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Integration of the potential of shallow geothermal energy into the information platform Bavarian Energy Atlas as database for spatial heat energy planning

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ABSTRACT

The Bavarian Energy Atlas, an online portal of the Bavarian state government to support the energy transition, provides local authorities and the public with comprehensive information on renewable energies. In order to promote the use of shallow geothermal energy and incorporate its potential into spatial heat energy planning, the potential for groundwater heat pumps, geothermal probes and horizontal collectors was quantified throughout Bavaria and integrated into the Bavarian Energy Atlas.

1. INTRODUCTION

The first amendment to the Bavarian Climate Protection Act (BayKlimaG) came into force in 2023. The state of Bavaria is to become climate-neutral by 2040, with a reduction in greenhouse gas emissions of 65% per capita by 2030 (compared to 1990). A heating transition in the building sector is essential for this. Local authorities in particular are called upon to implement this, with spatial heat energy on municipality level planning representing the first step, which is mandatory for municipalities (with inhabitants over 10,000 people) in Germany since the beginning of the year 2024. However, this requires detailed information on the potential of renewable energies in order to support citizens and decision-makers and enable measures such as energy advice or neighbourhood concepts. The basis for this is a local, quantitative assessment of the potential, in the best case on building level. An area-differentiated analysis of shallow geothermal energy potential enables the local determination of the heat load coverage through it and can thus be adequately integrated into spatial heat energy planning.

The Bavarian Energy Atlas provides an overview of the regional to local potential of renewable energies, but a quantitative analysis of shallow geothermal energy, particularly for specific buildings, has been lacking to date. However, in order to promote the use of shallow geothermal energy in Bavaria and incorporate its potential into spatial municipal heat energy planning, the potential for groundwater heat pumps (GWHP), borehole heat exchangers (BHE) and geothermal collectors throughout Bavaria is being quantified and integrated into the Energy Atlas.

2. CONCEPT

The integration of shallow geothermal energy potential into the Energy Atlas of Bavaria comprises two main aspects: the quantitative estimation of the potential and the heat demand on building level. To this end, a Bavaria-wide heat demand model was created on the basis of a building model. This forms the basis for the identification of an aim scenario for the heat transition, classifying favourable measures at specific areas by overlaying existing potentials with the existing heat demand.

The realisable geothermal potential is generally interpreted conservatively. Hydrogeological parameters and parameters for technical implementation are each assumed in such a way that a ‘minimum realisable potential’ is shown. The aim here is to avoid a situation in which a recognised potential is not achievable in reality. Conversely, however, this also means that the realisable potential is estimated to be higher in some cases than shown in this concept.

2.1 Data

Extensive data collection is required for the potential analyses, for example on hydrogeological fundamentals, rock thermal conductivity and exclusion areas based on existing regulations or technical limitations. The analyses are based on available geological data from the Bavarian State Office for the Environment (LfU), supplemented by work from the Technical University of Munich (TUM) and Friedrich-Alexander University Erlangen-Nürnberg (FAU).

The potential analysis utilises existing methods that have been adapted for the Bavarian Energy Atlas. It takes into account exclusion areas where the installation of geothermal systems is not permitted such as nature and drinking water protection areas, which differ between geothermal collectors and other systems. Further, suitability areas were analysed comprehensively, e.g. for groundwater heat pumps with regard to groundwater thickness, hydraulic permeability, groundwater spacing and hydraulic gradient or rock and soil thermal conductivity, underground temperature and climate conditions for borehole heat exchanger or horizontal collector potentials Also regulation and technical requirements like distance to buildings or other systems are considered in the concept. The accuracy of this data basis varies across the country, so that a quality assessment of the potential analysis was also carried out and presented.

2.2 Groundwater Heat Pumps

The potential analysis for groundwater heat pumps was carried out using the TAP method (Böttcher et al., 2019). The estimation of the available, extractable volume flow depends on the natural parameters of the saturated groundwater thickness (distance of the groundwater surface to the aquifer base), the distance from the groundwater surface to the top of the ground), the hydraulic permeability, the groundwater flow velocity and direction (or hydraulic gradient), as well as the technical conditions of the well. Three conditions are restricting the maximum technical production rate of a well doublet system:

- at the extraction well, a commonly agreed drawdown limit is one third of the saturated aquifer thickness to avoid an excessive utilisation of the available groundwater supply. This based on water authority regulations as well as technical, respectively planning requirements,
- at the injection well, in areas where the depth to the groundwater surface is low, the re-injection of water and thus the rise of the groundwater table should be restricted, to avoid surface or basement flooding. A safety distance of 0.5 metres from the ground surface was set as the limit value for the maximum injection.
- for a sustainable operation of a well doublet, hydraulic breakthrough and thermal recycling between extraction and injection well have to be avoided. Therefor a specific distance between production and injection well is set with a minimum of 10 m distance considering the practical implementation rules

The further apart the production and extraction wells can be, the lower the risk of a thermal-hydraulic short circuit and the higher the possible extraction rate. For the grid based calculations, with 10 m (for small systems) and 100 m (for larger systems), two distances between extraction and injection wells are used while for the plot based analysis, suitable well locations are defined in order to determine the maximum possible well spacing.

2.3 Borehole Heat Exchangers

The potential for borehole heat exchangers was analysed as shown in Figure 1. The effective thermal conductivity was calculated from the rock thermal conductivities available from the LfU using the possible drilling depth and the potential was then estimated using the German guideline VDI 4640.

The calculated potential for the utilisation of borehole heat exchangers (BHE) increases with increasing drilling depth. Therefore, the possible drilling depth permitted under the Bavarian authorisation law is of great importance for the geothermal potential for the use of borehole heat exchangers. The data set provided by the LfU specifies the maximum permitted drilling depth taking into account no drilling through the base horizon (first aquitard, respectively horizon with low hydraulic conductivity) of the first aquifer and areas where drilling is generally not permitted, such as in karst and sulphate rocks or areas with artesian groundwater.

2.4 Geothermal Collectors

The estimation of the quantitative potential for geothermal collectors (horizontal systems) and their special forms is based on a methodology developed by the shallow geothermal energy working group at FAU on the basis of the dissertation by Ramming (2007). This methodology combines the specifications of VDI 4640, Sheet 2 and VDI 4710 with the digital surface data of a detailed, high resolution soil map and the digital terrain model. The most important parameter for calculating the potential is the soil type with its characteristic physical properties. In addition, climatological data is used to derive the heating degree days in order to take regional average temperatures into account. Based on the climate information, heating degree days were derived, which were calculated for the whole of Bavaria depending on altitude using the digital terrain model. In addition, the extraction rates were correlated with heating degree days. The digital soil map allowed the influence of different soil types to be taken into account.

In general, shallow geothermal energy systems can be installed on all areas where the soil structure is > 1 m deep and none of the criteria listed contradict this. In existing residential buildings, the available undeveloped area should be used. In new buildings, areas can also be built over in individual cases or building components themselves can be activated.

Additionally to the exclusion areas above, areas with highly organic soils were also excluded from this study, as these have very poor thermal conductivity. Also, areas with a slope gradient of more than 15 %, bedrock or poor diggability, or areas with too extensive tree cover and bogs are unsuitable.

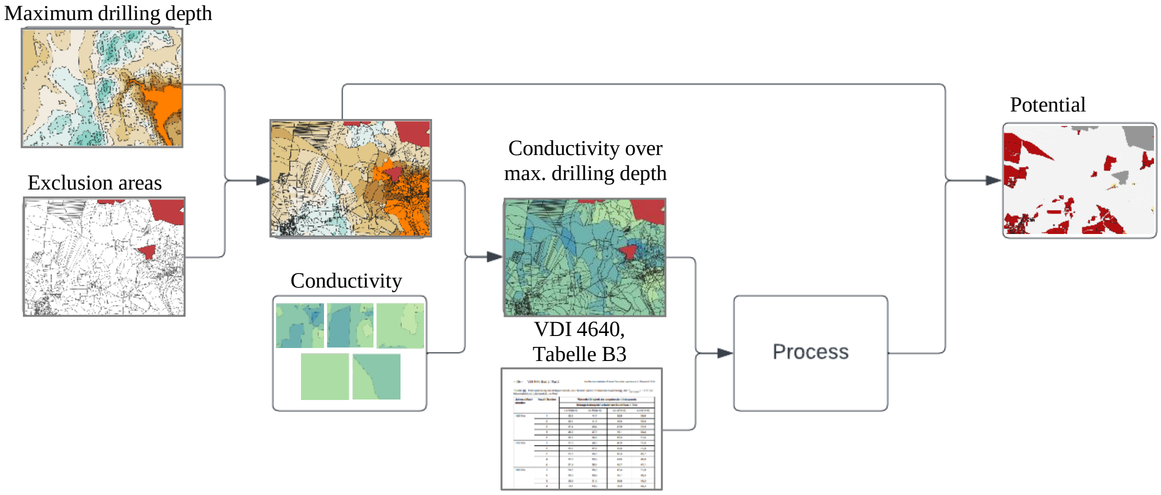

Figure 1: Concept for the calculation of the potential of borehole heat exchangers.

3. RESULTS

The results are presented on two scales: On the one hand, raster datasets are used to show the comprehensive potential throughout Bavaria for existing and new buildings so that currently undeveloped areas can also be taken into account in planning. On the other hand, the potential is calculated for use in spatial heat energy planning on municipality level on a plot-by-plot basis and then aggregated for each municipality for presentation in the Energy Atlas of Bavaria.

The potential was determined quantitatively for each system using the described different methods and presented as thermal output (MW) or as heat quantity (MWh/a) in relation to a defined area (10 m x 10 m raster cell or plot area) in order to be comparable with other renewable energy potentials in municipal heat planning**.**

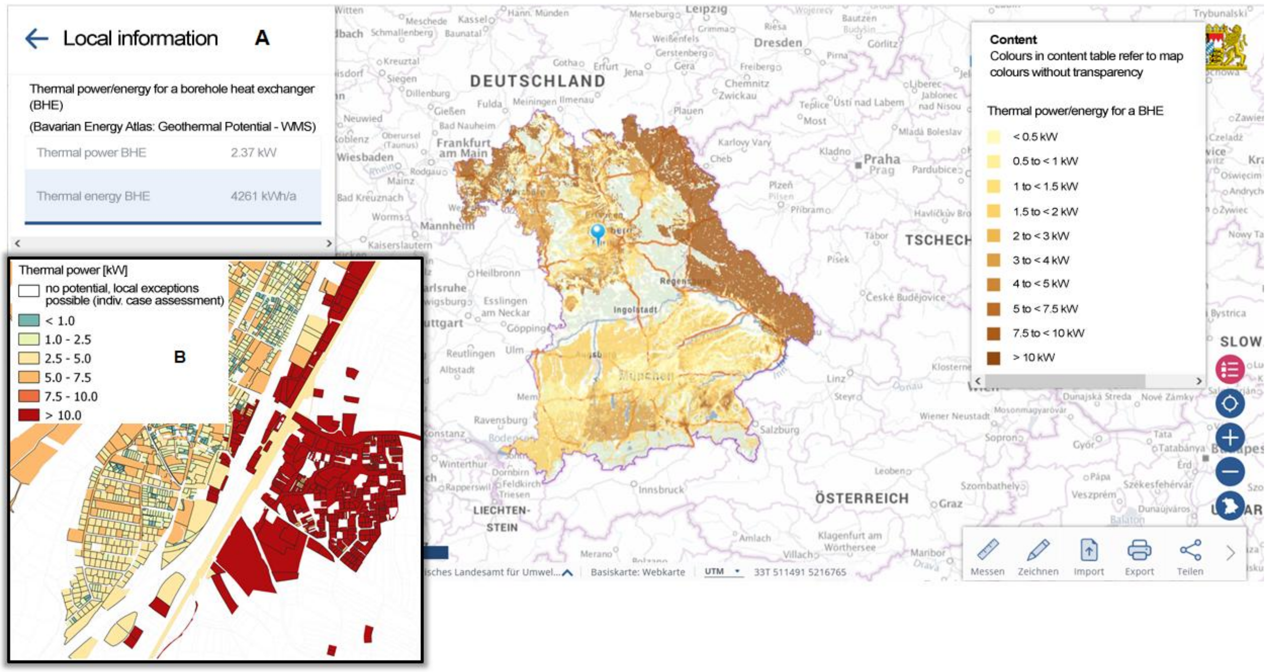

Figure 2: Quantified potential for the utilisation of geothermal probes in Bavaria. A: Potential illustration as 10m x 10m grid, shown in the Bavarian Energy Atlas with local information for a borehole heat exchanger. B: Calculation of the maximum potential of geothermal probes for a single plot of land.

The calculated potentials in the grid approach (10 m x 10 m) represent the extraction capacity for GWHP systems as a doublet with a distance of 10 m and 100 m (for larger systems), for BHEs in a 10 m x 10 m grid and the calculated extraction capacity per m2 for horizontal collectors. This information basis is now provided in the Bavarian Energy Atlas (www.karten.energieatlas.bayern.de) as an initial assessment for a location. An example of the potential of BHEs is shown in Figure 2 (A) and the potential of GWHPs in Figure 3.

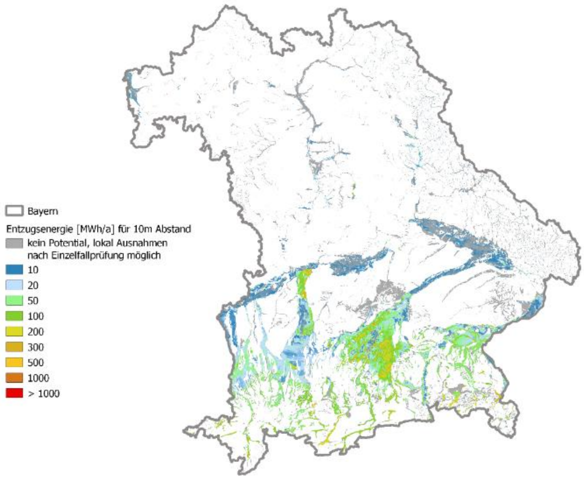

Figure 3: Quantified potential for the utilisation of groundwater heat pumps based on the application of TAP method (Böttcher et al., 2019)

In the plot-specific approach, the realisable potential was in a final step compared with the heat demand of the buildings in order to analyse how much of the current heat demand in Bavaria or in the respective municipalities can be covered by shallow geothermal energy.

When calculating the potential for each plot of land, distance rules from buildings, neighbouring properties and between probes and wells were taken into account. The maximum potential per property was determined under conservative conditions to ensure a high degree of feasibility.

It is planned to offer the property-specific potentials to the municipalities as soon as possible as data packages for municipal heat planning.

4. CONCLUSIONS

A general analysis of the geothermal potential shows that shallow geothermal energy systems can be used almost everywhere in Bavaria.

There are hardly any exclusion areas for the use of geothermal collectors in particular. However, their use is severely limited, particularly in urban areas, due to the limited areas available for installation on individual properties or plots of land. Due to the small number of areas excluded under licensing law and their versatile geological applicability, the collectors have great potential in Bavaria compared to the other systems, despite generally lower extraction rates. However, in dense urban areas, the space for geothermal collectors is limited and hence the potential is also less.

Borehole heat exchangers have a slightly lower overall potential, which is generally limited by the drilling depth restrictions that apply in Bavaria. According to information from planning and drilling companies, BHEs are only economically viable from drilling depths greater than 30 metres or 60 metres. The drilling of BHEs is generally not permitted on 31% of the area in Bavaria, and on a further 15% they can only be drilled shallower than 30 metres. These 46 % of Bavaria's area are excluded from the analysis as potential. In addition, the drilling depth is limited to less than 60 m in a further 17 % of the area. Although this area was taken into account in the analysis as possible potential for BHEs, due to the shallow depth, a larger number of probes usually have to be drilled on a parcel of land in order to cover the building's heat. However, this space is often limited on a parcel of land. This further reduces the analysed geothermal probe potential. Optimal conditions for the realisation of BHEs in Bavaria with permitted drilling depths of over 100 m can only be found in 20% of the area.

The use of GWHPs is limited to locations with accessible, groundwater-bearing layers. Due to the drilling depth limitation, the analysis focussed on quaternary aquifers, which are the most relevant for thermal utilisation. Deeper or tertiary aquifers were excluded in order to ensure compliance with authorisation requirements. The greatest potential lies in the south of Bavaria in the extensive glacio-fluviatile areas. In total, these geologically and legally suitable areas cover approx. 16 % of Bavaria. This limited area explains the low heat coverage by GWHPs, although they are usually the most efficient technology. Regionally, however, they can have high relevant potential.

The current discussion on the municipal heating transition highlights the challenge of identifying local renewable potential for supplying heat to neighbourhoods or blocks of flats. Local heating networks, especially cold local heating networks, are particularly suitable for this, with shallow geothermal energy being a frequently used energy source (e.g. Wirtz et al., 2022). The energy source does not necessarily have to be at the same location as the heat demand. However, this application, which increases the coverage potential in practice, was not taken into account in this analysis. The inclusion of covering cooling requirements, which could further increase the application potential of shallow geothermal energy, was also not considered here.

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