Renewable Energy 75 (2015) 335–347

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

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

D. Bertermann [a], H. Klug [b, *], L. Morper-Busch [b]

[a] University of Erlangen – Nuremberg, GeoZentrum Nordbayern, Schlossgarten 5, 91054 Erlangen, Germany
[b] University of Salzburg, Interfaculty Department of Geoinformatics, Schillerstr. 30, 5020 Salzburg, Austria

ARTICLE INFO

Article history:
Received 29 March 2014
Accepted 18 September 2014
Available online 24 October 2014

Keywords:
European soil database
Heat transfer
Spatial analysis
Particle size fraction
Soil water content
Thermal conductivity

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

* Corresponding author.
E-mail addresses: Hermann.Klug@sbg.ac.at, office@hermannklug.com (H. Klug).

http://dx.doi.org/10.1016/j.renene.2014.09.033
0960-1481/

[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