through the utilization of indigenous energy resources that would be economically competitive, reliable and with low environmental impact. According to worldwide experience, geothermal resources meet these criteria. In this context, the strategic development plan reflects the priority of the Ethiopian Government to support and facilitate the geothermal resources development in the Ethiopian Rift.

1.2 Current Energy Demand

Records of the recent history of electric demand in Ethiopian Interconnected System (ICS) show dramatic rise because of rapid new investment growth in all spheres of the economy, industrial, commercial, agricultural, domestic and rural besides the internal growth within these spheres.

Besides, rural electrification forecasts are treated separately based on the Government electrification target of increasing the existing low rate of electrification in line with the Universal Electricity Access Program. For currently unsupplied centers the high demand is developed from estimates of population, population growth, the level of interconnection and consumption per connection.

1.3. Energy Policy

Due to this rapid increase in demand for energy demand and through poverty eradication programme, the government devotes much 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 producer 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 agro-industry for export.

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.

Independent Power Producers (IPP) are encouraged to invest in power generation for supply to the grid. In order to facilitate private sector entry onto power development investment, government has separated operational and regulatory functions by transferring the licensing and regulatory functions from EEPPO to the Ethiopian Electricity Agency (EEA).

2. THE GEOTHERMAL RESOURCES OF ETHIOPIA

Ethiopia started a 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.

Since the late 1970s, 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, some of these being 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 1970s. 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 Afar region.

Exploration work peaked during the early to mid-1980s 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 encountered in the 200-600 m-depth range.

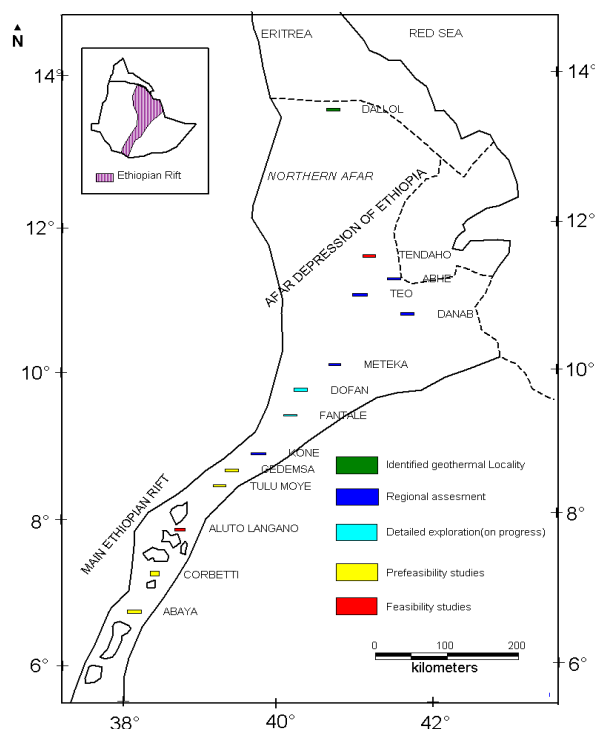


Figure 1: Location Map of the Ethiopian Rift and Geothermal Prospect Areas.

Resource utilization was delayed until 1999. The 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. At present, activities related to problem identification and putting the plant back into operation is carrying out at the Aluto-Langano geothermal field. The plant is partially rehabilitated and put back into operation of about 3 MWe.

During the three decades that geothermal resources 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 also 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 Aluto 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 1980s. The IAEA is assisting the GSE in the isotope geochemical study of hydrothermal fluids in the process 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) assists 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, Kenya (in cooperation with United Nations University- Geothermal Training Programme of Iceland and Kenyan Generating Power Company) contributed in human resource training and development.

2.1 The Explored Prospects

2.1.1 The More Advanced Projects: Exploration Drilling

Only two prospect areas have been subjected to exploration drilling to date.

The Aluto-Langano Geothermal Field

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

Two wells (LA3 and LA6) drilled on Aluto volcano produced 36 and 45 t.p.h. geothermal fluid at greater than 300°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 lower temperature. LA5, drilled in the far SE of the earlier two wells was abandoned at 1867m 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.



Figure 2: One of the Discharging wells (LA-3) of the Aluto-Langano Geothermal Field. Total Depth = 2.3 Km; Max. Temp = 320°C.

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 now the plant is partially rehabilitated and put back into operation of about 3 MWe.

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 2100 m) and three shallow exploratory wells (about 500 m) were drilled and yielded a temperature of over 250°C. 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 is estimated 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 230 kV transmission line to Semera, which is within ten km of the drilled wells at Dubti.



Figure 3: One of the shallow wells (TD-5) of the Tendaho Geothermal Field, Total Depth = 516 m; Maximum temperature = 253°C

2.1.2 Prospects Where Surface Investigations Were Carried Out

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 are enumerated below, from south to north. The more important areas are Abaya, Corbetti, Tulu Moye, Dofan and Fantale.

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 parts at the Wolayta Soddo substation located about 40 kms distance to the NNW of the prospect. This raises the

prospect for development of the resource once it is adequately explored, including by drilling.

The Corbetti Geothermal Prospect area

The Corbetti geothermal prospect area (Figure 1) is located about 250 km south of Addis Ababa. Corbetti is a silicic volcano system within 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 93-178 m (Kebede, 1986). A maximum temperature of 94°C was recorded. No further work was carried out since then. The data show the probable existence of a deep reservoir with temperatures exceeding 250°C.

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 branch of the highway to Kenya.

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 – 1.2 Ma) with abundant silicic per alkaline volcanic products (Di Paola, 1976) in the Tulu Moye-Gedemsa prospect area (Figure 1). 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 drawback of the hydrothermal manifestations 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 (150-200 m), confirmed the existence of potential geothermal reservoirs with 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, the associated 230 and 132 kV substations and transmission lines.

The Dofan Geothermal Prospect Area

Geological, geochemical, and geophysical investigations in the Dofan geothermal prospect (Figure 1) 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.

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

The Fantale Geothermal Prospect Area

The Fantale geothermal prospect is characterized by recent summit caldera collapse, felsic lava extrusions in the caldera floor and widespread fumarolic activity, suggesting thereby the existence of a shallow magma chamber. Active

tensional tectonics form fissures up to 2 m wide nearby 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 detail 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 detail geological, geochemical and geophysical investigations in order to delineate and select target areas for deep exploration wells.

2.1.3 Other Prospects at Reconnaissance Level

The strategic exploration and development plan deals with a total of six geothermal project areas which had been selected on the basis of proximity to areas of economic activity and the national power grid. However, past work has shown that there are several other attractive prospects that are suited for pursuing in the long run.

During the 1980s, reconnaissance geological, geochemical and geophysical investigations have been conducted at Dallol, Kone, Meteka, Teo, Danab 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, followed by exploration drilling. 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.

All of the prospects that have been dealt with above are located within the rift system, south of 12°N latitude (Figure 1). The region to the north of 12°N latitude comprises 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 and in the region 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. STRATEGIES FOR EXPLORATION AND DEVELOPMENT

During the past several decades, Ethiopia faced repeated cases of impending or actual power shortages. These could be expeditiously responded by resorting to development of more hydro-power based on the existing studies about, and

the prioritized ranking of, known potential hydro-power sites.

However, reliance on hydro-power has also 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 power generation mix. Specifically, this will be done through utilizing indigenous energy resources that are economically competitive, reliable and have low environmental impact. According to worldwide experience, geothermal resource meets 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.

Currently, the desire to increase geothermal development and utilisation in Ethiopia is on account of the: (i) Critical role of energy in socio-economic development of the country; (ii) Energy demand growth; (iii) Rural Electrification focus; (iv) increasing world oil price; (v) Vulnerability to drought of the hydro power (currently, the main energy supply); (vi) Availability of a Clean Development Mechanism (CDM); (vii) Opportunity to use Risk Mitigation Fund (RMF) of the World Bank through the ARGeo programme; (viii) Growth of interest of private investors (REI, JAPAN etc); (ix) Readily available local qualified geoscientists and engineers and equipment (Deep drilling Rigs etc.), for geothermal exploration and development; and (x) Existence of identified potential geothermal prospect areas.

The planning aspects of exploration and development of these six geothermal prospects comprises the following elements: (i) Review of existing information on a prospect; (ii) Detailed surface exploration (Geology, Geochemistry, Geophysics (Particularly MT coupled with TEM); (iii) Exploration drilling (Except for Aluto-Langano) and well testing (a minimum of 3 wells); (iv) Appraisal drilling (a minimum of 6 wells) and well testing; (v) Feasibility studies; (vi) Production drilling, power plant design, environmental impact assessment and reservoir evaluation; (vii) Power station construction and commissioning; and (viii) Reservoir Management and further development.

The possible strategies of each geothermal prospect area are developed in terms of: (i) Additional work required to fill the knowledge gap; (ii) Estimated time to complete the work; (iii) Estimated potential (MWe) of the field; and (iv) Required input to implement the project (Human resource, Finance, equipment).

3.1 Criteria for Prioritization of 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.

Based on these main criteria, the following geothermal prospect areas have been selected (in order of priority) for further exploration and development: (1) Aluto-Langano; (2) Tendaho; (3) Corbetti; (4) Tulumoye-Gedemsa; (5) Dofan; (6) Fantale.

4. EXPECTED OUTCOME

The completion of the works proposed in the strategic plan is expected to have the following outcome and impact:

- The greater availability of reliable information on the geothermal resources of the country during the earlier stages of the projects would encourage power developers, public and/ or private, to invest in the key industry of electricity generation and supply to a rapidly geographically expanding and growing market. From such investment would follow the following:
- Augmentation of power supply from hydropower plants, and improvement of the generation mix, for greater reliability of electricity supply.
- Diversification away from over-reliance on hydropower, to make more reliable and adequate electricity available to both urban and rural areas.
- Contributing to the replacement of diesel generating plants both within the national grid and outside it, as well as reducing the necessity for installing additional ones, and thus contributing to the reduction of green house gas emission and import dependence for fossil fuels.
- Contributing to the greater availability of electricity as an affordable, reliable and clean energy form to urban and rural households and reduction of environmental degradation, indoor pollution and loss of soil fertility arising from the high level of use of biomass fuel use.
- Supporting the improvement of access by the population to essential social services (health, education, clean water supply, information) for a betterment of the quality through more widespread supply of electricity to the facilities.
- Contributing to the more widespread use of electricity in productive economic activities, including in rural commerce and industry, thus supporting the increase of household incomes and the reduction of poverty.
- Supporting regional integration of national electricity systems, contributing to the generation of electricity export earnings and to regional economic cooperation and increasing integration.
- Creation of opportunities for remunerative employment and skill development for local populations in project areas during the exploration and resource development activities.
- Development of trained human resources, acquisition of equipment and machinery for further geothermal exploration and development in other potential sites thereby ensuring sustainability of capacities.
- Creation and cultivation of a collaborative regime in the East African Rift region that would enable the exchange of information and experiences and

optimization in the use of the human, institutional and infrastructural resources available in the region.

ACKNOWLEDGMENT

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REFERENCES

- Ayele, A., Teklemariam, M. and Kebede, S: Geothermal Resources Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian rift, Compiled Report, (2002).
- Electroconsult (ELC): Geothermal Exploration Project-Ethiopian Lakes District, Exploitation of Langan-Aluto Geothermal Resources, feasibility report. ELC, Milano, Italy, (1986), 150.
- Kebede, S: Results of temperature gradient survey and geophysical review of Corbetti geothermal prospect, EIGS, (1986).
- Cherinet, T. and Gebreegziabhier, Z: Geothermal geology of the Dofan and Fantale area. (Northern Ethiopian rift). Geothermal Exploration Project, EIGS (1983).
- Teclu, A.: Geochemical studies of the Dofan Fantale Geothermal Prospect Areas. South Africa, Internal Report. GSE (2002/2003).
- Teklemariam, M. and Beyene, K. (2005): Geothermal Exploration and Development in Ethiopia, *Proceedings*, World Geothermal Congress, WGC 2005, Antalya, Turkey (2005).
- United Nations Development Programme (UNDP): Investigation of geothermal resources of Power development Geology, Geochemistry and Hydrogeology of hot springs of the east African Rift System within Ethiopia. DP/SF/UN 116-technical report, United Nations, New York (1973), 275.
- Geothermal Division Internal Report (Geological Survey of Ethiopia): Strategic plan of Geothermal Resource Exploration and Development in Ethiopia (JULY 2008).
- Teklemariam, M.: Strategic Plan for Geothermal Exploration and Development in Ethiopia: Proceedings on Short Course for Decision Makers on Geothermal Energy, Entebbe, Uganda (November 2008).

TABLE 1: PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels*		Hydro*		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2008			107	27	600	2542	707	2569
Under construction in December 2008			38		884	3007	922	-

** Obtained from EEPCO data file

TABLE 2: UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009

Locality	Power Plant Name	Year Commissioned	No. of Units	Status ¹⁾	Type of Unit ²⁾	Total Installed Capacity MWe	Total under Constr. or Planned MWe
Aluto-Langano	Aluto-Langano Pilot-power plant	1999	2	Generate 4 MWe	Binary type	7.28	75
Total							

** Obtained from EEPCO data file

TABLE 3: UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

Locality	Type ¹⁾	Maximum Utilization					Capacity ³⁾
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy ²⁾ (kJ/kg)		(MWt)
			Inlet	Outlet	Inlet	Outlet	
Sheraton Hotel	B	0.005		58-78			
Filowha	B			44-77			
Ghion	B			41-50.6			
Hilton	B	0.007		67-75			
National Palace	B			28			
Greek Community	B			35.5			
St. Joseph School	B						
<div><u>NB</u> Total Thermal Wells ~ 15. Discharge rates are by in large pump dependant rather than potential. Record on thermal wells is unfortunately scarce. Data obtained from Gizaw, 2002</div>							

TABLE 6: WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

¹⁾ Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)*	
Exploration ¹⁾	(all)	5*				1
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total						

* Temperature Gradient wells

TABLE 7: ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	17					
2006	17					
2007	23					
2008	23					
2009	20					
Total	20					

TABLE 8: TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US\$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling Million US\$	Field Development Including Production Drilling & Surface Equipment Million US\$	Utilization		Funding Type	
			Direct Million US\$	Electrical Million US\$	Private %	Public %
1990-1994	9,600*					
1995-1999	2,000*	16,313**				100
2000-2004	0.407					100

** Obtained from EEPKO data file

* Source of fund is from government + foreign aid