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Geothermal Development in Republic of Djibouti
A Country Update Report

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ABSTRACT

The aim of this paper is to highlight the vision of future perspective of the new geothermal development strategies. Djibouti has a long history of geothermal resource exploration since 1970, as the country is endowed with numerous geological structures.

Located at the junction of three main active geological structures, the presence of subsurface geothermal manifestation are several with hot springs and fumaroles which gives has the country the potential to develop geothermal energy. The government's commitment has been very important over this period and intense studies throughout the country have been initiated and which enabled the discovery of an important potential estimated to generate around 1000 MW.

However, after several drill holes, it was discovered that some factors such as salinity limited the exploitation of the resource at the current state of technology. The Government of Djibouti were strongly committed to exploit the resource and asked financials partners to perform additional studies to help finding solutions to these limiting factors.

After a period of inactivity's, the country took the initiative in the last 10 years to drastically reduce fossil fuel dependence for power generation and promote development of geothermal potential according to the 2035 vision. In order to development sustainable geothermal sector, important initiative has been taken for the equipment and capacity building for the manpower with specialized support from several partners like United Nations University Geothermal Training Program .

Additional exploration studies has already started realized by the Research Center of Djibouti (CERD) began work on a exploration in the North-Ghoubhet , Lake Abhe and Obock fields, the preliminary studies demonstrate the existence of hot reservoir and exploration drilling are being planned.

Also, the country raise funds around 31 Million USD for exploration drilling in the Assal-Fiale geothermal field within financial from the World Bank, Afdb, OFID, AFD and the Djibouti government participation .In order to establishment the first tranche of 50 MW geothermal power plants, extended to 150 MW when potential is estimated around 356 MW (daher, 20only in that area.

In the institutional part, the strong political commitment and kenyan's sharing experience in creating the GDC company , Djibouti decide to create a new entity called ODDEG (Djibouti Office for Geothermal Energy Development) in charge to stimulate a rapid geothermal development.

1. INTRODUCTION

The Republic of Djibouti is partly located in the East African Rift Valley (EARV) system, and the geology is influenced by the rifting phenomenon of the Red Sea plate and the Gulf of Aden plate.

In term of geodynamic context, a huge quantity of energy is dissipated from the very shallow earth mantle to the surface. The Afar triangle and Iceland are the only two regions in the world where an oceanic ridge is accessible off shore for geothermal exploitation.

This exceptional geodynamic setting gives the country its geothermal potential. Since 1970, twelve (13) geothermal prospective areas were identified.

Several studies carried out in the past, in many prospective areas ranging from surface exploration to exploratory drilling, have estimated the geothermal potential of the country to be around 800 MW. However, the most potential resources have been identified in Asal-Ghoubhet fields, but limited due to factors that inhibit optimum exploitation.

Over the last 10 years, high-level political commitment was set up to promote and develop the geothermal sector in a sustainable way, thus reducing drastically the fossil fuel consumption for power generation. In fact, fossil fuel accounts for 50% of the electricity production in the country which leads to the high electricity costs in the region.

To achieve this objective the government set up in January 2014 a new entity called ODDEG (Djibouti Office for Geothermal Energy Development) in charge to stimulate a rapid geothermal development, and to ensuring sustainable development.

This paper presents the current energy situation, the current active potential fields and the development of this sector in the future.

2 STATUS OF ELECTRICITY PRODUCTION

2.1. Electricity sector

The electricity sector was highly developed over the last 5 years. Thermal energy represented the most important part of the power generation. A solar plant and an interconnection line from Ethiopian power company (EEPCO) were added with the energy offer in 2011.

The Ethiopia-Djibouti interconnector provides an additional electricity source, based on renewable (hydro), ranging from 180 to 300GWh per year. It is therefore covering between half and two-thirds of the demand. The line terminates at a 220/63/20 kV substation, 12 km west of Djibouti-Ville, where the voltage is stepped down to 63 kV for interconnection with the existing transmission system.

The transmission system is currently limited to a 63 kV inter-connector between the main stations, and two 20 kV transmission circuits from Djibouti-Ville to Arta, some 40 km away. There is also a 20 kV circuit between Dikhil and Ali Sabieh in the south of the country. The distribution system comprises 20 kV radial circuits emanating from the main substations. Most customers are supplied at low voltage (LV) via distribution substations.

More projects using renewable energy, including geothermal energy, are planned in the near future. Table 1 presents the proportion of different energy sources used.

Table1: Installed capacity and production for electricity generation from Edd (Edd[1], 2013).

Electricity generation	Thermal power	Solar power plant	Hydro-electricity (Imported)	Total
Installed capacity (MW)	120 MW	0.30 MWc	42 MW [2]	173 MW
Production (MWh)	66 637 MWh[1]	522 MWh[3]	354 901 MWh[1]	422 060 MWh

[1] Electricite de Djibouti (Edd).

[2] Average Imported Electricity from EEPCO.

[3] Production in 2012, CERD.

2.2. Electricity generation cost in Djibouti

Electricity generation from diesel and heavy fuels represent important cost for operation and maintenance of power plants. Hot weather can also lead to rapid fatigue of the mechanical components.

The cost of electricity was decided to assure an optimum service and to prevent electricity shortages. Government legislate the price of the electricity. The Government initiate in 2012 and in 2014, a decrease of the cost of energy for the lowest and middle class.
Table 2 describes the different cost of the electricity (Edd, 2011).

Customer	Price per kWh
Social tariff (1kVa)	15c$/kWh
Residential customer	55c$ to 40c$/kWh
Industrial customer	34c$ to 42c$ /kWh

2.3 Projects planned in the energy sector

Over the next 10 years, the country has a good and ambitious program to develop and expand its energy provision, to satisfy the local demand and increase the energy access in rural areas.

Renewable energy utilization represents a part of this energy development strategy including in the 2035 development vision. Renewable Energy available like solar, wind and geothermal energy are the most important resources of Djibouti.

In the solar energy sector, the government has several projects in the pipeline, for providing rural areas with access to electricity, financed by donors and development agencies. Also the first solar PV plant with 50MW is planned to be built in the central part of the country within private funds.

Wind energy is available with wind speed ranging between 5 to 10 m/s, in the north-eastern part. The first wind farm with 60 MW power is planned to be built in 2016 supported by Qatar Electric.

However, due to the stability on the electrical grid, and high resource availability, geothermal energy is the best resource to ensure a sustainable development.
To start with, the first plant in Asal-Fiale is planned for commission in 2018 with an installed capacity of about 30 to 50 MW extensible to 100 MW.
Also other private initiatives are on discussion to exploit potential site for electricity production.

3. STATUS OF GEOTHERMAL DEVELOPMENT IN THE COUNTRY

3.1 Geology

The geology of the country is affected by the junction of the Aden gulf, the Red sea oceanic ridge, and also by the East African rifting system which constitute the triple junction system. The Afar depression (Figure 1) is the region where crustal extension occurred caused by the separation of the Arabian and African plates. This establishes the connection between the current oceanic ridge in the Red sea, and the Gulf of Aden system, which evolved into laterally intra-continental rifts. The Afar depression is connected to the southwest, Ethiopian segment.
The Aden gulf and the Red sea ridge was the most active

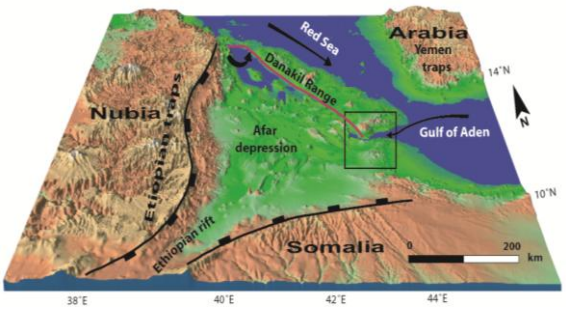

Figure 1: The rifting system and Afar depression

geological system. More than the EARV system and this lead to numerous tectonic activities over the last 20 to 30 Ma.

In the coastal areas, sedimentary rocks and rhyolites are found. Sedimentary rocks are also located in the southern

part of the country and along the stream beds (Jalludin, 2010). Almost all of the Afar depression is covered by basalt strata bound, which is partially hidden, and were created by the early stages of rifting (Barberi and Varet, 1977). Almost all the rock composition in the country is basaltic like Dalha basalts, Somali basalts, Stratoid basalts etc, as shown in Figure 2. In the north of the country Quaternary sediments are found.
Located in the south-east part of the Afar depression, the Republic of Djibouti has been the place of an important tectonic activity since the Oligo-Miocene period until today. All stages of rifting were followed by formation of depression which permits the establishment of volcanic series.

The seismicity assessment in the continental part of the rifting system describes an important movement collected in the Asal rift, the areas of the country with the most potential. Recent volcanic formation is mainly located in the Asal rift.

Figure 2 shows in dots, the surface manifestation located mainly on the rift stream bed (SW-NE trend): red dots represent the numerous hot springs and the blue dots show the fumaroles.

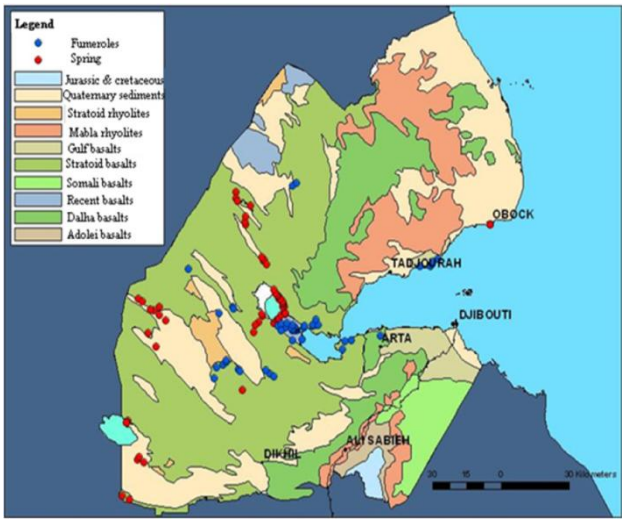

Figure 2: Geological Maps of Djibouti (CERD)

3.2 Previous study

Since 1975, several surface studies were done in the country which located around 13 potential areas for geothermal development. The main location of these prospects is along the main southwest northeast axis. The preliminary studies found an important potential area in the Asal-Ghoubhet zone, and due to the study, exploratory drilling was done in early year of 1987 in the Hanle prospect, and in the Asal prospect.

Table 3: show all the studies carried out between 1975 to 1990 from surface exploration to deep drilling in different prospects.

Geothermal Site	Exploratory Stage				Surfaces Manifestations	
	Geology	Geochemistry	Geophysics	Exploratory drilling	Hot springs	Fumaroles
Lake Asal	+ +	+ +	+ + +	+ + +	+ +	+
North-Goubhet	++	++	++		+	+
					++	++
Lake Abhe	+ +	+ +				
					+	+ +
Obock	+	+ +	+ +			
Sakalol-Alol-	+ +	+			++	+
Gaggadé	+ +	+ +	+ +	+	+	+++
Hanlé	++	+ +	+ +			++
Arta		++			++	++

Table 3: Preliminary studies in different prospects

3.3 Asal geothermal field

The Asal-rift geothermal field is located in the Ghoubhet Gulf near to the Asal Lake. This area is the most explored geothermal field in the country.

The first geothermal investigation was undertaken in 1970, by the French geological survey (BRGM). These investigations lead to the discovery of the high enthalpy geothermal reservoir. With the financial support of the World Bank and UNEP six (6) deep boreholes were drilled in the field. Table 4 resumes the characteristics of these wells drilled in the Asal field.

Table 4: Wells data in Asal geothermal field (CERD)

Wells	Depths (m)	Temp max (°C)	Gradient temperature (°C/100 m)
Asal 1	1145	261	18
Asal 2	1554	235	14,3
Asal 3	1316	280	15,51
Asal 4	2013	345	15,2
Asal 5	2105	360	15,2
Asal 6	1761	280	12,75

However, the exploration drilling showed also the high salinity of the geothermal resource, which caused scaling and corrosion of the wells. In fact, the recharge of the reservoir was affected by seawater from the Red sea, with salinity around 37 g/l and the Asal Lake, the second most saline place on the earth.

To avoid this salinity problem, the study expected to find in the Asal-Fiale caldera a better geothermal resource regarding the recharge and less saline than the previous reservoir. In 2008, geophysical measurements were carried out in this zone which confirmed the presence of geothermal resource and at a great depth. Figure 3 shows the location of the Asal-Fiale geothermal field.

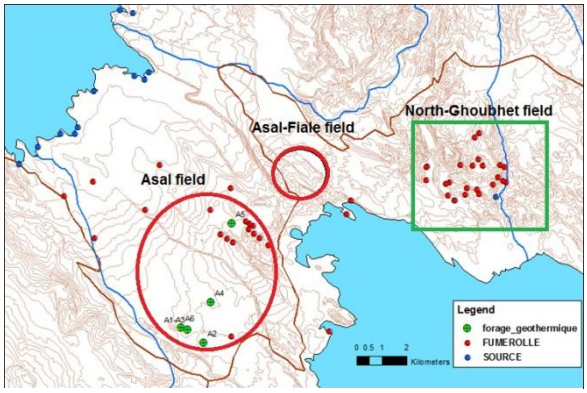

Figure 3: Location Asal field

Geophysical measurement was conducted using 106 TEM and 102 MT soundings and additional tectonic survey was conducted based on aerial and satellite images and field work data (Jalludin, 2010).

The resistivity maps in the figure 4 show a low resistivity zone around the caldera of Fiale, which demonstrates the presence of hot body in the zone. An Environmental Impact Assessment was already done in 2008 by Reykjavik Energy Invest (REI) for the Asal-Fiale zone.

This zone was the area with the most potential in the country and the previous assessment predicted a maximum reservoir capacity of about 300 MWe. The previous project (the Asal project) with the Icelandic company Reykjavik Energy Invest could not proceed as originally envisaged

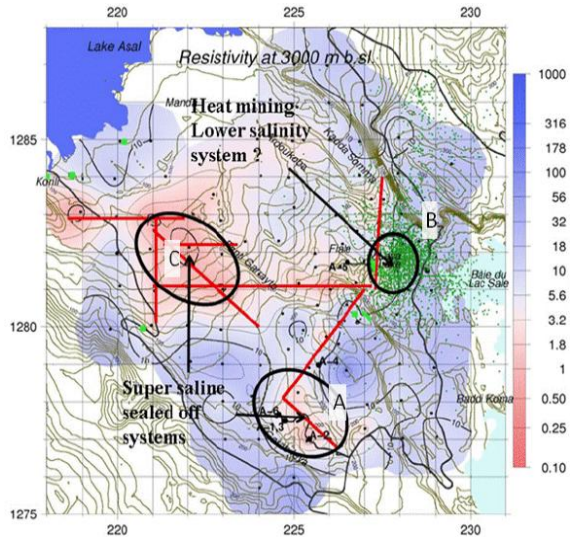

Figure 4: Resistivity maps at 3000 m.b.s.l. (REI, ISOR)

due to economic crisis experienced in Iceland in 2008.

Due to these difficulties, the Asal concession acquired by REI expired and the Djiboutian Government decided to develop the potential of the areas. In 2011, the Government of Djibouti was committed to financing and mitigating the high risk in the drilling of at least 4 wells. The World Bank (WB) are the principle financial partners in the project, with the drilling costs estimated to be around 20 Million USD.

The objective of this project is to quantify the technical and financial feasibility of the Asal-Fiale geothermal resource for large scale (50MW) power generation. This project was designed to implement exploration drilling program through which three to four full size production wells (9 5/8) will be drilled. This will be done in the Fiale Caldera, on the active rift axis, using derivate drilling techniques in order to reach good permeability conditions while crossing the vertical faulting

3.4 North -Ghoubhet Geothermal field

The North–Ghoubhet geothermal field is located close to the Asal Geothermal field in the northeastern part of the country. The area is limited to the north by the Goda mountain and the by the Red sea in the southern part, within elevation around 500 to 600 m.a.b.s.l.

The geological structure is composed mostly of basaltic rocks from Dalha and more recent basalt from Gulf. The tectonic activities of the zone are controlled by fracture networks from NW to SE following the Asal rift. Surface manifestations are mostly fumaroles along the valley of the Oued. Gravimetric measurements were done by the French geological survey (BRGM) in 1983 (figure 5) and lead to the discovery of heavy anomalies in different points but were delimited by the linear trend associated to the tectonic activity zone. Geophysical measurements using the electrical AMT were also done at the same time by the BRGM, revealed three main zones: The southern Asal rift, the northern part with heavy anomalies, and the central part along the trend NW-SE.

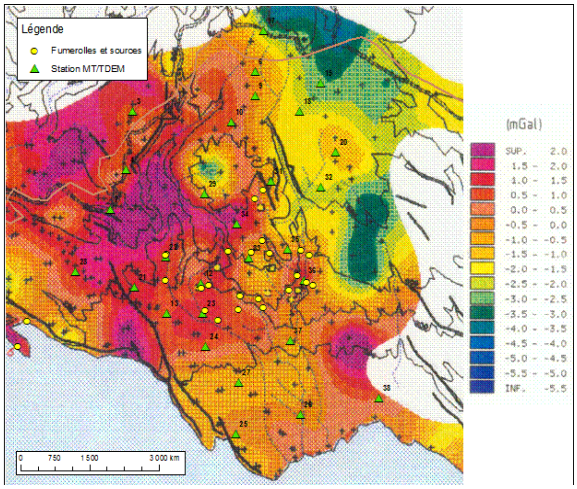

Figure 5: Gravimetry data in the North-Ghoubhet (BRGM, 1983)

To fulfill the previous study, the CERD (Center of Research of Djibouti), started an exploration study in 2010. The CERD geophysical team has done within 30 MT sounding and 26 TDEM stations with geophysical measurements using MT and TDEM measurements.

The geophysical measurements have shown that there is a conductive surface in the upper layer but in the deeper zone, at 1000 m.b.s.l, a heterogonous surface are found, with some conductive anomalies which may be associated with hydrothermal fluids.

However below the horst of Moudoueoud, the MT measurements confirmed low resistivity in the deeper zone. Geochemistry measurements were also done from fumarole sampling and the unique hot spring of the zone. The geothermometry gives a temperature range of 170°C to 220 °C for the reservoir. The chemistry of the condensate and the spring demonstrates low salinity of the fluid compared to the Asal field and the chemical mark of the fluid was bicarbonate. The recharges of the system are controlled by

the rain water from the Goda Mountain and intrusion of seawater.

This study has enabled the creation of a reservoir model of the geothermal system (Figure 6) to delineate a prospective area for exploration drilling around the horst of Moudoueoud and wells sitting for directional drilling. In the figure 6, the hot source (in red colour) is below the geothermal reservoir represented by the green color covered by impermeable zone in brown and the recharge water are displayed by the blue arrows from the Goda mountain and the marine intrusion.

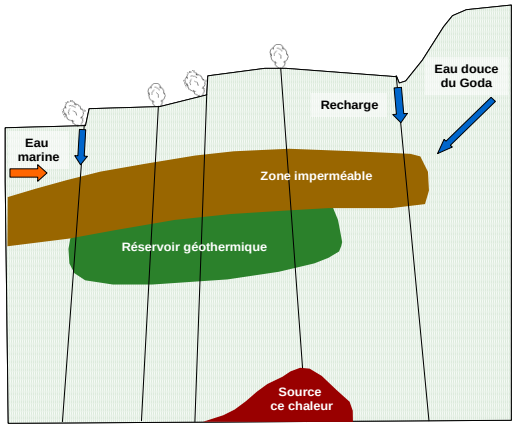

Figure 6: Conceptual model of the North-Ghoubhet field (CERD, 2010)

3.5 Lake Abhe geothermal field

The Abhe Lake is the area with the second most geothermal potential of the country. Located in the southwest of the country, the Lake named Abhe is shared between Djibouti and Ethiopia.

The geological structures of the areas were composed by stratoid basalt limited by E-W faults. Surface hydrothermal manifestations are numerous around the lake along with a rich variety of fumaroles, hot springs and many travertine constructions. Some of the travertine was higher than 60 m.a.b.s.l.

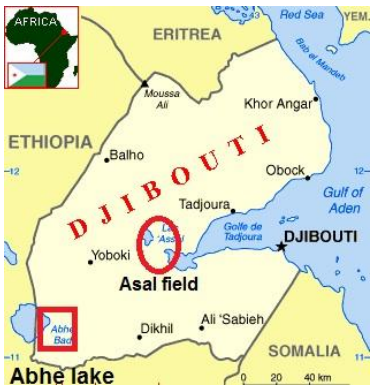

Figure 7: Field location

The hot spring manifestations are mainly located in the bottom of the travertine with high temperatures of more than 90°C. The chemical profiles of the hydrothermal source are alkaline-chloride in general and some bicarbonate from the previous studies.
In 2012, the CERD started an important surface exploration, geophysical survey with MT and TDEM and geochemistry survey are ongoing in the areas and the first results are expected at the end of 2012. Figure 8 shows in red dot the location of the hot spring and in blue the fumarole.

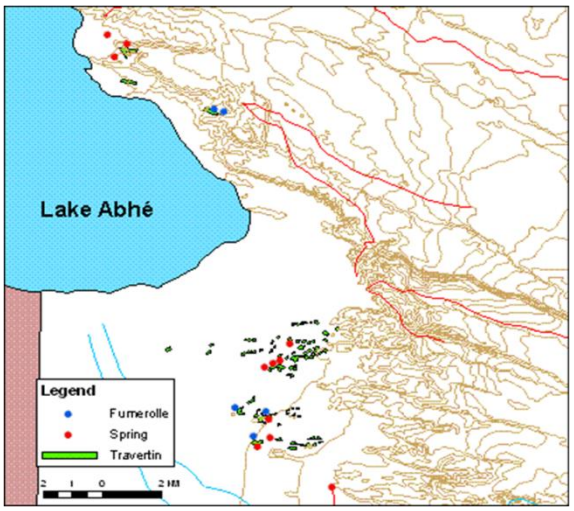

Figure 8: Lake Abhe geothermal field (CERD, 2010).

The Government has, been in discussion with private companies, to develop and exploit the geothermal field.

4. RECENT EXPLORATORY ACTIVITIES

A huge exploratory studies campaign who conducted from May 16th to June 19th, which focused on geological and geochemical studies of 13 sites with high geothermal potential distributed across the country, follows the request of the President of the Republic from the Japan Cooperation JICA.

The main focus on these studies whose to quantify and to value the undeniable potential of the basement of Djibouti to promote and develop to term these resources so that they become in the near future, the basic energy in the energy mix of the country.

This field exploration show that there are a very high potential available on the country and also permits to discovers a unknowns geothermal news site with surface manifestation (Hanle area) in the southwest part .

The maps show (figure 9) the main track location done by the JICA team and ODDEG during this field exploration campaign.

This exploration field studies takes around 40 days to cover the entire potential site within focus on geological survey of the geothermal site and the geochemistry survey.

Following this study, the result of this study will be available in mid September and a complementary study will be carry out in the end of this year, mainly a geophysical survey for a specific site selected in accordance with the management of ODDEG.

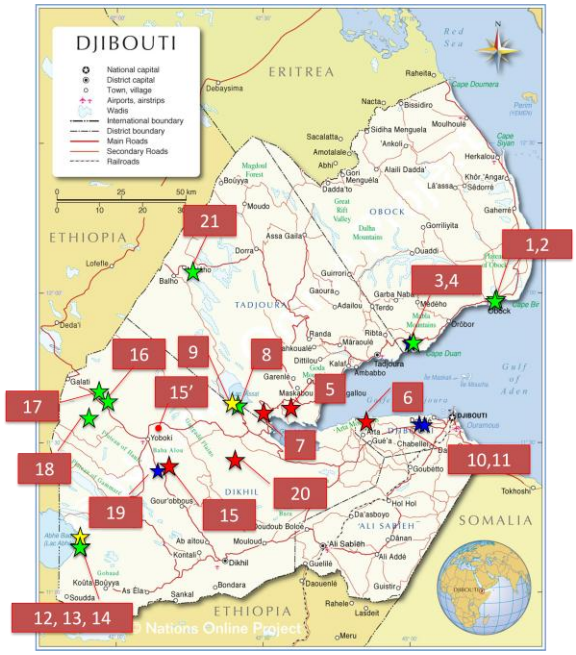

Figure 9: Sampling location point (JICA, ODDEG; 2014)

5. INSTITUTIONNAL ARRANGEMENT

In the institutional aspect, the government of Djibouti has taken several initiatives to develop and promote its geothermal resource. A clear framework has been set up; regarding the EIA assessment under the Ministry of Environmental, and Mining code manage the concession of geothermal fields under the Ministry of Energy.

The Ministry of Energy in charge of natural Resources is responsible for overall policy formulation in the energy sector. Within the framework of the policy defined by the Government, the new agency, ODDEG (Djibouti Office for Geothermal Energy Development), has these mains tasks:

- Identification of the various types of geothermal resources of the country
- The completion of exploration, reconnaissance and research work
- Conducting pre-feasibility studies and feasibility studies for the industrial development of these resources and the diversification of their uses
- The identification, with appropriate partners, public and private operators likely to ensure the development of geothermal energy, and any associated products

ODDEG is empowered to undertake all activities related to the geothermal resource development in order to make available geothermal resource for IPPs. This institution dedicated specifically for geothermal in Djibouti is under the umbrella of the Presidency of Djibouti.

6. PRIVATE SECTOR FACILITIES

The Republic of Djibouti is politically stable, and is located in a geostrategic position at the cross road of the three continents and has a favorable policy for investments.

The energy sector suffers high electricity costs in the region which enables the development of renewable energy projects and profitable businesses. The Government supports and assists the private developers through the national investment agency (ANPI) at different step of the process. Many infrastructures like operational electrical grid, dispatching control center assures interconnection of different energy resources on the grid is in commission before the end of 2012.

7. CONCLUSION

The Republic of Djibouti has an important potential in geothermal energy, estimated to be around 1000 MW. Between 2011 and 2014 active work has been done to develop the geothermal sector to achieve the government policy for green development.

The creation of the Djibouti Office for Geothermal Energy Development (ODDEG) supports this policy according to the vision 2035.

Practically, in the short term, ODDEG has to assess the huge geothermal potential available in the country through surface study and exploratory drilling.
And to set up a strategy for long term geothermal development in the country, in the other hand ODDEG is in discussion with German geological survey (BGR) for support on exploratory phase.

ICEIDA (Icelandic Agency for International Development) are helping ODDEG to build the capacity for the staff in drilling operation and management of geothermal project.

The geothermal resource will be the key to the economic development of the country and the attainment of the MDG goal and it will play a big role in improving access to electricity.

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