THE GLOBAL GEOTHERMAL RESOURCE BASE: A EUROPEAN PERSPECTIVE

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ABSTRACT

We present preliminary results of a global geothermal resource assessment for both direct heat utilization and electricity production. The amount of thermal energy stored in the subsurface and available for geothermal energy depends on the Earth's heat flow, reservoir volume, and thermal properties. We compiled existing regional subsurface temperature and heat flow datasets to construct a global subsurface temperature model extending to a depth of ten kilometer below the surface. To quantify the geothermal resource base, we applied a volumetric heat-in-place method on this global subsurface temperature model. The geothermal resource base was assessed for its technical and economic potential, applying a discounted cash-flow model to present-day and future techno-economic scenarios. The results are displayed in a series of maps showing geothermal potential and minimum levelized cost of energy (LCOE). The minimum drilling depth required to reach a threshold of LCOE can be used as an indicator of economic performance and technical feasibility.

1. INTRODUCTION

To quantify techno-economic potential, we apply a volumetric heat-in-place method. We explain how associated subsurface temperatures are calculated using global geological and geophysical data sets. We estimate the geothermal potential for electric power and for generalized direct heating applications.

2. TEMPERATURE MODEL

Temperatures from the calibrated European thermal model from Limberger et al. (2018b) were used as fixed values in the corresponding grid cells. For other cells (Iceland, N-Scandinavia, parts of Eastern Europe and Turkey), temperatures were calculated using a heat flow extrapolation (Fig. 2). For those parts, we used a two-layer setup to assign values for *k* ($Wm^{-1}K^{-1}$). We assumed a generic layer of sediments based on sediment thickness maps (Exxon Production Research Company, 1995; Laske and Masters, 1995; Tesauro et al., 2008) and assigned a value of 2 $Wm^{-1}K^{-1}$. For all other rock types, we assumed a value of 2.5 $Wm^{-1} K^{-1}$ (Beardsmore et al., 2010).

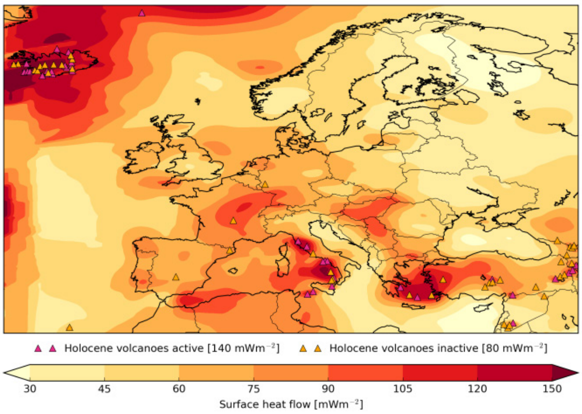

Figure 1: Surface heat flow compilation after Limberger et al. (2018a).

For each *x-y* column, values of radiogenic heat production A (μWm^{-3}) were calculated and assigned assuming that 32% of surface heat flow Q_0 (mWm^{-2}; See Fig. 1) is being generated by radiogenic heat production in the crust (c.f. partition model from Pollack et al., 1977). We use the surface heat flow compilation from Limberger et al. (2018a), based on Artemieva et al. (2006), Davies (2013), and Cloetingh et al. (2010). A strongly elevated heat flow of 140 mWm^{-2} was chosen for areas with active volcanoes and 80 mWm^{-2} for regions that experienced Holocene volcanic activity with assigned heat flow values based on Nagao and Uyeda (1995). Volcano locations were taken from the Global Volcanism Program Database (2013). The heat flow at the base of the model at 10 km depth was calculated by subtracting the radiogenic heat production from the upper 10 km. As boundary conditions for the top and bottom of the model, annual mean surface temperatures and heat flow at 10 km depth were used, respectively. Zero heat flow was assumed along the vertical edges of the model. The 3D heat equation is solved with a finite difference method (Limberger et al., 2014).

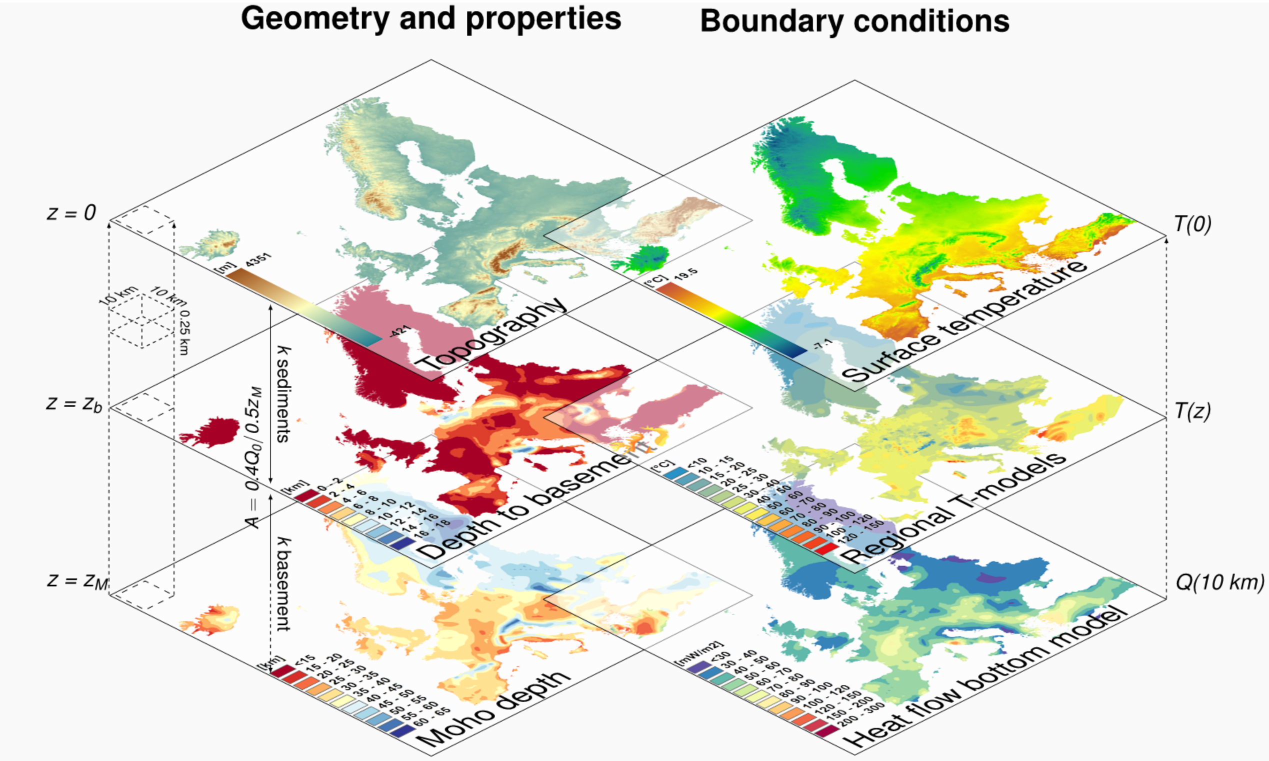

Figure 2: Model work flow combining heat flow extrapolation with available regional thermal models. After Limberger et al. (2014).

3. TECHNO-ECONOMIC MODEL

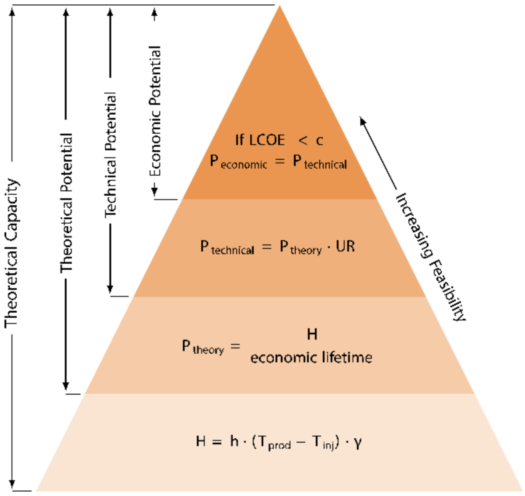

Figure 3: Assessment of the potential power output from a geothermal system after Limberger et al. (2014).

We used a volumetric heat-in-place assessment that incorporates economic parameters to estimate the European techno-economic geothermal potential of electricity and direct heat (after Limberger et al, 2014; 2018). The main outputs from this method are the minimum LCOE and the economic power and heat potential (Fig 4-7). Both are calculated on the basis of the temperature model described earlier in section 2. As depicted schematically in Fig. 3, the theoretical capacity or heat in place *H* (J) is the amount of thermal energy physically present in the reservoir rocks of a certain area or prospect. The theoretical potential P_{theory} (MW) describes the total amount of power that can be converted from the theoretical capacity within a certain period of time using a given conversion efficiency. The technical potential $P_{technical}$ (MW) is that part of the theoretical potential that can be exploited with current technology available, calculated using a recovery factor. The economic potential $P_{economic}$ (MWe or MWth) describes the part of the technical potential that can be commercially exploited for a range of economic conditions. For our maps (Fig. 4-7), we used a LCOE (c) cut-off value of 200 EUR/MWh for power and 30 EUR/GJ for heat. Since it is not enough data is available to construct a European scale reservoir model, fixed flow rates have been used for the calculations, assuming that natural permeability can be enhanced – through stimulation – to sustain the assumed flow rates. The most important assumptions for this assessment are summarized in Table 1.

Table 1: Most important assumptions for the 2020 resource assessment.

Parameter	Power	Heat
Maximum depth	7000 m	
Flowrate	50 L s^{-1}	
COP	30 MWth/MWe	
Well cost model	Limberger et al. (2014)	
Stimulation costs > 1 km	1 M EURO per km	
Min. Prod. T	100 °C	40 °C
LCOE cut-off	200 €/MWh	30 €/GJ

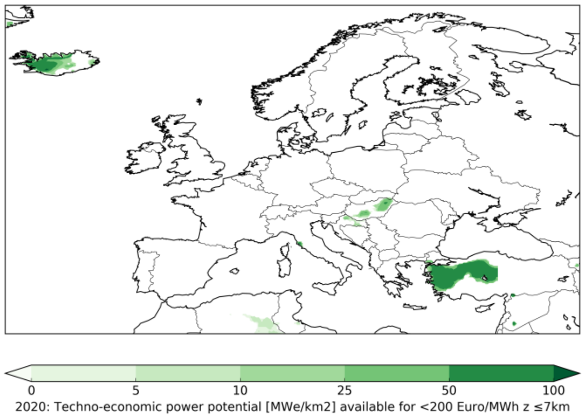

Figure 4: Calculated economic potential for geothermal electricity based on a levelized cost of electricity threshold of 200 EUR/MWh in 2020, up to a depth of 7 km.

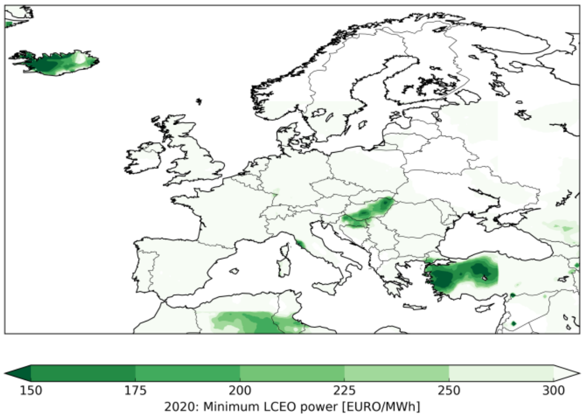

Figure 5: Calculated minimum levelized cost of electricity (for each stacked x-y column) in 2020.

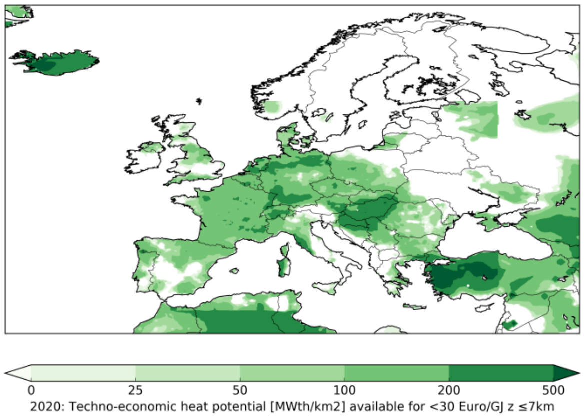

Figure 6: Calculated economic potential for geothermal direct heat based on a levelized cost of heat threshold of 30 EUR/GJ in 2020, up to a depth of 7 km.

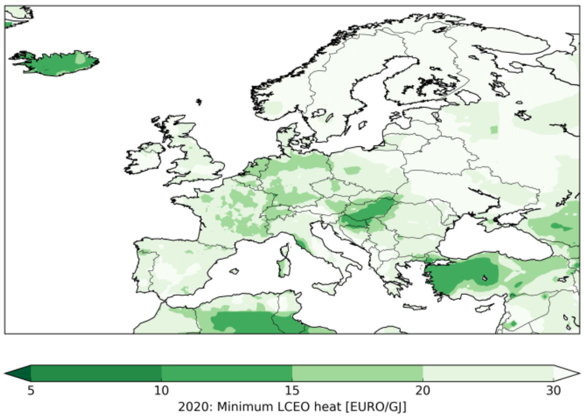

Figure 7: Calculated minimum levelized cost of heat (for each stacked x-y column) in 2020.

4. PRELIMINARY POTENTIAL ESTIMATES

Our resource assessment of geothermal energy in Europe demonstrates that only limited areas in the Europe have sufficiently high geothermal gradients to allow for present-day economical geothermal electricity production. These regions are mostly limited to volcanically active regions in Iceland, Italy, and Turkey, as well as the Hungarian Pannonian basin and the Franco-German Rhine Graben (Fig. 6). A more substantial part of Europe – mainly SW of the Trans-European Suture Zone – shows potential for direct use of geothermal heat.

It is important to stress the large inherent uncertainty of such a large-scale resource assessment. It is primarily caused by the lack of detailed knowledge on local reservoir conditions, compelling us to use generalized assumptions (i.e. fixed flow rates). Actual local geothermal potential is therefore likely to (strongly) deviate from these estimates. Furthermore, no distinction has been made between national differences regarding the economic situation, legislation, regulation and stimulation. The relatively high LCOE threshold values used for the maps could be point of discussion, but in this way, we provide an outlook of areas with future geothermal potential.

We will be able to take these non-geological factors into account by feeding our resource base estimates and cost-curves into integrated assessment models (e.g. Stehfest et al., 2014). This, combined with improvements of the thermal model will allow us to further constrain the present-day geothermal potential, as well as making a more detailed comparison with current installed capacity (e.g. Bertani et al., 2016; Lund and Boyd, 2016, Dumas et al., 2017). Finally, it will also improve our estimates for future geothermal potential.

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