CREATING SHALLOW GEOTHERMAL POTENTIAL MAPS FOR FINLAND

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ABSTRACT

Utilisation of shallow geothermal energy especially in larger building complexes and storing energy to the ground is a crowing business area in Finland. This study provides public information about the geothermal energy potential of the uppermost 300 m of Finnish ground. The purpose of this study is to increase basic knowledge of geothermal reservoir and present how machine learning can be used to evaluate geothermal potential. We calculated the energy which can be utilised from one 300 m deep borehole. We also calculated the stationary heat flux through the borehole wall. The utilisable energy amount of one borehole area ranges from 0.6 GWh in the North to 4.5 GWh in the South and renewable power from 1.4 to 9.6 MW respectively. The sum of thermal energy stored into the ground is approximately 300 to 350 PWh. The theoretical potential of shallow geothermal energy is enormous in Finland and geothermal energy could be utilised for space heating and cooling significantly more than currently is done.

1. INTRODUCTION

The rapid increase of greenhouse gas concentrations in atmosphere has started transitional period from the use of traditional energy reservoirs towards renewable energy utilisation. The increased utilisation of renewable energy has revolutionised international policy to moderate the energy sector (Stehfest et al. 2009; Valkila et al. 2010). For example, the European Council (2014) has decided to reduce greenhouse gases from 40% below 1990 levels by 2030 and the European Climate Foundation (2010) has develop "Energy Road Map" to find a solutions to reduce greenhouse gas emissions from 80% below 1990 levels by 2050.

Geothermal energy provides one solution to renewable energy production. The utilisation of geothermal energy for heating has been continuously increased in Europe (Dumas et al. 2017). In the Nordic countries, excluding Iceland, shallow geothermal utilisation for heating is the most widely used geothermal resource. Shallow geothermal means low enthalpy energy utilisation from relative shallow depths; 100 to 400 m below ground level, and most often a heat pump is needed to arise the fluid temperature at a reasonable level for heating purposes. According to the Official Statistics of Finland (2019) approximately 5 TWh of heating energy was produced by heat pumps in Finland in 2017. The heat pump energy production is increasing approximately 0.5 TWh annually (The Finnish Heat Pump Association, 2018).

To increase the geothermal energy utilisation and public awareness more information about geothermal energy potential is needed. Continental geothermal potential maps (i.e Chamorro et al. 2014) and several country or state size estimations (i.e. Busby and Terrington 2017; Blackwell et al. 2006; Schuster and Bloomquist 1994; Jessop et al. 1991) has been successfully published earlier. However, most of geothermal energy publications are related to deep geothermal energy potential where the thermal energy of the Earth can be utilised for electricity production or heating systems which are operating in temperature regime where heat pump is not needed. Shallow geothermal energy potential has been reported earlier for example from Canada (Majorowicz et al. 2009) and from Finland (available only online: www.maankamara.fi). More shallow geothermal potential reports are related to utilisation of shallow groundwater in so called open loop systems (i.e. Arola et al. 2014; Kerl et al. 2012; Allen and Milenic 2003) than to utilising energy from shallow level soil and/or bedrock with closed loop system where heat exchangers are installed to the ground.

In this study we represent shallow geothermal energy potential maps version 2.0 for Finland. We introduce two raster maps that provide an overall view of the quantitative shallow geothermal potential of the ground in Finland, that is, (1) the thermal energy of the ground [GWh] that can be utilised from 300 meter deep borehole, and (2) the renewable heating power [W] that can be extracted from a 300 meter deep borehole in stationary condition. The term ground is used to refer to the bedrock and quaternary sediments overlaying it. The purpose is to support the national energy policy and regional planning, and to promote the sustainable utilisation of geothermal energy for space heating and cooling of households and larger properties and to promote energy storage in ground. The potential maps also aim to show the influence of geological and geophysical factors and to increase the quality of planning of targets utilising geoenergy.

2. MATERIAL AND METHODS

The shallow geothermal potential was estimated computationally by simulating heat transfer in the ground using an axisymmetric borehole model (Fig 1). The active depth of the borehole was fixed to 300 metres and it includes the effects of both the bedrock and the quaternary deposits that possibly overlay the bedrock. Conductive heat transfer in the ground was simulated in an axisymmetric geometry using COMSOL Multiphysics® version 5.3. The boundary between the borehole and the ground was set to 0 °C and simulation was carried out until a thermal equilibrium was reached between the borehole and ground. The solution domain was set to be 5 km x 5 km.

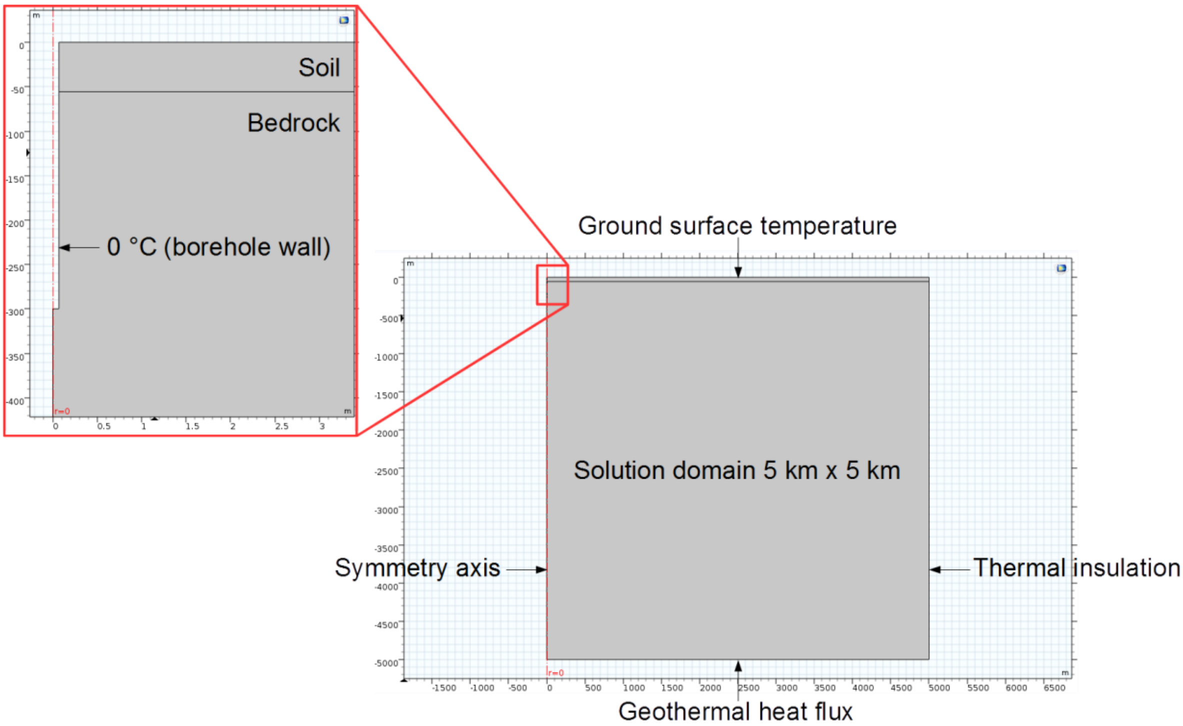

Figure 1: The principle of shallow geothermal energy potential calculation.

2.1 Parameters

Lithological units map (1:1 000 000) and superficial deposit map (1:250 000) of Finland was used as a base maps. The mean annual ground temperature was calculated from mean annual air temperature (Pirinen et al. 2012) using the relation Tground = 0,71 · Tair + 2,93 (Kukkonen, 1986), thickness of Quaternary sediments was based on the superficial deposits thickness map of Finland (available only online: www.maankamara.fi). Birch's law (e.g. Kukkonen 1989) was used to derive a heat flux database. The law relates geothermal heat flux to radiogenic heat production. The relation was estimated to be Qgeothermal = 10,491 • Qradiogenic + 15,792 based on 54 data points of geothermal heat flux and radiogenic heat production, and was used to calculate the heat flux dataset from 1054 heat production values presented by Kukkonen (1989). Other geological and geophysical parameters and their references are presented at Table 1.

Table 1: Geological and geophysical parameters and their references.

Parameter	Unit	Reference
Thermal conductivity of overburden	W/(mK)	Blomberg et al. 2015; Aittomäki and Saviharju, 1971.
Volumetric heat capacity of overburden	MJ/(m^{3}K)	Blomberg et al. 2015
Thermal conductivity of bedrock	W/(mK)	Peltoniemi and Kukkonen, 1995.
Specific heat capacity of bedrock	J/(kgK)	Kukkonen, 2015.
Bedrock density	kg/m^3	Pirttijärvi et al. 2013

2.2 Modelling

The potential maps were completed in three stages; a random sample of 4356 training points representing boreholes were chosen and parameter values for each of the borehole were determined. Heat transfer simulation was then calculated for each point which resulted in values of heat flow through the borehole wall as a function of time. The heat flow approaches asymptotically a constant value which represents the renewable heating power at the calculation point. The amount of heat stored at the borehole was estimated by integrating the heat flow through the borehole wall in time and subtracting the effect of the renewable heating power from the result. Secondly, values of renewable heating power (W) and heat energy (MWh) for every 1 km^2 were estimated using neural networks that were fitted to the 4356 randomly sampled training points (Fig 2). The computations were carried out using the Python programming language and the TensorFlow™ and Keras libraries. Finally results of machine learning estimation was validated using 1144 independently selected points.

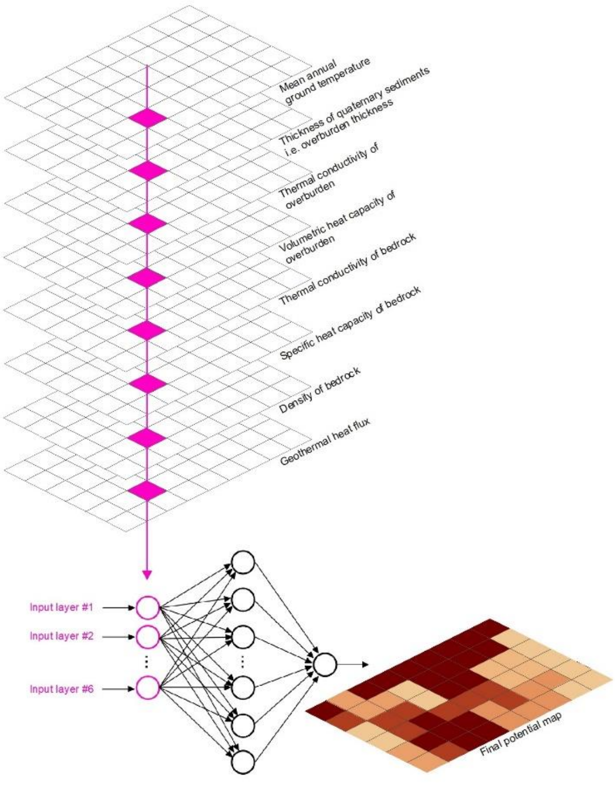

Figure 2: Parameter layers were used as feed to machine learning modelling. Final potential map is a result of input layer information.

3. RESULTS

Shallow geothermal energy potential is higher in Southern and Western than in Northern and Eastern Finland (Fig. 3 and 4). Influence of geological features and geographical location to geothermal potential can be observed. For example the high radiogenic heat production granites in Southern Finland and quartzite rich rocks in Central Eastern part of the country can be noticed in renewable power map and areas with thick clay deposits in Southern Finland in energy storage map respectively.

Utilisable geothermal heating energy on the area of one borehole varies from 0.6 to 4.5 GWh and renewable power from 1.4 to 9.6 MW respectively (Fig 3 and 4). Total amount of stored heating energy is approximately 300 to 350 PWh. The cell size in raster map is 1 km x 1 km.

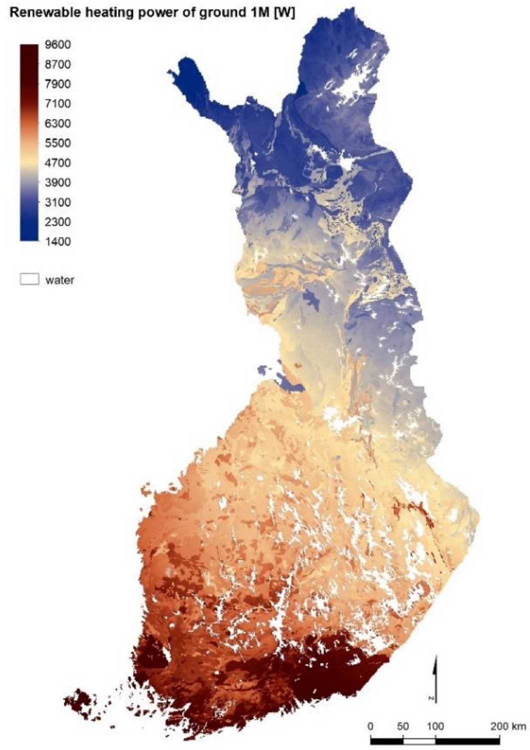

Figure 3: Renewable heating power (W) map.

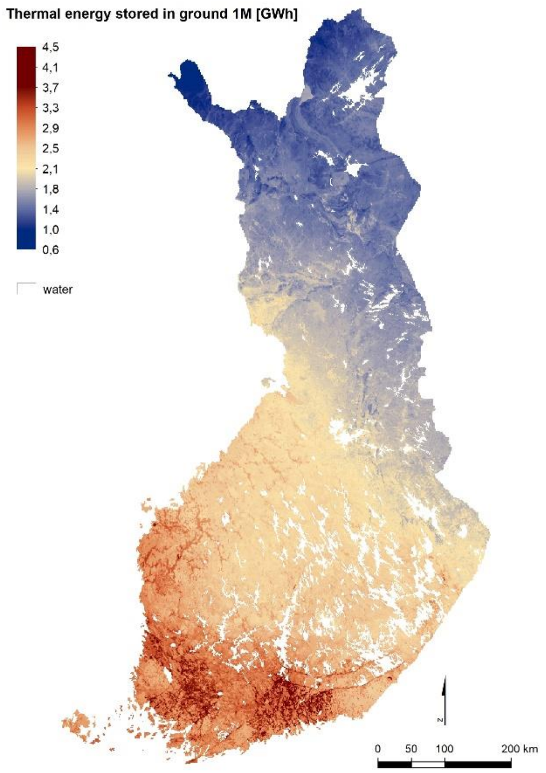

Figure 4: Stored energy, i.e. "heat in place" map.

4. DISCUSSION AND CONCLUSIONS

Variations in ground temperature is the main non-geological features which affects the geothermal potential in Finland. Geologically the Northwest-Southeast orientated border between Archean and Pre-Cambrian continent can be observed.

The maps provides information for both the shallow geothermal energy utilisation and energy storage. Energy storage map describes the utilisable "heat in place" and renewable power map the stationary heat flow through the borehole wall. The stationary heat flow will be remained after the energy reservoir is utilised. Areas with elevated thermal conductivity values have a high renewable energy potential and low thermal storage potential. The thick soil layer and/or rocks with low thermal conductivity insulates heat movement which reasons larger natural energy storage than on the areas where thermal conductivity is higher and heat can "escape" to the atmosphere. The high thermal conductivity enables high heat transfer rate between ground and borehole which makes the shallow geothermal system operating powerfully in heating or cooling mode. However, if one wants to store energy to the ground high thermal conductivity enables energy to flow further off the borehole and reduces the storing effect.

The amount of stored energy, approximately 300 to 350 PWh, is enormous. Combined district heating production and industrial heat production was 92 TWh in Finland in 2017 (Official Statistics of Finland, 2019). Hence, theoretically the energy which is stored to the first 300 m of Finnish ground could provide heating power for the whole country for next 3500 years. This calculation lacks the influence of continuous renewable power which provides basically infinite heat flow. This heat flow should be added to the total energy reservoir also. Hence, the real theoretical potential is larger than a calculated energy storage. We calculated the potential for one 300 m deep borehole. The cell size of the raster maps is 1 km x 1 km. It can be estimated that the area where heat is flowing to the borehole is smaller than one km^2 and hence the boreholes are not interrelated. Hence, our results are conservative estimations of total energy and power available from the ground.

The current trend in geothermal energy business in Finland is to drill deeper to the level of 500 m to 2000 m. There is also interest to utilise deep geothermal energy from 6 to 8 km below ground level. Hence, further research is needed to presents deeper energy potential of the Finnish ground. Research is also needed to develop and expend machine learning in geothermal reservoir evaluation.

The maps represents the theoretical potential (Rybach, 2010) of shallow geothermal energy in Finland which means that the technical and economic utilisable energy and power values are much lower than presented here. However, these theoretical results has already gained public interest and can promote the utilisation of shallow geothermal resources in Finland.

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