PROCEEDINGS, 48th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 6-8, 2023
SGP-TR-224

Web information systems for shallow geothermal energy – An example from Austria

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Keywords: geothermal energy, renewable energy, groundwater, hydrogeology, borehole heat exchangers, groundwater heat exchangers, webinformation system

ABSTRACT

Inquiries on possibilities for switching to renewable energy resource are growing in the light of raising gas prices and increasing awareness of the climate crises. Requests for renewable heating and cooling sources have risen very strongly in the last year. This calls for a better display of resources to raise awareness of niche technologies, such as shallow geothermal energy (SGE), for a sustainable use of the available resources and for a reduction of dependency on energy imports. The project "Spatial Energy Planning for Heat Transition" (GEL-SEP), with a project lifetime from June 2018 to May 2021, as part of the Austrian research initiative Green Energy Lab embarked on it by providing a sound basis for the integration of heat in private and public planning processes and for the implementation of the energy infrastructure of the future together with energy providers.

Three federal states of Austria (Vienna, Styria, and Salzburg), their capital cities and pilot-municipalities worked together to provide information necessary for the implementation of heat into spatial planning – as role model for Austria and other countries. The GIS-based web-tool 'Heat-Atlas', which is still under construction, will provide data on available, local energy sources in a harmonized way and serve as information platform for project developers and regional planning for each state. Goal of this tool is to foster the use of all available sustainable energy resources and infrastructures to their full extent. The system of the information platform is scalable and is aimed to be expanded to other regions of Austria on interest.

SGE is one source covered in the GEL-SEP Heat-Atlas and covers horizontal - (hCLS: shallow heat collector), vertical closed loop (vCLS: borehole heat exchanger) as well as open loop systems (OLS: groundwater heat exchanger). The Geological Survey of Austria developed methods to provide a broad compilation of resource and limitation of use data sets. New methods to estimate capacity and energy content combine location-specific geological and hydrogeological parameters such as thermal conductivity, underground temperature, and groundwater availability with system-specific parameters such as mode of operation, operational hours, geometry, and threshold values demanded by official regulations. So-called traffic light maps combine all possible limitations of SGE use. All data sets together give an area-wide overview about where the use of SGE is possible and to what extent. They also serve as input for location specific queries, which consider parameters such as heating and cooling demand, operational hours, and size of the property. This enables the estimation of the overall energy resources and the cover ratio of the property. An automatically generated report will make all this sit-specific information available to the users.

The content on SGE of the statewide GEL-SEP Heat-Atlas will also be transferred into a nation-wide Geothermal-Atlas. The Geological Survey of Austria currently establishes a Geothermal-Atlas, which will serve as central point of information for the use of geothermal energy in Austria. The Geothermal-Atlas starts with the city of Vienna, with the content available in 2023.

1. INTRODUCTION

In many countries, the awareness of technological options and resources linked to the use SGE is still rather low. This is the case even for countries with an already established market, such as Austria. The EU GeoERA project MUSE (https://geoera.eu/projects/muse3/) found that raising awareness of this technology in Europe is an important task, only by doing so can untapped shallow geothermal resources make their contribution for the decarbonization of the heating and cooling sector (Kłonowski et al., 2020). The energy transition towards renewable and green sources must be accelerated in light of the climate crisis. A positive side effect from relying more on SGE as a local resource is that the heating and cooling supply becomes more independent from energy imports. Therefore, efforts to increase the share of shallow geothermal heating and cooling should be intensified.

A large-scale rollout of SGE would be advisable for any country. It should become the default solution, not come on the scene after all other more inefficient technologies have been ruled out. Aside from a simple legal framework, other steps to achieve this are to include it into public planning procedures and raise the general awareness of the technology. Including it in spatial energy planning depends on a variety of required geoscientific an non-geoscientific data. Knowledge of resources, possible limitations of use and the regulatory framework (including licensing procedures and requirements for monitoring and operating) are key to use the full potential of SGE in a sustainable manner.

Web information systems for SGE are an excellent instrument to provide all this information as clearly and completely as possible. They can:

- be a **starting point** to get familiar with the topic of SGE use (general public),
- provide an **overview of resources** to be able to compare different locations (general public, investors, city planners),
- provide **specific information about resources on selected properties** (new house owners, investors, authorities),
- provide **specific information about resources in given areas** e.g. city districts (authorities and city planners),
- provide **contact information** about related authorities, planners and installers.

A web map viewer to present spatial datasets is the typical tool for web information systems related to SGE. However, this is not the only useful way to provide information. Several existing web information systems for SGE include the additional tools, such as:

1. **Pre-dimensioning tool for properties** (based on spatial data sets)
2. **Database for experts**, that provides data sets for direct download, e.g. data from environmental or installation monitoring
3. **Knowledge repositories/bibliographies, which** are useful to point to related literature or projects
4. **Glossary of terms, which** can be a good starting point to get familiar with the topic
5. **Yellow pages** to identify regional professionals, planners, installers or authorities
6. **E-government tools** to connect users with authorities for a direct exchange of e.g. application forms, data required for licensing or monitoring data

This broad range of functionalities allows to easily disseminate information to stakeholders on different levels of expertise. In the project GEL-SEP, we focused on the creation of spatial data sets for a new web information system including a pre-dimensioning tool for properties of OLS, vCLS and hCLS in the pilot areas. Table 1 summarizes already available web information systems in Europe and their content.

Table 1: Non-exclusive list of web information systems related to shallow geothermal energy in Europe (List from https://geoera.eu/projects/muse3/ extended). OLS – open loop system, vCLS – vertical closed loop system, hCLS – horizontal closed loop system.

Area covered	Link to Webtool	Content
International (Austria, Germany, Switzerland, Italy, France, Slovenia)	http://greta.eurac.edu/	WMS layers about resources and possible limitations of use for OLS and vCLS
International (Austria, Germany, Poland, Slovakia, Slovenia, Czech republic)	https://portal.geoplasma-ce.eu/webgis	Web map viewer for resources and possible limitations of use, including location specific query, yellow pages, glossary of terms and database for experts for OLS and vCLS
International (Europe)	https://www.thermomap.eu/	Web map viewer showing geoscientific information for hCLS in Europe
International (Europe)	https://data.geus.dk/egdi/?mapname=muse_preview#baslay=baseMapGEUS&extent=744360,127720,6401480,4733550	Web map viewer for resources and possible limitations of use for OLS and vCLS in 15 European cities.
Austria (State of Salzburg)	https://www.salzburg.gv.at/sagismobile/sagisonline/map/Energie/W%C3%A4rmepumpen	Web map viewer for resources and possible limitations of use including a location specific query for OLS and vCLS.
Austria (Vienna)	https://www.wien.gv.at/stadtentwicklung/energie/themenstadtplan/erdwaerme/	Web map viewer for resources and possible limitations of use for OLS and vCLS
France	https://www.geothermies.fr/viewer/	Web map viewer with resources, existing vCLS and OLS and Thermal Response Tests
Germany (Baden-Württemberg)	http://isong.lgrb-bw.de	Webmap viewer including location specific query focusing on geoscientific data for vCLS

Germany (Bavaria)	http://www.umweltatlas.bayern.de/	Webmap viewer including location specific query focusing on geoscientific data for vCLS and OLS
Germany (Nordrhein Westfalen)	https://www.geothermie.nrw.de/	Webmap viewer including location specific query focusing on geoscientific data for vCLS and hCLS
Netherlands	https://www.thermogis.nl	Web map viewer of resources for SGE
Netherlands	https://wkotool.nl	Web map viewer of existing vCLS and OLS installations
Spain (Catalonia)	https://www.icgc.cat/en/Public-Administration-and-Enterprises/Tools/Geoindex-viewers/Geoindex-Shallow-geothermal-energy	WMS layers about geoscientific data for SGE resources
Switzerland	http://www.erdsondenoptimierung.ch	Broad information including documents and links about how to optimize vCLS

Setting up a completely new web information system requires many resources and a lot of advertising in order to increase its visibility and get stakeholders accustomed to it. An advantage of a new system is that it can be designed freely without having to consider existing structures. Another approach would be to integrate spatial data sets and specific tools related to SGE into existing systems, e.g. for cities or entire regions. On the one hand, the SGE tools could thus benefit from the popularity of a well-known system and people can work with a system they are generally familiar with. On the other hand, having to deal with existing structures could complicate the implementation process. The GEL-SEP project intends to include all results into the general web information systems of the participating federal states of Austria (Styria, Salzburg and Vienna).

1.1 Goals of GEL-SEP

The project GEL-SEP "Spatial Energy Planning for Heat Transition" as part of the "Green Energy Lab", which is funded by the national funding body FFG, created the necessary basis for the implementation of spatial energy planning to accelerate the heat transition in Austria, specifically in Styria, Salzburg and Vienna. The renewable heat resources will be made available in the so-called Heat-Atlas, a web information system that will provide a sound information basis for the strategic development of sustainable heat supply infrastructure and shall thus become the basis for efficient energy planning.

The GEL-SEP Heat-Atlas will show potential renewable heat sources (including SGE), heating demand as well as existing heat infrastructure. The recently funded “GeoSphere Austria” (known as Geological Survey of Austria until 31 December 2022) compiled necessary geological and hydrogeological input data sets and developed a methodology to calculate and display the resources of SGE. The aim was to apply a harmonized methodology for a comparable and uniform presentation of all resources, which can be implemented in all study areas. All most common SGE systems in Austria (groundwater heat exchangers - OLS, borehole heat exchangers - vCLS and shallow heat collectors - hCLS) were part of the project. The Friedrich-Alexander-Universität (Erlangen-Nürnberg, Germany) took over the resource estimation for vCLS. Pilot areas of the project were: Vienna, the permanent settlement area of Salzburg and the city of Graz, the municipality of Kapfenberg, the energy region of Weiz-Gleisdorf in Styria as well as the region of Eastern Styria. Locations of the pilot areas are provided in Figure 1. Since hCLS are less interesting for Vienna due to the limited space available in a large city, the resources for this technology were only determined in the pilot areas of Salzburg and Styria.

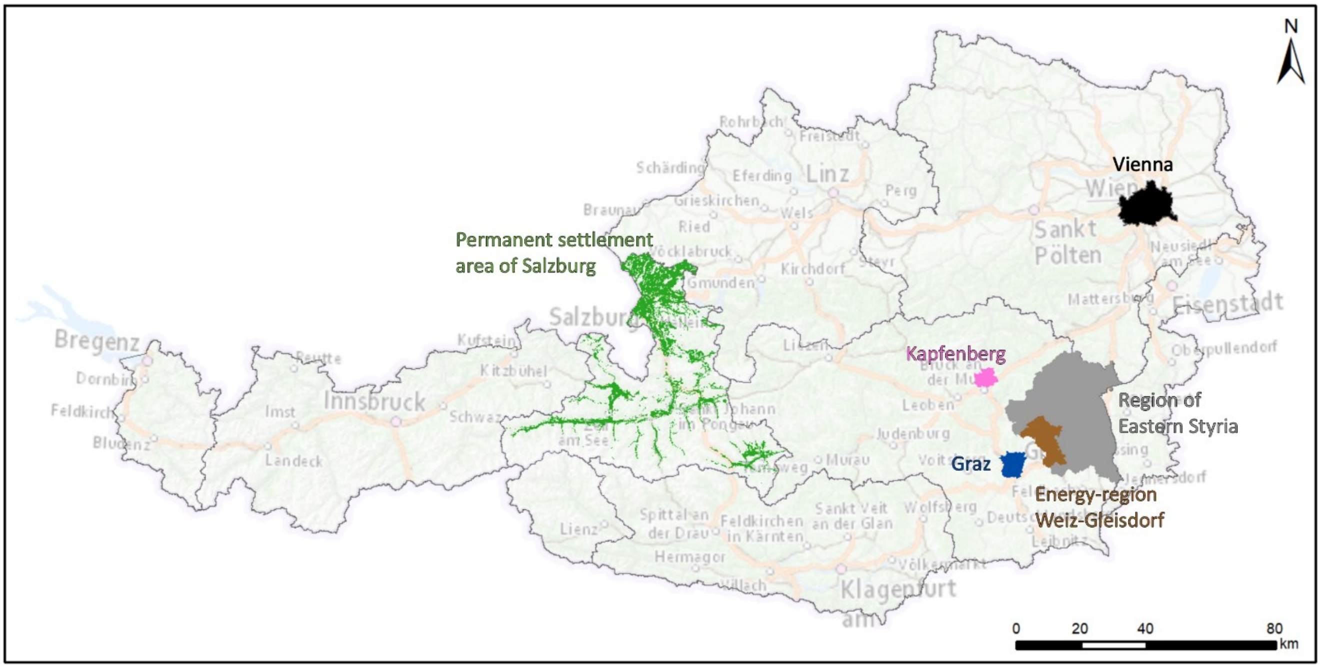

Figure 1: Pilot areas of the GEL-SEP project in Austria.

At first, area-wide input data sets were developed and compiled for these pilot areas. In a next step, this data base was used to derive resources and any limitations of use. Categories and textual descriptions for the display in the GEL-SEP Heat-Atlas accompanied the results. Three tools will present the project's outputs in the GEL-SEP Heat-Atlas. A web map viewer (TOOL 1), a location specific query for land properties (TOOL 2) and a regional query for city blocks/districts (TOOL 3). For a basic overview of the functions see Table 3 and more detailed descriptions are provided in chapter 5. Stakeholder workshops were part of the GEL-SEP project to adapt the contents and tools of the GEL-SEP Heat-Atlas to the needs of the stakeholders in the best possible way. The technical implementation of the GEL-SEP Heat-Atlas is at the responsibility of the project owners, who will implement the datasets into the GIS systems of the responsible federal states in Austria.

In this paper, we show the outcomes of the GEL-SEP project related to SGE. We present the applied methods of the resource estimation as well as the resulting outputs. Since the implementation of the results into the GEL-SEP Heat-Atlas has not been accomplished yet, we provide an outlook on the implementations planed. Where applicable, we refer to a nation-wide Geothermal-Atlas, which is currently under development at GeoSphere Autria and will focus on presenting spatial information about geothermal energy in Austria (including the outcomes of the GEL-SEP project) in a single unified web information system.

2. INPUT DATA

Due to the planned timely development of the data sets, extensive data assessments, such as field campaigns, have not been carried out. The data basis used had largely been created in preliminary studies or were available at public archives. However, to fill relevant gaps, some data were collected from archives of authorities and companies. This included Thermal Response Tests (for all pilot areas) to gain temperature profiles and information about the thermal conductivity of the underground, and pumping tests (for Styria and Vienna) to gain additional data about the hydraulic conductivity.

Input data sets were not available in the same quality and density throughout the pilot areas. We saw a generally high contrast between urban areas and non-urban areas. Inside cities, the main groundwater bodies are described in detail, whereas for minor shallow groundwater bodies, which could still be still suitable for OLS use, information on groundwater level and thickness as well as hydraulic conductivity were often missing.

In general, we relied on geological and hydrogeological data sets. The first task was to derive basic input data sets from point data, where they were not already available for entire areas. These geoscientific data sets already serve as important information for planners of SGE systems themselves. Therefore, we assigned them as output data sets as well. All input data sets used to derive a specific resource output data set are shown in chapter 4 (Table 2). Some output parameters do not solely depend on geoscientific data, but also on operating parameters, which had to be set for the calculation of resource maps. The chosen operating parameters are described in chapter 3.

Aside from resources, we looked into possible limitations of SGE use. To create summarizing traffic light maps (chapter 3), input data sets from authorities were used and new data sets were created that show possible limitations of use. The following limitation of use parameters were included in the traffic light maps:

- Groundwater protection areas
- Nature protection areas
- Confined groundwater zones
- Landslide areas (active/possible)
- Karstic areas
- Permissions for groundwater use
- Swellable and leachable rocks
- Contaminated areas
- Public underground traffic structures

3. METHODS

There are many parameters that can show resources and possible limitations of SGE for larger areas. In the GEL-SEP study, we generally distinguished "resources" and "limitations". The resource parameters show the potential for use primarily in a quantitative way. However, apart from this technical potential, there may be restrictions on SGE use in certain areas, for example, due to prioritized subsurface use or risks posed by or to the SGE system. Since the technical potential is generally not affected by those restrictions, we calculated the resources separately. Possible limitations of use are provided for the vCLS and hCLS for the entire pilot areas, and for OLS, the information is limited to the suitable groundwater bodies.

A harmonized methodology was developed for the preparation of the data sets, which is applicable both in areas with high data density (primarily urban areas) and with low data density (primarily rural areas). Thus, uniform approaches have been implemented irrespectively of the density of input data to achieve comparable results. The chosen methods produce maps that cover all pilot areas and include all known and accessible data. Some general uncertainty remain using this area-wide approach even in case of very good data. In any case, a disclaimer on data uncertainty must be included in further use. The methodology for vCLS and OLS and the possible limitation itself is a further development of the resource estimates started by the Geological Survey of Austria in the projects IIOG-S (Götzl et al., 2016), WC-33 (Fuchsluger, 2016), and GeoPLASMA-CE (Görz et al., 2017, 2019). The GeoZentrum Nordbayern at the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) in Germany performed the resource estimation for hCLS (Schwarz et al., 2022). The chapters below present a summary of the applied methods, and the project reports explain the methodology in more detail (Steiner, Götzl, et al., 2021c, 2021a, 2021b; Steiner, Turewicz, et al., 2021). The workflows to delineate area-wide spatial data sets of resources and limitations of use have also been applied in the GeoERA project MUSE to European urban areas (Steiner, Goetzl, et al., 2021).

3.1 Resources for open loop systems

Basic hydrogeological data is necessary to calculate the resources in energy and power units. The first step was to delineate the suitable shallow groundwater bodies. Within a suitable groundwater body, the pumping rate and therefore also the thermal power of a groundwater well doublet depends primarily on aquifer properties, such as thickness, hydraulic conductivity, depth to groundwater level, and groundwater temperature. Based on this hydrogeological information, energy and power units can be calculated. Figure 2 shows all input data used for the calculation and the resulting output data sets.

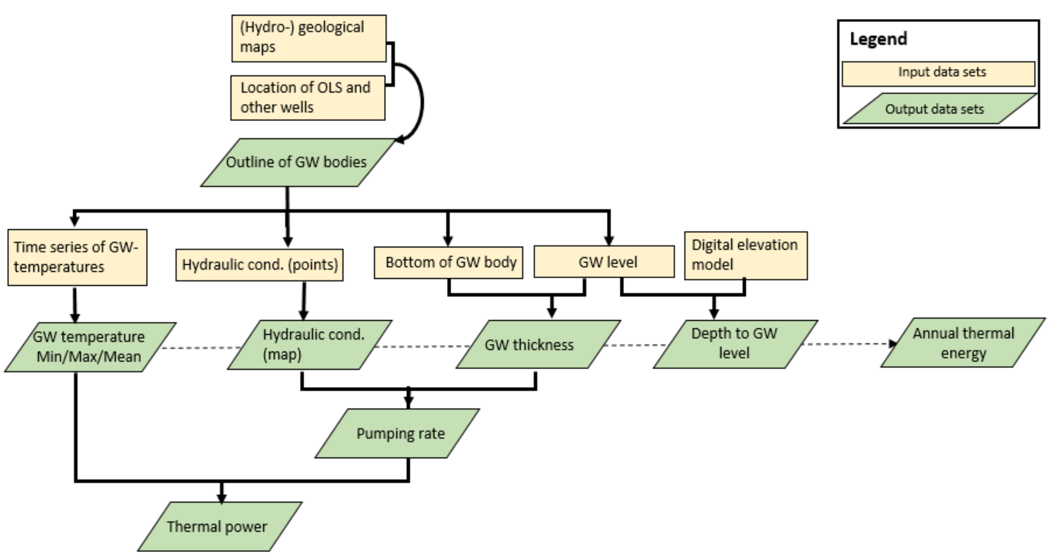

Figure 2: Flowchart of the resource estimation for OLS applied in the GEL-SEP project. GW - groundwater, cond. - conductivity.

3.1.1 Outline of GW bodies suitable for OLS

Outlines of shallow groundwater bodies were revised based on new hydrogeological research. Porous groundwater bodies were considered suitable and divided into two categories. For areas with a productive groundwater body and known groundwater top and bottom, all quantitative data sets could be provided. The remaining areas mostly only have local or limited groundwater flow and area-wide hydrogeological information is lacking. Since groundwater temperatures had a higher availability, we could at least provide this information there.

3.1.2 Groundwater thickness and depth to GW level

The determination of both parameters depends on the groundwater level. For most urban areas, groundwater isolines were available and we used data representing a low level for the resource estimation following a conservative approach. Where this information was lacking, we calculated groundwater level maps based on measured groundwater levels in single boreholes. As the porous aquifers we investigated were mostly connected to rivers, we interpolated the level of adjacent rivers and available groundwater levels in boreholes for an estimation of the groundwater level.

The groundwater thickness could be determined in areas with area-wide known bottom of the groundwater body and groundwater level. The depth to the groundwater level corresponds to the thickness of the unsaturated zone and was derived from the digital elevation model and the groundwater level.

3.1.3 Hydraulic conductivity

For two urban areas (Graz - Styria and parts of Vienna), we could use hydraulic conductivity maps derived from calibrating numerical groundwater models. In most areas, information about the hydraulic conductivity was scarce. Since pumping rates of wells (respectively the hydraulic potential of OLS) are very sensitive to the hydraulic conductivity, we conducted literature research and collected pumping test data from archives to improve input data quantity. The pumping test were revaluated with a joint process (Hölting, B.; Coldewey, 2013) to derive the hydraulic conductivity.

3.1.4 Groundwater temperatures

The methods to calculate thermal power and annual thermal energy required information about mean, minimum and maximum groundwater temperature. The mean groundwater temperatures are also considered in the calculations for the underground temperature for vCLS. In this study, we derived area-wide groundwater temperatures based on measurements in boreholes and wells. This largely inhomogeneous input data set consisted of measurements with varying depths and timelines. It contained manually applied measurements in multiple depths as well as automatically and manually applied single point measurements. In a first harmonization step, we derived the mean values of each measurement day. In a second harmonization approach we used an algorithm to fit a sine wave to each time series, which allowed us to cover gaps and take seasonal changes as well as the temperature trend into account in the calculation of a standardized day for mean, minimum and maximum values in 2020. They were then interpolated to groundwater temperature maps. This approach was suitable for areas with a good availability of temperature data.

For areas with low data density, we used available data points to derive a correlation between depth and groundwater temperature, and between surface temperature and groundwater temperature, and applied the correlation onto areas, where information of the groundwater thickness was lacking.

3.1.5 Pumping rate, thermal power and annual thermal energy

The pumping rate was calculated based on the Dupuit-Thiem Formula for unconfined groundwater, taken from ÖWAV guideline 207 (Österreichischer Wasser- und Abfallwirtschaftsverband, 2009). The ranges of influence for drawdown and recovery were limited to a radius of 25 m. Accordingly, the resulting pumping rate and the thermal power apply to well doublets with a distance of 50 m between the extraction and injection wells. Additional restrictions are a maximum drawdown of the groundwater level of 5 m or 1/3 of the net groundwater thickness as well as a maximum cap of the net groundwater thickness of 20 m.

The calculation of groundwater energy is based on the storage capacity of the aquifer. This was calculated from the heat capacity of the aquifer, the groundwater thickness and the temperature shift between the extraction and injection wells. In the balanced mode of operation, the entire energy stored within the groundwater can be used for heating and cooling on an annual basis. In the heating and cooling mode of operation, the thermal energy can only be used over the predefined lifetime of operation (given in the unit years). However, heat is also allowed to be exchanged from the bottom and the top boundary of the groundwater body due to the temperature differences. The usable temperature shift for heating depends on the minimum groundwater temperature in the winter season and the lower temperature limit to return the groundwater (5 °C). The usable temperature shift for cooling depends on the maximum groundwater temperature in the summer season and the upper temperature limit to return the groundwater (18 °C). The two temperature limits correspond to the limits given in ÖWAV Regelblatt 207 (Österreichischer Wasser- und Abfallwirtschaftsverband, 2009).

3.2 Resources for vertical closed systems

The heat extraction rate of a vCLS depends on:

- **Underground properties** at the given location (temperature and thermal conductivity)
- **Coupling of the probe** to the subsurface (borehole resistance)
- **Geometry of the vCLS** (borehole radius, depth of the singular probes, number and distance of the probes)
- **Mode of operation** (heating and cooling load, and the energy balance heating/cooling)

A geometry function (g-function) summarizes the geometry and mode of operation. For the subsurface properties, we produced maps as inputs for further calculation of power and energy resources (Figure 3).

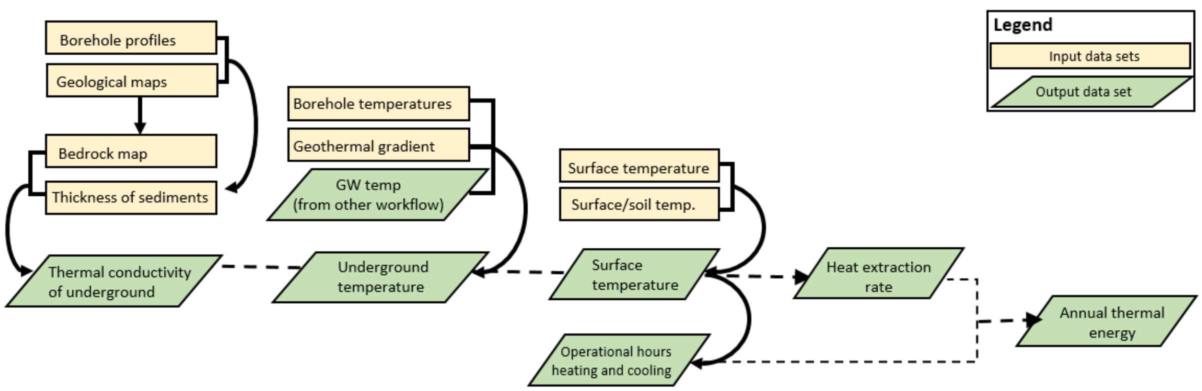

Figure 3: Flowchart of the resource estimation for vCLS applied in the GEL-SEP project. Temp. – temperature

The target depth for the resources of vCLS was set to 100 m. An analysis of existing vCLS in Vienna and Salzburg revealed 100 m as mean depth in both federal states. Therefore, the geological base data sets and the energy and power data refer to this depth.

3.2.1 Thermal conductivity - underground

The thermal conductivity of the underground differs, depending on the rock type and on the water saturation. Regarding the rock type, the difference between solid rock and unconsolidated rock (e.g. fillings in sedimentary basins) is decisive: Sediments tend to have a lower conductive thermal conductivity (≤ 2 W/m/K), whereas thermal conductivities of solid rocks range from 2 to 4 W/m/K. This clear difference represents the basis of our workflow. Advective processes influencing the thermal conductivity, such as groundwater flow, have not been considered in this approach.

The first step was to create basic 3D geological models of the sedimentary basins, based on geological borehole profiles and structural maps of sedimentary basins using the software SKUA-GOCAD. The data quality varied regionally and depended mainly on the density of the available digital borehole profiles. Outside and below the sedimentary basins, the thermal conductivity was determined based on the rock type on the bedrock map. Within the sedimentary basin, the lithological information from boreholes was included in the calculation of thermal conductivity. To serve as input data for the calculation of power and energy resources, the resulting data set shows the mean conductive thermal conductivity for a depth interval from 0 to 100 m.

3.2.2 Surface temperature

The temperature of the land surface can be determined by correcting satellite data. Land surface temperature maps, that we used for our study, were created with this approach for Europe (Metz et al., 2014). This Europe-wide dataset represents a mean annual temperature on a raster with a cell size of 250 m x 250 m. It had been compared in the GeoPLASMA-CE project (Görz et al., 2019) with measured soil temperatures at various locations in Austria. The surface temperature from the satellite data at the stations aligns sufficiently with the soil temperatures, which justified the application within this study.

3.2.3 Underground temperature

Direct measurements of the underground temperature are the most important input data for the creation of underground temperature maps. They are typically carried out in boreholes during Thermal Response Tests in newly installed heat exchanger probes. A temperature profile documents the underground temperature at various depth intervals. They are good input data to derive temperature gradients.

Unfortunately, the spatial distribution of available temperature profiles does not allow an interpolation of temperatures between the boreholes. Our approach was to cluster the profiles according to geological and hydrogeological homogeneous areas. For each cluster, a mean geothermal gradient was determined using the temperature profiles. Individual temperature profiles were obtained for each grid cell, starting at the actual surface temperature, and extending to the depth of the geothermal influence area. The mean groundwater temperature of the shallow groundwater bodies (Chapter 3.1.4) was included as well. A combination of these data sets led to the mean underground temperatures for the depth interval from 0 to 100 m.

3.2.4 Standard operating hours

Assumptions had to be made on the operating mode and the heating and cooling load of the SGE system. Those parameters basically depend on the building type (residential, office, commercial), building size and the climate. The climate-dependent part is often linked to heating degree days or cooling degree days. In the Swiss standard SIA for the dimensioning of vCLS, the SIA 384/6 (Schweizerischer Ingenieur- und Architektenverein, 2021), this climate factor is coupled to the surface temperature or the sea level, respectively, in the form of standard operating hours. This basic approach was also chosen in this project and the full load hours were taken for the power and energy calculations. The altitude dependence of the standard operating hours from the SIA was modified and calculated back to the dependence on the surface temperature. This formula was further modified with 200 h to consider the energy demand for domestic hot water. For cooling the buildings, it was assumed that no cooling is required below 8 °C mean surface temperature. Thereafter, the cooling demand increases linearly to obtain about 1000 full load hours at 13.5 °C. This function represents a first estimation and has potential for improvement in future updates.

3.2.5 Heat extraction rate and annual thermal energy

For the calculation of power and energy resources for vCLS a Python program ‘BHEseppy’ (Borehole Heat Exchangers for Spatial Energy Planning with pygfunction) was developed, which is based on the theory of the finite line source and on the basis of the g-functions (Eskilson, 1987). The g-function can be determined fast with analytical calculations using the Python plugin "pygfunction” (Cimmino, 2018) and can be used free of charge. With the g-functions, it is also possible to consider heating, cooling and natural regeneration of the vCLS as simplified operating functions. Two modes of operation were set up. Within the mode “standard operating hours”, the operating function for the resource data sets were automatically determined from the default annual operating hours for heating and cooling for 20 years. Operating hours were also adapted for a storage mode (balanced use), where the system is used equally for heating and cooling.

After entering the geoscientific properties (thermal conductivity and subsurface temperature), the operating function (operating hours heating and cooling) and the geometry of the vCLS, BHEseppy calculates the specific heat extraction and based on this, the annual thermal energy and outputs it as a grid. The heat extraction rate is determined for a single probe with a length of 100 m and the output is watts per linear meter (W/m). For the energy quantities, two vCLS with an area requirement of 1156 m² each were selected. This corresponds to a field size of 4x4 (16 probes) at 10 m spacing or a field size of 7x7 (49 probes) at 5 m spacing. Kilowatt hours per square meter and year (kWh/m²/a) were chosen as the result unit for this. Consequently, this data set shows a site comparison of the annual energy amount of a 1156 m² field when it is operated with standard operating hours or when it is operated as a storage system with a balanced heating and cooling production. The mutual thermal influence of the probes within the field is included in the calculation, the influence of a neighboring vCLS is not. Nevertheless, this value serves well as an initial estimate, since the average fields are smaller in practice, but a neighboring influence is possible. This result is not valid for vCLS with a significant deviation from standard operating hours.

3.3 Resources for horizontal closed systems

Almost all producers offer their own specific hCLS, with a specific type of collector. Hence, there is a huge bandwidth on non-standardized collectors on the market. The German standard VDI 4640-2 (Verein Deutscher Ingenieure, 2019) contains at least five most common types. Due to their different geometries a general area specific heat extraction rate of the systems impossible. For this study, the FAU has adapted the heat extraction rates provided by the VDI 4640-2 for German climate zones to the Austrian pilot areas. The annual thermal content was derived from the heat extraction rate and the standard operating hours. Figure 4 shows all input data used for the calculation and the resulting output data sets.

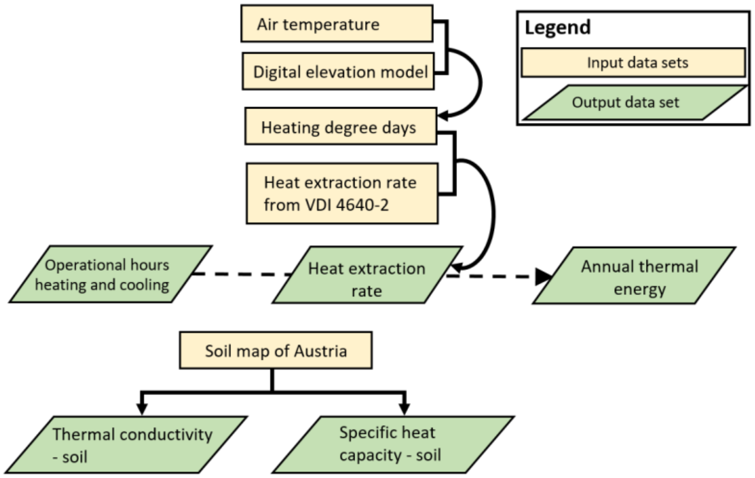

Figure 4: Flowchart of the resource estimation for hCLS applied in the GEL-SEP project.

3.3.1 Thermal conductivity and specific heat capacity - soil

Thermal conductivity and specific heat capacity of the soil were derived from different models for a depth of 1 – 2 m (Schwarz et al., 2022). Soil type (grain-size category), humus content, water content and dry-density were the input data to the models for thermal conductivity and specific heat capacity (Kersten, 1949). The digital soil map of Austria (https://bodenkarte.at) provides this information with data gaps in built and forested areas. To close the data gaps, the resulting maps were interpolated as a last step.

3.3.3 Heat extraction rate and annual thermal energy

The German standard VDI 4640-2 (Verein Deutscher Ingenieure, 2019) provides heat extraction rates for different soil types (sand, loam, silt and sandy clay) and the heat extraction rates are given for the following five collector types:

- Horizontal collector (for PE-pipe 32 mm x 3.0 mm)
- Capillary mats (mat width: 1.5 m)
- Earth basket conic (Geometry 1.3 x 1.3 m)
- Earth basket cylindric (Geometry 2.0 x 0.5 m)
- Trench collector

The heat extraction rates of the VDI had been determined for 15 German climate zones. To transfer them, they had to be adapted to the Austrian climate. This was accomplished by firstly correlating the heating degree days, calculated according to the Austrian ÖNORM B 8110 (Austrian Standards International, 2019) for selected Austrian weather stations, with the elevation of the weather stations to get area-wide heating degree days. The heating degree days for weather stations in Germany were also calculated using the Austrian ÖNORM B 8110 and linked to the heat extraction rate provided in VDI. This correlation was then applied on the Austrian heating degree days to derive the heat extraction rates for the specific soil and collector types. The heat extraction rates could therefore be assigned to the Austrian soil map. To close gaps in the soil map, the resulting maps were interpolated as a last step.

For the calculation of annual thermal energy, the heat extraction rate was multiplied by the standard operating hours for heating (chapter 3.2.4). The VDI does not take an alternate heating and cooling mode into account.

3.4 Possible limitations

Sometimes, resources of SGE (technical potential) cannot be used, due to given restrictions. These could be conflicts with public interest (e.g. protection areas) or risks that might be harmful through the installation (e.g. swellable rocks) as well as to the use itself (e.g. corrosive groundwater). The first ones are often political, whereas the second group refers to geological information. Overall, there are a couple of parameters to be considered. To avoid flooding the web information system with many data sets, which might confuse the user, we introduced traffic light maps, based on the concept of GeoPLASMA-CE (Görz et al., 2017, 2019). A traffic light map includes all possible limitations of use for one SGE system. Three categories contain three degrees of suitability (green – SGE use is generally possible, yellow – additional information is necessary, pink – SGE use is generally not possible). We chose pink instead of red as highest category to ensure a good readability for people with red-green visual impairment. Where multiple limitations of use overlap each other, the traffic light map shows the one with the highest priority (pink over yellow over green). All other limitations should be presented in location specific queries as a report to include all information. The traffic light colours were determined in accordance with the authorities. There are slight differences of the categories and used input data, depending on the licensing procedures and geological settings of the federal states. The results were tailored to the situation in the federal states respectively. Political restrictions are subject to change over time, e.g. the number of installations that have to be considered in the planning process changes over time. Hence those data sets get out-dated quickly. To avoid having to manually update the limitation of use maps frequently, an automatic process was proposed. Data that is subject to change should be harvested automatically and the traffic light map should be compiled accordingly.

4. RESULTS

In general, the data situation in urban areas was very good and all planned output data sets were achieved using the described methods. However, not all output data sets aimed at for OLS could cover the entire area of suitable groundwater bodies, due to the inhomogeneous availability of input data. In non-urban areas, especially hydrogeological data (e.g. groundwater level and bottom of the groundwater body) were missing. This affected the resources for OLS and capacities and energy content could not be determined in some areas. A total of 90 output data sets were derived about resources for SGE use (Figure 5). The numbers of resource data sets for Salzburg and Styria are higher, due to the inclusion of hCLS in those federal states. For each of the SGE systems, one traffic light map was created to show all possible limitations in one map. The number of limitations considered is different in the pilot areas, because the frameworks for approval of a SGE license and the geological settings vary between the federal states.

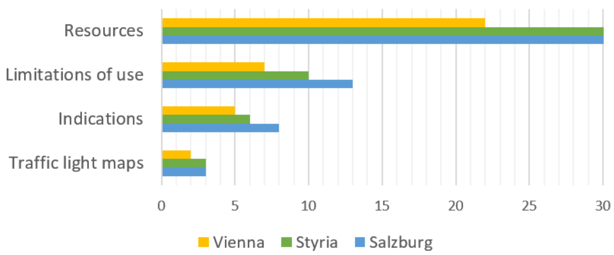

Figure 5: Histogram of output data sets in the pilot areas of GEL-SEP.

All ouput data sets shown in Table 2 were derived in the GEL-SEP project. They are all planned for publication on the web map viewer of the information systems including their tools described in the following chapter. The data sets of Vienna will also be published at the Thetys Research Data Repository (https://tethys.at).

Table 2: Output parameters of the GEL-SEP project and their corresponding input parameters.

A) OPEN LOOP SYSTEMS (OLS)

Output parameter	Input parameters	Unit	Description
Outline of GW bodies suitable for OLS	hydrogeological maps, location of existing wells and OLS	-	GW bodies that are suitable for the use of OLS
Depth to GW level	GW level at boreholes, GW level maps, digital elevation model	m	Depth to GW level from b.g.l
GW thickness	Depth to GW level, borehole profiles, GW bottom maps	m	Thickness of saturated zone
Hydraulic conductivity	kf-values of pumping tests, literature and numerical models	m/s	Estimated hydraulic conductivity
Mean GW temperature	time series of GW temperatures at boreholes	°C	Mean annual groundwater temperature of 2020
Minimum GW temperature	time series of GW temperatures at boreholes	°C	Minimal groundwater temperature of 2020
Maximum GW temperature	time series of GW temperatures at boreholes	°C	Maximal groundwater temperature of 2020
Maximum pumping rate	outline of GW bodies, hydraulic conductivitiy, GW thickness	l/s	Maximum yield at well doublets with 50 m distance
Thermal power	outline of GW bodies, hydraulic conductivitiy, GW thickness, GW temperatures	kW	Maximum thermal capacity at well doublets with 50 m distance
Specific annual thermal energy for OLS - Heating and cooling with standard operating hours	outline of GW bodies, hydraulic conductivitiy, GW thickness, depth to GW level, GW temperatures	kWh/m²/a	Specific energy content of the GW body for heating and cooling with standard operating hours

Specific annual thermal energy for OLS - Balanced mode of operation	outline of GW bodies, hydraulic conductivitiy, GW thickness, depth to GW level, GW temperatures	kWh/m²/a	Specific energy content of the GW body for equal heat extraction and injection

B) VERTICAL CLOSED LOOP SYSTEMS (vCLS)

Output parameter	Input parameters	Unit	Description
Standard operating hours - heating	Surface temperature	h/a	Annual operating hours for heating depending on surface temperature
Standard operating hours - cooling	Surface temperature	h/a	Annual operating hours for cooling depending on surface temperature
Thermal conductivity - underground	Thermal response test data, borehole profiles, geological maps	W/m/K	Mean conductive thermal conductivity from 0 - 100 m b.g.l.
Surface temperature	Temperatures from Metz et al. (2014), Measured air temperatures Vienna	°C	Mean annual surface temperature
Underground temperature	Surface temperature, Mean GW temperature, Underground temperature profiles	°C	Mean temperature for 0 - 100 m b.g.l.
Heat extraction rate - Heating and cooling with standard operating hours	Thermal conductivity - ground, Underground temperature, Surface temperature	W/m	Heat extraction rate of one 100 m deep vCLS depending on standard operating hours
Heat extraction rate - Balanced mode of operation	Thermal conductivity - ground, Underground temperature, Surface temperature	W/m	Heat extraction rate of one 100 m deep vCLS, for equal heat extraction and injection
Specific annual thermal energy for vCLS - Heating and cooling with standard operating hours	Thermal conductivity - ground, Underground temperature, Surface temperature	kWh/m²/a	Energy content of a vCLS with 4 x 4 boreholes 100 m deep and 10 m apart
Specific annual thermal energy for vCLS - Balanced mode of operation	Thermal conductivity - ground, Underground temperature, Surface temperature	kWh/m²/a	Energy content of a vCLS with 7 x 7 boreholes 100 m deep and 5 m apart

C) HORIZONTAL CLOSED LOOP SYSTEMS (hCLS)

Output parameter	Input parameters	Unit	Description
Thermal conductivity - soil	ditigal soil map of Austria (bodenkarte.at)	W/m/K	Thermal conductivity of soil
Specific heat capacity - soil	ditigal soil map of Austria (bodenkarte.at)	MJ/m³/K	Specific heat capacity of soil
Heat extraction rate for geoenergy baskets 1 and 2, trench collector, horizontal collector, capillary tube mats	ditigal soil map of Austria (bodenkarte.at), German VDI 4640 Part 2	W/m²	Area-specific heat extraction rate for 5 hCLS with different geometries
Specific annual thermal energy for geoenergy baskets 1 and 2, trench collector, horizontal collector, capillary tube mats	Standard operating hours heating, heat extraction rate for hCLS	kWh/m²/a	Area-specific energy content for 5 hCLS with different geometries for standard operating hours of heating

5. TOOLS OF THE GEL-SEP HEAT-ATLAS

The GEL-SEP Heat-Atlas enables an initial assessment of the resources and possible limitations of use for SGE. This is intended to increase the visibility of SGE. A web information system presenting the output data sets of the project can in no way be a substitute for detailed planning. There is no guarantee for the correctness of the information in all functions and no liability is assumed. This has to be made clear in the form of disclaimers in the GEL-SEP Heat-Atlas.

Based on the findings of stakeholder workshops and the experience of previous projects, three tools for the presentation of the results in the GEL-SEP Heat-Atlas were conceptualized. The tools (see Table 3) provide information at different scale levels and are tailored to their respective target groups. All tools access the output datasets mentioned in chapter 4.

Table 3: Short description of the tools designed for the GEL-SEP Heat-Atlas.

Tool	Content	Goal and stakeholders
TOOL 1	**Web map viewer** with overview maps about resources and limitations of use	**Initial assessment and regional site comparison** For: Planers and investors
TOOL 2	**Location specific query** as PDF. Values of TOOL 1 at the selected property with additional specific calculations depending on the size of the property.	**Preliminary dimensioning of a system for a selected property** For: Planers, investors and house builders
TOOL 3	**Regional query** as PDF. Information about the suitability to use SGE in the selected area, its overall resources and cover of demand.	**Initial resource assessment of a city block or district** For: Municipalities, regional development and planning

5.1. TOOL 1 – Web map viewer

In the web map viewer, traffic light maps and all resource data sets will be displayed. Since the traffic light maps comprise all limitations of use, we recommended to abstain from showing the limitation of use data sets additionally. Explanatory information about the data sets aside from legends should be provided for all maps. In case of the GEL-SEP Heat-Atlas, a short description of the parameter and the direct value at a selected location is planned. At the nation-wide Geothermal-Atlas, this will be achieved by a list that shows all parameters of a selected location.

For reasons of simplicity the Geothermal-Atlas will have separate viewers for the different geothermal energy systems. This turned out to be good option to limit the number of maps and values to be displayed and therefore to increase the usability. The individual selectable maps for each system will be further grouped according to the classes “geological basics” and “energy and power”.

5.2. TOOL 2 – Location specific query

Since numerous results are available at the property level, a summary report is purposeful. At the nationwide Geothermal-Atlas the report will be shown on screen and can be downloaded as PDF. The report provides all results for a selected property. The property selection is best made possible by mouse click and additionally by an address input. The report includes information from TOOL 1 as well as an initial estimate of available resources based on the size and needs of the property. From TOOL 1, all basic hydrogeologic/geologic data sets will be integrated, as well as the limitations (yellow and pink areas for the traffic light maps at the property).

For the location specific query, the contents of the data sets could be taken from midpoint of the property or by aggregating all information available. The following suggestions exist for how this can be implemented:

- Limitation: If there is a restriction, the percentage of the property affected by it is indicated.
- Resources: Calculation of the average value for the property and indication of the percentage of the property for which this statement is valid (important for groundwater heat exchangers, where there is no area-wide potential).

For the GEL-SEP Heat-Atlas it is planned to provide further information on the creation of the data sets in the report. Documents that provide an abridged version of the methodology could be linked. This is especially interesting for users already familiar with the topic SGE to gain additional insight.

5.3. TOOL 3 – Regional query

The regional query is solely intended as PDF report on municipality level as well as on city district level in the capital city Vienna. In contrast with the others, TOOL 3 provides comparable information, not only between the geothermal energy systems, but also to other renewable energy sources that are part of the GEL-SEP Heat-Atlas. Goal of TOOL 3 is to provide information about the suitability to use renewable resources in the municipality, its overall resources and the coverage of demand. All areas with a geological/hydrogeological potential excluding any pink areas from the traffic light map and areas restricted by infrastructural constraints (surface water, forest, built environment etc.) are as suitable. For those areas the totally available resources can be estimated. This is achieved by summarizing the specific annual energy content. The overall resources are compared to the demand in order to obtain the coverage of demand.

6. CONCLUSION

Based on the data sets available in the project, we could achieve a good quality of output data sets. However, in some areas quantitative estimates about the resources could not have been given due to a lack of input data. Data preparation was a time consuming process, because some raw data (e.g. borehole profiles) from analogue archives had to be digitized at first. The need for a good data basis is emphasized since clients are often not aware of the time-consuming process to create high quality hydrogeological and geoscientific data sets. This project was a first step to point out the importance of such data. High-resolution results in areas with high data densities can be a role model for other municipalities by showing all possibilities. This could increase the willingness to invest in new data collections, field measurements and to digitize archives. For each pilot area, we recommended specific tasks and measures to improve the data quality for further resource assessments. A large amount of data remains in archives of authorities and engineering companies. Retrieving this data would improve existing databases even without new measurements.

The pilot areas of the project covered rural as well as urban areas. We found that the most detailed input data was available for productive groundwater bodies in urban areas. In the cities of Salzburg, Vienna and Graz, we received necessary input data sets for all aimed outputs and they had a higher quality than the ones in the more rural areas. For areas with lower data density, estimates were made based on experience and literature, and some output parameters could not be calculated at all. Inevitably, this led to a certain spatial bias of prediction accuracy. Determining a qualitative or let alone quantitative classification of the data accuracy and finding a way to display it without complicating matters too much was not part of the project. This could be addressed in follow-up projects.

The resource analysis for the pilot areas showed that OLS can be used in most areas having a shallow groundwater body. Productive shallow groundwater bodies in the pilot areas are often connected to rivers and therefore located mainly in valleys. With many cities close to rivers, these areas have a naturally higher population density and therefore a higher heating and cooling demand. This is a favorable condition for the use of OLS, which could be applied more extensively. The use of vCLS is less restricted from a technological point of view. Only few parts of the pilot areas are covered by an unfavorable geology, such as zones susceptible to karstification or confined groundwater bodies. The majority of non-suitable areas is due to infrastructural or legal restrictions (e.g. protection areas).

It is essential to keep the data sets shown on the web information system up to date. A regular update for the resource maps elaborated with the presented method is generally not necessary as they only rely on geoscientific data, which do not change frequently. This is different for limitation of use maps. Besides geological information, they include political data sets, e.g. contaminated sites or protection areas, which underlie a more frequent change. In the GEL-SEP project, we proposed a method to harvest this data from their host organisations and integrate it into the Heat-Atlas automatically. Merging the updated individual input data sets to the traffic light map makes it easy to keep the data up to date. This approach has one inconvenience, it is more complicated as an automatized interface between the geothermal web information system and external data sources is required.

Resource data sets that do not take existing installations into account should be updated, if new hydrogeological or geoscientific data sets are available. Resource data sets that consider already existing installations would have to be updated regularly. The energy content and capacity maps produced in this project do explicitly not consider interactions and summation effects with possible existing nearby SGE installations. To take summation effects into account, reliable information on existing installations would be needed. Currently, licenced quantities for OLS are stored in public water registers in Austria. However, information on the actual amount of water used as well as the applied temperature shift between the production and the injection well is missing. In the case of vCLS, there are no separate registers on existing installations. Some federal states include them in the water registries. Therefore, existing installations may only be estimated with a significant effort and a high uncertainty.

Another important lesson learned from the project is that (1) finding a suitable method and applying it in the pilot areas to estimate resources, and (2) setting up a user-friendly web information system to show the results, are two completely different but equally time-consuming processes. Geothermal energy experts are undoubtedly important for the first task. However, they also should be involved within the design and set-up of the web information system. A close cooperation between geothermal energy experts, to bring in the content, and application developers, to present the content in a functional and user-friendly way, ensures a high benefit for the stakeholders. Even though when resource and limitation of use data sets should feed into an existing web information system, the necessary time to achieve this must not be underestimated.

What one might find missing in this concept of a geothermal web information system is a way to easily compare the suitability of different geothermal systems on the same location. This could be realized by decision-support tools to compare the geothermal systems. Such a tool could be developed by e.g. merging the traffic light maps for all geothermal systems as well as the outline of suitable groundwater bodies, as this information is the most compelling one for a comparative analyse and system selection.

REFERENCES

Eskilson, P. Thermal Analysis of Heat Extraction Boreholes. University of Lund (1987).

Fuchsluger, M.: Projekt WC-33 Potenzialkarte für die integrative Planung thermischer Grundwassernutzungen in Aspern Nord. Geologische Bundesanstalt (2016)

Görz, I., Heiermann, M., Götzl, G., Steiner, C., Ciapala, B., & Hofmann, K.: Evaluated guidelines on harmonized workflows and methods for urban and non-urban areas. Project GeoPLASMA-CE - Interreg CENTRAL EUROPE (2019).

Görz, I., Hofmann, K., Götzl, G., Riedel, P., Steiner, C., Černák, R., Fricovsky, B., Janza, M., Hajto, M., Ciapala, B., & Krentz, O.: Harmonized workflows for urban areas. Project GeoPLASMA-CE - Interreg CENTRAL EUROPE (2017).

Götzl, G., Pfleiderer, S., Fuchsluger, M., Bottig, M., & Lipiarski, P.: Endbericht Pilotstudie "Informationsinitiative Oberflächennahe Geothermie für das Land Salzburg" (IIOG-S) (2016).

Hölting, B.; Coldewey, W. G.: Angewandte Hydrogeologie. In Hydrogeologie. Springer Spektrum, 239-389 (2013).

Kersten, M. S.: Thermal properties of soils. University of Minnesota, Institute of Technology. Bulletin No. 28 (1949)

Kłonowski, M. R., Lipińska, O., Żeruń, M., Kocyła, J., Konieczyńska, M., Ryżyński, G., García-Gil, A., & Goetzl, G.: Deliverable 3.1 Report on the current legal framework, procedures and policies on SGE use in selected European cities (2020).

Metz, M., Rocchini, D., & Neteler, M.: Surface temperatures at the continental scale: Tracking changes with remote sensing at unprecedented detail. Remote Sensing, 6(5), 3822–3840. https://doi.org/10.3390/rs6053822 (2014).

Österreichischer Wasser- und Abfallwirtschaftsverband: ÖWAV-Regelblatt 207, Thermische Nutzung des Grundwassers und des Untergrunds - Heizen und Kühlen, 2. vollständig überarbeitete Auflage (2009).

Schwarz, H., Jocic, N., & Bertermann, D.: Development of a Calculation Concept for Mapping Specific Heat Extraction for Very Shallow Geothermal Systems. Sustainability (Switzerland), 14(7). https://doi.org/10.3390/su14074199 (2022).

Schweizerischer Ingenieur- und Architektenverein: SIA384/6 Erdwärmesonden. SIA Zurich (2021).

Steiner, C., Goetzl, G., Cypaite, V., Arno, G., Herms, I., Bishop, H., Šram, D., García-Gil, A., Erlstroem, M., Kłonowski, M., & Ditlefsen, C.: D 2.1 Catalogue of evaluated methods and guidelines on exploration, assessment and technical monitoring of shallow geothermal energy use in urban regions (2021).

Steiner, C., Götzl, G., Fuchsluger, M., Bottig, M., Nyeki, E., Turewicz, V., Schriebl, A., Brüstle, A., Hoyer, S., Bertermann, D., Schwarz, H., & Jocic, N.: Projekt GEL-SEP Salzburg "Informationssystem Oberflächennahe Geothermie für Salzburg" - Endbericht. (2021a).

Steiner, C., Götzl, G., Fuchsluger, M., Bottig, M., Nyeki, E., Turewicz, V., Schriebl, A., Brüstle, A., Hoyer, S., Bertermann, D., Schwarz, H., & Jocic, N.: Projekt GEL-SEP Steiermark - Graz "Informationssystem Oberflächennahe Geothermie für die Steiermark" - Endbericht (2021b).

Steiner, C., Götzl, G., Fuchsluger, M., Bottig, M., Nyeki, E., Turewicz, V., Schriebl, A., Brüstle, A., Hoyer, S., Bertermann, D., Schwarz, H., & Jocic, N.: Projekt GEL-SEP Steiermark "Informationssystem Oberflächennahe Geothermie für die Steiermark" – Endbericht (2021c).

Steiner, C., Turewicz, V., Götzl, G., Fuchsluger, M., Nyeki, E., Brüstle, A., & Hoyer, S.: Projekt GEL-SEP Wien: "Informationssystem Oberflächennahe Geothermie für Wien": Endbericht (2021).

Verein Deutscher Ingenieure.: Thermal use of the underground, Ground source heat pump systems VDI 4640 Part 2. www.vdi.de/richtlinien (2019).