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Potential Assessment of Geothermal Resources in the North Eastern Part of Morocco

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ABSTRACT

The volumetric method is one of the most applicable methods of low-temperature geothermal resource assessment. While applying volumetric method, the values of uncertain parameters should be determined. An add-in software program to Microsoft EXCEL, @RISK, is used as a tool to define the uncertainties of the parameters in the volumetric equation. Monte Carlo simulation is used as the probabilistic approach for the assessment of low temperature in north-eastern Morocco. In this region, the utilisation of this resource is limited. Assessment studies using triangular and uniform distribution type functions for each parameter are used to give the mean values of recoverable heat energy of the field.

1. INTRODUCTION

Comparing to other energy sources, geothermal energy is a clean, renewable, constant and available worldwide. Due to its reduction capacity in greenhouse gas emissions, this energy is already being used for electricity generation and direct utilization (Barkaoui, 2016). For Morocco, the use of geothermal energy, among other renewable resources, is primordial in order to break the current dependence on fossil fuel and electricity imports (Barkaoui, 2013).

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 MW 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 MW) of its total energy mix to come from renewable sources by 2020.

In Morocco, 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 North-eastern province is considered as the most important geothermal aquifer in the country. 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 – as shown in the investigation on geothermal potentials in Morocco overall (Zarhloule, 1999) and a study on the surface geothermal potentials (Zarhloule et al., 2001). Geodynamic studies linked the zones showing geothermal gradient and heat flow exceeding 50 °C/km and 100 mW/m2 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".

The aim of this work is to approach the power potential in the study area. After successful exploration of a geothermal prospect, stakeholders are always eager to have those results. This comes as early as after completion of surface geo-scientific exploration or even after initial exploration drilling. The earlier estimates of power potential give confidence to the project owners to source for more resources to undertake subsequent stages of development. With high uncertainty and scanty data available during initial stages of exploration, stochastic and risk analysis methods are frequently used to estimate the range and probable distribution of stored heat reserves and hence, exploitable energy base of the newly explored geothermal prospect or fields. These methods have been borrowed from the oil industry where they have been used for a long time to estimate probabilistic hydrocarbon-in-place and oil and gas reserves in sedimentary basins.

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. 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 water sources in Morocco and found that eleven of them release CO2 and are partially of deep origin. These water sources are mainly located on a NE-SW line from Nador to Taza, and from Fes (Moulay Yacoub) to Oulmes south of the Rif frontal thrust, along the so-called Moroccan Hot Line (MHL). Tassi et al. (2006) confirmed that CO2-rich thermal waters with 3He anomalies are likely related to MHL. The contemporary presence of 3He anomalies and minor recent basalt outcrops indicate that CO2 originates from mantle degassing or deep hydrothermal systems in these thermal discharges. The regional pattern highlights heat flux increasing northeastward, from less than 60 (north Mauritania) to more than 80-90 mW·m-2 in the eastern Rif, northeastern Morocco, Alboran Sea and northwestern Algeria. The largest values of the geothermal gradient are fond in the northeastern part of Morocco, where they can reach 50 °C·km-1

To understand better the behaviour of the thermal water inside the liasic geothermal reservoir, many water boreholes were logged, especially in the north-eastern part of the country. Among the recorded thermal profiles, Fig. 1 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 50 ºC. 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 untill 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., 2007) 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 carbonate 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.

3. THERMAL ENERGY CALCULATION

An important factor in a geothermal assessment is an assessment of the volume of the geothermal system in question using the volumetric method. We assume, for simplicity, that the volume is a box with a surface area A in the xy plane and height (thickness) z1-z0 along the z-axis, where z1 and z0 are the lower and upper limit of the geothermal system, respectively.

When the volume of the geothermal system has been assessed, the choice has to be made on how to calculate the useable heat that the system contains. For simplicity, it can be assumed that the heat capacity and temperature are homogeneous in the xy plane and are only dependent on depth.

The volumetric method is used to estimate the amount of energy in a geothermal resource. This method involves calculating the amount of thermal energy contained in a given volume of rock and water and then estimating how much of this energy maybe recoverable given a reference temperature. The volumetric method uses the volume of the rock, the specific heat and temperature of rock to calculate the energy (Pálmason, 2005). This method is patterned from the work applied by the USGS to the Assessment of Geothermal Resources of the United States (Muffler and Cataldi, 1978). The equation used in calculating the thermal energy for a liquid dominated reservoir is as follows:

$$QT = Qr + Qw \quad (1)$$

$$Qr = A.h * (\rho r.Cr * (1-Ø) * (Ti-Tf) \quad (2)$$

$$Qw = A.h * (\rho wCw * Ø * (Ti-Tf)) \quad (3)$$

where:

QT = total thermal energy, kJ/kg

Qr = heat in rock, kJ/kg

Qw = heat in water, kJ/kg

A = area of the reservoir, m^2

h = average thickness of the reservoir, m

Cr = specific heat of rock at reservoir conditions, kJ/kgK

Cw = specific heat of water at reservoir conditions, kJ/kgK

Ø = porosity

Ti = average temperature of the reservoir, °C

Tf = final or abandonment temperature, °C

ρr = rock density, kg/m^3

ρw = water initial density, kg/m^3

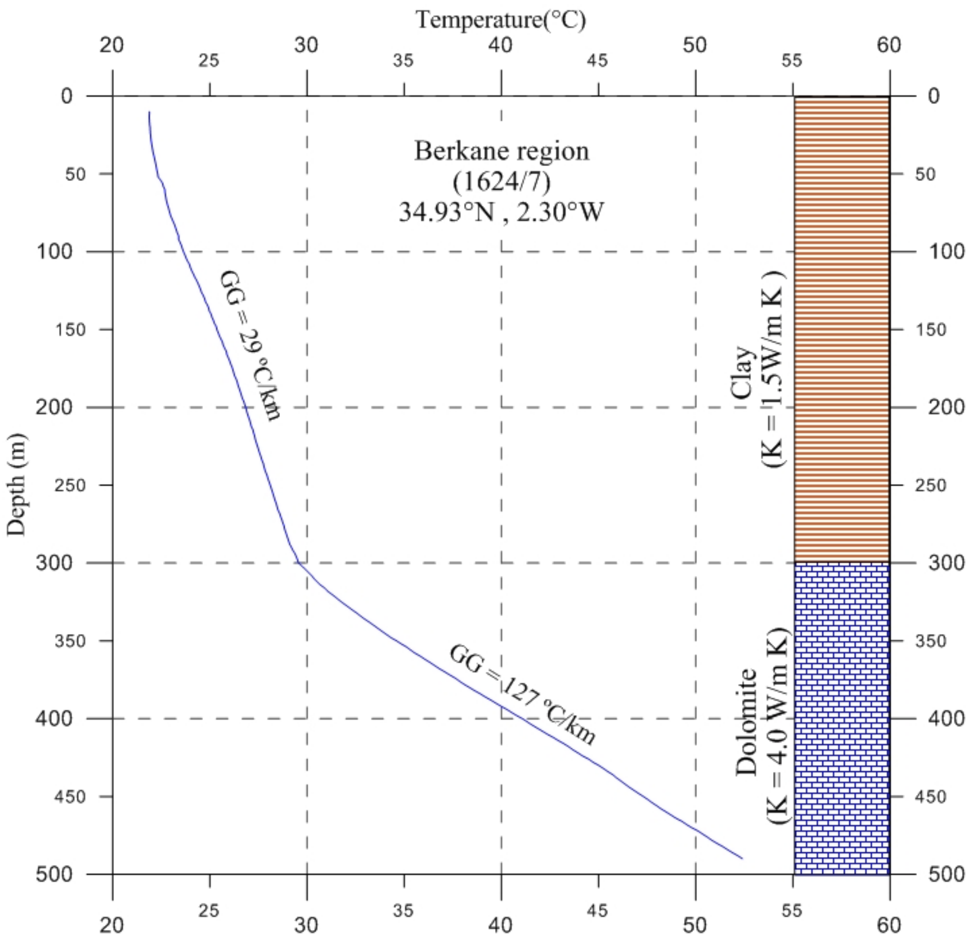


Figure 1: Thermal profile of the borehole 1624-7 located in the region of Berkane

3.1 Power plant sizing

The above calculations only provide for the total thermal energy in place in the reservoir. To size the power that could be supported by the resource, the following equation is further introduced.

$$P = \frac{Q_t \times R_f \times C_e}{P_f \times t} \quad (4)$$

where

P = Power potential (MWe);

Rf = Recovery factor;

Ce = Conversion efficiency;

Pf = Plant factor; and

t = Time in years (economic life):

3.2 The Monte Carlo Simulation

The reserves estimation is done using commercial software that provides for a probabilistic approach of calculating uncertainty in the occurrence of events or unknown variables. The most common commercial software is @Risk which is used in assessing risks in investment, pharmaceuticals, petroleum reserves and mining evaluation. Monte Carlo simulation can also be programmed using an Excel spreadsheet. In this study, to obtain a good representation of the distribution, sampling is done through 1,000 iterations with continuous calculation.

3.3 Modeling Scenarios

Two scenarios were considered for modeling:

1) Power Generation Scenario - implemented when reservoir temperatures show sufficiently high values for power generation from a binary geothermal plant. In this scenario, in addition to quantifying heat in resources and reserves (equation 1), the power that can be sustainable in the life cycle of a plant is also quantified as indicated by equation 4;

2) Direct Use Scenario - A direct use of geothermal heat scenario was implemented, recovering inferred, probable and proven resources, and applying the thermal energy recovery factor available for the use of geothermal heat. (equation 1).

3.4 Parameters used in the model

Based on the geological and geophysical data, the geothermal reservoir underlies the entire town and its suburbs (40 km2), but its permeability in the major part is not high enough for reasonable geothermal development. The maximum temperature input into the calculations was the highest recorded temperature 52 °C in surface. Higher temperature can be reached if drilling deeper. By extrapolating those values and using the geothermal gradient of 49 °C/km a temperature of 120 °C can be expected at a depth of 1,042 m.

The fluid density and specific heat capacity into the simulator were obtained from steam tables based on the reservoir temperatures. The values for those two parameters are respectively 800 Kg/m3 and 4248 J/Kg°C. The deep geothermal reservoir in North-Eastern Morocco is considered to be composed mostly of sedimentary rocks ; therefore, the value for the heat capacity of the rock, is equal to 920 J/Kg°C,. The porosity φ of the Limestone rocks in the study area is of the order of 10 %. The average density of the rock is set at 2,900 kg/m3 on the basis of the gravity available data.

The geothermal recovery factor (Rf) refers to the fraction of the stored heat in the reservoir that could be extracted to the surface. It is dependent on the fraction of the reservoir that is considered permeable and on the efficiency by which heat could be swept from these permeable channels. This factor is assumed to be around 0.25 as a most likely value. The Conversion efficiency takes into account the conversion of the recoverable thermal energy into Electricity, in this study the value of this parameter is around 6 %.

The plant factor refers to the plant availability throughout the year taking into consideration the period when the plant is scheduled for maintenance, or whether the plant is operated as a base-load or peaking plant. The good performance of many geothermal plants around the world places the availability factor to be from 90-97 %. In this study, a 95 % load factor is used. The economic life of the project is the period it takes the whole investment to be recovered within its target internal rate of return. This is usually 25-30 y.

4. RESULTS AND DISCUSSION

4.1 Electricity Generation Scenario

In the study area, reservoir temperatures can reach 125 ° C in the deepest parts of the Lias aquifer. Such a temperature level is favorable for the production of energy, in binary cycle plants, using fluids at low boiling temperatures. Table 1 shows the parameters taken into account in the modeling of the reserves and the sustainable energy power.

All parameters were assigned as described in the previous section. The total heat in place is estimated at about 1379 MWhth on average, with a 95% probability that the thermal reserves are greater than 413 MWhth. Given the percentiles, P90, P50 and P10, the estimated potential reserves are 2018 MWhth, while the probable reserves are 1329 MWhth and the proven reserves are 830 MWhth (Figure 2-3).

In the case of a plant operating for 30 years, with a conversion efficiency of 0.065 and a recovery factor of 0.25, these resources would correspond to a sustainable electricity potential with an average of 2.9 MWe and ranging from 1, 48 to 4.82 MWe (90% confidence interval). The probability that the area can sustain a 2 MWe power plant for 30 years is over 81% (Figure 4-5).

4.2 Scenario of direct use

The direct use scenario for the Berkane / Fezouane area differs from the previous scenario by: i) the minimum required temperature value, and hence; (ii) the area of the reservoir; and (iii) the depth of the reservoir in which the use of resources could be implemented; iv) the re-injection temperature set at 25 ° C, as recommended in the European Atlas of Geothermal Energy. Temperature dependent parameters, such as fluid specific heat and conversion efficiency, also varied accordingly (Table 2).

The total heat in place is estimated at 392 MWhth on average, with a 95% probability that the thermal reserves are greater than 170 MWhth. The potential reserves estimated by the P90 percentile are 570 MWhth, while the probable reserves (P50) are

388 MWhth and the proven reserves (P10) are 212 MWhth. With a recovery factor of 0.25, the average recoverable heat is close to 97 MWhth, with a 90% confidence that the average recoverable energy is 41 MWhth at 159 MWhth (Figure 6).

Table 1 – Parameters for the electricity generation scenario in eastern Morocco

Parameter	Units	Min	Most likely	Max	Mean	Std	Distribution
Area (A_{res})	km^2	8	20	40			triangular
Thickness (H)	m	1000	1500	2000			triangular
Rock density (ρ_r)	kg/m^3	2900	2900	3000			triangular
Porosity (Ø)	%	0.01	0.1	0.2			
Recovery Factor (R_f)	%	0.2	0.25	0.3			f(por)
Rock heat capacity	kJ/kg°C	0,85	0,90	0,92			triangular
Temperature (T_{res})	°C	100	110	120			triangular
Fluid density (ρ_l)	kg/m^3	780	800	820			
Conversion efficiency (C_e)	-	0,06	0,065	0,07			f(temp), triangular
Fluid heat capacity (C_l)	kJ/kg°C	4,19	4,19	4,19			f(temp, pressure), triangular
Plant life (t)	years						Constant (30 years)
Load factor (P_f)	-	0,90	0,95	0,97			triangular
Rejection temperature (T_f)	°C						Constant (55 C)

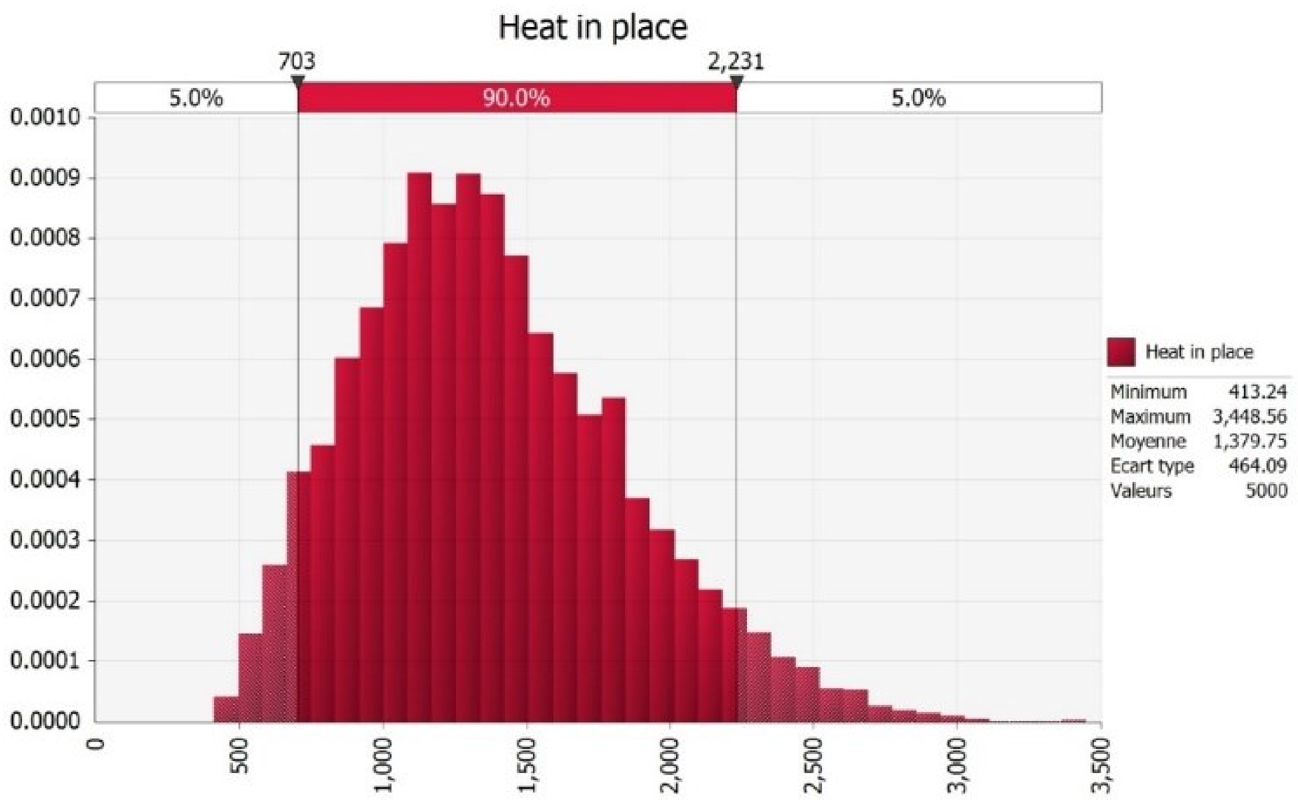
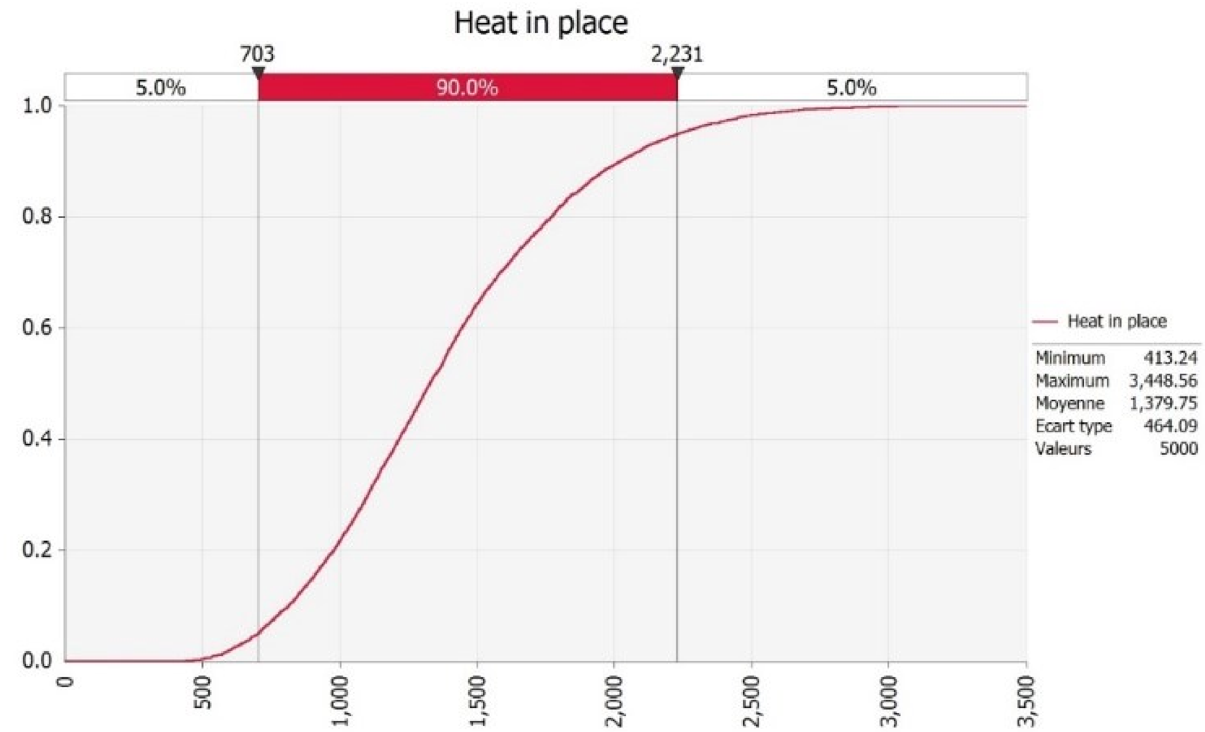


Figure 2 – Probability distribution of reserves (MWhth) in eastern Morocco



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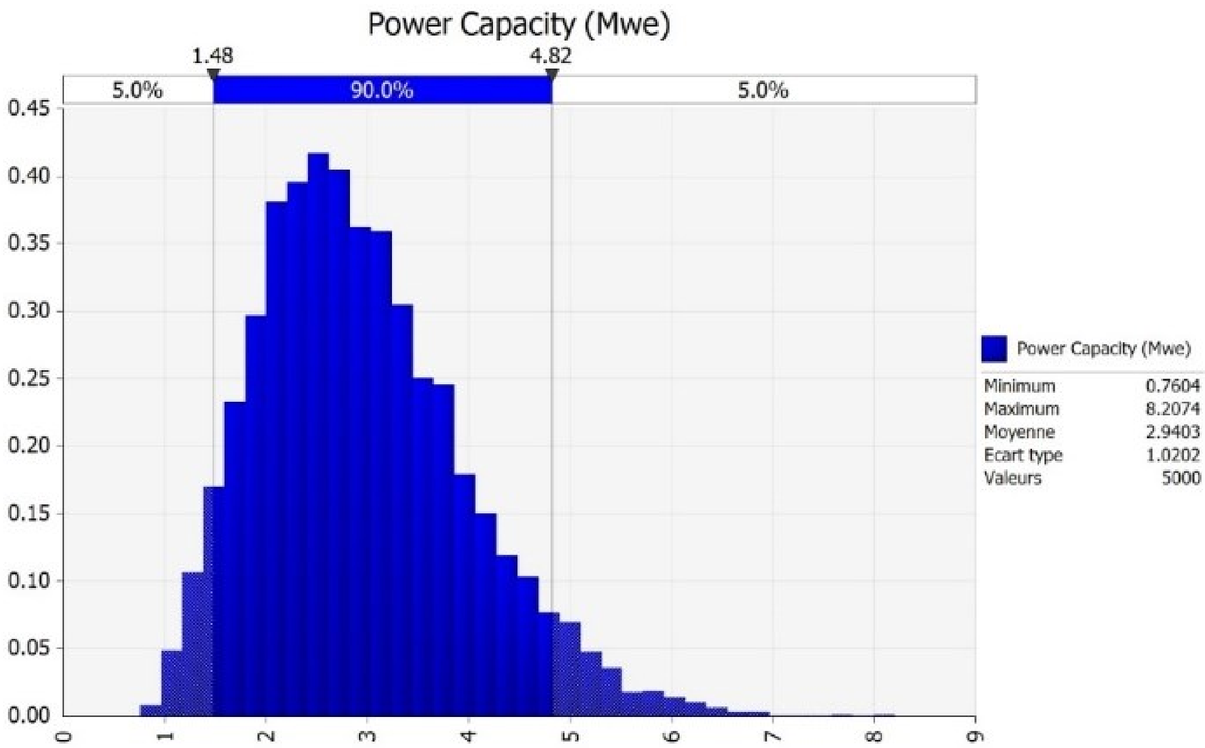

Figure 4 : Sustainable power in MWe for a binary cycle plant in eastern Morocco. (Distribution of cumulative probabilities).

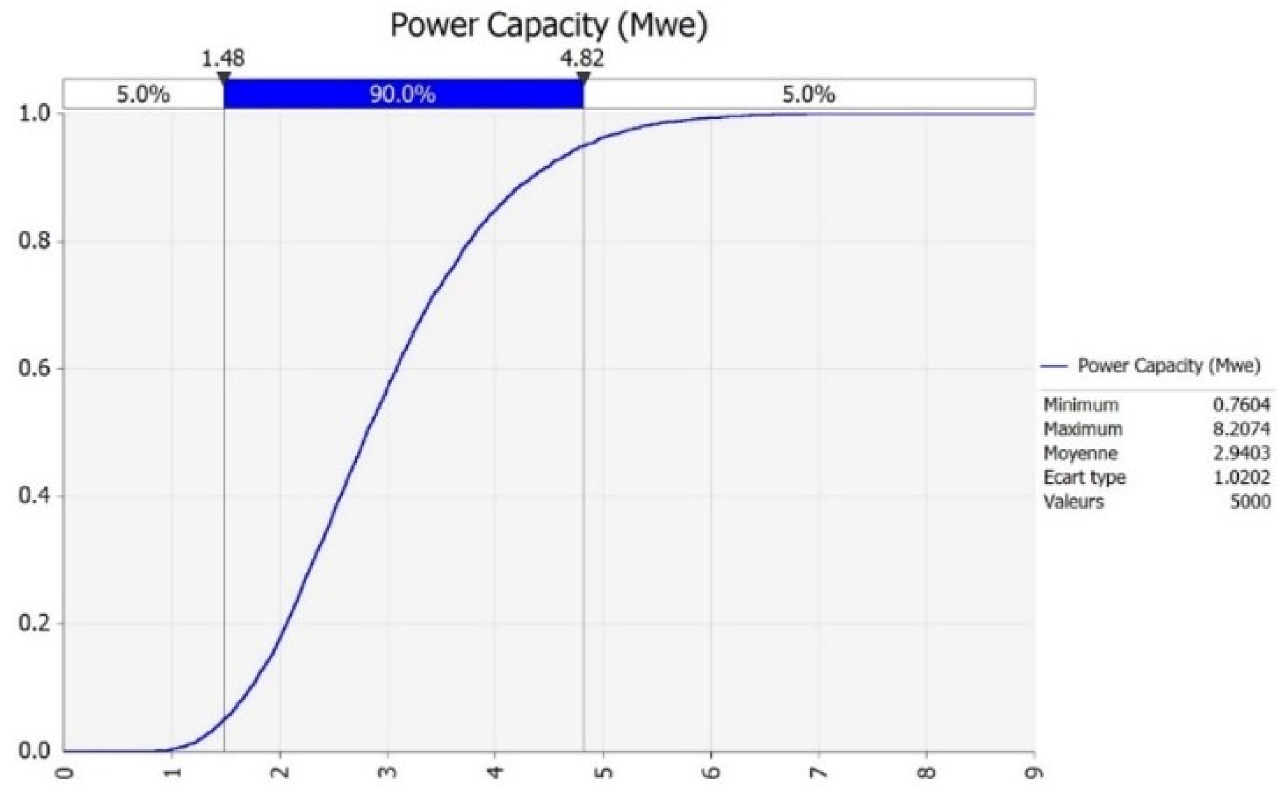

Figure 5 : Sustainable power in MWe for a binary cycle plant in eastern Morocco. Distribution of relative frequencies

Table 2 – Parameters for the direct use scenario in Berkane / Fezouane (only the different ones from the electricity generation scenario)

Parameter	Units	Min	Most likely	Max	Distribution
Area (Ares)	km^2	8	50	60	triangular
Thickness (H)	m	170	200	250	triangular
Rock density (ρ_r)	kg/m^3	2900	2900	3000	
Porosity (Ø)	%	0.01	0.1	0.2	
Recovery Factor (R_f)	%	0.2	0.25	0.3	
Rock heat capacity	kJ/kg°C	0,85	0,90	0,92	
Temperature (Tres)	°C	60	90	120	triangular
Fluid density (ρl)	kg/m3				f(temp)
Conversion efficiency (Ce)	-	0,05	0,05	0,06	f(temp), triangular
Fluid specific heat (Cl)	kJ/kg°C	4,16	4,19	4,19	f(temp, pressure), triangular
Rejection temperature (Tf)	°C				Constant (25°C)

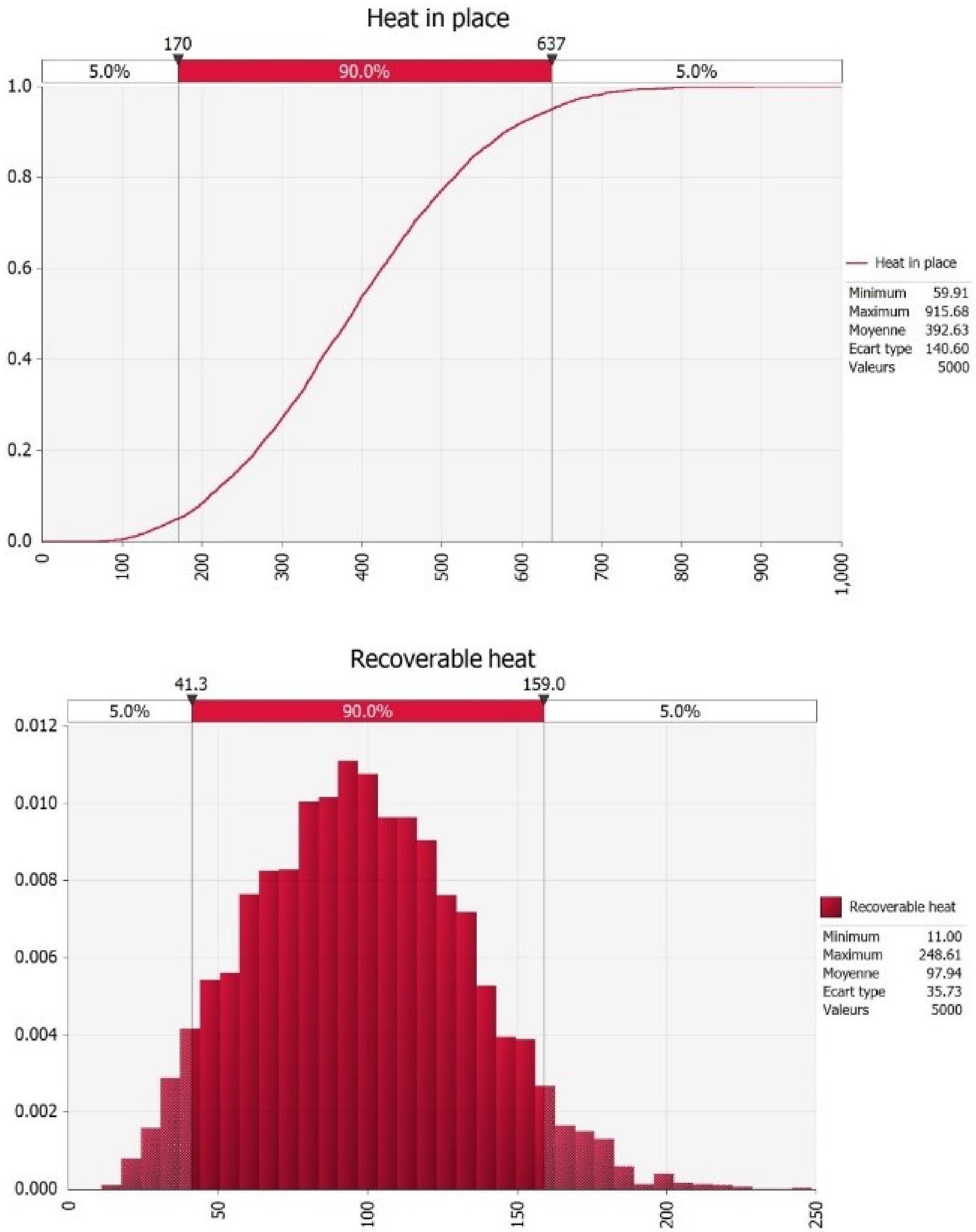

Figure 6 – Cumulative probability (top) of reserves and probability distribution of recoverable MWhth reserves (bottom) by direct use in the Berkane / Fezouane area.

5. CONCLUSION

A Monte Carlo volumetric capacity assessment, based on the available data, has been performed. An estimate for the electric power, which can be produced from the recoverable heat in Northeastern Morocco has been calculated. According to the results, 2.9 MWe can be produced. For more certitude and with 90 % confidence, 1.48 MWe can be produced in North-Eastern Morocco if the recoverable heat is used for 30 y. The wide range of these estimates simply reflects the uncertainty in the size, temperature and recovery factor of the study area. For direct use, the possibility to use geothermal heat is very high with a 90% confidence that the average recoverable energy is from 41 MWhth to 159 MWhth.

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