ThermoMap - An Open-Source Web Mapping Application for Illustrating the very Shallow Geothermal Potential in Europe and selected Case Study Areas

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ABSTRACT

Due to climate change and new political reasons to use more sustainable energy forms (turning away from nuclear, coal and other non-renewable resources), alternative energy sources are needed. Therefore, the geothermal energy sector can become one of the important energy resources in the future.

Geothermal energy (heat) is CO_2-neutral, quasi-inexhaustible and available decentrally at any time and almost everywhere. The exploitation of deep geothermal resources for producing electricity is not only an important component for creating innovative and renewable energy systems, but the use of shallow (focus: up to 400 metres depth) and even very shallow (focus: up to 10 metres depth) geothermal potentials is also significant, e.g. for sustainable heating and cooling of residential and industrial buildings, etc. Furthermore in Europe, the installation and operation of very shallow heat collector systems is not as restricted by national and regional legislation as for deeper systems. Compared with the well-researched and already implemented solar, wind and hydropower domains, less research has been done in the analysis of very shallow geothermal energy potentials at the European level.

1. INTRODUCTION

ThermoMap (Area mapping of superficial geothermic resources by soil and groundwater data) is a European Commission co-funded project under the auspices of the FP7-ICT Policy Support Programme. 12 partners from research and industry from the nine European countries of Austria, Belgium, France, Germany, Greece, Hungary, Iceland, Romania and the United Kingdom are involved in this interdisciplinary project (duration: September 2010 – August 2013).

The key aim of the ThermoMap project is the mapping of very shallow geothermal energy potentials (called ‘vSGP’) across Europe, defined as the natural thermal conductivity of unconsolidated ground to a maximum depth of 10 metres. It has solely made use of existing harmonised data sets.

The project wants to provide general information for private and public stakeholders about parameters which are relevant for the installation of horizontal shallow geothermal systems (Fig. 1) as well as other special types of (vertical) heat collector systems.

Figure 1: Installation of a horizontal heat collector system near Viechtach (Bavaria/Germany).

The resulting geothermal potential values – estimated on the basis of various geoscientific data sets and published formulae – are integrated in an Open-Source WebGIS as well as providing the background geodata used for mapping the varying potentials.

The participating project partners defined one or two test sites in each of the nine countries. The edited geodata and the calculated geothermal potential values are illustrated for three depth layers (maximum 10 metres depth) within these 14 test areas at differing scales (1 : 5,000 to 1 : 40,000). At European level a shallow geothermal potential ‘Outline Map’ at a smaller scale of 1 : 250,000 has been created (Fig. 2).

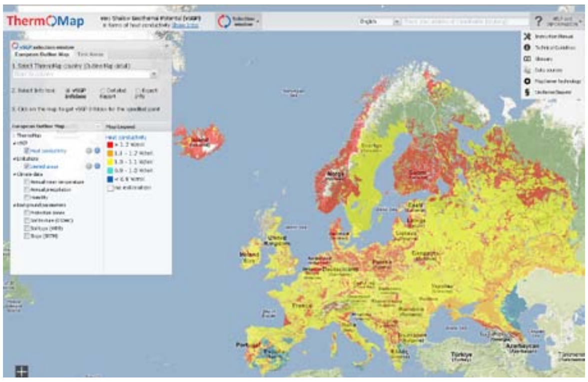


Figure 2: Overview of the European Outline Map (EOM), visualised in the specially developed ThermoMap MapViewer, showing a first estimation of the very shallow geothermal energy potentials (vSGP) across Europe.

2. ESTIMATION PROCEDURE, USED DATA SETS AND WEBGIS TECHNOLOGY

As mentioned in section 1, the ThermoMap project is divided up into two parts. 14 test areas have been investigated to illustrate the very shallow geothermal energy potential (vSGP) in detail to a maximum depth of 10 metres below surface.

Whilst, the European Outline Map (EOM) aims to give a first overview of the shallowest zone’s geothermal conditions in terms of thermal heat conductivity for the whole of Europe.

Before calculating the vSGP estimation, several limiting factors for both the test areas and ‘Outline Map’ had to be considered. These parameters are ‘Legal constraints’, ‘Topography’ and ‘Climate’.

Protection zones may be legal constraints in limiting the installation of horizontal and vertical heat collector systems. At the test site level there is no explicit definition of a protected area, since each country has different legislation concerning environmental protection. Based on this fact, it is quite difficult to provide a general definition of a protection zone.

In the ThermoMap project context each country partner independently decided whether a chosen test area contained a protected zone or not. Such zones include regions for protecting water resources (in the form of national or natural parks, Natura 2000 zones, flood areas, etc.). Each respective country partner provided related data for integration into the WebGIS.

For the Outline Map, the data sources used are Natura 2000 zones of Central Europe (2012), provided by the European Environment Agency (EEA); and for Iceland and other countries not covered by this, the Nationally Designated Areas based on country deliveries (Owner: EEA 2011).

The second parameter is ‘Topography’ expressed by the digital evaluation model (DEM) raster data set. The slope map layer for the Outline Map has been calculated using the SRTM (Shuttle Radar Topography Mission) 90m Digital Elevation Database v4.1 (resampled at 500 m and 1 km) and DEM3 (Auxiliary DEM of Iceland). For the test areas national data sets have been used.

The third parameter ‘Climate’ takes into account the effect of basic climatic elements on the very shallow geothermal potential.

As data about precipitation and temperature are readily available with blanket coverage these parameters are used exclusively and correlated to be able to differentiate between drier areas and wetter ones, both for the test areas and at the ‘Outline Map’ level.

For the ThermoMap project a ‘Humidity Index’, based on biogeographical and climageographical aspects using formulae according to Schreiber (1973), has been developed and applied.

It reflects five classes of humidity (from arid/dry to humid/wet) influencing the moisture content of the unconsolidated underground and hence its geothermal properties.

In the following subsections the data sets and calculation steps for the two different map scopes are outlined with the aim of showing similarities and differences between the two estimations.

2.1 Test area level

The scale of the test sites principally depends on the resolution of the available data sets.

For the 14 ThermoMap test areas across Europe (Table 1) scales ranging from 1 : 5,000 to 1 : 40,000 have been used.

Table 1: Overview of location and extension of the 14 ThermoMap test areas.

Country	Name	Extension
Austria	Mondsee catchment	248 km^2
Belgium	City of Gent	1,600 km^2
Belgium	City of Liège	600 km^2
France	Agglomeration of Orléans	334 km^2
France	Eure-et-Loir department	5,880 km^2
Germany	Büchenbach	2.5 km^2
Germany	Röttenbach	0.04 km^2
Greece	City of Kalamata	72 km^2
Hungary	Budapest	113 km^2
Hungary	Zalakoppány	34.8 km^2
Iceland	Mosfellssveit-Kjalarnes	120 km^2
Iceland	Otradalur	20 km^2
Romania	Constanta	7,100 km^2
United Kingdom	Drayton St Leonard	25 km^2

The test areas are considered as country-specific 'data hotspots'. In the long term, it would be ideal, if this large scale, high quality test site data was available to cover all areas.

In the meantime, the European Outline Map can be regarded as providing some generalised information which covers both the ThermoMap partner countries and other areas at a medium scale and allows the very shallow geothermal potential (vSGP) to be roughly approximated.

The interrelation between the two systems and the development process is depicted in Figure 3.

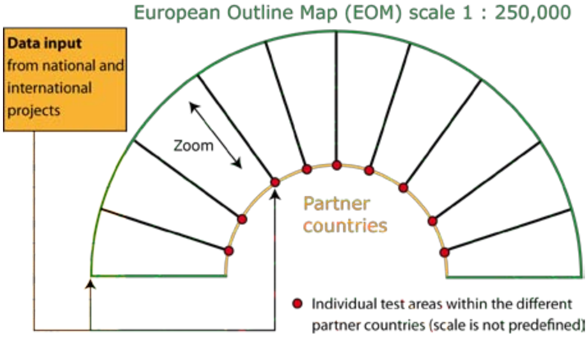


Figure 3: System interrelation between test area and European Outline Map (EOM) level.

Within the test areas, the depth range is up to 10m, provided that this is not limited by hard rock. Furthermore, this complete depth range is divided into three layers (0-3 metres, 3-6 metres and 6-10 metres) based on the different types of very shallow heat collector system technologies available.

The size of the individual test area(s), within the partner countries, as well as the resolution of the used data sets has been selected flexibly due to variations in data quality and quantity. This flexibility ensured that the individual data providing partners could use the most appropriate national data sets.

Some of the most important factors to estimate the very shallow geothermal potential (expressed by the thermal heat conductivity and the volumetric heat capacity) at the test site level and also for the 'Outline Map' are pedological parameters: soil type and soil texture.

These provide valuable information about the properties of the investigated soil and soft rock zone in the context of the ThermoMap project.

Soil type is used to identify areas unsuitable (e.g. fens) for sustainable utilisation of shallow geothermal energy potentials. The World Reference Base for Soil Resources (WRB, 2006) is the most common classification system for this parameter, and is available in digital format for each European country.

The soil texture, based on the grain size distribution of the soil matrix, is also a very significant factor for the calculation of heat conductivity and heat capacity. The Kersten (cf. Kersten 1949) and Dehner (cf. Dehner 2007) formulae are used in the project context.

Several important parameters can be derived from the grain size distribution. These are the air capacity (ac), field capacity (fc) and dead water content (dwc); the proportions of each depending on the individual pore size distributions of the different texture classes.

The definition of specific terms and values relating to the pedological water and air regime as well as their ranges are summarised in Table 2.

Table 2: Definitions and ranges of the specific pedological water and air regime (modified according to Ad-hoc-AG Boden 2005).

Soil moisture tension [hPa]	< 60	60 to < 300	300 to < 15,000	≥ 15,000
pF – value	< 1.8	1.8 to < 2.5	2.5 to < 4.2	≥ 4.2
Porosity equi-valent [µm]	> 50	50 to > 10	10 to > 0.2	≤ 0.2
Porosity term	large coarse pores	narrow coarse pores	inter-mediate pores	fine pores
Soil water regime	swift-flowing	slow-flowing	plant available	not plant available
	percolating water		adhesive water	capillary water
Pedo-ecologic termi-nology	air capacity (ac)	available field capacity (afc)		dead water content (dwc)
		field capacity (fc)		
	total porosity volume (pv)			

As already mentioned the pore size distribution can be derived for each grain size texture class in a generic manner.

The relationship is graphically shown in an idealised form in Figure 4.

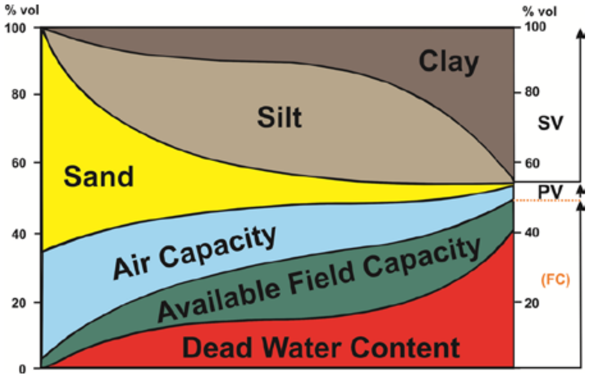


Figure 4: Water, air and substance volumes of soils (SV Substance Volume, PV Pore Volume, FC Field Capacity = Available Field Capacity + Dead Water Content; modified after Kuntze et al. 1994).

With decreasing sand volume and hence decreasing proportion of coarse pores, the air capacity reduces, whereas the dead water content increases with clay content and accordingly the proportion of fine pores. Soils dominated by loam show mainly intermediate size pores and therefore in many cases have an optimal distribution of air capacity and available field capacity.

These soil specific ranges in combination with a standard classification system for the soil texture allow each texture class to be assigned a volume-related percentage of air capacity (ac), field capacity (fc) and dead water content (dwc).

For reasons of comparability and due to differing national systems, the project partners agreed on the use of the more simplified soil classification system of the United States Department of Agriculture (USDA). The related texture triangle is depicted in Figure 5.

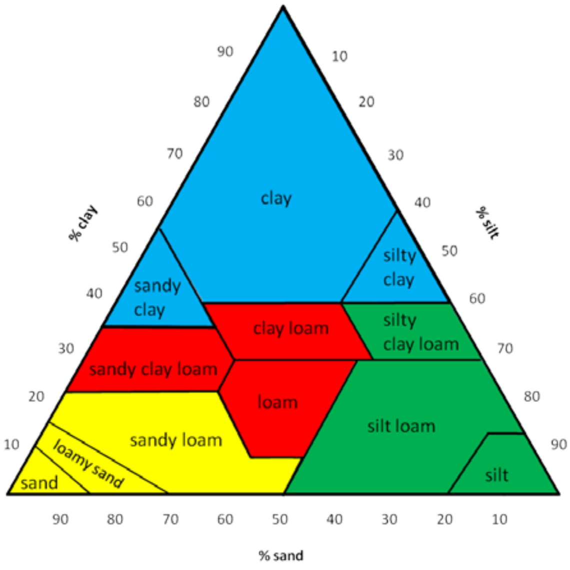


Figure 5: USDA soil texture triangle (modified according to Berry et al. 2007).

The individual grain sizes of the soil texture classes of the fine fraction of soil matrix particles (< 2 mm), are the sand fraction ranging from 2 to 0.05 mm, silt from 0.05 to 0.002 mm and clay less than 0.002 mm. The colours reflect the main texture groups with similar texture classes merged into one combined group.

Based on the USDA classification system graduated accuracy levels of soil texture data for the respective test areas can be derived. These hierarchical levels (Table 3) depend to a large extent on the quality of the associated existing data sets.

Nevertheless, it is always possible to calculate the thermal heat conductivity and the volumetric heat capacity for each level of detail as the values of the pore size distribution can also be adequately merged in the same manner as the textural classes.

Table 3: Overview of hierarchical levels of soil texture data (1 = highest / 4 = lowest).

Hierarchical level	*Possible combinations of individual soil texture classes of the different main soil texture groups*
1	One of the 12 classes according to the USDA classification system (e.g. based on sieve analysis data)
2	Combination of two neighbouring classes within a main texture group
3	One of the 4 main texture groups (sand / loam / silt / clay)
4	Combination of two neighbouring main texture groups

It is also possible to assign more general soil texture data to at least one specific texture group or combination (level 3 or 4, Table 3). To illustrate this type of consolidation, the four main soil texture groups are shown graphically in Figure 6. The colours again reflecting the four main texture groups formed by the merging of similar texture classes into one combined group (sand all, loam all, silt all, clay all).

Figure 6: USDA soil texture triangle at group level (modified according to Berry et al. 2007).

The soil texture (mean grain size distribution) must be determined for all three depth layers at test site level (Figure 7), to calculate the respective values of the thermal heat conductivity and the volumetric heat capacity, where they are not limited by hard rock.

In the ThermoMap project context 'hard rock' means unweathered or weakly weathered rock material which is regarded as unattractive for the utilisation of very shallow geothermal energy potentials for technical and economic reasons.

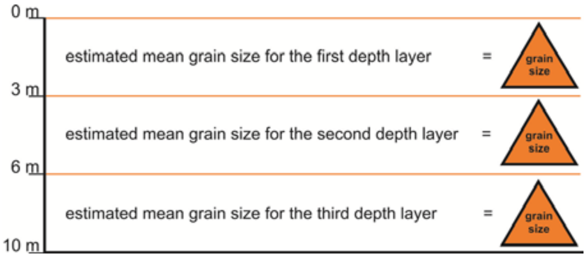


Figure 7: Schematic approach of estimating the mean grain size distribution (texture) of the three depth layers.

For the calculation procedure, an exact value of bulk density as the relationship between mass and volume of a specific material had to be assigned for each of the three depth layers (Table 4). These values reflect the fact that soil and soft rock material usually becomes more compacted with increasing depth below surface.

Table 4: Bulk density classification according to the three depth layers.

Depth range	*Bulk density*
Layer 1 / 0 – 3 metres	1.3 g/cm³
Layer 2 / 3 – 6 metres	1.5 g/cm³
Layer 3 / 6 – 10 metres	1.8 g/cm³

An important step within the estimation process is the combination of the determined grain size distribution (texture) with the respective bulk density value. This combination (Figure 8) is essential to carry out the calculation of the thermal heat conductivity and the volumetric heat capacity in accordance to the Kersten and Dehner formulae.

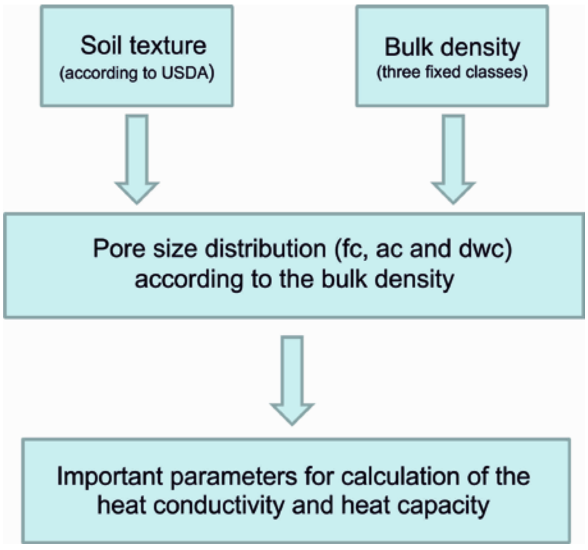


Figure 8: System correlation of soil texture (grain size distribution) and bulk density.

In a final step the respective heat conductivity and heat capacity values are calculated, both for the test area and the ‘Outline Map’.

The thermal heat conductivity is the foreground parameter, illustrated in the ThermoMap MapViewer (section 3), at both levels.

2.2 Outline Map level

The overall aim of the European Outline Map (EOM) is to show an overview of the very shallow geothermal energy potential (vSGP) across Europe.

Due to the fact that it is difficult to find and use already available and harmonised data sets with blanket coverage of the whole of Europe (and beyond) the EOM should be interpreted as a first overview for interested private and public stakeholders. It cannot replace detailed planning by a specialist installation company of shallow geothermal systems using data sets at higher resolutions.

In principle, the estimation steps, as well as the calculation procedure, for the European Outline Map are similar to those used for the test areas, but the accuracy and the scale of the data sets used are different. The EOM is at a scale of 1 : 250,000.

There are also some other basic differences compared to the test area maps. The estimation of all the depth layers down to 10 metres depth is not possible due to inadequate data being available for estimating the thickness and mean grain size distribution of the soft rock zone.

Therefore all values, presented in the developed WebGIS application regarding the thermal heat conductivity, have been calculated using the uppermost bulk density value of 1.3 g/cm³.

More detailed conclusions on a larger scale, as feasible for the test area level, are not possible. For this reason, the depth estimation as well as the calculation of the respective geothermal potential for the second and third depth layer cannot be carried out at the moment.

Moreover, for the European Outline Map only the parameter thermal heat conductivity has been calculated since this is regarded as the more relevant parameter for illustrating the very shallow geothermal energy potential (vSGP).

The freely available digital European Soil Database (distribution version V2.0, Panagos et al. 2012) of the European Soil Data Centre (ESDAC; established by the JRC – Joint Research Centre, Institute for Environment and Sustainability) was chosen as the basis for the estimation of the grain size distribution (soil texture).

Using this harmonised database, the dominant surface texture for the whole of Europe is classified into five classes. For the EOM the classification of the textural classes of the ESDAC dataset was modified slightly, but is comparable to the hierarchical levels 3 and 4 (cf. Table 3 and Figure 6) used in the test areas. The classes ‘fine’ and ‘very fine’ were merged into one class. The modified texture triangle on the basis of the USDA soil texture triangle is shown in Figure 9.

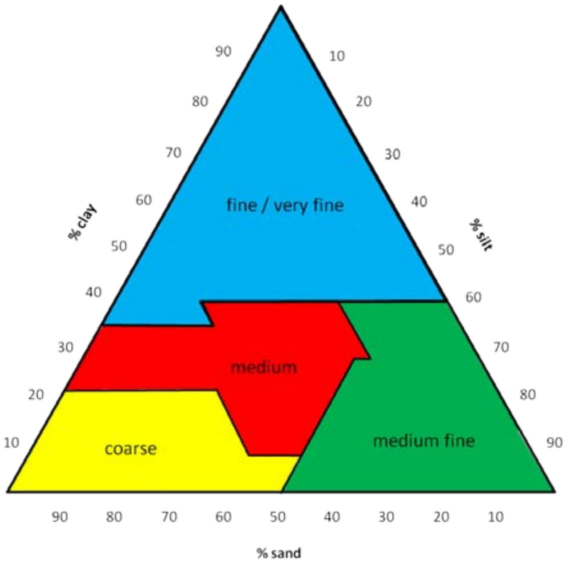


Figure 9: USDA soil texture triangle (modified according to Berry et al. 2007 and Panagos et al. 2012) illustrating the texture classes according to the ESDAC database.

2.3 WebGIS technology (ThermoMap MapViewer)

The resulting values from both the pan-European map (EOM) and selected case study areas (test area level) were integrated into an open-source WebGIS, with all the necessary background geodata, using distributed data sources.

For the 14 test areas as well for the ‘Outline Map’ the geodata and calculated potential values are provided as Web Map Services (WMS) and visualised in a MapViewer – the client application of the WebGIS.

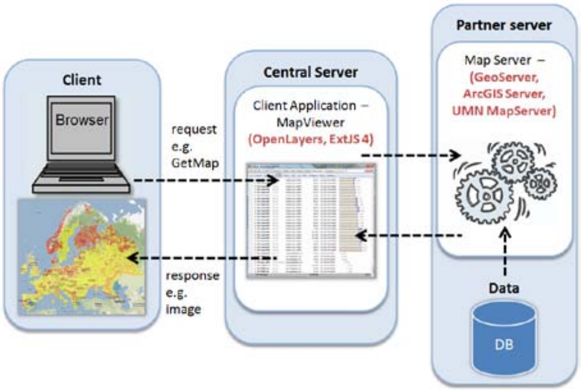


Figure 10: WebGIS architecture with client, server and data components.

The distributed data storage is the most important technical principle in the context of the ThermoMap project. The data for the 14 test areas are spread across 10 partner servers.

No spatial analyses are performed in the WebGIS. The partners process the data in their local GIS and it remains on the partner servers, from where it is published as WMS layers.

The technologies used for the publication of WMS include ESRI ArcGIS Server and open-source GeoServer with an underlying PostGIS database, but the data structure and compliancy to Open Geospatial Consortium (OGC) standards to retrieve the required information are defined.

The WebGIS interface was developed using the open-source frameworks OpenLayers and ExtJS 4, which are JavaScript application programming interfaces that make it possible to combine interactive maps with a complex user interface.

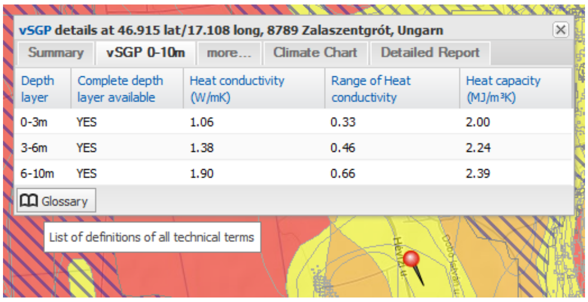
OpenLayers' functionality is enhanced with GUI components of ExtJS 4, which are required for a demanding layout of map windows, toolbars, map layer trees and legend windows by which the user can interact with the application.

The purely client-side JavaScript application is therefore independent of any server technology.

WMS requests from the client, via the client application, are sent to the partner servers, which then return the desired responses to the client. Request and response formats are standardised by the OGC.

The used WMS requests are 'GetCapabilities', 'GetMap' for georeferenced map images, 'GetLegendGraphic' for legend symbols and 'GetFeatureInfo' to attribute values of map layers to a specified map pixel.

With a special query tool, using the 'GetFeatureInfo' response, a clear compilation of all necessary background parameters and results is shown for a selected map location, which eventually can be displayed in a detailed report as a printable 'Location Information Sheet' that contains up to five pages, enriched with map details and schematic diagrams.



vSGP details at 46.915 lat/17.108 long, 8789 Zalaszentgrót, Ungarn

Depth layer	Complete depth layer available	Heat conductivity (W/mK)	Range of Heat conductivity	Heat capacity (MJ/m³K)
0-3m	YES	1.06	0.33	2.00
3-6m	YES	1.38	0.46	2.24
6-10m	YES	1.90	0.66	2.39

List of definitions of all technical terms

Figure 11: Special attribute query tool, the 'vSGP Infobox'.

The ThermoMap WebGIS MapViewer is intended for use by the public, planners and engineers, public bodies, and scientists, in order to provide an overview or, in the case of the different test sites across Europe, more detailed information and usable data about the local shallow geothermal conditions.

Private users for instance can check the potential of their residential district; community planning and administration authorities can test the geothermal potential of their entire administrative unit.

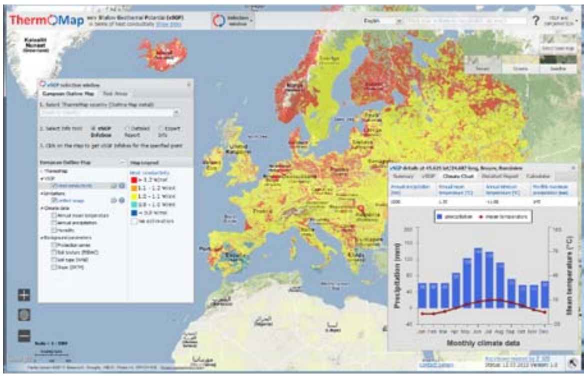


Figure 12: ThermoMap MapViewer – the specially developed WebGIS interface.

3. CONCLUSIONS

Currently Europe is undertaking an energy transition with the aim to turn away from nuclear, coal and other non-renewable energy sources towards green energy developments.

Renewable energy resources are becoming more important in this context. Compared with the well-researched and already implemented solar, wind, and hydro power domain, less research has been done in the analysis and appropriate visualisation of very shallow geothermal energy resources at European level.

Thus, the ThermoMap project targets the very shallow geothermal potential (vSGP) in Europe, defined as the natural thermal conductivity of unconsolidated ground up to a maximum depth of 10 metres.

The very shallow geothermal energy within the first 10 metres below the earth's surface is predominantly influenced by solar energy input rather than by heat from the earth's core.

Variations of air and soil temperature and heat flow at shallow depths are controlled by external variables such as effective solar radiation, distribution of precipitation and water infiltration processes based on site specific pedological as well as hydro-/geological conditions.

This energy resource can be best exploited in the saturated and unsaturated zone of the unconsolidated rock zone where access to the ground is easier.

The local soil, climate and groundwater parameters have a decisive influence on the design and the sustainability of very shallow geothermal installations which are not centralised but in-situ systems. This is why it has been extremely difficult so far to obtain clear and usable specifications for these types of shallow horizontal and vertical installations.

To approach this problem the ThermoMap project was launched in 2010 in order to help find favourable areas for very shallow geothermal energy exploitation in a relatively short time and without high costs.

ThermoMap provides a European Outline Map (EOM) for a first overview of the very shallow geothermal energy potential at a scale of 1 : 250,000 using the thermal heat conductivity as the foreground parameter.

In 14 test areas spread across the nine partner countries the very shallow geothermal potential was mapped in detail to a maximum of 10 metres depth, subdivided into three different depth ranges. The map scale in the test areas depends on the data sets used and ranges from 1 : 5,000 to 1 : 40,000.

In the recently started testing phase of the project, the key objectives are to improve and enhance the user-friendliness of the WebGIS visualisation system (ThermoMap MapViewer) by organising user seminars and creating an online questionnaire for feedback of potential users.

Furthermore, soil and soft rock material from the test sites is currently being analysed for parameters such as soil texture and thermal heat conductivity under different moisture conditions (Figure 13).

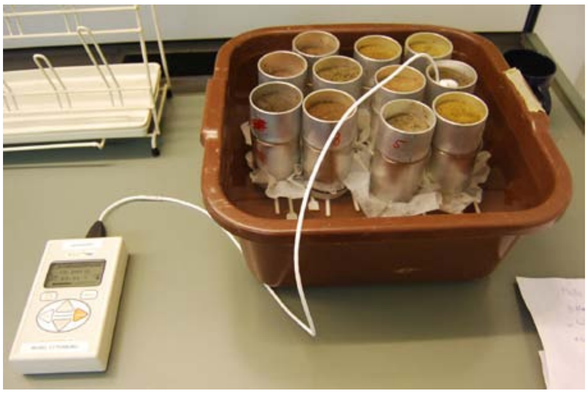


Figure 13: Measuring thermal heat conductivity at the University of Erlangen-Nuremberg.

These measurements will provide valuable data to the project consortium to validate the project results with measured and literature data for optimising the estimation system.

First results show a good agreement between measured data, which have been interpolated to similar moisture content and bulk density values for reasons of comparability, and the estimated soil texture and thermal heat conductivity values.

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