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Geothermal Country Update Report of Morocco (2010-2015)

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ABSTRACT

The Moroccan subsoil has geothermal energy potential still unexploited, especially in the northeastern part where the estimated installed capacity is around 5 MWe. Geothermal data so far obtained, especially from deep exploration oil wells, highlight a heat flux increasing northeastward (80–140 mW/m^2) in the eastern Rift, northeastern Morocco, Alboran Sea, southeastern Spain and northwestern Algeria. The highest value for geothermal gradient in Morocco is found in the northeastern part where it can reach 50°C/km. The new temperature data, recently recorded in a water borehole located in the Berkane and Oujda areas revealed an average geothermal gradient of more than 120ºC/km at depths greater than 300 m. Such a high geothermal gradient, exceeding by far the ones already determined for northeastern Morocco, could act as a stimulus to programs aimed at the geothermal exploitation of high temperature aquifers limited until now to drinkable water distribution or to balneology.

1. INTRODUCTION

The Kingdom of Morocco is the only North African country with no natural oil resources and is the largest energy importer in the region with 96% of its energy needs being sourced externally. Morocco has small quantities of gas and it has large reserves of oil shale. However, in the absence of a proven specific industrial process that can produce oil and gas from this unconventional source, Morocco has turned to implementing a number of strategies that promote renewable energy and energy efficiency. In 2009, the total installed capacity and the electricity generation in Morocco reached the levels of 6,370 MWe and 21 TWh, respectively. 4.6 TWh was imported from Spain to recover the power demand which reached 25 TWh. In 2008, Morocco launched the national energy strategy, with renewable energy and energy efficiency plan as the main pillars. The country has one of the most ambitious renewable energy programs in the region. It expects 42% (equivalent to about 6,000 MWe) of its total energy mix to come from renewable sources by 2020. (Table 1).

Table 1. Present and planned production of electricity

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		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 2014	-	-	4350	57470	1770	2980	-	-	280	430	6400	60880
Under construction in December 2014	-	-	1182	-	300	-	-	-	150	-	1632	-
Funds committed, but not yet under construction in December 2014	-	-	-	-	-	-	-	-	-	-	-	-
Estimated total projected use by 2020	-	-	6743	-	2000	-	1000	-	5164	-	13743	-

About geothermal research in Morocco, the interest to this source of energy has been increased since 1968 with studies conducted for academic or economic purpose. Temperatures were sometimes not directly determined, different authors tried to take the most of it in order to approach the real formation temperature. In many cases some corrections have been operated, on measured or deducted temperature values from suitable geochemical tools. Whatever their direct or indirect link to the potential geothermal resources evaluation, these investigations endowed Morocco of an important mass of information on the geothermal gradient, the heat flow and the underground temperatures spatial distribution.

The thermal waters are mainly hosted within sedimentary reservoirs, consisting of Liassic limestones with a thickness up to 500 m. The geothermal fluid is characterized by a complex deep circulation and it ascends through complex fault systems. The Liasic reservoir of the northeastern province is considered as the most important geothermal aquifer in the country.

It belongs to the Atlas domain (Fig.1) which is characterized by a succession of NE-SW horst and graben structures of pre-Miocene age and by Plio-Quaternary basaltic volcanics, produced by crustal thinning. This reservoir feeds more than twenty-four thermal manifestations, with temperatures ranging from 26 to 54°C. Some of these hot aquifers, e.g. Fezouane, near Berkane and Hammam Ben Kachour at Oujda play an important role in the economy of the area (Zarhloule, 1999; Zarhloule et al., 2001).

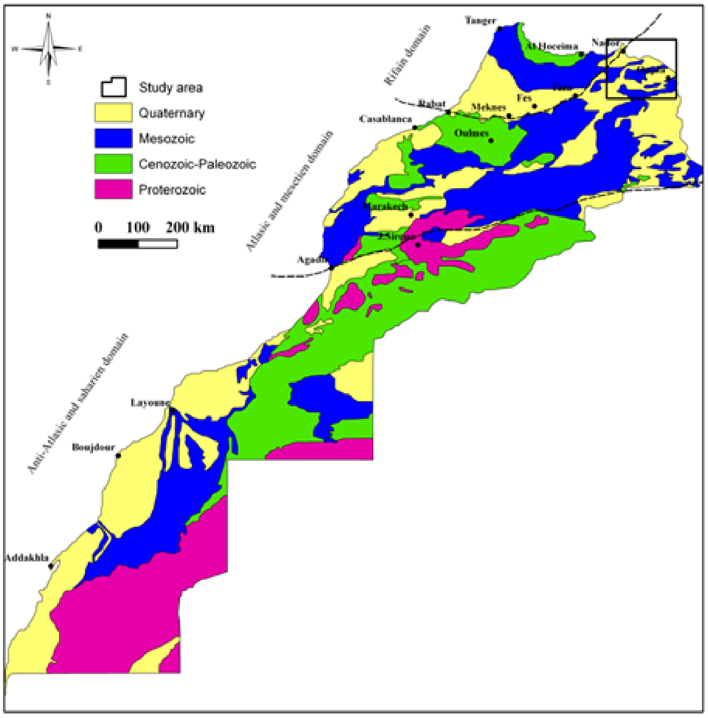

Figure 1 - Main structural and geological traits of Morocco.

Geodynamic studies linked the zones showing geothermal gradient and heat flow exceeding 50°C/km and 100 mW/m^2 respectively, to Neogene - quaternary volcanic and neotectonic activities. However these thermal phenomena are still not developed and their exploitation limited to drinkable water distribution or to balneotherapy “ancient Hamam”.

2. GEOTHERMAL RESEARCH

2.1 Summary of geothermal activities in Morocco

In 1968, the Ministry of Energie and Mining supervised the first studies to evaluate geothermal Moroccan resources (Facca 1968, Alsac et al. 1969 and Cornet et al. 1974) unfortunately these studies were not positively conclusive. In spite of the hydrogeothetmal potential of Morocco, the support of research & development in the field of geothermics remains under the interest of the university researchers. Geothermic research undertaken so far was generally carried out by university teams since 1980 (Bahi et al. 1983, Rimi & Lucazeau 1987, Rimi et al. 1998, 2008, Rimi,1999, 2000, 2005, Ben Aabidate 1994, Lahrach 1994, Zarhloule 1994, 1999, 2003, 2004, Zarhloule et al., 1998, 1999, 2001, 2005, 2007a, 2010, Boukdir 1994, Ziyadi 1993, Bellouti 1997, El Morabiti 2000, Benmakhlouf 2001, Cidu & Bahaj 2000, Winckel 2002, Tassi et al., 2006, Barkaoui et al., 2013a, 2013b, 2014). These researches were carried out within the framework of PhD theses or bilateral cooperative projects between Moroccan and European universities namely, France, Italy, and Portugal and also Tunisia in order to measure and map the distribution of the underground temperatures, the heat flux density, the temperatures in the aquifers, the geochemistry of the thermal springs and hydrothermal modeling. These research tasks made it possible to highlight Moroccan hydrogeothermal potentialities and the possibilities of geothermal energy utilization.

2.2 Geothermal Potential

Geological and hydrogeological data from boreholes show the Liassic carbonates to be the main hydrogeothermal reservoir in the region. This reservoir is highly variable in thickness. An example of this aquifer in Ben Kachour station is shown in Figure 2. The meteoric waters penetrate from the surface through the outcrops of the Liasic limestones in the southern part of the Angad plain, continues flowing downward through the same formation that becomes deeper going to the north.

According to Zarhloule (1999), the hot temperature and the artesian rise of most of the thermal springs are due to groundwater circulating at depth within a framework of a recent volcanic area and a system of basement faults, forming horsts and grabens. Winckel (2002) performed a thorough geochemical analysis of the main thermal waters in Morocco and found that eleven of them release CO_2 and are partially of deep origin. These waters are mainly located on a NE-SW line from Nador to Taza, and from Fes (Moulay Yacoub) to Oulmes south of the Rift frontal thrust, along the so-called Moroccan Hot Line (MHL). Tassi et al. (2006)

confirmed that CO_2-rich thermal waters with ^3He anomalies are likely related to the MHL. The contemporary presence of ^3He anomalies and minor recent basalt outcrops indicate that CO_2 originates from mantle degassing or deep hydrothermal systems in these thermal discharges.

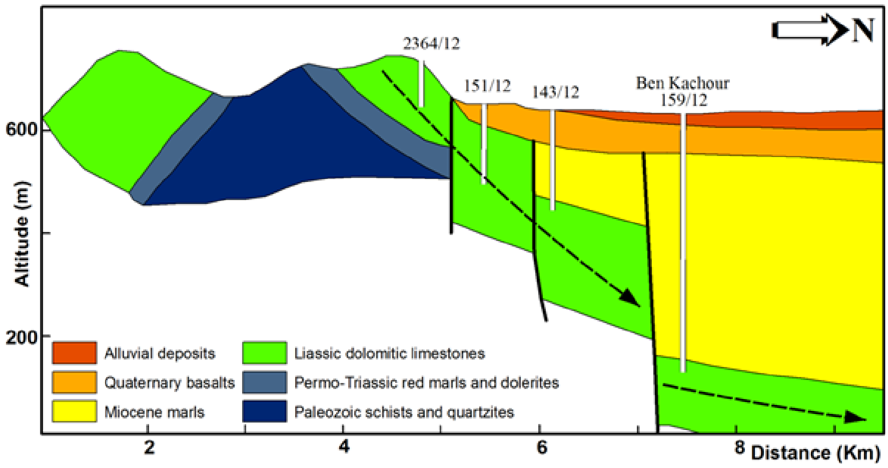

Figure 2 Geological cross-section for Ben Kachour station

Figure 3 shows the heat flow density map obtained from data available from Morocco and the surrounding regions (Rimi, 1999). The regional pattern highlights heat flux increasing northeastward, from less than 60 (north Mauritania) to more than 80-90 mWm^{-2} in the eastern Rift, northeastern Morocco, Alboran Sea and northwestern Algeria. The Gibraltar Arc region is characterized by a radial heat flow pattern, with increasing values from the outer ranges towards the central and eastern part of the basin.

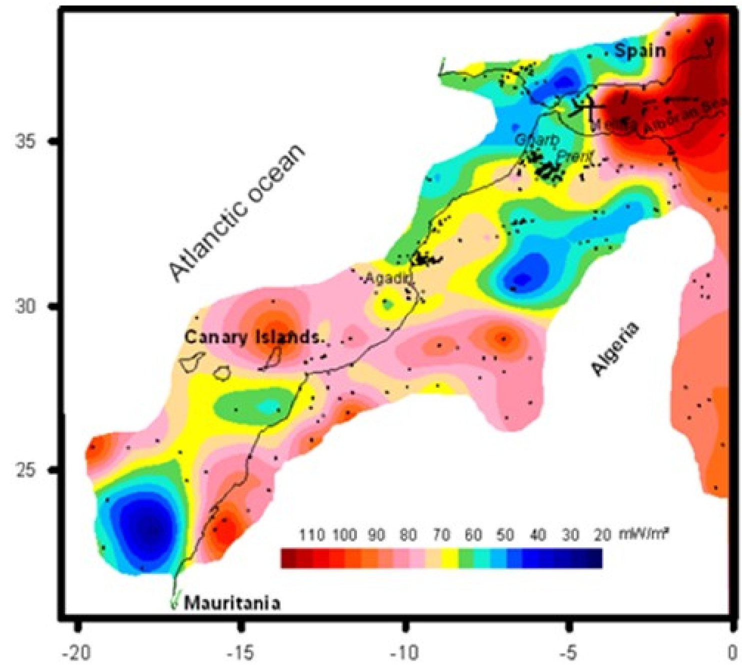

Figure 3 Terrestrial heat flow density in Morocco and neighbouring regions (Rimi 1999).

The distribution of the geothermal gradient (Rimi, 1999; Zarhloule et al., 2010) is shown in Figure 4. The largest values are located in the northeastern part of Morocco, where they can reach 50°C km^{-1}. This part of the country is also characterized by high residual magnetic anomalies related to widespread Quaternary volcanism.

2.3 New data

To understand better the behavior of the thermal water inside the liasic geothermal reservoir, many water boreholes were logged, especially in the northeastern part of the country. Among the recorded thermal profiles, Fig. 5 shows one interesting example for well 1624/7, located west of Berkane. This hole is characterized by an increase in geothermal gradient at 300 m depth from 29 to 127°C km^{-1}. At the same depth, the lithology changes from clay to dolomite. At about 470 m depth, the temperature is about 50ºC. The shape of the thermal profile suggests a conductive thermal regime both in the upper (clay) and in the lower (carbonate) section of the hole. The dolomitic formation continues until the hole bottom (1,042 m depth). By extrapolating the thermal gradient inferred in the lowermost section of the hole, a bottom temperature of about 120°C is inferred. The lithology change cannot explain the increase of geothermal gradient. As dolomite is expected to have much greater thermal conductivity than clay (see e.g. thermal conductivity data for NW Morocco rocks (Zarhloule et al., 2007b) and the recent compilation by Pasquale et al., 2011), one would expect the geothermal gradient to decrease. An explanation for the anomalous pattern of the thermal gradient might be found in the advective heat transfer, which can occur at depth in the carbonatic formation. We may argue that heat advection occurring in the main deep thermal aquifer, encountered at 1,042 m depth, can yield the increase of thermal gradient observed in the overlying dolomitic layers.

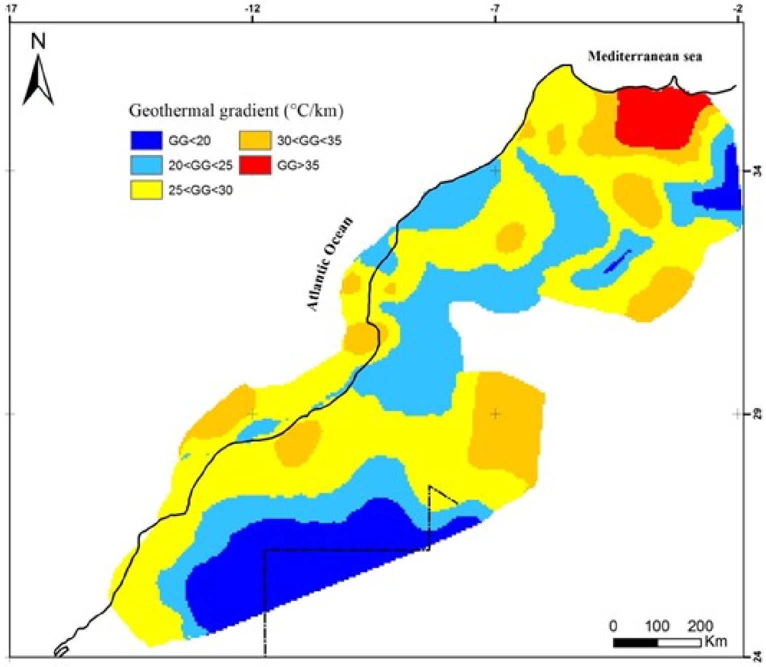

Figure 4 Geothermal gradient map of Morocco (Zarhloule 1999).

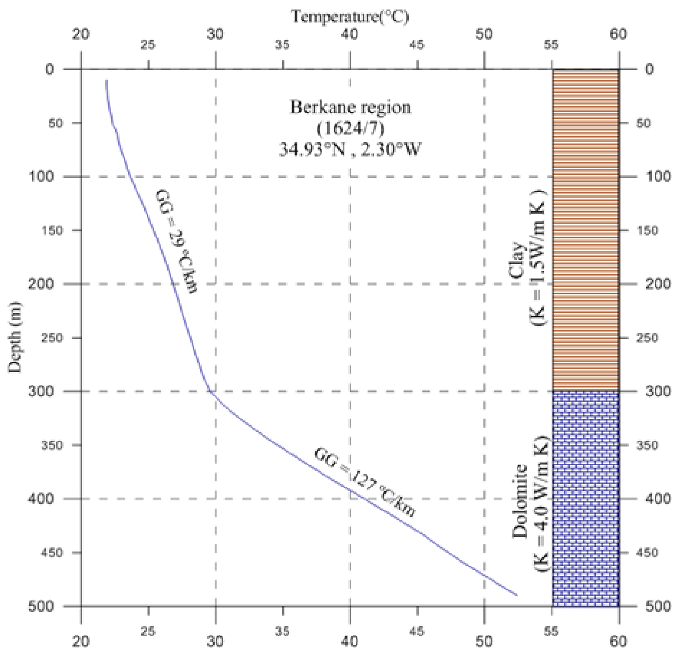

Figure 5 Thermal profile of the borehole 1624-7 located in the region of Berkane

2.4 Geochemical approach

Different geochemical approaches were applied to infer the temperature of the geothermal reservoir (especially in the northeastern part of the country). Generally the discharge temperatures are ranging from 26 to 54°C, Discharge rates range from 2.5 to 40 l s^{-1} and TDS varies from about 30 to 30,000 mg l^{-1}. The thermal waters are mainly of Ca-Mg-HCO3 and Na-Cl type, and they fall close to the Mg corner in the field of mixed waters in the Na–K-$Mg^{1/2}$ ternary diagram (Figure 6). Reservoir temperatures were estimated using several techniques (Barkaoui 2013a). Average temperatures span from 102°C, as inferred from quartz, chalcedony and Na-K geothermometers, to 122°C as obtained from the analysis of mineral equilibria. The silica-enthalpy mixing model (Figure 7) gives average temperatures (108°C) higher than geothermometers, thus indicating that most of the hot reservoir waters probably mix with shallow cold water. Moreover, conductive cooling probably takes place during the upflow of the hot water. The inferred reservoir temperatures are consistent with those found by extrapolating the temperature gradient obtained from borehole thermal data especially in the well 1624/7.

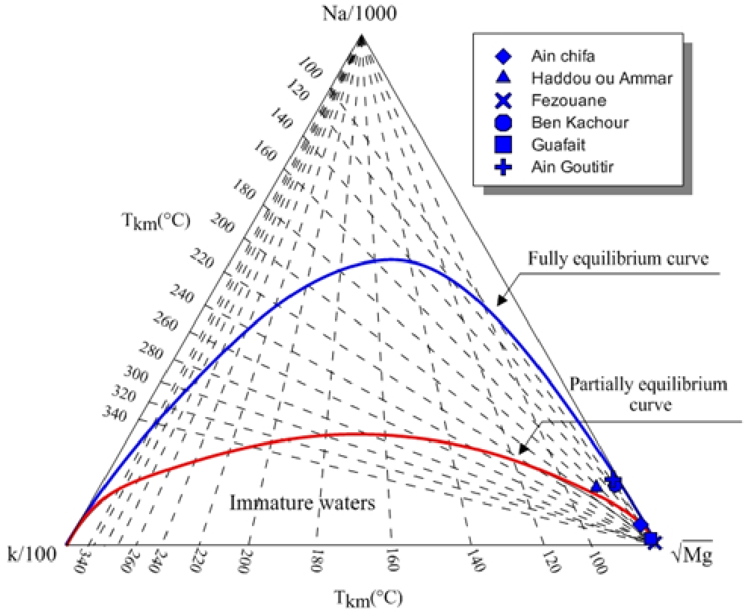

Figure 6 Classification of thermal waters from northeastern Morocco on the basis of their relative Na, K, and Mg content (Barkaoui 2013a)

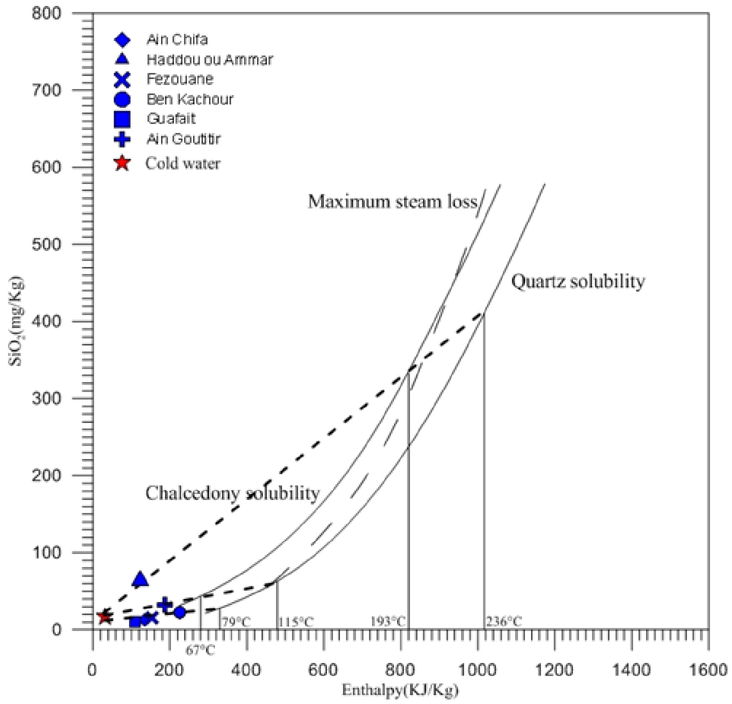

Figure 7 silica-enthalpy mixing model for thermal samples from northeastern Morocco (Barkaoui 2013a)

The compilation of the obtained geochemical results, with the geological and the hydrogeothermal data allowed the construction of a conceptual model (Figure 8). According to the δ 18O vs δ2H data, meteoric waters are the origin of the thermal water. The recharge is ensured at the level of the Liasic outcrops. Those recharge areas are characterized by shallow cold water and low apparent geothermal gradient. The waters are mainly HCO_3-Ca-Mg type, resulting from the great influence of carbonate rocks. The discharge zones are characterized by relatively shallow hot water and high apparent geothermal gradient. The hot springs are generally Na-Cl or Ca (Mg)-HCO_3 type, resulting from the main influence of evaporitic rocks. The upward moving water is related to the existence of faults and fractures.

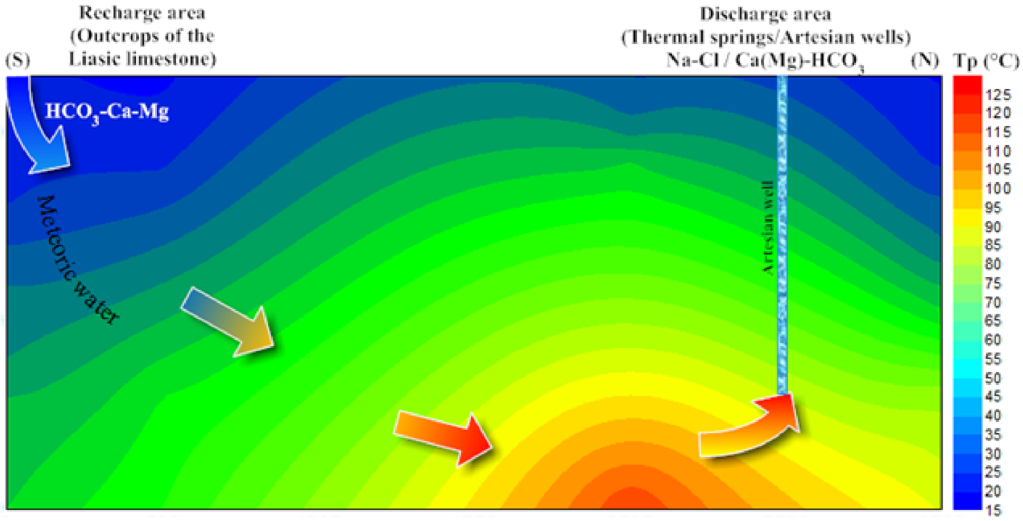

Figure 8 Conceptual model of the NorthEastern Morocco showing the circulation of thermal water. The reservoir temperature is inferred from geochemical results and borehole temperature logging. (Barkaoui 2013a)

3. GEOTHERMAL APPLICATIONS IN MOROCCO

In Morocco, the thermal water application is mainly limited to balneology, swimming pools and potable water bottling, despite the potential market (Figure 9). The key application for developing geothermal energy use in Morocco is related to agriculture (greenhouse). It is well know that the economy of the country is strongly related to this sector. The use of geothermal energy will help Morocco to be self sufficient, producing enough food for its domestic market, as well as for export. Morocco has also a long tradition of using warm springs for bathing and therapy. The geothermal energy used annually by the natural hot baths in Morocco, correspond approximately to a capacity of 5 MWt (Table 2).

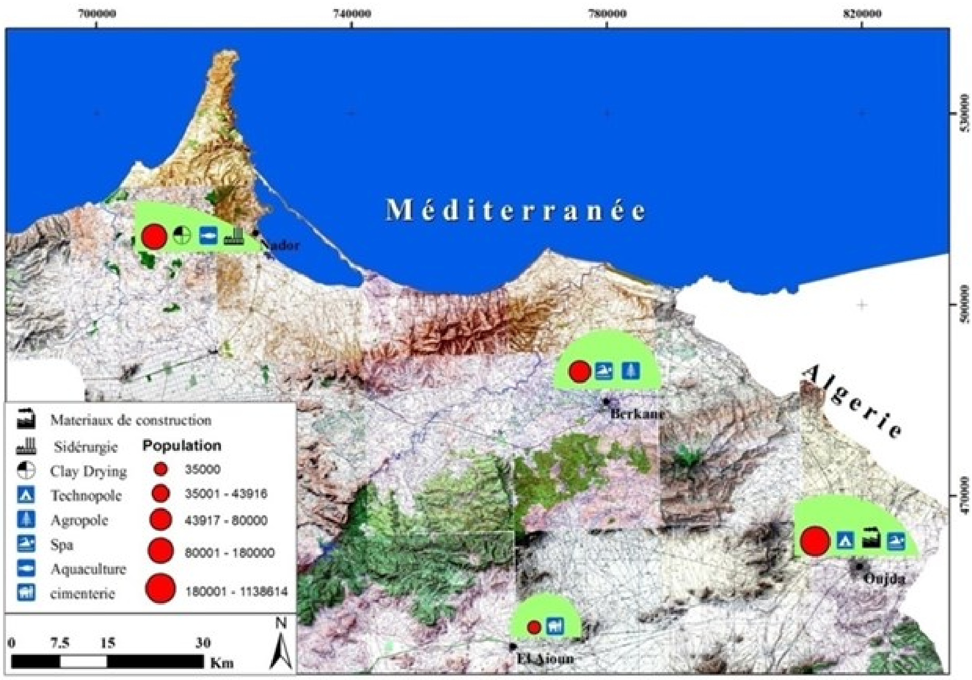

Figure 9 Potential heat-market in northeastern Morocco (Barkaoui 2013b)

4. DEVELOPMENTS AND CONTRAINTS OF GEOTHERMAL RESEARCH

Geothermal research in Morocco has been only ensured by university teams mainly Mohamed V-Agdal University in Rabat and Mohammed I University in Oujda (Table 3). Though limited equipment and after years of research in hydrogeology, geochemistry and geophysics, these published or to be published works allowed to identify the geothermal potentialities of Morocco. Thus, to go from the phase of resources identification into the phase exploitation or development of geothermal energy, Morocco must install an adapted institutional framework to encourage the private sector to invest in this field. Also, Morocco will have to encourage geothermal research, and to mobilize more financing support to work out a development strategy which will have as objectives:

- Geothermal master project;
- Detailed geological mapping, identification of the resources area and geographically associated needs
- Tax incentives and
- Public and professionals' information.

Table 2. Summary table of geothermal direct heat uses as of 31 December 2014

Use	Installed Capacity	Annual Energy Use	Capacity Factor
	(MWt)	(TJ/yr = 10^{12} J/yr)	
Individual Space Heating			
District Heating			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying			
Industrial Process Heat			
Snow Melting			
Bathing and Swimming	5	50	0.3171
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL	5	50	0.3171

Table 3. Allocation of professional personnel to geothermal

	Professional Person-Years of Effort					
Year	(1)	(2)	(3)	(4)	(5)	(6)
2010						
2011						
2012				2 (Portugal)		
2013				3 (Hungary)		
2014			10	4 (Croatia+Greece)		
Total			10	9		

5. CONCLUSION

The Kingdom of Morocco is the largest energy importer in northern Africa. Until now, fossil fuels resources are limited in the country. In order to achieve its ambitions, Morocco has based its energetic plan on the mobilization of domestic resources by the rise of the renewable energies. The use of geothermal energy among other renewable sources is a real need to reduce dependence on conventional energy sources which will lead to sustainable development and environmentally sound.

Geothermal research undertaken showed a country with real potentialities either by its important deep aquifers or by the relatively high values of geothermal gradient and heat flow. Historical data revealed that the geothermal energy could be a very promising alternative of development and that hot water resources are a primary key to the future economic progress of several regions in Morocco. Currently, in Morocco, geothermal water is used for bathing, tourism and washing with little economic return. Thanks to a consistent database and present competences in geothermics, it is actually possible to establish a strategic route for geothermal energy whose role will be:

- to establish an exhaustive census and an inventory of the national potential;
- to set up a true policy of research in geothermics with the facilities granted to other sectors; and
- to encourage the private sector in the research and development in the geothermic field

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