

## Economic, geological and technical potential mapping test for GSHP systems in Europe

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### ABSTRACT

The present work shows a method to produce techno-economic maps that represent the feasibility of double-U closed-loop shallow geothermal systems for different case studies in Europe and the potential savings that could be introduced by newly developed Cheap-GSHPs (**C**heap and **E**fficient **A**pplication of reliable **G**round **S**ource **H**eat exchangers and **P**umps) technologies.

First an empirical method for creating techno-economic maps related to closed-loop geothermal systems was conceived. The method started with the collection of data at European level. In particular, data from other tasks of the project were collected and homogenized in order to provide an overview of geological, climatic and energetic conditions across Europe. Other economic information retrieved by the partners of the consortium was used as reference basis for costs calculation. The collected data was the basis for the execution of a large amount of numerical simulations that correlate ground surface temperature (GST), thermal conductivity ( $\lambda$ ) and required BHE length for given energy demands (17 referential building types). Regression algorithms between mappable parameters (GST,  $\lambda$  required BHE-length) for each reference building type were developed. Maps of required BHE-length were developed as a starting point to calculate a specific capital cost index, €/kW of installed capacity.

A first set of numerical simulations was performed for double-U heat exchangers whilst a second set was performed for a large coaxial probe developed by Cheap-GSHPs, in order to compare the economic improvements on a spatial basis. Seven case studies across Europe were considered for the application of the regressions, to test their reliability for different geologies, climates and data availability. The deployment of the new drilling and HE technologies coming from Cheap-GSHPs seems to be very positive in terms of €/kW savings, with savings that frequently range from 8 to 20%, depending on country.

### 1. INTRODUCTION

The definition and quantification of the feasibility and potential for different locations is fundamental to promote the deployment of shallow geothermal closed-loop systems at European scale. The assessment of the energetic potential is more valuable if performed spatially at different scales, since spatial information presented as thematic maps allows optimization of the decision process, identifying more suitable or unsuitable zones.

Small scale maps of the potential (e.g.  $\geq 1:100,000$ ) could improve the political territorial planning over large areas by helping identifying the most suitable or unsuitable zones for the installation of new GSHP systems, promoting the deployment of GSHPs whilst protecting groundwater resources. Mapping is also useful at large scale (e.g.  $< 1:100,000$ ) to produce

preliminary techno-economic estimates or cost/return on investment evaluations for new systems. Both mapping procedures have the final aim of persuading potential stakeholders to invest in shallow geothermal energy. The applied methodology is a complex process that gathers a lot of different data from various scientific areas of interest including geology, climate, technology, economy and policies, with obvious issues of data availability, reliability and accuracy.

Published literature dealing with mapping procedure applied to shallow geothermal energy are not very common and quite recent execution (Gemelli et al., 2011) (Galgaro et al., 2015) (Garcia-Gil et al., 2015) (Schiel et al., 2016) (Bertermann et al., 2015), but the topic is continuously growing in importance.

The purpose of the presented work is the development of low enthalpy geothermal energy potential maps that could take into account geological, technological and economic aspects of GHSP systems. The shallow geothermal potential is expressed as €/kW, which can be defined as a specific capital cost: it considers main costs (drilling, probes, grouting and heat pump) and system power of the prevalent peak demand. The proposed mapping procedure was conceived to have not only a qualitative representation of feasibility but also providing a semi-quantitative tool to pre-emptively estimate installation length and costs of closed shallow geothermal systems. Another innovative aspect of the work is the spatial estimation of potential savings in installing a newly developed Cheap-GSHP coaxial heat exchanger compared to double-U. Further outcomes of the work are feasibility maps for Cheap-GSHPs helicoidal HE, dividing the territory into suitable, unsuitable and moderately suitable zones for the installation. The €/kW index groups geological, climatic, energetic and economic information together in order to provide an estimate of the techno-economic feasibility of both actual-state double-U systems as well as newly developed Cheap-GSHPs technologies, compared with existing ones.

## 2. ASPECTS CONSIDERED FOR THE TECHNO-ECONOMIC MAPPING

### 2.1 Aspects related to the natural resource

The main parameters related to the natural resource that affect the heat exchange and consequently the feasibility and potential of GSHP systems are usually identified in:

- geological & hydrogeological setting;
- local geothermal gradient;
- climate conditions

The amount of exchanged heat for conduction within a medium is proportional to temperature gradient and to  $\lambda$  (thermal conductivity), as described in Fourier's law. It is then obvious that higher values of  $\lambda$  (the gradient being equal) would lead to a better heat exchange between the probe and the surrounding ground. To thermally characterize the subsurface from a mapping perspective, the procedure usually consists in separately characterizing the outcrops and the

unconsolidated material they require different types of geospatial elaborations. Outcrops are commonly thermally characterized using values taken from literature or bibliography: in some cases, however, a very detailed and widespread thermal characterization using thermal conductivity measurement techniques is performed, as done within Cheap-GSHPs project. The characterization of the unconsolidated portion of territory is even more important, since typically human built-up areas (and consequently GHSP systems, which satisfy a defined energy demand) are located in valleys, alluvial fans, plains, where the main observed lithologies are unconsolidated. Another crucial aspect, which is mainly observed in unconsolidated aquifers, is represented by the occurrence of groundwater. The saturated/unsaturated thickness of the subsurface and groundwater Darcian velocity have huge influence on the weighted vertical thermal conductivity (Luo et al., 2018). Moreover, an anomalous geothermal gradient influences the heat exchange between the probe and the ground, given constant thermal properties of the subsurface. Climate is a factor that affects both the energy demand and the natural resource within the underground. The mean annual air temperature (MAAT) gives an indication of the temperature that will be observed within ground surface and within the subsurface since MAAT is almost always proportional to the mean annual ground surface temperature (GST) (Banks, 2012) and to the undisturbed ground temperature. Ground temperature is fundamental in the quantification of the geo-exchange potential because the difference between thermo-vector fluid and ground temperature drives the heat exchange and the required BHE length is often inversely proportional to the difference between ground temperature and fluid temperature.

### 2.2 Aspects related to the technology

The main parameters related to the technology of vertical closed-loop shallow geothermal systems that affect the heat exchange (and therefore €/kW) are usually identified in the characteristics of the geothermal system and the building loads.

#### 2.2.1 Geothermal system characteristics

The mechanical, physical and energetic characteristics of the geothermal systems which will exploit the thermal energy from the subsurface are extremely important to estimate a €/kW index. In order to perform geothermal mapping, referential closed-loop GSHP systems must be considered: this means that system type (single U, double U, helicoidal HE...), dimension of borehole, probes material, flow rate, thermo-vector fluid type, maximum fluid temperatures etc. must be chosen in advance, since the mapping products will refer to a specific system type.

#### 2.2.2 Building type & energy demand

The envelope and thermal characteristics of the building shell affect the amount of energy demand needed to obtain a thermal comfort for the people working or living within these environments.

The building loads are fundamental to understand the geo-exchange potential of a GSHP system: monthly energy demands, peak loads and their durations must be identified in advance since a GSHP system has to be dimensioned for providing energy both in base load and peak energy demand conditions.

### 2.3 Aspects related to economy

The economic aspect is a crucial constraint to the feasibility of a vertical closed-loop system and hugely affects €/kW index. Drilling costs represent the most discouraging term of the whole vertical closed-loop GSHP systems market. That is because the cost of drilling per linear metre of collector is normally quite high and the occurrence of rock or purely gravelly lithologies contribute to increase it for different reasons. €/kW index is therefore affected by costs related to drilling, heat pump, probe, grouting and to a series of ancillary costs (installation, connections etc.). It should also be noted that the evaluation of the installation costs in euro/kW depends on the different market prices in the each nation, which, in turn, are influenced by currency changes that vary over time.

### 2.4 Aspects related to policy

These aspects should need a further and longer discussion because they include a series of socio/economic parameters, not always convertible into thematic maps. The parameters took into account in the mapping procedure are the potential presence of political support in terms of financial subsidies given by each country's government or local authorities and the potential presence of groundwater protection zones. The first aspect is very important to calculate the final €/kW index and to understand which are the countries that mainly invest in GSHP systems while the second is fundamental to locate the areas where, despite high or low potential, the installation of new GSHP systems is forbidden because they could harm the safety and quality of groundwater by linking different aquifers or creating preferential pathways for the infiltration of pollutants in the groundwater.

## 3. METHOD

The method follows the guidelines previously tested in both southern Italy (Galgaro et al. 2015) and Cantone Ticino, a region located in southern Switzerland, reported in Perego et al., 2019. The method starts with the identification of representative European climates, lithologies, referential building types and their energy demand that are the basis for the realization of a large series of EED (Hellstrom and Sanner, 2010) simulations: these simulations allows identifying and quantifying empirical regressions that could correlate quite easily mappable parameters such as GST and  $\lambda$  with the estimated required BHE length for a defined set of building types. The spatial estimation of the design BHE length for a specific building type along with reference costs for linear metre of collector and heat pumps allowed the specific capital cost, €/kW to be spatially estimated. As explained in the following paragraphs, to identify the empirical regressions we selected 7 lithotypes that could be representative of

Europe's geology, 17 building types (4 residential buildings with 3 insulation types + 5 non-residential buildings) and 10 locations, representative of Europe's latitudes range and climate classes. The energy demands for each climate and for each referential building were calculated in TRNSYS (10), producing 170 monthly energy profiles. Then a GSHP system dimensioning with EED was performed for each of the 170 energy profiles taking into account 7 different lithotypes (paragraph 3.1.1.), for a total of 1190 simulations of estimated required BHE length. The execution of this large number of EED simulations varying geology, climate, energy demand and system size allowed the extrapolation of polynomial regression formulas that could empirically correlate GST (climate),  $\lambda$  (geology) and required BHE length (technology) for a specific system type.

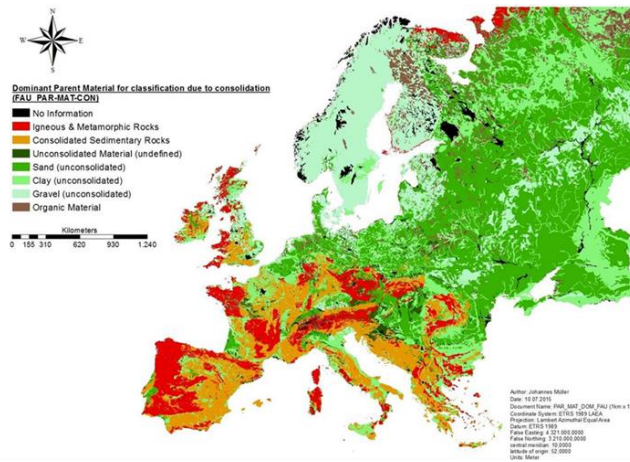
After having obtained these empirical regressions, these were applied on GST and thermal conductivity maps for 7 different real case studies across Europe. The application of the empirical regressions to the GST and thermal conductivity maps allowed the creation of required BHE length maps and the calculation of a €/kW index for specific reference building types.

A first set of 1190 EED simulations was performed to obtain regressions for double-U heat exchangers and for each building type, while a second set of 1190 EED simulations was performed to obtain regressions for Cheap-GSHPs coaxial HE for each building type (described in paragraph 3.1.4). This allowed comparative €/kW maps for two different scenarios to be generated and the estimation of the potential savings originated from the adoption of Cheap-GSHPs technologies against market ready alternatives. As far as the helicoidal system is concerned the method could not be applied (a required length for a helicoidal system is tricky to obtain), therefore only qualitative feasibility maps were developed. Moreover, the use of this technology is restricted to small energy demands, to specific favourable lithologies and hydrogeological conditions. Qualitative maps were developed as the best way to promote Cheap-GSHPs helicoidal technology.

### 3.1 Data used for identification of empirical regressions

#### 3.1.1 Reference lithological contexts for EED simulations and thermal database for case study site thermal characterization

FAU\_PAR-MAT-CON dataset, produced within Cheap-GSHPs project (Figure 1, Müller et al., 2018), was used to describe Europe's most representative predominant parent lithologies: average thermal properties for each lithological context were used in EED simulations.



**Figure 1 - Final dataset FAU\_PAR-MAT-CON**

At the other hand, to thermally characterise the geological maps for the local case studies, the level 2 detailed thermal database produced in Cheap-GSHPs was used. This database includes a series of reference thermal properties for different lithologies derived from laboratory measurements, including: 8 sedimentary rocks, 10 igneous rocks, 7 metamorphic rocks as well as unconsolidated deposits including gravel, clay and peat both in saturated and dry conditions. It has to be noted that the map scale of representation does not allow the representation of the local geological details. Therefore, this map must be used consciously with its limits. It does not provide all the necessary information of a site-specific project. Conversely, it provides information useful to orient the territorial policies in order to encourage the use of GSHP.

*3.1.2 Climatic database*

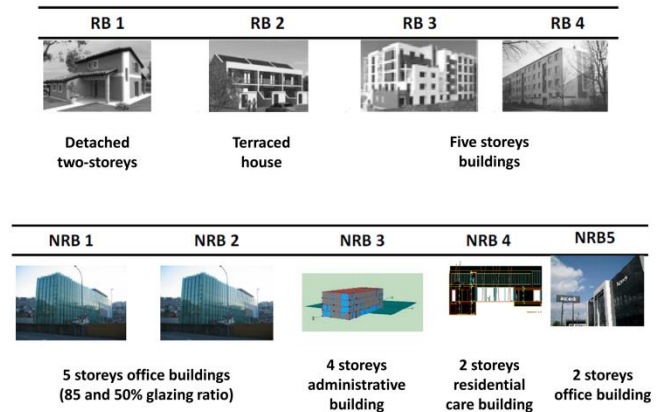
Ten locations were selected depending on Köppen-Geiger climate classification and base on the work written by De Carli et. al, 2018. The considered cities, representative of Europe’s most frequent climate types were:

- for Csa climate type : Madrid, Athens;
- for Cfa climate type: Venice, Milan;
- for Cfb climate type: Dublin, Bruxelles, Zürich, Debrecen;
- for Dfb climate type: Helsinki, Berlin;

*3.1.3 Reference building types and energy demands*

Cheap-GSHPs project took into account 4 options of residential buildings with 3 different types of insulations (good, low, no insulation) and 5 options for non-residential buildings. All of the 17 (4 residential with 3 insulation types + 5 non-residential, reported in **Figure 2**) building types were taken into account for the 10 locations mentioned before, giving a total of 170 produced TRNSYS energy demands and peak loads, later implemented in EED. By multiplying 7 types of lithologies and 170 energy demand profiles, 1190 simulations were performed. A first set of simulations was performed taking into account an double-U system, while the second set of simulations considered a newly

developed Cheap-GSHPs large coaxial heat exchanger. This allowed calculating maps of potential savings between actual double-U technology and Cheap-GSHPs one.



**Figure 2 - List of referential buildings for which energy demand was calculated and used for EED simulations**

*3.1.4 Reference geothermal systems*

Comparison between technologies can be made after having produced maps of the shallow geothermal potential for each system type and this is one of the most significant outputs of the work. Within Cheap-GSHPs, two reference geothermal systems were considered: one actual-state double-U heat exchanger with actual-state heat pump and one newly developed large coaxial heat exchanger powered by a high efficiency heat pump developed by the engineering partners of the project. The parameters of the two referential systems are reported in Table 1.

**Table 1 - Characteristics of the two reference BHE types used for EED simulations**

DOUBLE-U			CHEAP- GSHPs large coaxial		
BOREHOLE	Borehole diameter	152.4 mm	BOREHOLE	Borehole diameter	100 mm
	Filling $\lambda$	2 W/mK		Filling $\lambda$	2 W/mK
	Volumetric flow rate per borehole	0.5 l/s		Volumetric flow rate per borehole	1 l/s
DOUBLE-U PIPES	Outer diameter	32 mm	INNER COAXIAL PIPE	Outer diameter	32 mm
	Thickness $s$	3 mm		Wall thickness	2.9 mm
	$\lambda$	0.4 W/mK	$\lambda$	0.5 W/mK	
	Shank spacing	100 mm	OUTER COAXIAL PIPE	outer diameter	76.1 mm
		wall thickness		3.6 mm	
THERMO-VECTOR FLUID	Specific heat capacity	3795 J/kgK	THERMO-VECTOR FLUID	Specific heat capacity	3795 J/kgK
	$\lambda$	0.48 W/mK		$\lambda$	0.48 W/mK
	Density	1052 kg/m <sup>3</sup>		Density	1052 kg/m <sup>3</sup>
	Viscosity	0.0052 kg/ms		Viscosity	0.0052 kg/ms
	Freezing point	-14°C		Freezing point	-14 °C

### 3.1.5 Reference costs

For the double-U system, a cost analysis was performed by country by estimating the total drilling costs based on the perforation, probe, grouting and ancillary costs. For the newly developed Cheap-GSHPs large coaxial HE, costs were derived from the real costs obtained from the installation of the novel heat exchanger in Italy and Belgium.

The reported results refer to €/kW maps and savings considered for referential residential building n°1 (RB1), a detached two storeys house with 210 m<sup>2</sup> of net area and 567 m<sup>3</sup> of net volume with a prevalent peak load of 9.1 kW. The ground floor is divided among a living area, that contains a laundry, a cellar and a bathroom, and two other areas used as garage and thermal power plant site.

## 4. APPLICATION ON CASE STUDIES

### 4.1 Erlangen

The German case study is located in the Eltersdorf district of Erlangen, Bavaria. The geological context is influenced by the presence of the Regnitz river which deposited a large amount of coarse, medium-sized and fine-grained sediments (mainly gravels and sands) and by the presence of large outcrops of sandstones, which dominate the local geology. These sandstones can be found both horizontally in the study area and vertically in the subsurface as well as claystones. The stratigraphy of the case study location is defined by an alternation of medium (sand) and fine-grained material (silt and

clay) which overly a thick succession of sandstones and claystones.

#### 4.1.1 Creation of GST map

The ground temperature for Germany was calculated through the model AMBETI, which was developed at the agrometeorological research centre in Braunschweig (13). The interpolation method is a regional multiple linear regression with geographical longitude, latitude and height of location as input variables and a subsequent triangulation, covering Germany with a resolution of 1x1 km (14). The resolution of this dataset, however, was inadequate for the aims of the mapping procedure, since the lithological map had a higher spatial detail. Therefore point based data of ground temperature were collected from the German meteorological service and a regression model using latitude, elevation and ground temperature was built. This regression was applied on latitude and elevation raster of the Erlangen/Eltersdorf case study area to obtain a 25\*25 m map of mean annual GST for Germany. We compared the developed map with the smaller scale one created by Deutscher Wetterdienst: the GST map was therefore adjusted accordingly to its values, producing a more spatially accurate product (25 m pixel size instead of 1 km). In this area, the derived mean annual GST ranges from 10.7 to 10.9 °C.

#### 4.1.2 Creation of thermal conductivity map

1:25,000 geological data in form of shapefiles were collected from the Bavarian State Office for the Environment website (15). There was also the presence of a large groundwater protection area, right in the South of the installation site, where GSHP installations are not allowed. Thermal properties according to geological thermal database were assigned and reference drillability values for Germany were derived. Unconsolidated sediments were assigned two different values of thermal conductivity, one for dry conditions and one for wet conditions. This was fundamental to estimate a weighted thermal conductivity that could take into account the unsaturated and saturated portion of the subsurface to a depth of 100 m (typical installation depth of vertical double-U systems). The historical series of piezometric levels was retrieved from the Environmental agency of Bavaria, in particular Erlangen Q5 groundwater well was considered. Annual average data for 2016 and 2017 highlighted that the representative depth of the groundwater table was quantified in 0.87 m below ground level. Bedrock information from geological profiles reported in the geological maps highlighted the presence of thick layers of sedimentary rocks which deepen far below 100 m depth. Moreover, geological profiles clearly showed the very small thickness of Quaternary deposits compared with the underlying bedrock composed of sedimentary rocks as sandstones and claystones. This geological framework was also confirmed by the 2006 stratigraphy log executed at the test site. According to this well log, the average thickness of Quaternary unconsolidated deposits was set to 10 m for the riverbeds and for the Quaternary

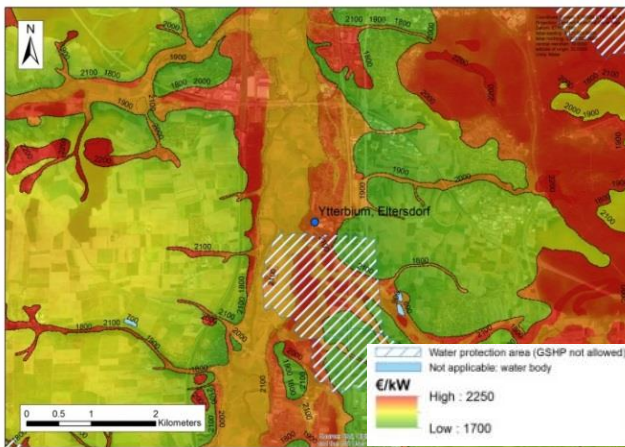
areas, while the underlying claystone-mudstone bedrock was estimated to be 90 m thick for the whole area where unconsolidated deposits were observed. A 3D mapping approach was performed: a weighted thermal conductivity based on the stratigraphic succession available for the test site and by unsaturated/saturated conditions was calculated. Sandstones were assigned a  $\lambda$ -value of 2.9 W/mK while other lithologies were assigned computed values of  $\lambda$  taking into account water saturation and bedrock thickness.

#### 4.1.3 Presence of subsidies

In Germany, financial aids are provided for closed-loop systems if a series of technological and bureaucratic requisites are satisfied. In particular the subsidies apply on the cost of the heat pump. The newly developed Cheap-GSHPs coaxial system present an average COP of 4.5, so available subsidies amount were € 150/kW starting from a minimum system of 45 kW (up to € 6750) to a maximum of 100 kW (up to € 15000).

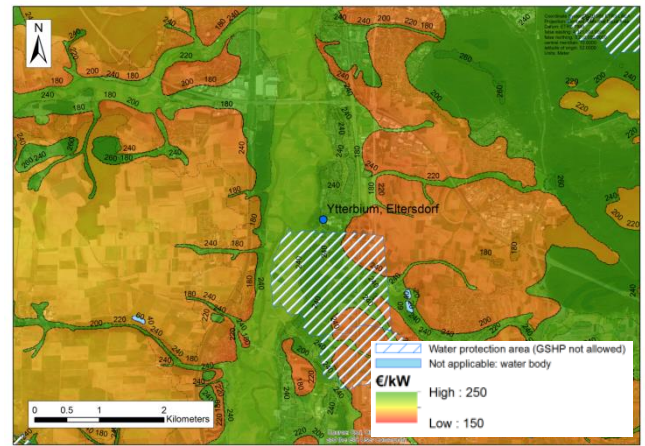
#### 4.1.4 Results

Results of €/kW index for actual-state double-U systems highlight lower costs for areas showing consolidated sedimentary rocks compared to riverbeds (Figure 3). This result arises from the imposed stratigraphy, which was composed of 10 m of unconsolidated sediments and 90 m of mudstones, which show quite low thermal properties for a rock (1.95 W/mK).



**Figure 3 - Estimated €/kW map for double-U systems at Erlangen**

This has an impact on the required BHE length, which is higher in the riverbeds and lower where sedimentary rocks are observed. From the results we can see that the specific capital cost ranges from 1700-1800 €/kW in consolidated sedimentary rock to 2000-2100 €/kW within riverbeds. These costs refer to a small geothermal system, therefore the specific capital cost is higher than for large systems, which would cost much less per kW.



**Figure 4 - Estimated savings between double-U system and Cheap-GSHPs coaxial one expressed as €/kW for Erlangen**

€/kW maps for Cheap-GSHPs coaxial HE were subsequently created and a comparison between the two technologies (double-U vs Cheap-GSHPs large coaxial) was performed. The results are reported in Figure 4: it is clearly seen that the major savings would be located in the fluvial valleys, while the savings would be lower within consolidated sedimentary lithologies. The average savings would be around 200 €/kW which can be estimated approximately as the 10% for a small residential building of the initial cost.

As previously explained, the area shows two main lithotypes: mainly unconsolidated deposits within fluvial valleys and consolidated sedimentary rocks outside them. Helicoidal systems could be therefore installed without particular issues within unconsolidated deposits of fluvial valleys while the installation is not feasible within rock, due to impossibility to drill rock with enlarged easy drill technique. The groundwater table is also observed at low depth, ensuring a proper contact between the helicoidal system and the ground. This is favoured by the presence of the river Regnitz which affects the shallow depth of the groundwater table. There is also the presence of a large groundwater protection area, right in the South of the installation site, where GSHP-installation is not allowed, and not even helicoidal ones (portrayed in white in Figure 5).



**Figure 5 - Helicoidal HE feasibility map for Erlangen**

#### 4.2 Valencia case study (Spain)

The Spanish test site is placed nearby the Polytechnic University of Valencia (UPV), in an estuarine-deltaic sedimentary environment related to the river Turia and other minor ravines. This area has been affected by lithological subsidence in the last million years. It is not expected to find a real “bedrock” at least in the first 150-200 m, so considering 100 m depth, the stratigraphy could be assumed as mainly composed of fine unconsolidated deposits from ground level to 100 m. Some hard layers associated to coastal bars or fossil beach may be present at deeper levels but not in the first 100 m.

##### 4.2.1 Creation of GST map

Meteorological data in terms of climatic normal for the referential period 1981-2010 were taken from AEMET (Agencia Estatal de Meteorología – Spanish Meteorological Agency) (16). This dataset reported only air temperature, so an estimation of GST from MAAT had to be executed. MAAT was mapped over Valencia case study using an empirical regression produced for the entire Spain between MAAT in a specific location, elevation taken from the EUEDEM (an open-access digital elevation model produced by the European Commission) (17) and latitude expressed as decimal degrees. This correlation allowed producing a MAAT map, which was used to estimate a GST map by adding 2 °C degrees, since no GST measurement or climatic normal data were available. The map shows that the GST ranges from 19-19.5 °C within the study area.

##### 4.2.2 Creation of thermal conductivity map

Geological data came from 1:50000 geological maps requested to IGME (Instituto Geológico y Minero de España) (18), in particular Hoja 722, Valencia and Hoja 696, Burjasot sheets were used in the mapping procedure. Thermal properties were assigned according to the thermal database described in paragraph 3.1.1. As for the German case study, the used approach foresaw the representation of a weighted average thermal conductivity along the stratigraphic column using both real data coming from UPV and mean annual

groundwater level (“3D approach”). According to historical groundwater data, a referential annual average value of 2 meters below ground level was set for the groundwater table, so for a 100 m of stratigraphic column 2 m of unsaturated subsurface (dry) and 98 m of saturated subsurface (wet) were used. 3D thermal conductivity map was created by hypothesizing that the 100 m of subsurface where the case study is located (sandy silts) was represented by the stratigraphy provided by Universidad Politecnica de Valencia. In this stratigraphy the subsurface is characterized by successions of silty clay, gravel and sand. The materials were previously thermally characterized by UPV, so the thermal conductivity of the 100 m column was set as the weighted average. The sandy silt lithology covers the area almost completely, so the weighted thermal conductivity is estimated to be 1.4 W/mK over almost all domain.

At the moment of writing, available TRT analysis yielded a parametric relation between rock thermal conductivity and borehole thermal resistance and not a single value, which is necessary for a rough comparison between the mapped and measured thermal conductivity: it is possible that real values are higher than the mapped ones.

##### 4.2.3 Results



**Figure 6 - €/kW map for Valencia taking into account a Double-U system**

In Figure 6 the €/kW map for an actual-state double-U HE is reported. The index ranges from values of 1700 €/kW for limestone outcrops to almost 1900 €/kW for the coastal area, with an average value of 1840 €/kW. Excluding outcrops, due to their low required BHE length caused by high thermal conductivity, the most feasible zones for the installation of conventional double-U systems would be in the North-Western part of the city, where slightly lower GST values are observed. The less attractive area would be the dock area, where slightly higher GST values are observed. However, the variations of GST and  $\lambda$  are extremely low for this area, therefore local scale differences in GST and stratigraphy seem to be very important in order to quantify the specific capital cost.

Maps representing €/kW for the Cheap-GSHPs large coaxial HE were subsequently derived and they were compared against the previously produced €/kW map for the referential double-U system. Figure 7 shows the results of the comparison: all of the studied area would be favourably affected by the installation of Cheap-GSHPs coaxial systems, since the savings would be estimated in approximately 155 €/kW, which represent the 8.4% of the specific capital cost for reference residential building RB1. In this case it seems that Valencia will benefit from Cheap-GSHPs technologies, also due to the presence of subsidies from the Valencia community that were not taken into account in the mapping because their amount was not clearly quantified: higher savings would therefore be observed. According with the map, the major savings would be mainly located near the shore. Moreover, the presence of soft unconsolidated sediments in the area even at 100 m depth will surely facilitate the use of piling technology (that directly uses the stainless coaxial tube both as a drilling rod and as a heat exchanger), with consequent decrease in drilling costs.



**Figure 7 - Estimated savings between double-U system and Cheap-GSHPs coaxial one expressed as €/kW for Valencia**

The feasibility map for the helicoidal system was produced by assigning different categories to the mapped lithologies (Figure 8). According with experimental tests performed in the field within the Cheap-GSHPs project, the installation of helicoidal GSHE in rocks is not feasible, while in silty lithologies it is feasible only in specific conditions, such as low groundwater depth (better thermal contact due to groundwater) and moderate groundwater flow. In this case it is known that the groundwater table is found at approximately 2 m depth, so the unsaturated portion should not strongly affect the performance of the system. However, the groundwater table in the whole area could not be as shallow as near the UPV test site, so a verification of this aspect has to be made on site. The entire area is therefore moderately suited for the installation of helicoidal HEs, while the installation is unfeasible in the North Western part of the area, where limestone outcrops are present. Within riverbeds,

where the prevalent lithology goes from sandy silt to pure sand and sand with gravel, the installation becomes more feasible.



**Figure 8 - Helicoidal HE feasibility map for Valencia**

## 5. CONCLUSION

The method was applied both to these 2 described case studies and to other 5 case studies throughout Europe, in particular to Pikerimi (Greece), Dublin (Ireland), Putte (Belgium), Zagreb (Croatia) and Chiasso (Switzerland): it proved to be successful even with poor data availability, for different climates, and geologies. The same method could be applied to completely different heat exchanger types, drilling technologies, costs and locations than the ones used in this project, but it will be still applicable and robust. The proposed and applied approach takes into account all of the data previously produced within the project and combines empirical modelling applied to the spatial mapping. It is also the first attempt to produce numerically reliable maps of techno-economic feasibility of closed-loop shallow geothermal systems, considering different types of heat exchangers and drilling technologies.

The deployment of the new drilling and HE technologies developed within Cheap-GSHPs project seems to be very positive in terms of €/kW savings.

The magnitude of savings should frequently range from 10-30% depending on the location. Results are clearly affected by the technical and economic uncertainty of the retrieved data, by the empirical nature of the method and by the mapping procedure itself. However the mapping products were always compared with in-situ measurements and with previous literature.

The identified empirical regressions could be used by planners, designers and architects to perform pre-emptive design of geothermal systems considering the whole supply chain (building-hydraulic plant-ground), while the produced maps are aimed at giving a first quick look of the potential economic savings produced by Cheap-GSHPs' innovations.

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