Geothermal Energy in Madagascar: Assessment Development Update

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Abstract

The overall objective of the study is to develop geothermal energy to complement hydro and other sources of power to meet the energy demand of rural areas in sound environment.
The exploration of geothermal energy in Madagascar is still at an early stage. In last recent years, the country evaluated its geothermal resources using geology, geochemical data analyses and geophysical measurements. The preliminary results of this exploration indicate that about 130 natural geothermal outcrops are recognized in the country. The distribution of thermal springs, heat flow and the nature of the geothermal reservoirs are controlled by the geological structures. The geothermal areas can be divided in three sections: volcanic terrain, fault zone, and sedimentary basin. Resources and geothermal systems are of two types: volcano-tectonic and tectonic. Low and medium geothermal energy are widely spread in the vast area of the island.
Concerning the possibility of electrical geothermal energy production, Madagascar is believed to have a geothermal potential which is estimated to be in excess of 350 megawatts and it presents a huge number of medium and low enthalpy geothermal zones of interest. It is well known that the geothermal systems of medium temperature exist in the recent volcanic area, and the possibility of drilling into a medium temperature geothermal reservoir is high, especially in the north and the central part of the country.
Despite the availability and enormous potential in direct use applications, little use has been made of low to medium enthalpy fluids in Madagascar. Available opportunities are numerous including swimming, bathing, balneology, agricultural, aquaculture and in residential and industrial sectors.
This paper gives an overview of Madagascar energy sector and presents the geothermal development update of the country. Barriers to direct use development, recommendations to accelerate direct use growth and benefits to the Malagasy economy are also reviewed.

Keywords: *Madagascar, exploration, geothermal energy, electricity, direct use*

Résumé

L'objectif principal de la présente étude est de développer l'énergie géothermique en complément des centrales hydroélectriques ainsi que d'autres sources pour pouvoir faire face à la demande d'énergie des régions rurales dans un environnement sain.
L'exploration géothermique est encore au stade de début. Depuis quelques années, le pays a évalué ses ressources géothermiques en utilisant les données géologiques, géochimiques, géophysiques et thermodynamiques. Les résultats préliminaires de cette prospection indiquent à peu près 130 occurrences en sources thermales recensées dans le pays. La distribution de sources chaudes, les sources de chaleur et la nature des réservoirs géothermiques sont contrôlées par les structures géologiques. Les régions géothermiques peuvent être divisées en trois sections: terrain volcanique, zone de faille et bassin sédimentaire. Les ressources et les systèmes géothermiques sont de deux types: volcano-tectonique et tectonique. Les régions géothermiques de basse à moyenne énergie sont largement étendues dans l'île.
Concernant la possibilité de production d'électricité, Madagascar possède un potentiel géothermique estimé à plus de 350 mégawatts et présente un certain nombre de zones géothermiques intéressantes de basse à moyenne enthalpie. Il est universellement admis que les systèmes géothermiques de moyenne température existent dans les champs volcaniques récents, et la possibilité d'effectuer des forages dans un réservoir géothermique de température moyenne est ainsi très élevée surtout dans les régions centrales et nord du pays.
Du point de vue usage direct de la géothermie, en dépit de la disponibilité et de l'énorme possibilité, on n'utilise qu'une faible partie pour les fluides de faible à moyenne enthalpie. Les occasions disponibles concernent la balnéothérapie, l'agriculture, l'aquaculture ainsi que les secteurs résidentiels et industriels.
Ce rapport de synthèse donne une vue d'ensemble du secteur énergie à Madagascar et présente la mise à jour du développement géothermique du pays. Les barrières dans le développement de la géothermie, les recommandations pour accélérer son exploitation et les avantages pour l'économie nationale sont examinées.

Mots clés : Madagascar, exploration, géothermie, électricité, usage direct

1. PROBLEM STATEMENT AND OBJECTIVES

Madagascar is currently confronted to an energy supply problem. Indeed,

- Energy consumption in Madagascar is low in per capita terms and underdeveloped by structure;
- Most of the population use firewood and charcoal and thus creating deforestation;
- Imported petroleum fuels on the other hand dominate the local industries energy;

The solution to this problem is the use of alternative energy.

Knowing that:

- Madagascar has considerable potential for developing a broad range of renewable energy resources (RES), principally geothermal, biomass, mini hydro, solar, and wind;
- Madagascar has a large number of discharging thermal springs and
- There are many sites throughout the country that may have potential for utilization of geothermal resources.

The long term solution is the geothermal development.

These are the main reasons why we are developing this study in which the objectives are

- to provide a description and explanation on geothermal resources in Madagascar as one of the priority of energy development,
- to develop geothermal energy (electricity) to complement hydro and other sources of power to meet the energy demand of rural areas in sound environment,
- to mitigate rural poverty through sustainable geothermal energy development, and
- to present the geothermal development update of the country **.**

2. ENERGY STATUS

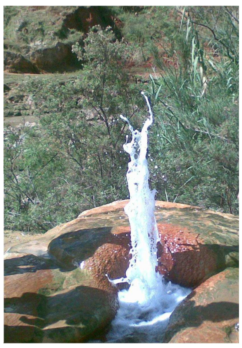
Madagascar has an installed total electricity generating capacity of 810 megawatts (1MW = 10^6 watts). However only 753.3 MW (data of 1999) is consumed. The bulk of the capacity (electricity production by source) is derived from fossil fuel (37.04%, imported) and from hydro source (62.96%). The national cover rate is of about 15% only and the rate of access in the rural environment is less than 5%. The average cost of electricity for domestic consumers is about US$ 0.14 (276 MGA) per kilowatt hour. This high cost is principally due to use of expensive imported diesel fuel to feed the thermal plants.

Therefore, the priority is to develop other indigenous energy resources of the country, such as geothermal energy, in order to meet the increasing energy demand and reduce polluting thermal stations.

3. GEOTHERMAL POTENTIAL

The geothermal potential of Madagascar is estimated to be more than 350 MW (Andrianaivo, 2008a). Madagascar hosts several signs indicating the presence of geothermal resource such as volcanoes (young/dormant), hot springs, geyser, travertine mound and seeps (Figures 1a and 1b).

The distribution of hot springs, heat flow and the nature of the geothermal reservoirs are controlled by the geological structures. Based on the association of geological setting, the geothermal areas can be divided in three sections: volcanic terrain, fault zone, and sedimentary basin. Resources and geothermal systems in Madagascar can be grouped into two main types: volcanotectonic and tectonic. Geothermal potential in the field volcano-tectonic generally may have a moderate to medium potential.



Figures 1a and 1b: Seep and geyser at Andranomandevy Itasy

Following preliminary reconnaissance studies, three important zones presenting a geothermal potential interest for electricity production can be selected (Andrianaivo, 2008a):

- the northern part geothermal zone : Ramena, Sambirano, Ankaizina
- the Itasy geothermal zone and
- the Antsirabe geothermal zone in the central parts (Figure 2).

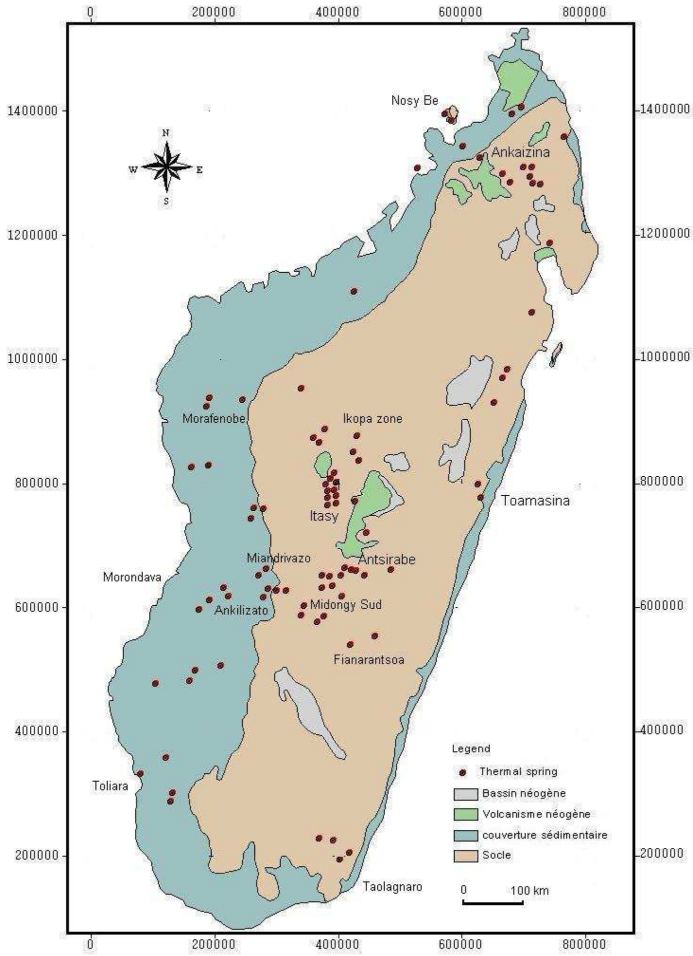


Figure 2: Map showing the localization of thermal springs (Besairie, 1959a)

4. GEOTHERMAL ASSESSMENT DEVELOPMENT

Exploration of geothermal energy is still at early stage. The important dates are summarized as follow:

- 1927-1959 (Besairie et al): reconnaissance mission and limited surface exploration (thermal springs data collection)
- 1980 (Virkir Co): reconnaissance survey for geothermal resource showing 5 sites of interest with reservoir temperature of more than 150°C (Gunnlaugsson et al, 1981)
- 2007 – 2008: beginning of geothermal project (by Marshfield Energy PTE Ltd., and by "GNS Science")
- 2008: investigation of Itasy and Antsirabe areas indicating reservoir temperature of more than 150°C).

The current study has focused on geology, geochemistry, hydrology and geophysics with the aim of elucidating subsurface temperatures and the spatial extent of the geothermal systems.

The results indicate that the geothermal activity in the three areas is related to volcanic and tectonic activities (Table 1), which has a higher heat flow than the surrounding Precambrian crust.

Subsurface temperatures between 60-155°C for the northern part of the island (Ramena, Sambirano, Ankaizina), 92-154°C for Itasy and 75-171°C for Ankaratra-Antsirabe in the central part have been predicted by geothermometry and mixing models (Gunnlaugsun et al, 1981; Sarazin et al, 1986; Manissale et al, 1999; Andrianaivo, 2008a; Ramasiarinoro and Andrianaivo, 2010).

Table 1: Potential and distribution of geothermal systems in Madagascar

Type		Temperature/Enthalpy	Potency	Example
Volcanic	Single Stratovolcanic	High > 200°C	High > 100 MW	?
Volcano-tectonic	(graben and volcano)	High – Medium 150 - 200°C	High – Medium 50 - 100 MW	Itasy, Ankaratra, Nosy be, Mt. Ambre, Ankaizina
Non volcanic	Intrusion	Low – Medium < 150 °C	Low – Medium < 50 MW	Fault zone: Andavakoera, Antongil-Doany, Anosyan chain, Sambirano, sedimentary basin

5. GEOTHERMAL ENERGY POTENTIAL ESTIMATION

The method used in estimating the amount of potential geothermal energy could be done by using the comparison method and the volumetric method. Comparison method is used to estimating the speculative potential resource and volumetric method is used to estimate the potential of geothermal energy resources of hypothetical, possible, probable and proven reserves (White and Williams, 1975; Brook et al., 1979; Miyazaki et al., 1990, Ofwana, 2005, etc.)

For example, the obtained prospect area (Andranomafana) is approximately 9 km^2, which was predicted based on geochemical anomaly, soil anomaly, the presence of a group of small geyser, griffin and the presence of deposit tufa trend.
The estimated reservoir temperature is at about 160°C considering the geological environment which is still associated with Quaternary volcanism.

The calculation of geothermal energy potential is made using the following assumptions (Andrianaivo, 2008a):

- The average rate of saturated density = 2.5 * 10E3 (kg/m^3)
- The average rate of specific heat = 1 * 10E3 (kJ/kg °C)
- The average thickness of reservoir =1 * 10E3 (m)

For Andranomafana geothermal area, the heat storage (J) obtained is:

$$HS = T(°C) * A(km^2) * 10E6 * 1 * 10E3(m) *2{,}5 * 10E3(kg/m^3) * 1 * 10E3(J/kg\ m^3)$$
$$= 3{,}375 * 10E18\ J$$

To calculate the electric potential, the following assumptions are used (Andrianaivo, 2008a):

- basic temperature of heat source for minimum generation of 120°C
- 30 years of exploitation period (=1 * 10E9 s)
- Rates of resource extraction efficiency and generation efficiency = 0,035

The electric potential (MW) is

$$P = 2{,}5 * 10E15 * A(km^2) * (T- T_{cut\text{-}off}) * 1 * 10E\text{-}6 * 0{,}035 * 1 * 10E\text{-}9\ (/s)$$

For $T_{cut\text{-}off}$ = 120°C,
The potential = 0,0875 * A (km^2) * (T-120°C) ≈ 31,5MW
For $T_{cut\text{-}off}$ = 150°C
The potential = 0,0875 * A (^{km2}) * (T-150°C) ≈ 7,5MW

Thus, the potential of electricity that can be generated from geothermal field of Andranomafana, depending on the type of plant that determines the turbine inlet temperature from 7,5 MW to 31,5 MW for 30 years of exploitation (Andrianaivo, 2010; Andrianaivo, 2009; Andrianaivo, 2008a; Andrianaivo and Ramasiarinoro, 2010).

Indeed, from an economic and technical point of view, a geothermal field would have yielded profit after 30 years of operation. By this time, the wells, pipelines, power plants and other facilities might have also given in to normal wear and tear. However, the field can continue producing steam and generating power by drilling new wells and installing new facilities. The favorite example is the first geothermal field in Larderello Italy which was developed in 1904 and today, is still being used for power generation. With proper management, including "recharge" a geothermal resource can be made sustainable.

6. GEOTHERMAL RESOURCES UTILIZATION

The two main utilization categories power generation and direct use are already introduced in many countries around the globe; further, expanding distribution is possible and should be increasingly enforced.

Direct heat use is one of the oldest, most versatile and also the most common form of utilization of geothermal energy. Bathing, swimming and balneology (therapeutic use) are the best known forms of utilization in Madagascar (Figures 3 and 4).

Figure 3: swimming pool

Figure 4: Balneotherapy station

Other opportunities include: geothermal space conditioning (heating and cooling), agricultural applications (mainly greenhouse heating and some animal husbandry), aquaculture (mainly fish pond), industrial processes, and heat pumps (Andrianaivo and Rasolomanana, 2011).

7. ADVANTAGES OF GEOTHERMAL ENERGY

The advantages of geothermal energy are numerous: great, still only marginally developed potential, available around the clock (= provides base-load power), ubiquitous, indigenous, environmentally friendly, economically rewarding energy.

Deep geothermal energy is an ecologically and economically worthwhile possibility to utilise existing resources in the environmental-friendly way. That renewable generation of energy provides a base load supply around the clock, independently from sun, wind and primary or secondary fuel. There is no smoky air around geothermal power plants (no environmental problem).

Unlike the fossil energy such as oil and coal, the geothermal is categorized as renewable energy by maintaining the water content that interacts with the heat source in the subsurface.

Geothermal power plants can have modular designs, with additional units installed in increments when needed to fit growing demand for electricity.

Geothermal projects can offer all of the above benefits to help developing countries grow without pollution.

8. BARRIERS

Barriers to the development of geothermal energy are discussed in previous study (Andrianaivo and Rasolomanana, 2011). The following are some of the examples:

- There is no detailed research on the geochemical characteristics of various Madagascar geothermal resources
- Insufficient information is publicly available to evaluate the individual resources
- Barriers to the financing of geothermal energy may be:
  - ✓ high front-end capital cost per kW installed and negligible variable costs (operation and maintenance),
  - ✓ many renewable energy technologies remain expensive compared to conventional energy supplies,
  - ✓ limited human capital investment and development , etc.
- Non-technical Barrier:
  - ✓ lack of government policy support
  - ✓ lack of consumer awareness on benefits and opportunities of renewable energy
  - ✓ lack of stakeholder/community participation in energy choices and renewable energy projects, etc.

9. CONCLUDING REMARKS

Madagascar has not reached advanced stages in surface exploration. However, volcanic areas, geological context, hydrothermal manifestations indicate the existence of potential geothermal system.

The following activities need to be done before each area is recommended for the prefeasibility study:
- Carry out detailed geophysical surveys (e.g. magneto telluric MT, Transient Electomagnetism TEM, microseismics, etc.) to delineate geothermal anomalous areas
- Updating of the geothermal model and location of drill sites.

Detailed assessment of Madagascar geothermal resources is urgently needed in order to properly evaluate the country geothermal prospects.

Policy and legislative framework must to be harmonized to avoid creating uncertainties to the would-be private developers.

Tax incitatives should be enacted to provide tax savings, giving concessions and waiving duties for geothermal resource development work; this reduces the budget and will make geothermal much more economically attractive and thus much easier to finance hence attracting investors.

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