Assessment of closed-loop shallow geothermal potential in Catalonia using GIS tools

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ABSTRACT

The closed-loop shallow geothermal potential is defined as the thermal power that can be efficiently exchanged by a BHE (Borehole Heat Exchanger) and it determines the economic suitability of shallow geothermal installations. In this research, the G.POT method has been used to determine shallow geothermal potential of Catalonia taking into account the spatial distribution of the ground thermal properties and climatic conditions.

One of the most sensitive parameters in the shallow geothermal potential assessment is the Heating Season Length (HSL). Usually, this is a discrete value calculated with the average daily temperature data at meteorological stations by setting a temperature threshold value; otherwise, the HSL could be fixed as a constant value for the shallow geothermal potential assessment.

In this research, a continuous and spatially distributed value of the HSL has been obtained by using a Multiple Linear Regression (MLR) and anomaly corrections of half-hourly meteorological data to obtain hourly air temperatures maps from 2013 to 2017. The considered climate variables in the MLR were altitude, latitude, longitude and distance to the Mediterranean Sea coastal line.

Anomalies were corrected using real data from 187 automatic weather stations (AWS) all around the territory by interpolating errors at each location using the inverse distance (ID) interpolation technique.

1. INTRODUCTION

Catalonia is located in the NE of the Iberian Peninsula covering 32.108 km^2 with 7.5M residents (Fig. 1).

Figure 1: Study area. Catalonia and the area where the G.POT method was applied are marked in red colour.

The wide range of altitudes (from 0 up to 3100 m.a.s.l.) (Fig.2), the complex geology and the wide range of mean air temperatures require an application of a quantitative method to assess and map shallow geothermal potential using GIS tools.

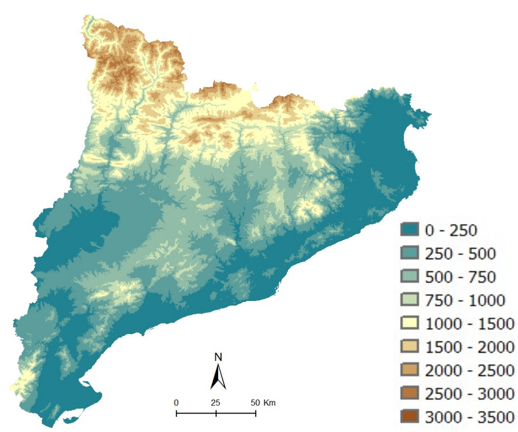

Figure 2: Hypsometric map of Catalonia (m.a.s.l.).

Due to orographic variability a strong temperature and precipitation contrasts exist (Martín Vide et al., 2008). Mean annual temperatures ranges from 0ºC to 17ºC (Fig.3) and mean annual precipitations range from 400 mm to 1200 mm depending on the location. Furthermore, Catalonia is a Mediterranean region where quick changes on weather conditions are frequent.

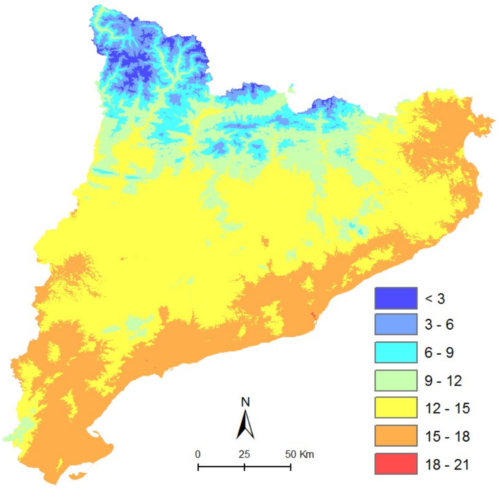

Figure 3: Map of annual air temperature (ºC) in Catalonia. Shallow Geothermal Viewer (ICGC, 2019).

In Catalonia, the use of shallow geothermal energy (SGE) has been increasing in the last years, especially after the Europe 2020 objectives were declared in March 2007 (20% reduction of energy consumption and CO_2 emissions, and 20% of energy needs covered by renewable energy sources). The Directive 2009/28/EC on the promotion of the use of energy from renewable sources also had a pivotal role, since it establishes that the geothermal energy captured by heat pump is considered as a renewable energy and provides quotas of renewable energy coverage for new and refurbished buildings.

In the absence of any official inventory, the ICGC has made a compilation with the available information provided by ICAEN (*Institut Català d'Energia*) and other public access information. It could be estimated that at least 27MWt have been installed in Catalonia until now (ICGC, 2019). This is a rather low value compared to other European countries such as Sweden and Germany.

With the aim of increasing the end users knowledge on SGE and to provide initial data for feasibility study of vertical heat exchange systems, the *Institut Cartogràfic i Geològic de Catalunya* (ICGC), started to develop a shallow geothermal online viewer of Catalonia (Arnó, G. et al, 2016). The online viewer includes geological, soil and hydrogeological information layers, spatial distribution of ground thermal properties, ground temperatures, climatic information layer sets and shallow geothermal potential for closed-loop systems. To estimate geothermal potential in Catalonia the G.POT method developed by Casasso and Sethi (2016) has been applied using GIS software and taking into account the spatial distribution of the main parameters including the Heating Season Length (HSL).

Three real cases were analysed in the province of Lleida and Barcelona (one in the Pyrenees and one in the Vallès area), to compare the results obtained by the G.POT method with real data coming from monitored closed-loop systems.

3. HEATING SEASON LENGTH (HSL)

3.1 Definition

The Heating Season Length (HSL) is defined as the average of the total number of days in a year, when the average outside daily temperature is below a threshold value. It is assumed that for a building at design conditions and during the heating season the difference between the outside and inside temperatures generates a certain heat loss that makes it necessary to turn on the heating system to achieve a more comfortable inside temperature. This is directly related to the suitability, design and economic feasibility estimation of a shallow geothermal installation.

As Stamper (1979) indicates, the HSL could be calculated using the normal daily mean temperatures for all the years for which the records are available. In the resulting curve (Fig. 4), the heating season begins when the normal daily mean temperature crosses downward the threshold temperature value (usually 15 to 18 ºC), and ends when it crosses upward over the same line (Fig. 4).

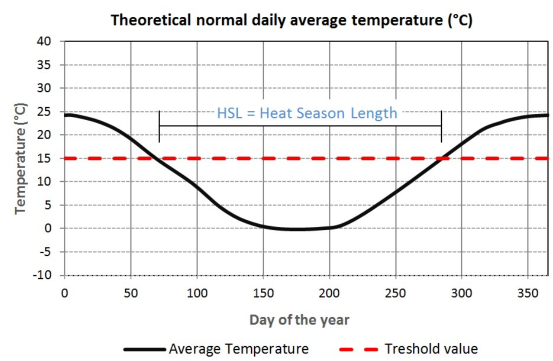

Figure 4: Theoretical normal daily average temperature. Modified from Stamper (1979).

Analysing the available hourly temperature datasets (2013 to 2018), we observe that the daily mean temperature reaches the lowest values in December and January and the highest values in July (Fig. 5). However, abrupt temperature changes from one day to another are quite common. This makes it difficult to apply the Stamper (1979) method, since the temperature threshold value is crossed more than 2 times. Therefore, it is assumed that in Catalonia HSL is discontinuous over the year, which seems the more accurate and realistic solution. Then HSL is the total amount of days in one year when the average air temperature (defined as the arithmetic mean of the 24-hourly registers) is below the fixed threshold value.

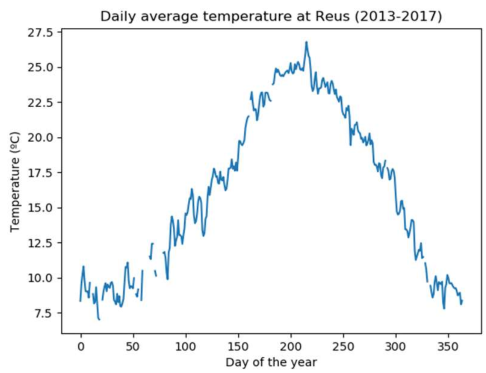

Figure 5: Normal daily average temperature plot in Reus (Catalonia).

3.2 Data source

Air temperature data with 30-minute time resolution are available in the network of 187 Automatic Weather Stations (AWS) located in Catalonia and managed by the SMC (Meteorological Service of Catalonia). Most of them are placed around the main urban areas, a few of them (12) are distributed at different altitudes between 1000 and 2000 m a.s.l. and 12 stations are installed higher in the mountain summits of the region (Fig. 6). Flat areas and low altitude areas are appropriately represented, whereas there is a lack of stations in middle altitude zones. Data is available from 2013 up to date. For the HSL calculation data form 2013 to 2017 have been used.

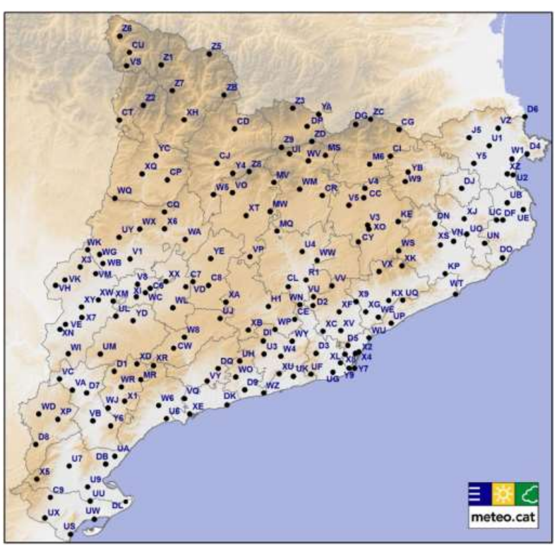

Figure 6: Location of AWS in Catalonia with 30-minute air temperature data available from 2013 to 2018.

3.2 Methodology and results

To calculate the HSL, hourly air temperatures maps have been generated using a spatial interpolation scheme based on Multiple Linear Regression (MLR) and anomaly corrections. This methodology has already been applied successfully in the region at monthly and annual scale (Ninyerola et al., 2000).

The methodology scheme includes:

a) Calculation of the regression model using the MLR method with all available data from meteorological stations.

b) Generation of hourly modelled air temperature maps applying the global model obtained by the MLR.

c) Calculation of the differences between the modelled temperatures values and the observed values at meteorological stations.

d) Interpolation of the errors to obtain hourly anomaly corrections maps which reduce the error level at weather stations.

e) Combination of hourly air temperatures and anomaly correction maps to obtain the final global model for hourly air temperature distribution assess.

f) Generation of annual and average HSL maps for the total period (2013-2017).

The global model can be expressed as:

$$\mathrm{Y}_i = \sum_k \beta_k x_{ik} + \in_i \qquad [1]$$

Where Y_i is the dependent variable (in this case the hourly air temperature), β_k are the coefficients of linear regression, x_{ik} are the considered variables and ϵ_i are the residual error, which are the difference between the predicted and observed values.

The considered climate variables are geographically dependant, such as the altitude, latitude, longitude and distance to the coast of Mediterranean Sea. All of them have been obtained from the Digital Elevation Model (DEM) at 15x15m resolution from the ICGC. All weighting factors (elevation and distance to the coast) are based on a Gaussian function, which means that those stations with similar geographic characteristics will have more important weight than the rest of the stations.

To interpolate temperature data, a script made with Python 3.6 was used. After reading the station data for a specific time, the multiple linear regression is calculated using the Scikit-learn library (Pedregosa, 2011). Once the regression parameters are obtained, they are applied to the DEM and distance to the coast matrices, using the NumPy library.

Root Mean Square Error (RMSE) was calculated for each AWS. It varies from <1ºC to 3ºC and locally up to 4.5ºC. The RMSE map distribution shows that regions which have the lowest uncertainty are plains and urban areas with high station density. The highest average errors occur on areas with orographic complexity and/or with low station density. Overall, 43800 maps of the calculated hourly air temperature have been generated with 270x270 m resolution in GeoTiff format.

The local differences between the calculated air temperature values and the values measured at weather stations were interpolated using inverse distance (ID) interpolation method. The resulting anomaly corrections maps have been combined with the maps of the calculated hourly air temperature, thus obtaining the final version of the maps useful for the HSL calculation. Thereby, predicted values at weather stations match observed values.

The threshold air temperature value to assess the HSL and Heating Degree Days (HDD) was set to 15ºC, AENOR (1988). A Python 3.6 script was used to perform the calculation of HDD. The resulting map is shown in Fig. 7. The HSL varies from 150 days in the warmest locations near the coast to the 365 days in the highest mountain regions where heating would be necessary all the year round. Nevertheless, urban areas where closed-loop systems could be installed are placed below the 1000 m a.s.l, where HSL is between 150 and 250 days a year.

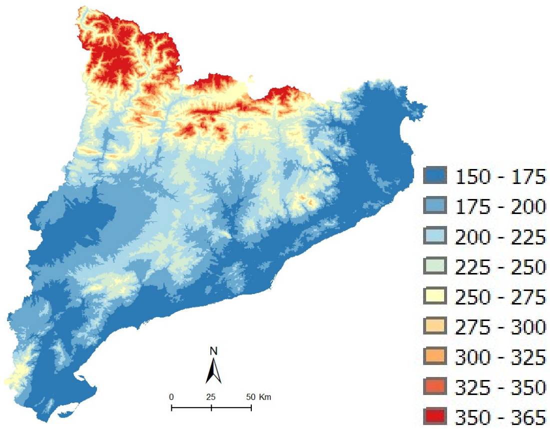

Figure 7: HSL map for Catalonia with 15ºC threshold value. (ICGC – METEOCAT, 2018).

4. SHALLOW GEOTHERMAL POTENTIAL

4.1 The G.POT method

The G.POT is a mathematical method developed by Casasso and Sethi (2016) to calculate the geothermal potential, defined as the yearly average thermal load that can be exchanged with the ground by a 100 m deep Borehole Heat Exchanger (BHE) coping with a minimum/maximum temperature threshold of the heat carrier fluid.

It is based on the assumption that the application of a cyclic thermal load on a BHE with a length L, for an operating lifetime t_s, induces a time-varying thermal alteration of the ground and the heat carrier fluid, with respect to the initial temperature T_0 (ºC) (Fig. 8). Then, the shallow geothermal potential $\bar{Q}_{BHE}$ is the thermal load for which the maximum difference between the T_0 (ºC) and a threshold value T_{lim} (ºC), corresponding to the minimum temperature of the heat carrier fluid, is achieved over the lifetime t_s.

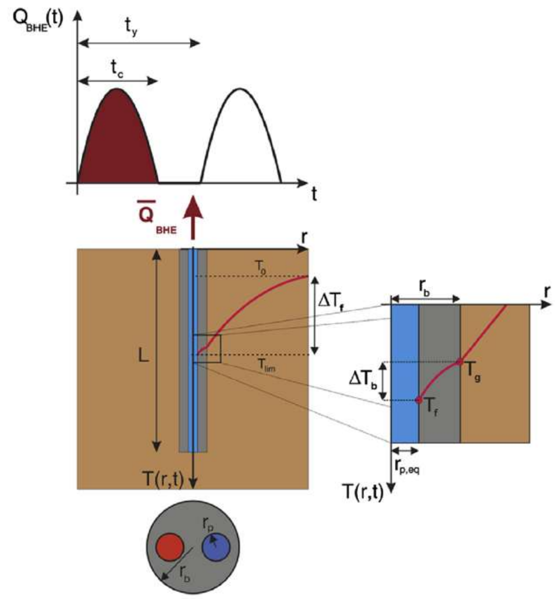

Figure 8: Input parameters for the estimation of the shallow geothermal potential (QBHE) with the G.POT method. Original from Casasso and Sethi (2016).

The $\bar{Q}_{BHE}$ is described by the following formula:

$$\bar{Q}_{BHE} = \frac{\alpha \cdot (T_0 - T_{lim}) \cdot \lambda \cdot L \cdot t'_c}{Gmax(u'_s, u'_c, t'_c) + 4\pi\lambda \cdot R_b} \qquad [2]$$

Where λ is the ground thermal conductivity expressed in $Wm^{-1}K^{-1}$ and α is 8 if $\bar{Q}_{BHE}$ is expressed in W, or $7.01 \cdot 10^{-2}$ if $\bar{Q}_{BHE}$ is expressed in MWh/y.

R_b is the borehole thermal resistance (mKW^{-1}), which could be assigned based on typical values (0.07÷0.15 mKW^{-1}), on test results or with formulae from the literature.

G_{max} is a function of three non-dimensional parameters.

$$G_{max}(u'_s, u'_c, t'_c) = -0.619 \cdot t'_c \cdot \log(u'_s) + (0.532 \cdot t'_c - 0.962) \cdot \log(u'_c) - 0.455 \cdot t'_c - 1.619 \qquad [3]$$

Being:

$$t'_c = t_c / t_y \qquad [4]$$

$$u'_c = \rho c \cdot \frac{r_b^2}{4\lambda t_c} \qquad [5]$$

$$u'_s = \rho c \cdot \frac{r_b^2}{4\lambda t_s} \qquad [6]$$

Where t_c is the length of the heating or cooling season in seconds (s), t_y is the length of the year, ρc is the thermal capacity of the ground ($Jm^{-3}K^{-1}$), and t_s is the lifetime considered in seconds (s).

4.2 Geothermal potential assessment in Catalonia

In order to calculate the heating geothermal potential of Catalonia a common set of BHE parameter values has been set:

Table 1: List of constant and calculated parameters for geothermal potential assessment in Catalonia using the G.POT method.

Assumed constant parameters			
Simulated lifetime	t_s	50	years
Borehole length	**L**	100	m
Pipe number	**n**	2	units
Borehole radius	r_b	0,075	m
Pipe radius	r_p	0,016	m
Thermal conductivity of backfilling	λ_{bf}	2	$Wm^{-1}K^{-1}$
Minimum fluid temperature	T_{lim}	-2	°C
Calculated constant parameter			
Borehole thermal resistance	R_b	0,0954	mKW^{-1}

Several input parameters are related to the geology of the subsoil and the climate so they have a specific geographical distribution and have therefore been mapped for the entire territory of Catalonia:

Table 2: List of geographic dependant parameters considered for geothermal potential assessment in Catalonia using the G.POT method.

Mapped parameters		
Length of the heating season	t_c	days
Undisturbed ground temperature	T_0	°C
Ground thermal conductivity	λ	$Wm^{-1}K^{-1}$
Thermal capacity of the ground	ρc	$Jm^{-3}K^{-1}$

The undisturbed ground temperature is the temperature that is reached in the subsoil approximately between 5 and 15 m depth, below which the daily and seasonal air temperature oscillations are dissipated. Its value is assumed as similar to the average annual air temperature at a certain location. This layer is available at the shallow geothermal online viewer of Catalonia (ICGC, 2019). It has been prepared in collaboration with the Animal Biology, Vegetal Biology and Ecology Department of the Autonomous University of Barcelona (UAB) based on available climatological data and using multiple regression techniques (Ninyerola et al, 2007). In this case, the factors that were considered in the theoretical model of calculation were: altitude, potential solar radiation, topographic humidity index (Topographic Wetness Index, TWI), topographical position index (Topographic Position Index, TPI), the complexity of the terrain (Terrain Ruggedness Index, TRI), latitude and continentally.

The thermal conductivity map used is based on the Geological Data Base of Catalonia 1: 50,000 from the ICGC (Fig.9). Depending on the age, the lithology of materials and their percentage, the thermal conductivity of each of the outlying cartographic units has been assigned using the values proposed by the UNE 100715-1 (AENOR, 2014) and several authors: Robertson (1988), Fernández & Banda (1986), Horai & Baldridge (1972), Marzán (2000), Peña (2013). The resulting value has been corrected by means of a porosity coefficient that takes into account the compaction of the materials, which is the relationship defined by Manger (1963) for the reduction of porosity according to the geological age. This layer is available at the shallow geothermal online viewer of Catalonia (ICGC, 2019).

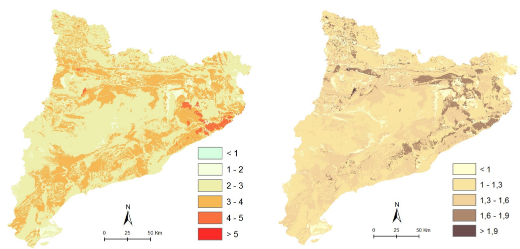

Figure 9. Thermal conductivity in $Wm^{-1}K^{-1}$ (left) and thermal diffusivity in mm^2s^{-1} (right) maps according to lithology and porosity.

The thermal capacity is defined as the amount of heat that is obtained from a volume of rock or soil as a result of decreasing its temperature by 1K. The thermal diffusivity is the ratio between thermal conductivity and thermal capacity, and it defines the capacity of a rock or soil to dissipate heat and depends on the thermal conductivity, density and the specific heat capacity of the materials. The thermal diffusivity map used to obtain the thermal capacity map is based on the Geological Data Base of Catalonia 1: 50,000 from the ICGC (Fig.9). Density and specific heat capacity values have been assigned to each one of the outlying cartographic units according to Waples & Waples (2004) and Robertson (1988).

The shallow geothermal potential map of Catalonia for closed-loop systems and for heating mode is shown in Fig. 10.

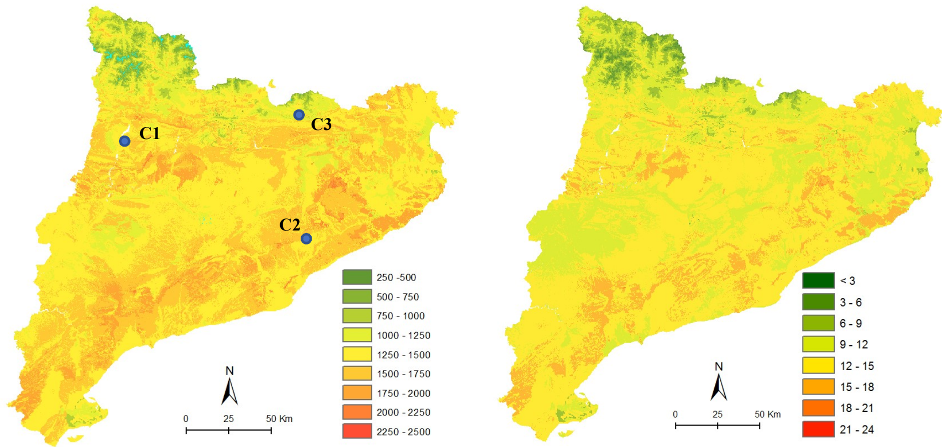

Figure 10. a) shallow geothermal potential map of Catalonia expressed in Watts (left side) and b) the energy potential in MWhy^{-1} (right side) for closed-loop systems in heating mode. The dots mark the location of the SGE facilities used for result validation (Case 1, Case 2 and Case 3).

The validation of the results has been a difficult task as there are few closed-loop monitoring systems with available data, and also because some available data depend not only on the geological and climatic characteristics of a certain location, but also on several factors related to the field and BHE design and operational use of the SGE installations differing from the G.POT method assumptions (Casasso and Sethi, 2016).

Even so, 3 real SGE installations have been analysed as shown in Table 3. The Figure 10a show its location. For all these cases the Measured Heat Energy Demand (E_{HD}) (kWhy-1), the Seasonal performance Factor (SPF), as the average Coefficient of Performance (CoP) of a heat pump over the full heating season, and the total BHE installed lengths, are available.

	BHE length (m)	Type of collector	E_{HD} (MWhy^{-1})	SPF	E_G (MWhy^{-1})	Q_{BHE} (MWhy^{-1})
Case 1	1400	Single U	85	3,4	60	9-12
Case 2	2300	Single U	378	4,0	283	12-15
Case 3	3240	Single U	217	3,9	161	6-9

Table 3: Characteristics of 3 real cases of monitoring in closed-loop geothermal systems. BHE: Total BHE length installed (m), E_{HD}: Measured Heat Energy Demand (kWhy^{-1}), SPF: Seasonal Performance Factor average coefficient of performance measured by the monitoring system, BHE estimated length, E_G: Energy extracted from the ground (kWhy^{-1})

The measured E_{HD} can be used to calculate the E_G (Energy extracted from the ground) as follows:

$$E_G = E_{HD} \frac{(SPF-1)}{SPF} \quad [7]$$

The Q_{BHE} (MWhy^{-1}) map obtained with the G.POT method estimates that a maximum of 9 to 12 MWhy^{-1} could be exchanged with the ground. That means that a total number of 5 to 7 BHE of 100 m length would be necessary to obtain 60 MWhy^{-1} from the ground. In this case, 10 BHE of 140 m length (1400 m of BHE) have been installed, but in this case the BHE field was overestimated to provide future new buildings up to E_{HD} = 180MWhy^{-1}. This value has been obtained using the same model built with GLD (Ground Loop Design) that was used to analyse the functioning of the installation (García-Cespedes, J., 2019).

In Case 2, the Q_{BHE} (MWhy^{-1}) map obtained with the G.POT method estimates that a maximum of 12 to 15 MWhy^{-1} could be exchanged with the ground. That means that a total number of 19 to 24 BHE of 100 m length would be necessary to obtain 283 MWhy^{-1} from the ground. In this case 2300 m of BHE have been installed.

In Case 3 the Q_{BHE} (MWhy^{-1}) map obtained with the G.POT method estimates that a maximum of 6 to 9 MWhy^{-1} could be exchanged with the ground. That means that a total number of 18 to 27 BHE of 100 m length would be necessary to obtain 161 MWhy^{-1} from the ground. In this case 3240 m of BHE have been installed. In that case, at the moment no new buildings are planned, so the discrepancy could be both the overestimation of the BHE field and from the uncertainty of the G.POT method.

It seems G.POT method is a useful tool as a first approximation of the maximum energy that can be exchanged with the ground for heating by a single borehole with defined characteristics allowing a preliminary estimation of a closed-loop geothermal system costs. However, it never can replace the detailed ground characterization, the execution of the Thermal Response Test (TRT) and the BHE field sizing and design to ensure an efficiently operating geothermal system.

5. CONCLUSIONS

Shallow geothermal potential is defined as the thermal energy that can be exchanged by a Borehole Heat Exchanger (BHE). The G.POT is a mathematical method to assess shallow geothermal potential for closed-loop systems in heating or cooling mode as the yearly average thermal load that can be exchanged with the ground by a 100 m length BHE coping with a minimum/maximum temperature threshold of the heat carrier fluid.

The G.POT method considers several parameters related with the ground thermal properties and with the BHE characteristics. The Heating Season Length (HSL) is a sensitive parameter that often has to be considered as a constant value.

In the case of Catalonia, a continuous and spatial distributed value of the HSL has been obtained by using a Multiple Linear Regression (MLR) and anomaly corrections of half-hourly meteorological data to obtain hourly air temperatures maps. The climate variables considered in the MLR have been altitude, latitude, longitude and distance to the Mediterranean Sea coastal line. The use of a HSL map in front of a constant value, allows calculating a more accurate shallow geothermal potential map.

Comparing the results obtained with several cases in Catalonia where monitoring systems are implemented, G.POT method seems to be a useful tool as a first approximation to the maximum energy that can be exchanged with the ground for heating by a single borehole with defined characteristics.

It allows a preliminary estimation of a closed-loop geothermal system costs. However, it never can replace the detailed ground characterization, the execution of TRT and the BHE field sizing and design needed to achieve success.

REFERENCES

AENOR Norma UNE 100002:1988 Climatización. Grados-día base 15 grados centígrados. (1988).

AENOR UNE 100715-1:2014. Diseño, ejecución y seguimiento de una instalación geotérmica somera. Parte 1: Sistemas de circuito cerrado vertical. (2014).

Arnó, G., Herms I., Camps, V., et al: The new digital Geothermal Atlas of Catalonia for very Low Temperature (GACvLT), (2016) *EGC2016*, Strasbourg, France, poster.

Casasso, A., Sethi, R.: G.POT: A quantitative method for the assessment and mapping of the shallow geothermal potential, *ScienceDirect*, Energy 106 (2016) 765-773.

Casasso, A., Pestotnik, S. et al. Assessment and mapping of the closed-loop shallow geothermal potential in Cerkno (Slovenia), *ScienceDirect*, Energy, (2017) vol 125 pp 335-344. https://doi.org/10.1016/j.egypro.2017.08.210

Casasso, A., Della Valentina, S. et al. Ground Source Heat Pumps in Aosta Valley (NW Italy): assessment of existing systems and planning tools for future installations. *Società Geologica Italiana,* Roma, Vol 46 (2018), pp 59-66. DOI: 10.3301/ROL.2018.53

Fernández, M. & Banda, E.: Heat pulse nne-source method to determine thermal conductivity of consolidated rocks. *Rev. Sci. Instrum*. 57 (11), (1986), 2832 – 2836.

García-Cespedes, J., Arnó, G., Herms, I., de Felipe, JJ., Characterization of efficiency losses in ground source heat pump systems equipped with a double parallel stage: A case study. Renewable Energy. Available 11 January 2019 (In Press) https://doi.org/10.1016/j.renene.2019.01.029

Horai, K. & Baldridge, S. Thermal conductivity of nineteen igneous rocks, I application of the needle probe method to the measurement of the thermal conductivity of rock. Physics of the Earth and Planetary Interiors, Volume 5, (1972). p. 151-156. https://doi.org/10.1016/0031-9201(72)90084-2

ICGC: Shallow Geothermal Energy. Geoindex (Viewer & Geoservices WMS), (2019)*, Institut Cartogràfic i Geològic de Catalunya,* Barcelona. [Last access: 2019/03/04].

Joly, D., Brossard, T., Cardot, H., Cavailhes, J., Hilal, M., & Wavresky, P.: Temperature interpolation based on local information: the example of France. *International Journal of Climatology*, 31(14), (2011), 2141-2153.

Manger, E.: Porosity and bulk density of sedimentary rocks. *USGS Bulletin, (1963),* 1144-E. 60 pp.

Margarit-Roset, J., Vilalta-Juvanteny, Ll., Escobar-Mariné, M. A.: Els graus-dia de calefacció i refrigeració de Catalunya: resultats a nivell municipal. *Estudis monogràfics: 14, (2003), Institut Català d'Energia, Departament de Treball, Indústria, Comerç i Turisme, Generalitat de Catalunya*.

Martín-Vide, J., Raso Nadal, J., and Morera Palacios, A.: Atles climàtic de Catalunya, període 1961-1990: termopluviometria. *Institut Cartogràfic de Catalunya i Servei Meteorològic de Catalunya*, Generalitat de Catalunya, Barcelona, (2018).

Marzán, I.: Régimen térmico en la Península Ibérica. Estructura litosfèrica a través del Macizo Ibérico y el Margen Surportugués. *Tesis doctoral*.

Departament de Geodinàmica i Geofísica. Universitat de Barcelona, Barcelona*,* (2000).

Ninyerola, M., Pons, X., & Roure, J. M.: A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 20(14), (2000), 1823-1841.

Ninyerola, M., Pons, X., Roure, J. M.: Objective air temperature mapping for the Iberian Peninsula using spatial interpolation and GIS. *Int. J. Climatol*., 27, (2007), 1231-1242.

Pedregosa et al.: Scikit-learn: Machine Learning in Python. JMLR 12, 2011, pp. 2825-2830.

Peña, D.: Evaluation of conductive heat transport in potencial high enthalpy geothermal reservoris. *MSc. UB-UAB*, Barcelona, (2013), 37 pàgs.

Robertson, E.C.: Thermal Properties of Rocks. *USGS Open-File Report*, (1988), 88-441. 106 pp.

Stamper E., Koral, R.: Handbook of Air Conditioning, Heating, and Ventilating. Building Systems Design. *Industrial Press Inc*, New York, (1979).

Vicente-Serrano, S. M., Saz-Sánchez, M. A, Cuadrat, J. M.: Comparative analysis of interpolation methods in the middle Ebro Valley (Spain): application to annual precipitation and temperature. *Climate Res*. 24, (2003), pp 161-180.

Waples, D & Waples, J.: A Review and Evaluation of Specific Heat Capacities of Rocks, Minerals and Subsurface Fluids. Part 1: Minerals and Nonporous Rocks. *Natural Resources Research V* 13, (2004), n2, pp 97-122.