Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Energy Country Update 2020 of Madagascar

Lala Andrianaivo

E-mail address, aandrianaivoo@gmail.com

Keywords: Thermal springs, direct use, geothermal energy, Madagascar.

ABSTRACT

To minimize the dependency on energy imports and to save foreign currency, the use of alternate energy sources using renewable resources has become of great importance. Geothermal development seems to be the long term solution to this problem. In last recent years, the Ecole Supérieure Polytechnique d'Antananarivo (ESPA) evaluated the geothermal resources using geology, geochemical data analyses and geophysical measurements with the aim of elucidating subsurface temperatures and the spatial extent of the geothermal systems. Though limited equipment and after years of research, these published works allowed to identify the geothermal potentialities of the country. The preliminary results of this exploration indicate that more than 120 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. Subsurface temperatures have been predicted by geothermometry and mixing models. 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. Subsurface temperatures of about 155°C for the northern zone, 154°C for Itasy and up to 171°C for Antsirabe-Betafo in central part have been predicted by geothermometry and mixing models. The prospects of Itasy and Antsirabe-Betafo are in advanced stages of surface exploration and will soon be subjected to exploratory drilling that will pave the way for a pre-feasibility study. The volumetric and comparative methods are used in order to estimate an average geothermal electricity of its prospect. Currently, geothermal water is used for bathing, swimming, balneology, tourism and washing with little economic return. This paper gives an overview of Madagascar energy sector, known geothermal resources and their potential. Present geothermal utilization and geothermal development update are given.

1. INTRODUCTION

The solution to the energy supply problem in Madagascar is the use of alternative energy. We speculate that one of the long term solution is the geothermal development.

Concerning the electricity policy, the Government is represented by the Office de Régulation de l'Electricité (ORE). The project consists in the regulation in mutation of the Electricity Sector, including: the energy transition oriented towards renewable energies, the regulatory framework more attractive and more securing for private investments, and incentive measures to facilitate the development of renewable energy.

This paper represents a summary of the important results of the geothermal development update of Madagascar.

2. GEOTHERMAL RESOURCES AND POTENTIAL

Madagascar hosts several signs indicating the presence of geothermal resource such as volcanoes (young/dormant), hot springs, geyser, travertine mound and seeps.

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 volcanotectonic generally may have a moderate to medium potential.

Following preliminary reconnaissance studies, three important zones presenting a geothermal potential interest for electricity production can be selected (Andrianaivo, 2008): the northern part geothermal zone (Ramena, Sambirano, Ankaizina), the Itasy geothermal zone and the Antsirabe geothermal zone in the central parts (Figures 1 and 2).

Exploration of geothermal energy is still at early stage. 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 following three potential areas is related to volcanic and tectonic activities, 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 zone 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, 2008; Ramasiarinoro and Andrianaivo, 2010).

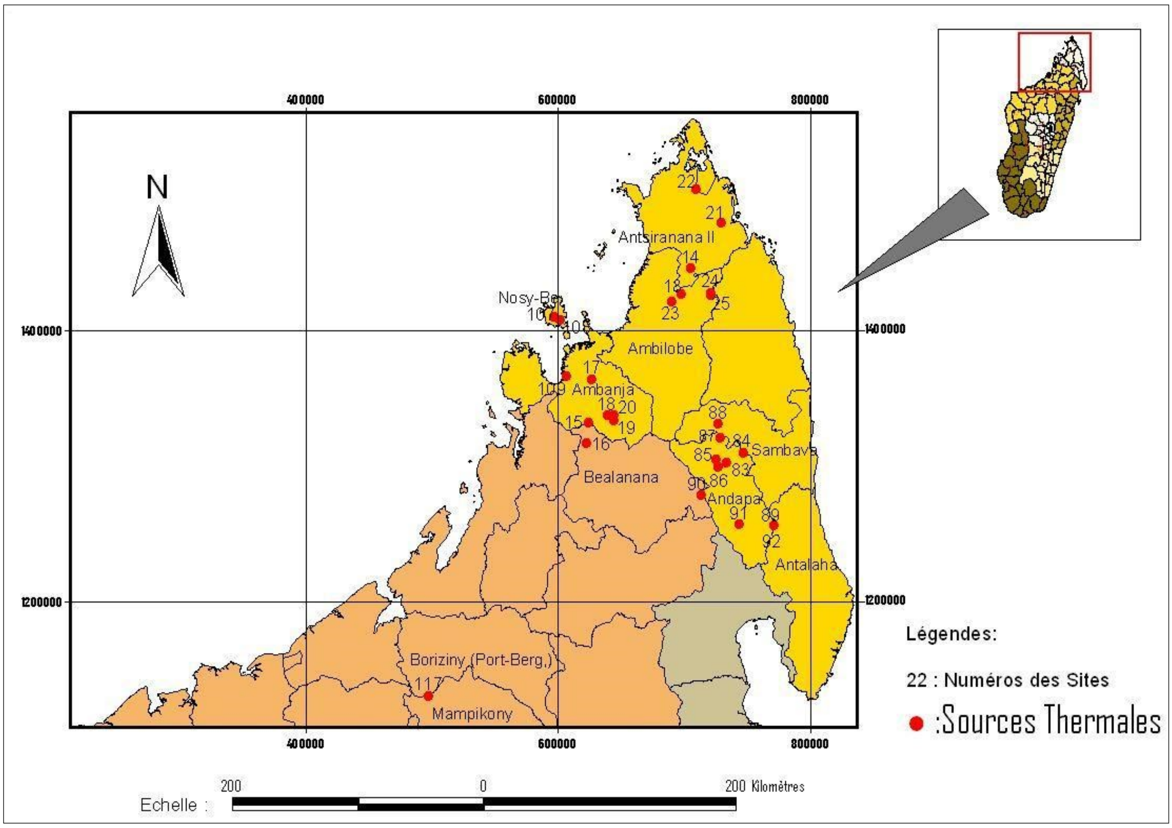

Figure 1: Thermal springs in the northern part of Madagascar (Virkir, 1981; modified after Lala Andrianaivo et al, 2010)

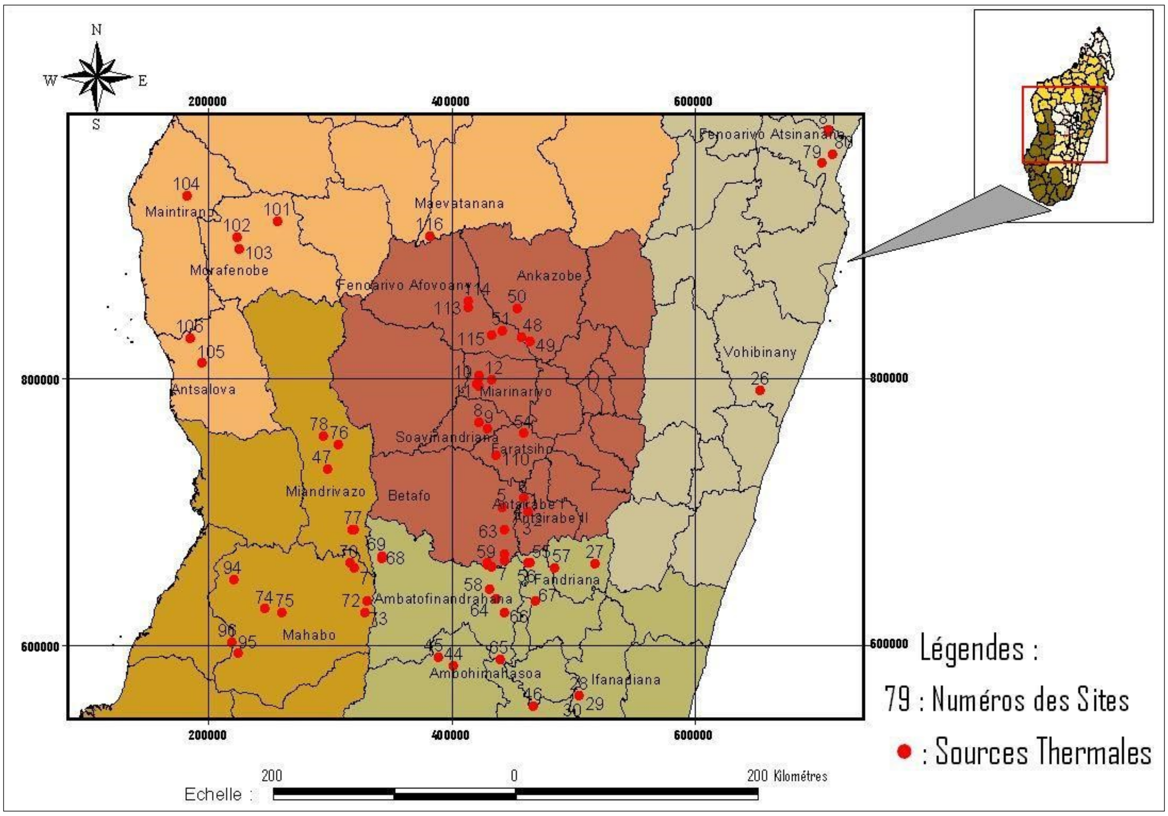

Figure 2: Thermal springs in the central part of Madagascar (Virkir, 1981; modified after Lala Andrianaivo et al, 2010)

3. GEOTHERMAL 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. The commonest uses of geothermal energy in Madagascar are the traditional ones: balneology and recreation. Bathing, swimming and balneology (therapeutic use) are the best known forms of utilization in Madagascar.

There are today in Madagascar five thermal water spas used for balneology, sports and recreation and as tourist centers. Thermal waters are also bottled by three mineral water bottling companies. Bottling of mineral water is regulated by the Law on Concessions.

A large hotel and rehabilitation center with a swimming pool is heated in Antsirabe Spa. A similar use is practiced in Ranomafana Namorona Spa near the Ranomafana National Park. Thermal springs in Bezaha Spa and in Betafo Spa are used for rehabilitation center and recreation center.

Drinking water out of taps allows massive use for disease prevention. Utilized water for relaxation, sanitary needs and prevention has the highest share in balneology.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (wind)		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	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2018			~199.8	~799.2	340.2	~1360.8			~13	~52	~540	~2035.8
Under construction in December 2018												
Funds committed, but not yet under construction in December 2018												
Estimated total projected use by 2020			~267	~1068	~476	~1904			~13	~52	~756	~3024

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2014 (other than heat pumps)

1) I = Industrial process heat; H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling); D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables); B = Bathing and swimming (including balneology)
F = Fish farming; G = Greenhouse and soil heating
K = Animal farming; O = Other (please specify by footnote)
S = Snow melting; Direct drinking to cure for gastroenteritis disease

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

		Maximum Utilization	Capacity3)	Annual Utilization

Locality	Type[1]	Flow Rate	Temperature (ºC)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Antsirabe Ranomafana I	B	2.3	51	30			0.202	2.2	6.094	0.956
Antsirabe Ranomafana II	B	1.5	51	30			0.132	1.25	3.462	0.833
Antsirabe Lac	B/O	0.25	35	25			0.010	0.22	0.290	0.880
Antsirabe Lac	B	0.7	38.5	26			0.037	0.5	0.824	0.714
Antsirabe Hôpital	B/O	0.58	42	27			0.036	0.5	0.989	0.862
Antsirabe Hôpital	B	1.5	45	30			0.094	1.2	2.374	0.800
Antsirabe Ranovisy	B/O	2.3	42	27			0.144	2	3.957	0.869
Antsirabe Ranovisy	B	2	46	35			0.092	1.7	2.467	0.850
Betafo Ranomafana	B	0.4	57.5	35			0.038	0.35	1.039	0.875
Ranomafana Betafo 1	B	0.5	58	30			0.059	0.4	1.477	0.800
Ranomafana Betafo 2	B	0.3	48	30			0.023	0.25	0.594	0.833
Ranomafana Betafo 3	B	0.3	46	25			0.026	0.2	0.554	0.666
Faratsiho Ramainandro	B	0.1	42	25			0.007	0.07	0.157	0.700
Soavinandriana Ranomafana	B	3.2	45	35			0.134	3	3.957	0.937
Itasy Masahona	B	3	57	35			0.276	3	8.705	1.000
Itasy Andranomangotraka	B	10	28	25			0.126	8	3.166	0.800
Itasy Marais d'Ifanja	B	3	46	30			0.201	3	6.331	1.000
Mahatsinjo Ambohipano	B	3	40	25			0.188	2.8	5.540	0.933
Ifanja Anosibe Ranomafana	B	5	49	35			0.293	4	7.386	0.800
Ranomafana Namorona 1	B	0.7	41	30			0.032	0.6	0.871	0.857
Ranomafana Namorona 2	B	0.9	44	30			0.053	0.8	1.477	0.889
Ranomafana Namorona 3	B	11.2	46.5	35			0.539	10	15.169	0.893
Ranomafana Namorona 4A	B	0.7	47.5	35			0.037	0.55	0.907	0.785
Ranomafana Namorona 4B	B	0.36	46.5	35			0.017	0.3	0.455	0.833
Ranomafana Namorona 4D	B	0.69	31.5	25			0.019	0.4	0.343	0.580
TOTAL							2.814		78.585	20.942

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2018

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			

Bathing and Swimming[7)]	2.814	75.585	0.852
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL	2.814	75.585	0.852

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2018 (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)	none	2			0.3
Production	>150° C	none				
	150-100° C	none				
	<100° C	none				
Injection	(all)	none				
Total		0	2			0.3

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

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2016		1	3			
2017		1	5			
2018		1	7			
Total		4	15			

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2018) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	none	none	unknown	none	unknown	none
2000-2004	none	none	unknown	none	unknown	none
2005-2009	0.009	none	unknown	none	100	none
2010-2014	0.001	none	unknown	none	100	none
2014-2018	0.135	none	unknown	none	100	none

4. DISCUSSION AND CONCLUSION

The primary energy production from domestic sources hasn't changed considerably during last five years. The highest shares get hydropower (63%) and thermal plant (37%). The contribution of renewable sources is jointly presented with hydropower.

According to the published report by the Ministry of Energy a target of 10% share of RES in 2020 could be achieved mainly by increasing the contribution of hydro power plants.

A National Program promoting development of renewable energy sources for the period 2015-2020 has been approved.
It is focused on the reduction of electricity and liquid fuels as sources for heating and their replacement with renewable.

A State Commission for Energy issues licenses and sets compulsory preferential purchasing prices for electricity generation from renewable. The prices are formed based on the analysis of investment expenditures by technology, expenses for energy generation by technology and the rate of capital repayment. No purchasing prices are available for electricity generation from thermal waters because such activity is still missing in the country.

A substantial problem in RES development in the country is the lack of coordination of this process. Still, no official register for renewable application is available.

Among different types of geothermal application only balneology (sanitary needs, prevention, treatment and rehabilitation), swimming pools, drinking water and relaxation have shown a growth. Some quantities of thermal water have been used to meet the demand of potable and domestic water. The total installed capacity for direct heat use runs up to 2,814 MWt (Table 2).

Major current barriers stated for the previous 5 years period for the geothermal development in the country remain the same:

Lack of preferential status to the use of geothermal energy for heat production.
Lack of expertise in preparation of exploration and business plan.
Insufficient commercial financing.
Local taxes and fees are important but very insufficient source of funds for the Municipalities budgets.
Lack of investments and organizational problems are still the major obstacles for the geothermal development in the country.

Existing Spa centers located in central Madagascar would increase the share of thermal water in their activity and the type of applications as well.

A process of assessment of the existing geothermal resource regarding possibilities for electricity generation by using modern technologies is in progress.

The project of the government, represented by the Office de Régulation de l'Electricité (ORE), consisting in the regulation in mutation of the electricity sector is also is in progress.

REFERENCES

Andrianaivo, L., (2008): Geothermal system and Resource in Madagascar: Preliminary Results. *Advanced report No.2008.1*, *Unpublished Project Study*, January 2008, MCC, Antananarivo, (2008)

Gunnlaugsson, E., Arnorsson, S., and Matthiasson, M.: Etude de reconnaissance des ressources géothermiques de Madagascar, *Projet MAG/77/104, Contrat 147/79 VIRKIR,* Traduction française, (1981), 1-101

Manissale, A., Vasseli, O., Tassi, F., Magro, G., and Pezzotta, F.: Thermal springs around the Quaternary volcano Ankaratra, Madagascar. *Geochemistry of the Earth's surface, Armannsson Edit*, Rotterdam, (1999), 523 – 526

Sarazin L., Michard G., Rakotondrainy and Pastor L.: Geochemical study of the geothermal field of Antsirabe (Madagascar). *Geochemical Journal*, **20**, (1986), 41-50

Ramasiarinoro V.J. and Andrianaivo L.: Geochemical Characteristic of Thermal Springs in Volcanic Areas of Antsirabe-Itasy, central Madagascar: Preliminary Results. *Proceedings*, World Geothermal Congress 2010, 25-30 April 2010, Bali – Indonesia, Paper 1413, (2010), 1- 6

Institut National de la Statistique (INSTAT) : Tableau de bord de l'économie de Madagascar, Direction Générale, Direction des Synthèses Economiques, Madagascar, (2011)

Ministère de l'Energie : Politique Sectorielle Energie, Direction Générale, Antananarivo, Madagascar, (2009).