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A pan-European planning basis for estimating the very shallow geothermal energy potentials

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ABSTRACT

After the Fukushima nuclear disaster, renewable energy resources have become increasingly important in Europe. Based on available pedological, climatological, topographical, and administrative data sets we analysed the pan-European very shallow geothermal energy potentials (vSGP) on a mapping scale of 1:250,000. International standards and unified spatial processing methods across Europe ensure comparability and seamless visualisation. An open source WebGIS dynamically serves spatially explicit maps of all input and result datasets. The results show unconstrained potential areas for exploitation where the thermal conductivity (W/m*K) varies between 0.8 W/m*K and 1.2 W/m*K within the soil matrix. Depending on parameters such as grain size distribution and humidity, the highest potentials for vSGP exploitation were found in Liechtenstein, Finland, Iceland, and Norway. With over 50% of the respective country affected, Andorra, Montenegro and Slovenia have the highest values assigned with a limitation for vSGP exploitation. The interactive tool for online searching, discovering and analysing the vSGP provide public, planners, and (non)-governmental organisations with information. This place based modelling approach is considered as an input to the National Renewable Energy Action Plans (NREAPs), contributing to the European Renewable Energy Sources (RES) Directive.

1. Introduction

After the Fukushima Daiichi nuclear disaster on March 11, 2011 the energy strategy in Germany and Europe changed profoundly [3,28]. The National Renewable Energy Action Plans (NREAPs, http://ec.europa.eu/energy/renewables/action_plan_en.htm) based on the Renewable Energy Sources (RES) [23] are pushing developments in the direction of using renewable energy forms. These replacements should serve to avoid nuclear disasters and to mitigate climate change. While migrating to de-carbonized energy systems, the renewables solar power, hydropower, biomass, biofuels, wind energy and geothermal systems have already been analysed, modelled, and harvested quite successfully [3,24].

The advantages and the great role of using geothermal energy resources are well known since decades [14,27]. As early as the nineties of the last century [7], acknowledged the nature and technology of geothermal energy use. He updated his findings on technologies and current status in 2002 [8]. More recently [9,46] and [51] published an article about the calculation and mapping of different renewable energy source potentials [34]. highlighted the world geothermal power generation in the period 1990–1994 and [35] for the period 1995–2000, while [12] covered the years 2001–2005 with an update on geothermal electricity generation for the period 2005–2012 [13]. Also [15] and [53] report on the world status of the efficiency and effectiveness of geothermal electricity production with different kinds of power plants.

Referring to the above mentioned literature, almost all countries analysed therein increased the geothermal power generation capacities from 1990 to 2012. However, all authors refer either to the deep electrical geothermal energy (a few kilometres deep), or the commonly used shallow geothermal energy, obtained in depths from 100 m to 400 m. The solar driven **very shallow geothermal energy potential (vSGP) up to 10 m below the Earth's surface** is insignificantly mentioned.

In contrast to above mentioned references [25] and [44] highlighted the heating and cooling possibilities of the vSGP for residential and office building heat exchange. Techniques to be used are described by Ref. [26]. Modelling approaches to analyse the vSGP on a regional scale are provided by Refs. [24,29] and [43].

To provide a concept valid and applicable throughout Europe, a common data basis including their attribute properties is required

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[10]. Many data repositories hold environmental data to be used for the estimation of the vSGP: the INSPIRE process (as a framework directive for establishing an infrastructure for spatial information in Europe to support community environmental policies [22], the European Environment Agency (http://www.eea.europa.eu/data-and-maps), the European Soil Data Centre [45], the ISRIC-WISE 1.1 Soil Profile Dataset [48], global climate databases e.g. from WorldClim [39], and the like.

Soil characteristics constitute the main basis when estimating the thermal properties [40]. The soil properties such as soil texture (grain size distribution) and bulk density influence the thermal conductivity, while the distribution of snow/water (soil moisture) and its thawing and infiltration process is important for the transportation of the thermal energy developed at the surface to the underground [5,32,33,47,49,52,54,55]. The underlying process principles have been laid down for instance by Refs. [18,19] and [16,38] explained the thermal principles of soils, which have been taken up in a planning guideline for the vSGP by Refs. [20] and [21].

The distribution of the temperature on the soil surface and in the topsoil changes daily to seasonally, with changing minima and maxima [17]. It equalises approximately 20 m below the surface. Even in 10 m depth the changes are insignificant under comparable water, soil texture, and bulk density conditions. Since the physical soil properties, namely soil texture, bulk density and water content underlie a diverse spatial pattern of change, the temperature curves for the northern hemisphere are also alternating. This principle is based on the thermal conduction function of Fourier's Law, describing the quantity of heat that passes through the soil per unit of time. Thus, based on the properties of the soil, the thermal conductivity (TC) expressed in Watts per meter Kelvin is spatially changing [40].

For integrated regional energy planning and estimation of regional energy potentials, the spatial mapping of the availability of energy resources is required [46,51]. Although we agree with these authors, we additionally argue that not only desktop analysis and mapping, but also public access to the modelling and mapping is required. This requires new approaches using the World Wide Web for facilitation [4,6,53].

By introducing and reviewing items of previous research in the area of vSGP, our objective is to develop a European Outline Map (EOM) illustrating the thermal conductivity in W/m*K, considered as a property that controls heat flow through materials of different type [1]. Since concepts and methodologies as described above have not yet been developed for, or applied to the whole of Europe, the question is, whether existing and publicly available pan-European datasets can be used to estimate the very shallow geothermal energy potential? If so, what are the related constraints? We hypothesise that digitally accessible pan-European datasets are sufficient to examine the vSGP on a scale of one to a quarter of a million (1:250,000). With the methodology and related spatial datasets developed herein, we contribute to the existing knowledge on the very shallow geothermal energy potential across Europe. We provide publicly available information for European and national stakeholders about indicators, which are relevant for the estimation of place based vSGP exploitation.

2. Materials and methods

2.1. Definition of vSGP

Independent from the Earth's internal heat, the very shallow geothermal energy potential is driven by solar irradiance. Dependent on the atmospheric conditions, relief, soil properties, land use, and water content, the surface temperature and the distribution of temperature within the soil is changing. Temperature changes in around 10 m below surface are insignificant under comparable property conditions. Also heat exchanging systems for heating and cooling purposes covering all vertical collector systems, and additionally some special collectors like heat baskets, trench collector, slinky collector, and double heat baskets are applied in a depth until 10 m below ground. Thus, we defined the vSGP as solar driven renewable energy source available up to 10 m below ground, while the energy potential includes the specific heat or volumetric heat capacity of a given location, which is exploitable with no legal or environmental limitations. Thus, the potential is only available in

Table 1
Datasets used for the European outline map.

Compartment	Parameter	Source	Purpose
Climate	■ Annual average precipitation and temperature data for humidity index, monthly data for climate chart	WorldClim [63]; http://www.worldclim.org/) [61]	To be used to calculate the humidity index according to [50].
Pedology	■ Soil texture according to ESDAC (European Soil Data Centre) ■ Soil type according to WRB [36]	The European Soil Database (ESDB v2.0 [45], from the European Soil Data Centre (ESDAC, http://www.eusoils.jrc.ec.europa.eu/wrb/) used datasets: ■ TXSRFDO (Dominant surface textural class) and WRBLV1 (World Reference Base for Soil Resources: Soil reference group) ■ Soil map of Iceland [57]	■ Indication of textural class 'no mineral texture (Peat soils)' with high share of organic material unsuitable for very shallow horizontal or vertical geothermal installations ■ Indication of soil types with limited suitability for very shallow horizontal or vertical geothermal installations (Histosols, Cryosols, Leptosols, Gleysols, Planosols)
Hydrology	■ Water table	Not available as pan-European dataset	Estimation procedure based on unsaturated conditions
Nature Conservation	■ Protection zones	Natura 2000 areas from the European Environment Agency European Environment Agency [60] and Nationally designated areas CDDA et al [60] European Environment Agency [59] for Iceland	Limited suitability criteria; legal constraints or complicated authorisation process for very shallow horizontal or vertical geothermal installations
Topography	■ Global 90 m SRTM data resampled to 500 m resolution (without Iceland) ■ Slope > 15°	Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM v4.1, http://srtm.csi.cgiar.org) in 90 m spatial resolution [62] and DEM3 (Auxiliary DEM of Iceland [58])	Limited suitability criteria; additional limited suitability criterion for installation, venting and operating of very shallow horizontal or vertical geothermal systems

those areas where the boundary conditions are not preventing its use.

2.2. Datasets used

The European Outline Map (EOM) on the vSGP aims to reflect the natural geothermal conditions mainly influenced by climatological, topographical, pedological, hydrological and geological properties, and can be inferred from environmental datasets. As indicated above, environmental datasets are expected to be available in the Infrastructure for Spatial Information in the European Community. INSPIRE addresses 34 environmental spatial data themes which are listed in three annexes (http://inspire.jrc.ec.europa.eu/index.cfm/pageid/2/list/7). Within these three annexes, the following sources are of importance for this study:

- Annex I: 9 Protected sites,
- Annex II: 1 Elevation, 4 Geology, and
- Annex III: 3 Soil, 11 Area management/restriction/regulation zones & reporting units, 14 Meteorological geographical features, 18 Habitats and biotopes, and 20 Energy Resources.

With a common data model and semantically and technically harmonized datasets across Europe, the processing of the vSGP would have been straightforward. However, the INSPIRE road map (http://inspire.jrc.ec.europa.eu/index.cfm/pageid/44) foresees "newly collected and extensively restructured Annex II and III spatial data sets" initially available in October 2015. Thus, we needed to consider other datasets, as listed in Table 1, for our calculations.

2.3. Modelling the vSGP at European scale

To estimate the TC at a European scale, we developed a modelling framework following the four steps as outlined in Fig. 1. These four steps are a combination of a place based suitability analysis and a quantitative thermal conductivity analysis.

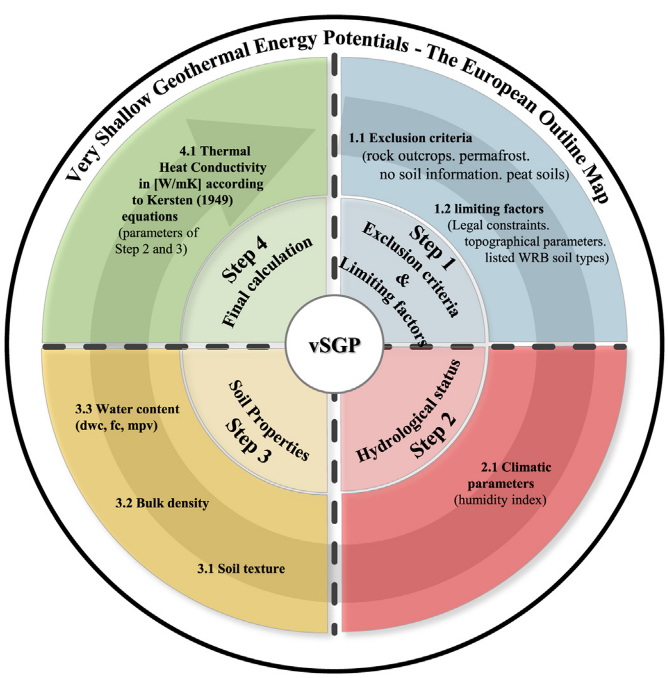


Fig. 1. The vSGP modelling approach for the European Outline Map (EOM).

Step1: Exclusion criteria and limiting factors.

Areas of unfavourable conditions for very shallow geothermal energy installations are either excluded for analysis, or assigned a certain limitation. Once an exclusion criterion is met, the process chain along the four steps stops and the area is assigned as unsuitable. Exclusion parameters are places of consolidated soils/rocks, rock outcrops, permafrost, no soil information and peat soils. Once a limitation criterion is met, the process chain does not stop, but the limitation is recorded and displayed in the results.

The first limitation is assigned in areas such as nature protection zones, water protection zones and flood areas, where installations are usually limited due to legal constraints. Legal constraints are restrictions on a legislative level, which particularly find expression in nature/environmental protection zones of various types and levels that are established in each European country [30]. As a common European dataset we used the NATURA 2000 and CDDA areas (see Table 1) as a reference for the limitation assignments.

As a second limitation parameter we consider a slope of >15° as unsuitable for instalments. The value is based on practical examples, which we enquired from instalment companies (e.g. Rehau). As indicated in Table 1, we used the SRTM 4.1 dataset to calculate slopes greater than 15°. The algorithm used to calculate the slope is shown in Equation (1).

Equation (1): Slope calculation in degree.

$$\text{slope} = \text{ATAN}\left(\sqrt{\left(\left[\frac{dz}{dx}\right]^2\right) + \left[\frac{dz}{dy}\right]^2}\right) * 57.29578 \tag{1}$$

The third limitation parameter can be extracted from the European Soil Database (ESDB [45]) mentioned in Table 1. The ESDB comes with many attributes; among them the attribute "Soil Classification according to WRB" (WRBLV1: Soil reference group). The identifier of the classification points to the World Reference Base (WRB) for Soils [36] providing important information about the Reference Soil Groups (RSG). A simplified identification key of the RSG according to WRB is shown in Fig. 2.

Following the procedure in Fig. 2, we assigned the following soil types, which are considered as inappropriate areas for the utilisation of the very shallow geothermal energy:

- Histosol (1, limited suitability due to a very high share of organic material, e.g. peat),
- Cryosol (2, limited suitability due to impacts of frost and ice),
- Leptosol (4, limited suitability due to its very shallow or extremely gravelly characteristic),
- Gleysol (8, limited suitability due to influence of groundwater), and
- Planosol (14, limited suitability due to impacts from abrupt textural discontinuities and stagnating water).

The inappropriateness of these soil type areas is based on the capabilities of present horizontal or vertical heat collector systems as mentioned above.

Step 2: Hydrological system status.

The water content proportionally increases the quantity of solar driven geothermal heat that passes through the soil per unit of time. Thus, the fourth limitation parameter considers climates where water is scarce. This is not a strict limitation as described previously, but soil moisture proportionally limits the thermal conductivity of soils. Since annual soil moisture or wetness maps were not ready to use, we applied the "Humidity Index" methodology according to [50] as a transfer function from climate conditions to the water content of the soil body. The Humidity Index correlates the mean annual precipitation and temperature values

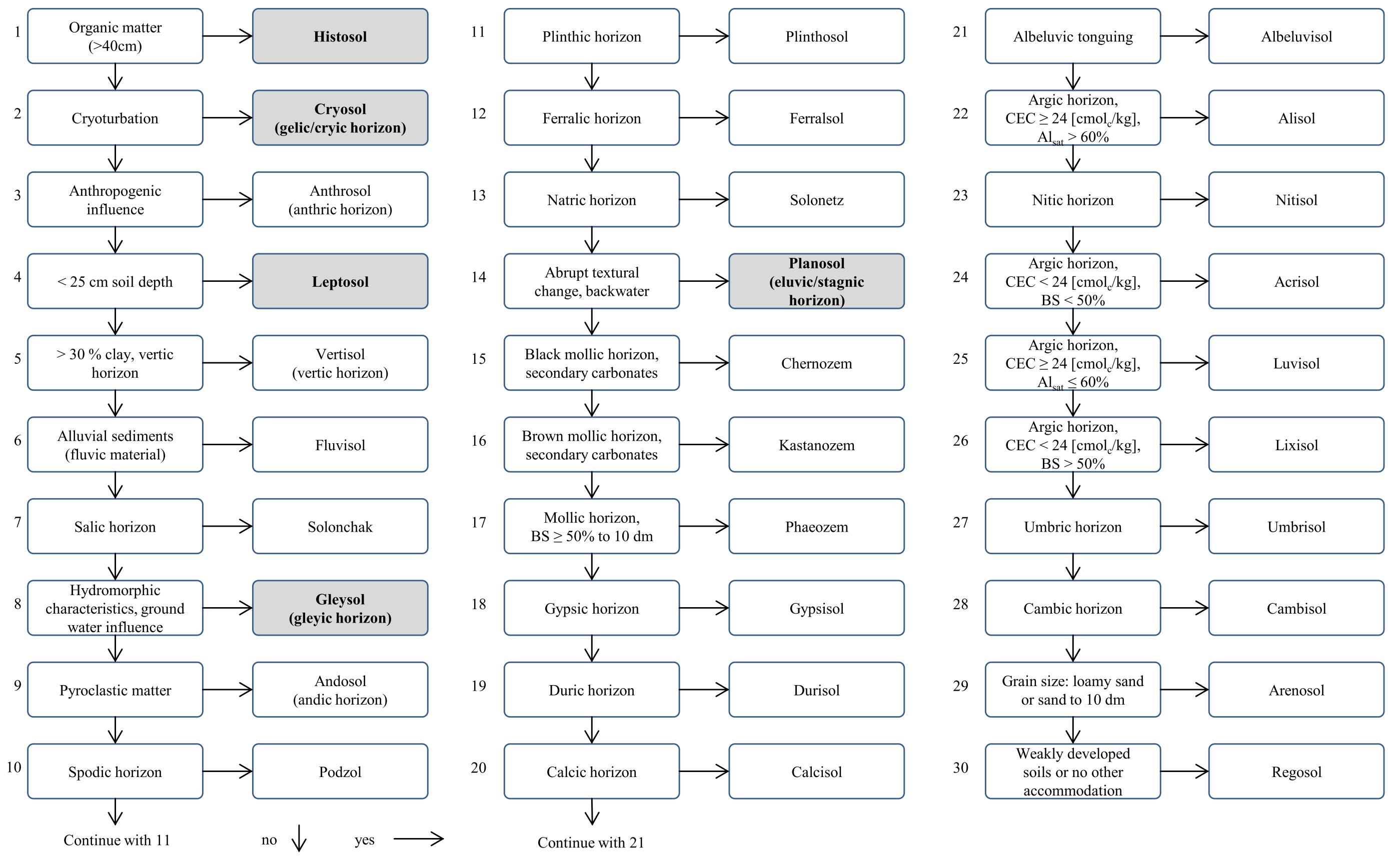


Fig. 2. Simplified identification key of the Reference Soil Groups (RSG) to filter soil types unsuitable for shallow geothermal energy instalments. Modified after [2] and [36]. Grey fields indicate soil types with limited instalment potentials. BS = Base Saturation; CEC = Cation Exchange Capacity; Al_{sat} = Aluminium saturation; horizon = diagnostic horizon of a soil type.

(see Table 1) and is expressed by five classes (arid, semiarid, sub-humid, humid, and per-humid). The classes can be calculated with Equations (2)–(5) where I is the respective class index, N is the mean annual precipitation in centimetres and T the mean annual temperature in degree Celsius. Each subsequent equation has been processed until it reaches a value smaller than 1. Once a value smaller than one has been derived, the respective class value can be obtained from the equation heading.

Equation (2): Humidity Index I < 1 is arid.

$$I = \frac{N}{0.5*(1.5T + 0.04T^2 + 20)} \tag{2}$$

Equation (3): Humidity Index $I < 1$ is semiarid and $I > 1$ is sub-humid.

$$I = \frac{N}{(1.5T + 0.04T^2 + 20)} \tag{3}$$

Equation (4): Humidity Index $I < 1$ is sub-humid and $I > 1$ is humid.

$$I = \frac{N}{1.5*(1.5T + 0.04T^2 + 20)} \tag{4}$$

Equation (5): Humidity Index $I < 1$ is humid and $I > 1$ is per-humid.

$$I = \frac{N}{3*(1.5T + 0.04T^2 + 20)} \tag{5}$$

The Humidity Index classes have been integrated in the calculation of the thermal conductivity in step 4. If the Humidity Index reflects arid or semiarid conditions, the pore size distribution values for dead water content (dwc) conditions (see step 3, Table 2 and Table 3) are used. In case of sub-humid to per-humid conditions, the pore size distribution values for field capacity (fc) conditions are used.

Table 2
Definitions and ranges of the specific pedological water and air regime (modified according to [2]; page 343).

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 equivalent in [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 percolating water	slow-flowing	plant available adhesive water	not plant available capillary water
Pedo—ecologic terminology	air capacity (ac)	available field capacity (afc) field capacity (fc)		dead water content (dwc)
	total porosity volume (pv)			

Table 3
The four main texture classes combined with the USDA soil texture classification.

Main texture classes according to the ESDB classification	Air capacity (ac) in Vol.-% Porosities > 50 µm (pF < 1.8)	Field capacity (fc) in Vol.-% Porosities ≤ 50 µm (pF ≥ 1.8)	Dead water content (dwc) in Vol.-% Porosities ≤ 0.2 µm (pF ≥ 4.2)
Bulk density $[\frac{g}{cm^3}]$	1.3	1.3	1.3
coarse	26	25	8
medium	13	41	21
medium fine	10	43	19
fine/very fine	6	47	31

Additionally we assume predominant permafrost conditions in case the mean annual temperature is equal to or smaller than zero degrees Celsius. This is a complementary exclusion criterion to the soil type Cryosols, which is excluded in the previous paragraph (see step 2).

Step 3: Soil properties.

The soil properties mainly refer to the organic content and the particle size of the soil, thus the soil texture. Soils such as peat soils and fens have been defined as inappropriate for very shallow geothermal installations due to their very high share of organic material.

Soil texture information is discovered from the ESDB. The attribute "Texture" (TXSRFDO: Dominant surface textural class) identifies the grain size distribution in five classes:

1. coarse with <18% clay and >65% sand,
2. medium with 18% to <35% clay and ≥15% sand, or <18% clay and 15% to <65% sand,
3. medium fine with <35% clay and <15% sand,
4. fine with 35% to <60% clay,
5. very fine with >60% clay.

The experts of the ThermoMap consortium decided to use the USDA soil texture classification system and its associated triangle as a reference base for soil texture analysis. Thus, the five soil texture classes from the ESDB need to fit into the four main texture groups (based on 12 texture classes) used in the USDA soil texture triangle classification system. Here we merge the classes "fine" and "very fine" into the single class fine/very fine due to similar physical and

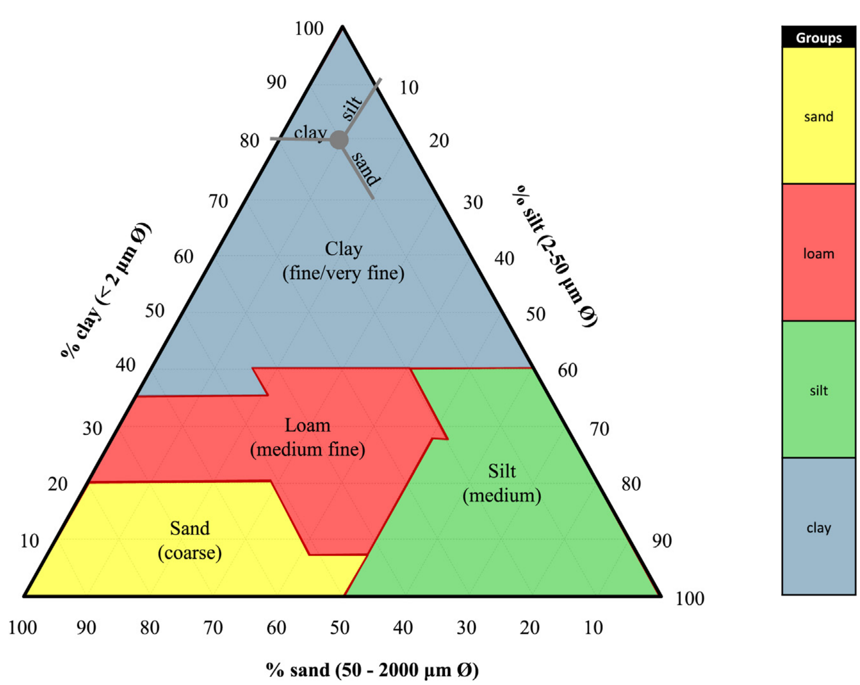


Fig. 3. Soil texture triangle with the four main soil texture classes.

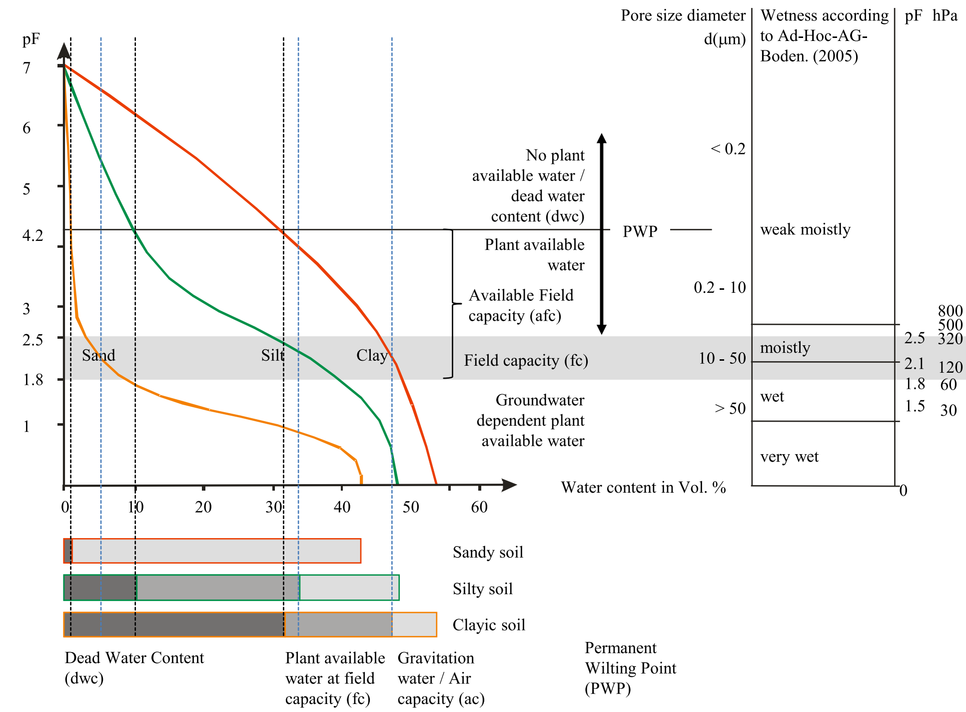


Fig. 4. Water and air volumes of soils dependent on texture and moisture tension.

thermal soil conductivity properties. The corresponding USDA texture triangle is shown in Fig. 3.

(modified after [11]).

From the USDA soil texture triangle and the ESDB texture classes we evaluate the pore size distribution with its corresponding air capacity (ac), field capacity (fc) and dead water content (dwc) values (see Fig. 4). With a decreasing sand volume, the coarse pores are also decreasing. With the reduction of the coarse pores, the air capacity reduces and medium pores proportionally increase with the field capacity. The dead water content proportionally increases within fine pores. Thus, soils dominated by loam show mainly intermediate sized pores. Considering the water regime conditions resulting in high thermal conductivity rates, loamy soils have the most appropriate distribution of air capacity and available field capacity with a smaller share of dead water content. With increasing clay percentages the dead water content increases and the available field capacity (afc) decreases.

According to Table 2 further water and air regime properties can be inferred. Both Fig. 4 and Table 2 are used as input functions for the calculation of the thermal conductivity in step 4.

The compactness (bulk density) of the unconsolidated soil has an impact on the thermal conductivity and is taken into account in step 4. Bulk density as the relation between mass and volume of a material is considered to proportionally increase with soil depth. However, pan-European information on bulk density in different depths is not available. Since an area-wide investigation about the estimation of the depth of the soft rock zone is not accomplishable, we assign 1.3 g/cm^3 to the entire depth.

Based on Table 2 and Fig. 4 the parameters air capacity (ac), field capacity (fc) and dead water content (dwc) can be cross-linked with the texture classes of the combined USDA and ESDB soil texture triangle (Fig. 3). For each of the four texture groups, pore size distributions have been assigned according to the bulk density of 1.3 g/cm^3. Table 3 shows the different pore size distributions of the textural classes according to ESDB classes related to volume percentage values.

Step 4: Final calculation.

The thermal conductivity (TC) reflects the ability of soil and soft rock material to conduct heat, expressed in Watts per metre and Kelvin (W/m*K). Step four contains the calculations of the TC for unconsolidated and unfrozen soil according to [38] and [20]. The calculation of the TC in Equation (6) and Equation (7) considers the percentage of sand from the used soil texture triangle (Fig. 5).

Based on Fig. 5 the following equations have been used:

Equation (6): TC for sand content > 50%

$$\lambda = 0.1442 * \left(0.7 * \left(\lg \frac{PSD}{BD}\right) + 0.4\right) * 10^{(0.6243 * BD)} \tag{6}$$

Equation (7): TC for sand content < 50%

$$\lambda = 0.1442 * \left(0.9 * \left(\lg \frac{PSD}{BD}\right) - 0.2\right) * 10^{(0.6243 * BD)} \tag{7}$$

Units

Thermal Conductivity:

$$\lambda = \frac{\boldsymbol{W}}{\boldsymbol{m} * \boldsymbol{K}}$$

Pore Size Distribution.

$$PSD = [\mathrm{Vol.} - \%]$$

Bulk Density.

$$BD = \left[\frac{\boldsymbol{g}}{\mathrm{cm}^3}\right]$$

Based on Table 3, the pore size distribution is selected according to the underlying texture class, and the class is identified from the Humidity Index according to [50]. The bulk density has been determined as 1.3 g/cm^3 due to insufficient European-wide data availability, as explained above.

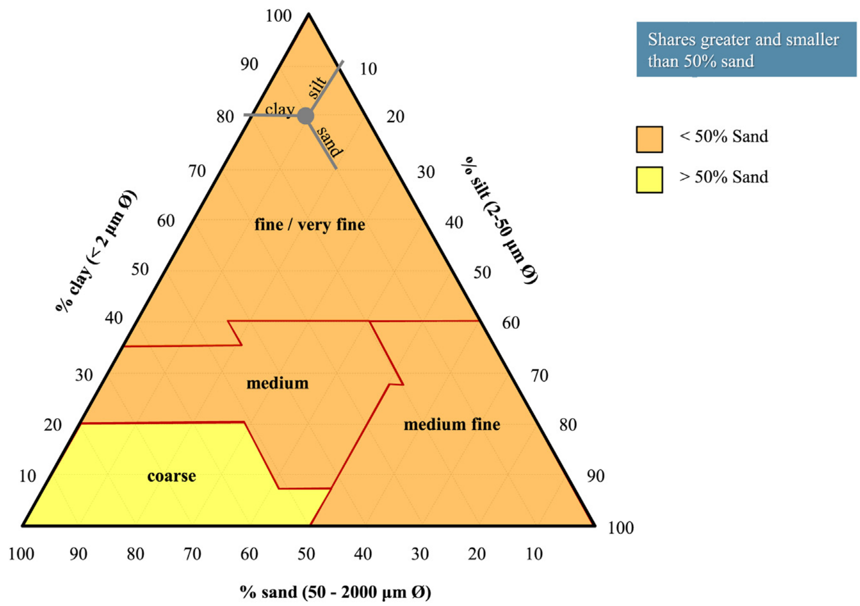


Fig. 5. The combined USDA and ESDB texture triangle showing >50% sand (yellow) and <50% sand content (orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.4. The visualisation system

The ThermoMap MapViewer (TMMV) is a three tier architecture consisting of a data base, the server, and the client (Fig. 6). The client is any web browser used by the public. The client application is the Map Viewer. The database (see Table 1) for the European Outline Map is located on the main server. The processing routines have been performed on a desktop GIS and the resulting layers stored in a database. They are made available from the main server as Web Map Services (WMS).

The technology used is based on open source products and international standards, e.g. Refs. [41,42]. The used open source frameworks "OpenLayers" and "ExtJS 4" are JavaScript programming libraries enabling the creation of interactive maps with a user interface. The pure client-side JavaScript application is not dependent on a particular server. The open source map server GeoServer with an underlying PostGIS spatial database are used for providing the WMS. The TMMV supports the following WMS requests: GetCapabilities (get information about service and map layers), GetMap (get a georeferenced map image), GetLegendGraphic (get legend symbols) and GetFeatureInfo (get attribute values of map layers to a certain map pixel).

3. Results

The publicly accessible European Outline Map on vSGP is visualised in the ThermoMap MapViewer (http://thermomap.mapviewer.sbg.ac.at/, Fig. 7). As the main result, the TC values calculated in step 4 are displayed in five classes. The graduated map of these five classes show low (blue (in web version)) to high (red (in web version)) vSGP, whereby blue (in web version) hatching areas symbolise usage limitations, and blank colour refers to excluded criteria.

The pan-European results on the TC vary between 0.8 W/m*K and 1.2 W/m*K. As indicated in Table 4 the values also vary slightly between countries. Here the highest average values, and thus the highest potential for vSGP exploitation, are found in Liechtenstein, Finland, Iceland, and Norway. However, Finland and Norway are also among the countries with the highest share of excluded areas. With over 50% of the respective country affected, Andorra, Montenegro and Slovenia have the highest values assigned with a limitation.

Mean THC value: single value areas per country in relation to entire usage country area (without exclusion areas); for the limited usage (protection zones, unsuitable soil types, slope > 15°), notice

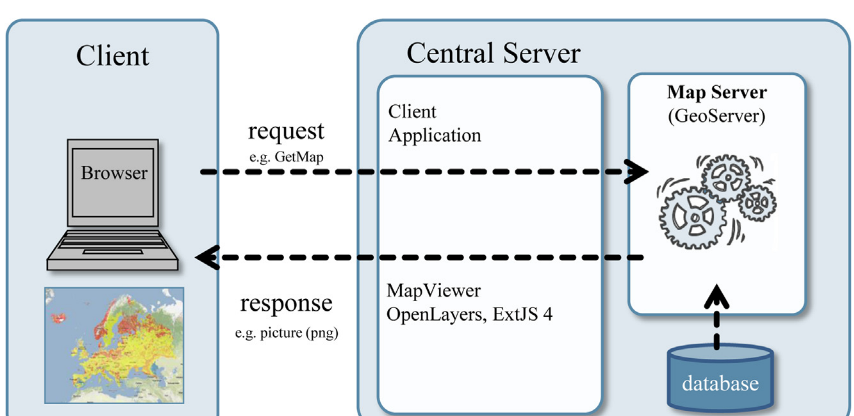


Fig. 6. The ThermoMap MapViewer architecture.

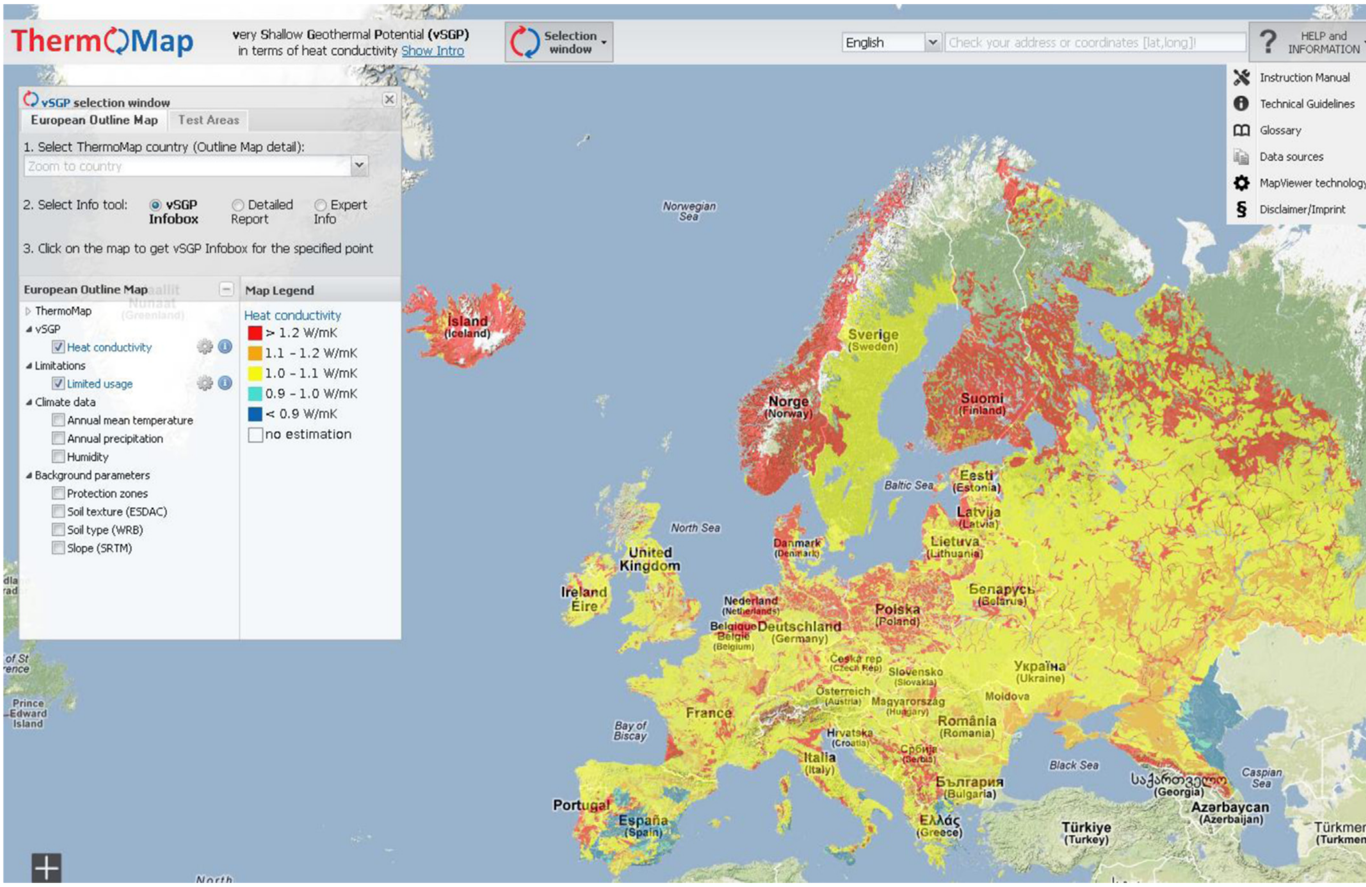


Fig. 7. The European Outline Map (EOM) on very shallow geothermal energy potentials (vSGP) visualised in the ThermoMap MapViewer.

that there is no protection zone data for Russia, Belarus, Ukraine and Moldavia; no absolute area values due to calculations using wgs84 data.

As explained in the methodology section, the TC has been derived from many information sources. For transparency reasons, the initial datasets, the pre-processed datasets and the results are available in the map viewer. Spatial data layers are available on precipitation, temperature, humidity index, protection zones, soil texture, soil type, and slope.

The different search and discovery functionalities are explained in the TMMV itself. As a summary, on mouse click the vSGP Infobox displays the TC values and all background parameters for each of the areas pointed to. A two page, printable or pdf-convertible report encompassing information on the before mentioned data layers is issued as a pop-up window (Fig. 8 and Fig. 9).

4. Discussion

Scientists are updated on a planning basis for estimating the very shallow geothermal energy potentials according to [38] and [20]; which we advanced to the conditions of pan-European available and accessible digital datasets. We deliver information on required parameters for the general estimation of very shallow geothermal energy potentials as defined above.

What we obtained from the pan-European exercise are datasets on background parameters (slope, soil type, soil texture, protection zones), climate data (humidity, annual precipitation, annual mean temperature), limitation areas, and finally thermal conductivity values. The TC map is a pattern of different vSGP, triggered by the underlying datasets. Most important for the pattern of thermal conductivity is the place based distribution of soil property related information. As indicated in Table 4, minimum, maximum, and average country values do not seem as relevant as certain places. This supports our hypothesis that place related information is important. We indicate places with different potentials on very shallow geothermal energy.

Unfortunately the intended estimation of the vSGP to a depth of 10 m was not possible with existing datasets. Adequate estimates regarding the thickness and mean grain size distribution (texture) of the soil and soft rock zone could neither be derived from the European Soil Database, nor from the International Geological Map of Europe (IGME 5000).

The soil parameters, especially soil texture, have a decisive influence on the design and the sustainability of very shallow geothermal installations. The soil texture was sampled at a local scale, transferred from mapping scales to national soil mapping classifications, and afterwards internationally unified before being publicly available. A combination of the USDA and ESDB soil texture classification was carried out to use the harmonised ESDB dataset. Due to different sampling techniques, analysis, aggregation, and reclassification procedures, all these processing steps incorporate inherent uncertainties. In the TMMV for instance, the classified TC values follow the Norwegian/Swedish border (Fig. 7). Here slight differences in soil texture paired with the classification in the assigned four classes create misleading TC representations. Thus, even with a harmonised soil database, it still remains difficult to obtain a pan-European consolidated picture of the vSGP. Uncertainties expressed in the metadata of e.g. the soil datasets are

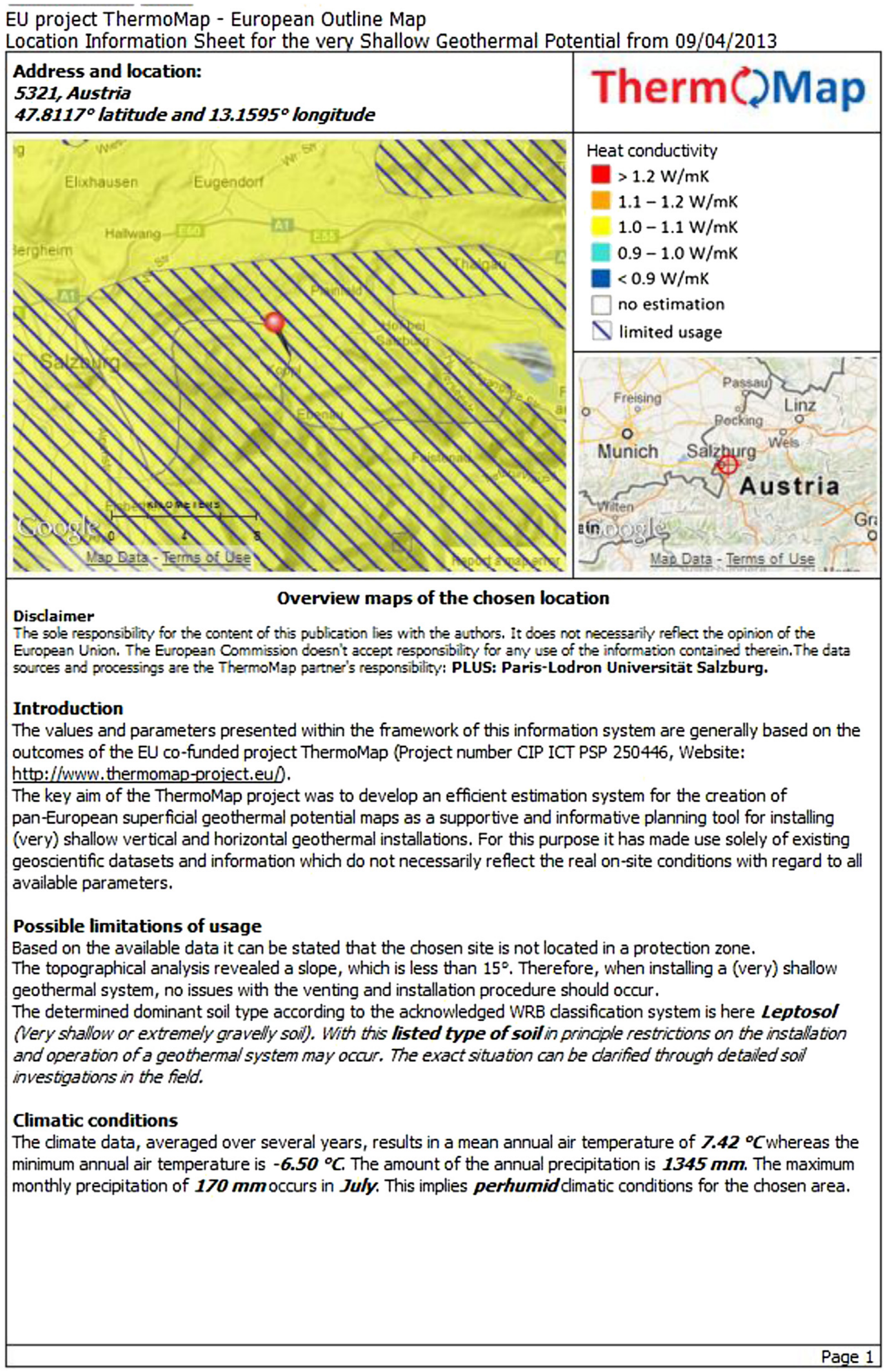
Table 4
The min, max, and average TC values per country.

Country	Min λ [W/m*K]	Max λ [in W/m*K]	Mean λ in [W/m*K]	Excluded area [in % of the country]	Limited area [in % of the country]
Albania	1.07	1.21	1.10	1.65	18.17
Andorra	1.07	1.07	1.07	0.00	72.98
Austria	1.07	1.21	1.08	4.95	41.25
Belarus	1.07	1.21	1.10	11.30	2.54
Belgium	1.07	1.21	1.11	1.72	11.95
Bosnia and Herzegovina	1.07	1.21	1.12	0.70	31.29
Bulgaria	0.79	1.21	1.09s	1.46	37.76
Croatia	1.07	1.21	1.09	3.79	47.85
Czech Republic	1.07	1.21	1.10	3.35	13.64
Denmark	1.07	1.21	1.16	6.27	11.92
Estonia	1.07	1.21	1.12	22.70	37.65
Finland	1.07	1.21	1.20	48.49	4.91
France	1.07	1.21	1.10	1.98	23.37
Germany	1.07	1.21	1.12	7.28	21.58
Gibraltar	1.07	1.07	1.07	73.45	26.55
Greece	0.83	1.21	1.04	3.44	49.81
Guernsey	1.09	1.09	1.09	43.48	0.00
Hungary	1.07	1.21	1.10	4.04	22.99
Iceland	1.07	1.21	1.20	21.09	14.28
Ireland	1.07	1.21	1.09	15.46	29.50
Isle of Man	1.07	1.21	1.10	7.77	6.35
Italy	0.79	1.21	1.08	3.07	24.12
Jersey	1.09	1.21	1.09	13.57	0.00
Latvia	1.07	1.21	1.13	7.73	19.05
Liechtenstein	1.07	1.21	1.21	0.10	23.54
Lithuania	1.07	1.21	1.11	3.84	11.85
Luxembourg	1.07	1.21	1.11	0.58	22.74
Monaco	1.09	1.09	1.09	23.75	20.52
Montenegro	1.07	1.21	1.10	2.67	65.26
Netherlands	1.07	1.21	1.15	14.32	13.79
Norway	1.07	1.21	1.20	43.24	9.84
Poland	1.07	1.21	1.15	6.50	19.98
Portugal	0.83	1.21	1.10	0.85	21.35
Republic of Moldova	1.07	1.21	1.11	0.61	3.55
Romania	0.79	1.21	1.09	1.60	22.32
Russian Federation	0.79	1.21	1.10	32.87	2.69
San Marino	1.07	1.21	1.08	0.00	0.00
Serbia	1.07	1.21	1.13	0.67	23.32
Slovakia	1.07	1.21	1.08	0.16	34.32
Slovenia	1.07	1.21	1.07	2.71	53.70
Spain	0.79	1.21	1.02	2.22	36.26
Sweden	1.07	1.21	1.08	27.10	7.97
Switzerland	1.07	1.21	1.13	31.56	30.55
The former Yugoslav Republic of Macedonia	0.83	1.21	1.14	1.92	32.66
U.K. of Great Britain and Northern Ireland	1.07	1.21	1.10	27.81	18.87
Ukraine	0.79	1.21	1.10	3.20	4.54

mainly expressed in a qualitative way, thus we refused to undergo a thorough statistical/mathematical uncertainty analysis of our modelled vSGP. Instead we refer to the practical findings of our instalment partners, field experiences, and the limitations described in the metadata of the datasets used. We also found it inappropriate to compare the results with *in situ* measurements since we operate on a mapping scale of 1:250,000. Processes, functions, and structures are very different from a local to pan-European scale. This is also the reason why settlements with typical urban structure and soil profiles are not adequately reflected in the results. Soil types, soil properties and respectively the vSGP vary much more on a local scale compared to the values derived in the EOM. Particularly in hilly regions, where soil texture and soil moisture changes at a large scale according to the pedologic toposequence, this small-scale variability is high. On a broader scale level this is confirmed by the European Soil Data Centre (http://www.eusoils.jrc.ec.europa.eu/esdb_archive/raster_archive/sgdbe_display_attributes.html#), assigning the confidence level of the dominant soil texture in Scandinavia from low to very low. However, in case more detailed (local) information is available, users can use our calculator tool in the ThermoMap MapViewer to calculate the location specific vSGP.

The EOM does not recognise that ground conditions change with each metre, since pan-European information was scarce. Assuming an increase in bulk density with soil depth, and an increase of bulk density causing higher thermal conductivities, the EOM values tend to underestimate the overall vSGP. This is also true due to non-available subsoil water saturation information.

A clear limitation of the derived vSGP is the non-reflected seasonal change in the thermal properties as indicated in Refs. [37] and [31]. The vSGP does not take into account near surface ground temperatures depending on the slope of the ground and the slope direction. This is the reason why the areas with TC values >1.2 W/mK are underestimated. However, ground or near surface temperatures are not available as geospatial datasets across Europe, but can be inferred from air temperature [56]. Thus we could only consider the air temperature. Ground temperatures also strongly depend on surface colour, water content and climate conditions. Additionally, snow cover might significantly limit the exploitation of the vSGP during the winter time. Similarly, other climatological


EU project ThermoMap - European Outline Map
Location Information Sheet for the very Shallow Geothermal Potential from 09/04/2013

Address and location:
5321, Austria
47.8117° latitude and 13.1595° longitude

ThermoMap

Overview maps of the chosen location

Disclaimer
The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Union. The European Commission doesn't accept responsibility for any use of the information contained therein.The data sources and processings are the ThermoMap partner's responsibility: **PLUS: Paris-Lodron Universität Salzburg.**

Introduction
The values and parameters presented within the framework of this information system are generally based on the outcomes of the EU co-funded project ThermoMap (Project number CIP ICT PSP 250446, Website: http://www.thermomap-project.eu/).
The key aim of the ThermoMap project was to develop an efficient estimation system for the creation of pan-European superficial geothermal potential maps as a supportive and informative planning tool for installing (very) shallow vertical and horizontal geothermal installations. For this purpose it has made use solely of existing geoscientific datasets and information which do not necessarily reflect the real on-site conditions with regard to all available parameters.

Possible limitations of usage
Based on the available data it can be stated that the chosen site is not located in a protection zone.
The topographical analysis revealed a slope, which is less than 15°. Therefore, when installing a (very) shallow geothermal system, no issues with the venting and installation procedure should occur.
The determined dominant soil type according to the acknowledged WRB classification system is here ***Leptosol*** *(Very shallow or extremely gravelly soil). With this* ***listed type of soil*** *in principle restrictions on the installation and operation of a geothermal system may occur. The exact situation can be clarified through detailed soil investigations in the field.*

Climatic conditions
The climate data, averaged over several years, results in a mean annual air temperature of ***7.42 °C*** whereas the minimum annual air temperature is ***-6.50 °C***. The amount of the annual precipitation is ***1345 mm***. The maximum monthly precipitation of ***170 mm*** occurs in ***July***. This implies ***perhumid*** climatic conditions for the chosen area.

Page 1

Fig. 8. Example of a report of a location of interest (page 1).

aspects such as evaporation and transpiration parameters have not explicitly been taken into account. This is due to the inadequate data access and data access policy situation across Europe. However, considering that a realisation of a geothermal project in practice often drastically modifies the microclimatic conditions, the parameter evaporation is not that relevant.

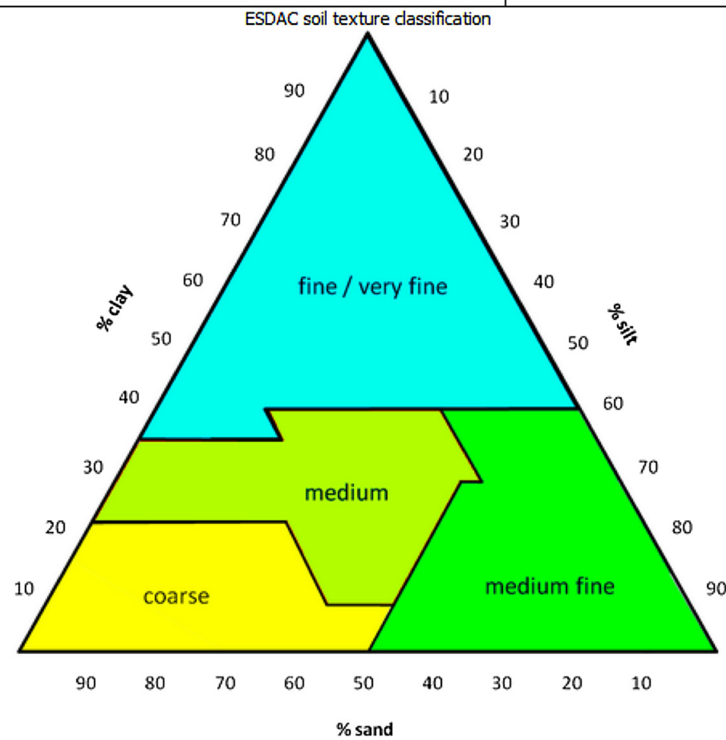
All above mentioned datasets have an inherent dynamic and can change rapidly but are not available or accessible in digital format and in sufficient spatial and/or temporal resolution across Europe. However, we do not consider it a limitation, reducing the complexity of the whole model presented here on a processing scale of 1:250,000. Thus, a pan-European model is only an abstract representation of environmental phenomena causing challenges where the system might not work properly due to special spatial conditions. Thus, TC values will be misleading if these conditions are not incorporated in the spatial datasets.

The intention of developing the TMMV was to provide a free of charge and publicly available overview of very shallow geothermal energy potentials across Europe. Not only the thermal conductivity map, but also the respective baseline datasets required for instalments of very shallow geothermal systems, should be provided free of charge in an open access/data environment.

EU project ThermoMap - European Outline Map
Location Information Sheet for the very Shallow Geothermal Potential from 09/04/2013

Address and location:
5321, Austria
47.8117° latitude and 13.1595° longitude

ThermoMap



Soil properties
In general, unsaturated conditions of the soil matrix were assumed for the estimation of the very Shallow Geothermal Potential (vSGP).
The dominant ***grain size*** distribution (soil texture) according to the ESDAC texture classification was ***medium*** (see Figure above for the estimated separates of sand, clay and silt).

Geothermal situation
The thermal heat conductivity of the soil matrix is defined essentially by its texture, water content and bulk density. At the chosen site the ***heat conductivity*** ranges from ***0.83 W/mK*** to ***1.07 W/mK***. These values were calculated by use of KERSTEN-formulas. On the basis of ***perhumid*** conditions a value of ***1.07 W/mK*** is probable. For this calculation process, an appropriate predefined value had to be assumed for the parameter bulk density which generally describes the relation between mass and volume. In this case the applied ***bulk density*** is ***1.3 g/cm³***.
These geoscientific parameters indicate that the chosen location is ***suitable*** with ***possible limitations*** for the utilisation of the very Shallow Geothermal Potential (vSGP) in terms of heat conductivity: occurence of *listed soil type Leptosol*.
For full system design, more detailed data for an optimal installation and operation of a GSHP system is necessary. Therefore, please get in contact with a relevant geothermal consultant for further planning.

Page 2

Fig. 9. Example of a report of a location of interest (page 2).

The Map Viewer is intended for the public, for planners and engineers, public bodies and scientists, to give them an overview about the solar driven very shallow geothermal energy resources in Europe. European policies may consult this information source as a contribution to the Renewable Energy Sources (RES) [23]. They might use it to infer the share of vSGP based on the total energy sources mix, presently changing from gas, coal and nuclear resources to renewable energy sources. Thus, stakeholders at a European level, but also national agencies responsible for the National Renewable Energy Action Plans (NREAPs) can use this information to estimate and value the vSGP in contrast to or in combination with other renewable energies. Planners and engineers may use this source to identify areas of interest for new instalments. Especially on new construction sites for residential and business buildings, these energy resources might be taken into account for sustainable heating and cooling purposes.

5. Conclusions

Stakeholder contact meetings in the ThermoMap partner countries confirm that the information provided with the TMMV are valuable information at European but also national level for renewable energy development strategies. The algorithms used here are found to be a robust, fast, effective and efficient method for detecting the vSGP. However, due to the data challenges outlined above, any interpretation of the information gained from the TMMV should be treated with care. The pan-European approach is not suitable respectively intended for calculating exact potentials on a local scale. The TC values visualised in the TMMV have been designed to inform European politics in a broad way for a first general overview on the vSGP. Thus, once the TMMV indicates a sufficient thermal conductivity potential without restriction to the user, the next step would be to contact business companies specialised in harvesting shallow geothermal energies. These companies should validate the estimated potential based on field measurements.

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