Proceedings of the 4th African Rift Geothermal Conference
Nairobi, Kenya, 21-23 November 2012

Geothermal Development in Djibouti Republic: A Country Report

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ABSTRACT

Djibouti is a small country located in East Africa in the area where the Gulf of Aden meets with the Red Sea. It is therefore a strategic place between Africa and Arabia with neighbors like Ethiopia, Eritrea, Somalia and Yemen. For Ethiopia, Djibouti is presently the only access to the sea. The port of Djibouti and the lines of communication such as roads, railways, electricity line between the two countries are developing very fast.(

The current population of the Djibouti Republic is estimated to be about 850 000, of which about 600 000 live in the main town of Djibouti-Ville, 95 000 in secondary towns and the remaining, 155 000, which includes a substantial nomadic population; in a rural setting.. The country's electrification rate is about 50%. Electricité de Djibouti (EdD), the national state-owned utility under Ministry of Energy and Water in charge of Natural Resources (MEERN), reports about 38 000 electricity connections for the Djibouti-Ville metropolitan area. Demand in Djibouti-Ville area is currently supplied from two main power stations – Boulaos and Marabout. Boulaos has an installed capacity of 100.3 MW and comprises 15 medium speed diesel generating units operating on heavy fuel oil. The older Marabout power station has an installed capacity of 14.4 MW, with 6 medium speed diesel generating units operating on diesel oil and is used only in summer (demand peak).

The Ethiopia-Djibouti interconnector became operational in May 2011 and 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.

Forecasts of future demand have been developed. In the base case, the peak annual demand is expected to increase from 75 MW in 2010 to 138 MW in 2015 and 219 MW in 2035. This provides an idea of a minimum target for geothermal energy development.

1. INTRODUCTION

1.1 A Unique Geodynamic Context

The position of Djibouti Republic is unique in terms of geodynamics. It is located at the eastern extreme of the Afar triangle where two oceanic ridges (Gulf of Aden and Red Sea) meet with East African Rift.

Owing to Djibouti's 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.

In contrast to Iceland however, the climate is rather arid, necessitating that geothermal exploration pays attention to the geothermal sites recharge conditions.. The experience obtained from the Asal site, since the 1970's, enables Djibouti to keenly consider the issue of hydrogeological parameters of the reservoirs - notably water recharge and quality.

2. DJIBOUTI'S GEOTHERMAL DEVELOPMENT PROJECT

2.1 Objectives

The three main objectives of the geothermal development program of the Ministry in charge of energy are to:

i. Develop a site located in a favorable situation that responds to Djibouti-Ville's, present energy needs estimated 50 MWe
ii. Explore the country's overall geothermal resource potential to respond to the needs of other consumption centers and
iii. Identify commercially exportable geothermal reserves for future broader interest developments.

2.2 The Project's Operations

The existence of Djibouti's geothermal resource has been known for 40 years. So far, there have been several unsuccessful efforts geared towards the resource's commercialization. Geothermal exploration therefore remains an important issue for the Republic, in regards to self-dependency in electric power production and climate change mitigation.

The new Ministry of Energy, Water and Mineral Resources is in charge of this ambitious development and works closely with its own team of professionals, . It now relies upon its own team, the Djibouti national scientific center (CERD), while benefiting from the assistance of various international agencies.

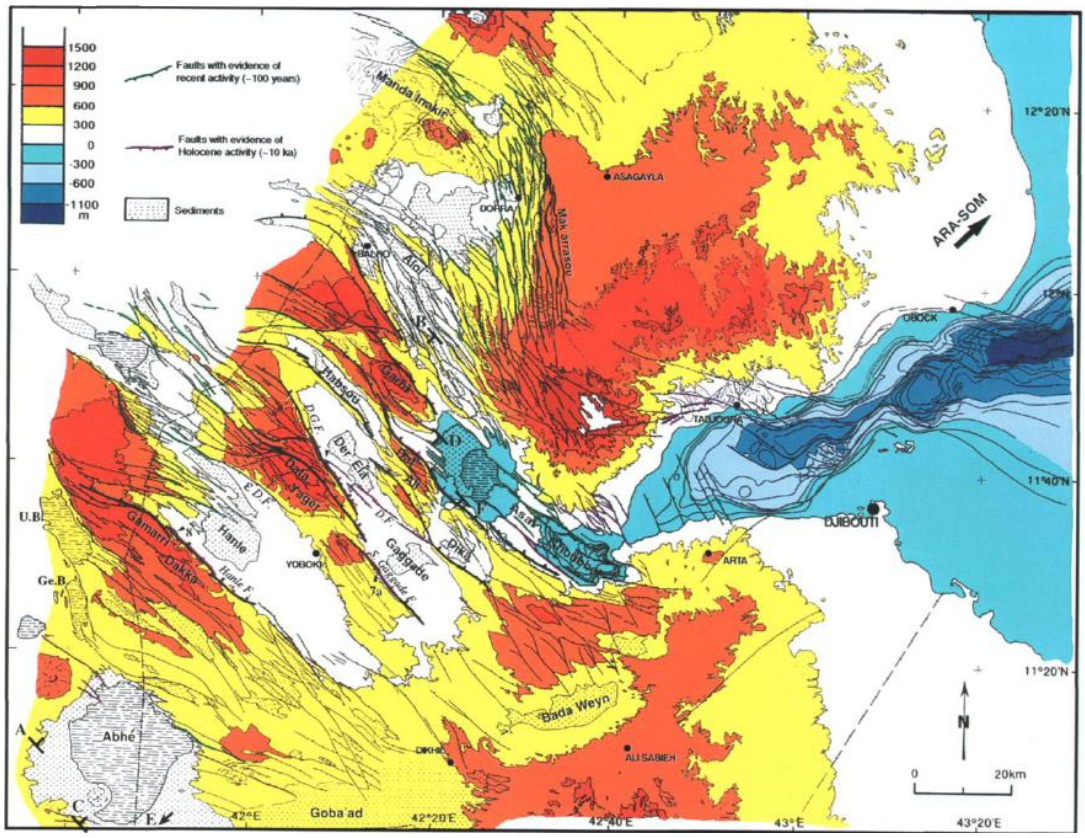

Figure 1: Topographic and bathymetric base map of Djibouti Republic with the . major tectonic features and Geothermal sites. . The penetration of the Aden Mid-Oceanic Ridge into the African continent is shown in the gulf of Tadjoura, with a progressive up-rise from East to West. The rift axis emerges in the Asal part of the Ghoubbet segment. Another active spreading segment is found North in Manda-Inakir, linked to Asal through the Makarassou (N-S) faulted zone.

3. HISTORY OF GEOTHERMAL EXPLORATION

Djibouti's geothermal exploration can be divided into two main historical phases:

Phase one: Focused around an exploratory survey conducted by BRGM (France) in 1970 which showed several possible potential geothermal areas from Lake Asal to Abhe Bad. With the two initial drillings in the Asal rift in 1975, BRGM recognized a deep reservoir at 1100m depth with a high mineralization fluid (120g/l) at 260°c. Well Asal1 showed low production and was eventually plugged with sulphides scaling at the flash point in the well.

Phase two: Centred around exploration of Hanle Gaggade area, in 1981 by Aquater (Italy), with the hope of finding less salty fluids away from the salt-saturated site of lake Asal. Two deep drillings in Hanle met only low temperature aquifers at depth; therefore the project continued to Asal rift with drillings of Asal3, Asal4, Asal5, and Asal6.

A scaling and corrosion study was also carried out by Virkir Orkint (from October 1989 to April 1990). Additionally, a second production test was performed by flowing Asal3 well. Wellbore scaling of Asal3 well was

also studied and some scale inhibition chemicals used in an attempt to alleviate the scaling problem. However, the program again failed on commercial developments due to the difficult fluid conditions.

More recently (from October 2007 to March 2008), the Iceland company named Reykjavik Energy Invest (REI) performed a new pre-feasibility study in the Asal rift zone. The results of this study were found to be conclusive and REI sought to proceed to the next feasibility and development phases. Due to of financial

crisis in Iceland, REI failed to perform the planned feasibility study, a situation that resulted in the stalling of the project for a few years.

A financial consortium led by the World Bank with AfDB, OPEC fund and eventually GEF and AFD are presently funding on-going geothermal efforts since a few months ago.

4. ASAL'S CURRENT GEOTHERMAL PROJECT

4.1 Background

To advance Djibouti's geothermal resource development, the government of Djibouti under the new minister of Energy, Water and Natural Resource, formally requested the World Bank's support, in 2011, for a new exploration and development program including the feasibility of Asal geothermal project centered on Fiale site. The financial support from the World Bank, together with ADB, OPEC fund, and eventually GEF and AFD will target drilling 3 to 4 deviated wells and carry on production tests so as to open the site for commercial development with much lighter industrial risks. This new approach is now under progress.

4.2 The Project's Objective

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 while ensuring the present base load needs of Djibouti are met. 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.

4.3 The Fiale Site

The Fiale site selected for this geothermal prospect is located in the South-Eastern part of Asal rift, a third of the way between Ghoubet al Kharab golf in the South-East and Lake Asal in the North-West. It is situated in a zone of crustal separation on the south Eastern outskirts of the Afar triple junction area. The Asal rift is located in an active volcanic area and it is presumed that seawater is infiltrating into the geothermal formation below sea level therefore the resulting fluid in the geothermal reservoir carries a large amount of dissolved solids. These solids precipitate out of the solution in the well of the geothermal wells and into the equipment connected to the well head when the well is flowing.

Therefore the Asal Rift is the most active structure in Djibouti. This volcanism is fed by a magma chamber that still exists below the rift at shallow depth.

A total of six deep wells have been drilled in the past. Four of these are in the South-West. Asal 4 is located 1.5km to the North- East of these wells and Asal 5 is 3.2km further to the North-East. The highest subsurface temperature was measured there.

The ISOR study essentially confirms the findings of the earlier studies and the presence of a magmatic heat source and the anticipated recharge of a geothermal reservoir by seawater which traverses the rift through permeable conductors (open faults) connecting the Ghoubet Sea to the Lake Asal. The presence of cross faulting characteristics which suggest geothermal fluid presence and recharge capacity was also confirmed. In addition surface manifestation including the presence of significant and active fumaroles support the conclusion concerning the presence of a shallow geothermal reservoir. Based on the conclusions of former geophysical studies performed in the Asal rift area, including the ISOR studies through REI, the governments of Djibouti and the World Bank concluded that the Fiale caldera provides the best potential for successful geothermal drilling and the project will therefore focus on this area (Figure 2).

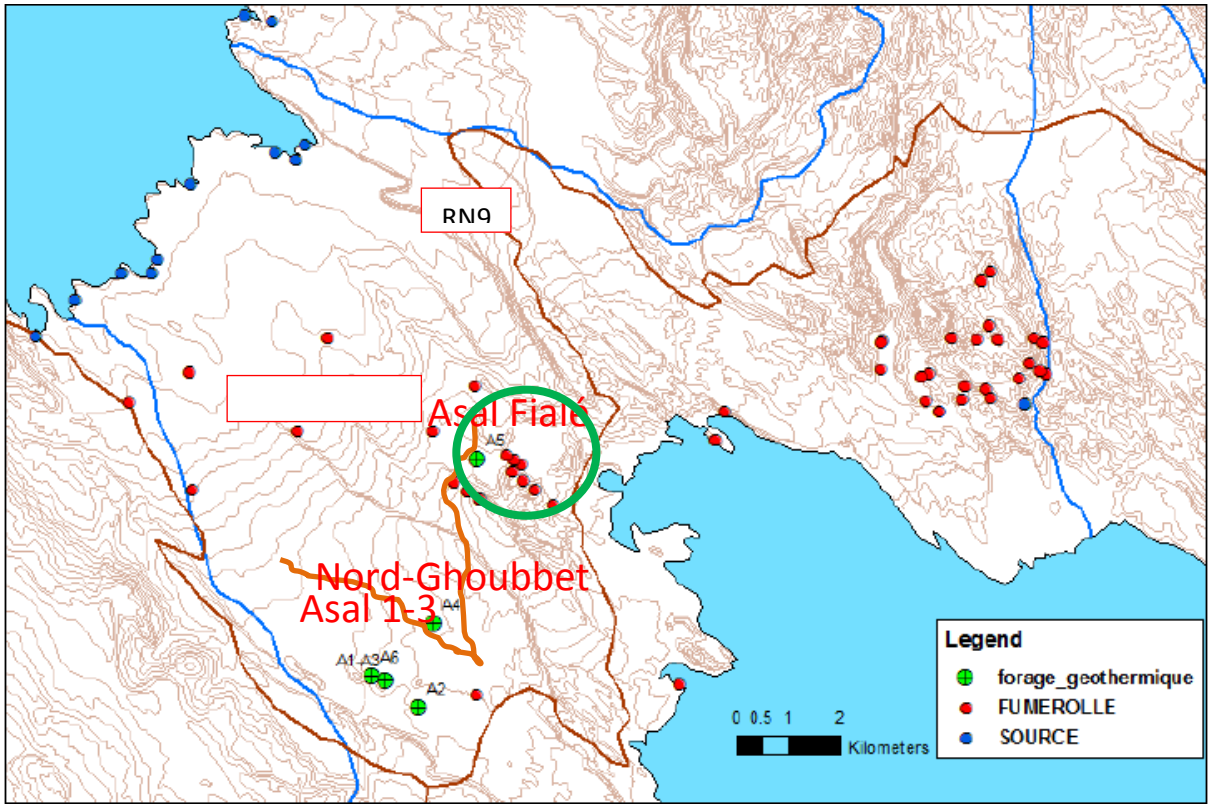

Figure 2: Topographic map of the eastern part of the Asal geothermal site, selected for geothermal development under a public banking consortium led by the Word Bank (green circle); also including the western part of the Nord-Ghoubbet block. The sites of previous exploration wells are shown (green dots), with A1 to A4 and A6 located on the southern flank of the rift, whereas the new targeted area (green circle) is located on the middle of the axis, in and around the Fiale Caldera where A5 was drilled. The numerous fumaroles are shown (red dots) along the rift axis as well in the Nord-Ghoubbet area in the surroundings of Waddi Afaï. The asphalted road (RN9) is shown and passes very near to the Fiale caldera. Also shown is the track reaching the geothermal area of Nord-Ghoubbet

5. CAPACITY BUILDING

This project is designed to strengthen local capacity. An international Project Manager will be recruited to lead this complex operation. However the project will be led by a Project Management Unit (PMU) focusing on local coordination and capacity building of the Local Deputy l Project Coordinator from the Ministry of Energy who will benefit from both the experience of the international Project Manager and the knowledge they will gain during this project's implementation.

6. NEXT STEPS

Recommendations made based on the positive drilling results for power feasibility, will be implemented. The Djibouti government will, with World Bank's support competitively offer the geothermal resource of up to 50MW, to Public-Private Investments (PPIs) for use in electric power generation, under a long term tariff power supply contract.

7. OVERVIEW OFDJIBOUTI'S GEOTHERMAL PROSPECTS

From general geodynamic and geologic considerations, it appears that Djibouti can potentially meet its large geothermal demands and eventually – as in Iceland - attract foreign energy consuming industries willing to benefit from renewable non-emissive energy sources located in proximity with sea transportation facilities.

There are at least seven prospect area (Fig.3), namely:

i. The Asal site already described
ii. Nord-Ghoubbet area
iii. Manda Inakir area
iv. Abhe bad area
v. Obock site
vi. Roueli area (near Tadjoura)
vii. Garabayis site

These geothermal sites directly result from the geodynamic conditions of the Djibouti Republic, explained as: Gulf of Aden spreading centers extends as a series of an echelon rifting units separated by transform faults into the gulf of Tadjourah and on to land at Ghoubbet al Kharab and Asal. The active rift then extends North Westward through Asal rift and further North to Manda Inakir rift through the Makarassou transform faults area. However, some spreading also develops along the NW extension of the Asal rift through the Alol and Sak Alol grabens, also affected by numerous thermal manifestations. A series of semi parallel depressions are found extending south to the border with Ethiopia. These may be old rifts but are known to also be seismically active, while they display thermal manifestations, due to tectonic readjustments (i.e.

block rotation) between the Manda-Inakir and the Manda Harraro major spreading rift segments.

- Djibouti's geothermal prospects can be divided into four groups on the basis of their geodynamic position. All are recognized by surface manifestations and fumaroles, hot springs, hydrothermal deposits and ground water anomalies:Those in an active emerged rift : Asal and Manda Inakir
- Those on site of intense deformation (transform fault and rotation) in the vicinity of active ridges: Nord Ghoubbet,
- Those located nearby and allowing to reach the oceanic ridge : Obock and Rouéli (East of Tadjourah),
- Those located inland along Graben (Abhe Bad, Alol-Sakalol) or on active transverse fractures: Garabbayis.
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According to the energy needs of the small town centres of the country, some of the prospects such as Obock, Rouéli (East Tadjoura), Garabbayis and Abhe Bad have higher priority.

8. TOWARDS A FUTURE DEVELOPMENT STRATEGY

Although not finalized yet, a development strategy is being conducted by the Ministry of Energy, Water and Natural Resources in order to respond to the present needs of the population and plan for future developments. The idea is for the development to prioritize on the use of local resources.

This calls for looking at the country from two categories:: those in which geothermal energy development is feasible, and those where other sources should be considered. In this respect, the Republic of Djibouti is gifted with two other renewable sources of energy: solar and wind. It appears that two areas should preferably rely upon wind and solar energy sources. These are the north-easternmost part of the country (along the Bab El Mandeb straight, at the southern end of the Red Sea), and the south-easternmost part of the country (the Ali Sabieh horst area). The two parts of the republic are characterized by geological formations older than 3 My, with rather stable geodynamic conditions and lack of thermal anomalies.

The rest of the country suits geothermal development, either through expansion of the electric distribution grid from major production units located in the central part of the country (that is Asal and Nord-Ghoubbet areas), or through development of local small to medium size power units using Organic Rankine Cycle (ORC) technologies. In this report, we will only refer to the names and the development perspectives of these sites, as other detailed papers presented in this conference describe the geothermal parameters of each of these area

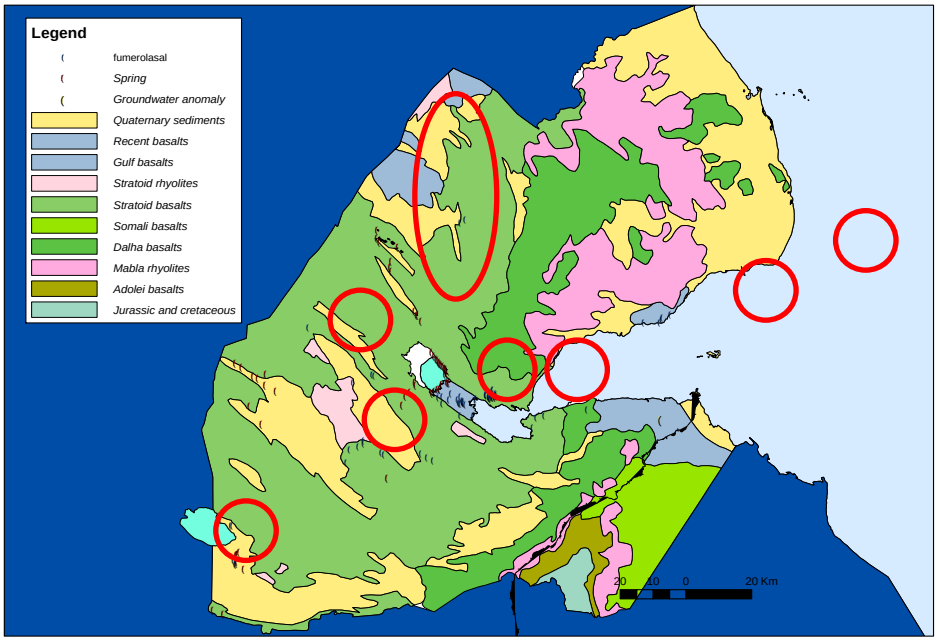

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Figure 3: Simplified Geologic map of Djibouti Republic, with indication of the hydrothermal manifestations : hot-springs (red), fumaroles (blue). The geothermal sites selected for further investigations and development are drown in red circles or ovals.

9. OVERVIEW OF DJIBOUTI'S GEOTHERMAL SITES

9.1 Geothermal Sites Along the Active Oceanic Ridge, Suitable for Conventional Geothermal Plants Development

In addition to Asal, the Nord-Ghoubbet site prospect is situated on the North-East shore of the Ghoubbet oceanic rift, close to the Asal rift zone. It constitutes an interesting geothermal site and represents the alternative or complementary zone after Fiale site. The advantage of this site, located in the immediate vicinity of the active Ghoubbet rift segment, is two-fold: it is deemed to have less saline fluid thanks to the water flowing from the Goda mountains, while it is affected by intense and multiple open faulting due to the rotation of this fragile block between the Asal-Ghoubbet rift segment and the more typically oceanic ridge in the gulf of Tadjoura.

The Obock prospect is close to the town of Obock on the Northern shore of the gulf of Tadjoura, whereas the Rouéli site is located East from Tadjoura, the most important town and port of northern Djibouti Republic. Resurgence of several hot springs and fumaroles are observed on several sites on the shores, whereas sedimentary beaches or rocky mountains, located along both normal rift (E-W to WNW-ESE) and transverse faults (NE-SW). Geochemical analyses indicate reservoir temperature of 210°c. These sites are in the short term considered ideal for local plant developments in the range of a few MWe, and in the long term for a more innovative, ambitious approach including the study of deep-seated supercritical fluids underneath the Tadjoura oceanic ridge in the frame of the International Deep Drilling (IDD) Project.

The Manda-Inakir site is located north, near to the triple boundary with Ethiopia and Eritrea. This wide area includes recent quaternary volcanic activity as well as fumaroles and hot-springs sites developed along rift as well as transverse faults. The demand is presently low, limited to answering the needs of small villages, but there is no doubt that providing local power would help for development, notably immediate agro-pastoral needs and future communication and transport network

Table 1: Scoring of sites for high enthalpy development located along the rift axis in Djibouti Republic

Geothermal site along the ridge	Heat source	Permeability	Water recharge quality	Potential size of the site	Geothermal knowledge	Demand size grid proximity
Asal	+++	+	-	++	+++	+++
N-Ghoubbet	++	+++	+++	+++	++	++
Rouéli	++	+	+	+	+	+
Obock	++	+	+	+	-	-
Manda-Inakir	++	++	++	++	-	-

10. POTENTIAL OPPORTUNITIES FOR MEDIUM ENTHALPY ORC PLANTS RESPONSIVE TO LOCAL NEEDS

Outside the identified oceanic ridge, several sites are already identified as suitable for answering the local needs. In this context, ORC plants can be developed, the size of which will depend upon two factors: the quality of the site in terms of geothermal potential, and the importance of the local demand. To this respect, some of the sites placed in the first category, i.e. suitable for eventually important high enthalpy development could justify installing in a first step, a small-size medium enthalpy plant only due to the limited demand at present. Note that in a few cases, the local demand may just be fed by the binary plant, due to the limitation of the resource parameters.

In the places located outside the above mentioned set, one interesting site was identified due to the demand locally, and to its limited but still attractive potential: that is Garabbayis answering the need of development axis of Dikhil-Yoboki.

The Abhé site could eventually be significant in size, but limited in terms of temperature to ORC technologies. However, due to the agro-pastoral potential of the area, other direct applications of the geothermal fluid could develop and could include drying, fish farming and cooling.

Besides those two places, several other sites are certainly suitable for small-size ORC medium enthalpy units exploiting local hydrothermal manifestations answering local demand. Several such sites were identified in the North-Western part of the Republic, notably North-East of Asal in populated areas of Allol and Sakalol as well as around Gaggadé to the East.

There is a need for exploration work to be developed specifically for this purpose, combining precisely the villages locations and population concentrations with the fumaroles and thermal emergences related to transverse faults. It may well be that up to 10 such sites could be identified. Table 2 tries to synthetize the present views of the ministry combining all site characteristics.

Table 2: First attempt to establish a hierarchy of potential geothermal sites of Djibouti Republic for development planning according to local geothermal potential and considering present and future demand (a base for discussion with experts, to be completed).

Geothermal site	Enthalpy	Future demand type	Present needs	Potential size of the site	Geothermal knowledge	Size order (short term)
Asal	High	High (grid)	50MW	Large	++++	50 MW 2016
N-Ghoubbet	High	High (grid)	Be prepared	Very large	++	50 MW 2020
Rouéli	High	Future high	Medium	Large	+	2 MW 2018
Obock	High	Future high	Small	Large	-	5 MW 2015
Manda-Inakir	High	Small	Small	Large	-	1 MW 2015
Abhé	Medium	Small	Small	Medium	++	1 MW 2015
Garabbayis	Medium	Medium	Medium	Small	+	1 MW 2015
Karapti San	Medium	Small	Small	Small	+	1 MW 2015
Balho	Medium	Small	Small	Small	-	1 MW 2015
sites to be identified (W)	Medium	Small	Small	Small	-	1 MW 2020 Up to 10

11. CONCLUSION

The Ministry in charge of Energy is presently confronted with two major issues. These are to develop:

(i) Practically, in the short term, the geothermal sites with a capacity to answer the immediate needs, and at the same time to engage a sound strategy for long term geothermal development in the country. This should rely upon the improvement of the geological knowledge of the sites, as well as upon the approach of the most appropriate technologies, in order to adapt the costs of the exploration and drillings to the targeted size of the site.

(ii) A prospective view of the demand, taking into account figures already available concerning Djibouti's capital and port, but also the future development axis (as f.i. the two railway projected lines and induced development).

This should take into account the attractiveness of the Djibouti Republic to foreign industrial investments due to the geothermal resources located along the coasts of the Gulf of Tadjoura (as in Iceland for aluminum plant developments along the coasts of the Reykjanes peninsula).

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