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Strategies for Fostering the Use of Shallow Geothermal Energy for Heating and Cooling in Central Europe - Results from the Interreg Central Europe Project GeoPLASMA-CE

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ABSTRACT

GeoPLASMA-CE stands for Planning, Assessment and Management of Shallow Geothermal Energy in Central Europe. Shallow geothermal energy (SGE) use for heating, cooling and seasonal heat storage represents a key technology for enabling the transition to a low carbon society. However, this technology is still barely visible compared to other renewable energy sources. In Europe, the level of awareness by decision makers, the legal frameworks as well as the market maturities vary greatly. This also applies to the access to information on resources and limitations of shallow geothermal energy use. The Interreg Central Europe project GeoPLASMA-CE (2016 – 2019) pooled knowledge and access to information of geological survey organizations, universities, SMEs, non-profit organizations and public administrators from the central European countries: Austria, Germany, Poland, Czech Republic, Slovakia and Slovenia to provide products for fostering the use of shallow geothermal energy. The achieved outputs cover harmonized workflows for mapping subsurface resources and conflicts of use, joint quality standards for an efficient management of SGE installations, harmonized strategies to promote SGE based heating and cooling supply as well as a joint web platform (https://portal.geoplasma-ce.eu). The outputs of GeoPLASMA-CE were tested and demonstrated in six pilot areas, partly covering trans-boundary regions, by involving local stakeholders like authorities and communities. Based on the experiences achieved in GeoPLASMA-CE, we developed joint strategies for the central European area to support an efficient and sustainable use of shallow geothermal energy. A key element of the developed strategies is represented by a proposed management cycle for managing shallow geothermal installations. The management cycle consists of the following interlinked key cornerstones: information system – planning and licensing – installation – operation and monitoring. This approach requires a change of paradigm from individual to integrative management approach supported by a digitized and user-friendly licensing procedures. That also includes a continuous feedback from the user to the authority by means of operational- as well as environmental monitoring.

The findings of GeoPLASMA-CE in the six project regions were finally transferred to a joint position paper to promote the efficient and sustainable use of shallow geothermal in Europe for the period 2021 - 2030. We identified a target indicator level for heat supply based on ground source heat pumps in the range of 210 Twh by 2030 in the EU. This implies a strong increase of the current growth rate of around 6% per year to almost 18% per year. The additional investments to realize the enhanced share of shallow geothermal would in turn pay off by increasing the overall heating efficiency of 14% through electricity savings in the range of 14TWh/year.

1. INTRODUCTION

1.1 Scope

The Interreg Central Europe project GeoPLASMA-CE (www.geoplasma-ce.eu), funded by the European Union, addressed the use of shallow geothermal energy (SGE) in 6 Central European countries (Germany, Poland, Austria, Czech Republic, Slovakia and Slovenia. GeoPLASMA-CE covered the following technologies linked to SGE:

- *Closed loop systems* (CLS) also known as vertical borehole heat exchangers or borehole probes;
- *Open loop systems* (OLS) also known as groundwater heat pumps or thermal groundwater use.

GeoPLASMA-CE did not focus on any other technologies linked to SGE like horizontal collectors or underground thermal energy storage (UTES) except for energetically balanced use of OLS and CLS by alternating heating and cooling supply. Neither, GeoPLASMA-CE focused on engineered systems linked to the foundations of buildings (e.g. energy piles).

As indicated in Figure 1, a uniform definition of SGE use is still missing in Central Europe. In most countries, the maximum depth of SGE use is referring to the required application of the national mining Acts for licensing of the drilling. This depth level varies in the countries, which were participating in GeoPLASMA-CE between 100 meters and 400 meters. In contrast, Czech Republic and Slovakia do not have a specific depth level for a facilitated procedure.

In GeoPLASMA-CE, the term shallow geothermal energy use was defined in the following way:

- The use of the uppermost 400 meters of the subsurface or the maximum depth level at which the Mining Act goes into force for closed loop system;
- The use of the uppermost, mostly phreatic groundwater body;
- The use of the subsurface for heating supplied by heat pumps;
- The use of the subsurface for cooling (both free and forced cooling);
- The use of the subsurface for balanced energy use (heating and cooling).

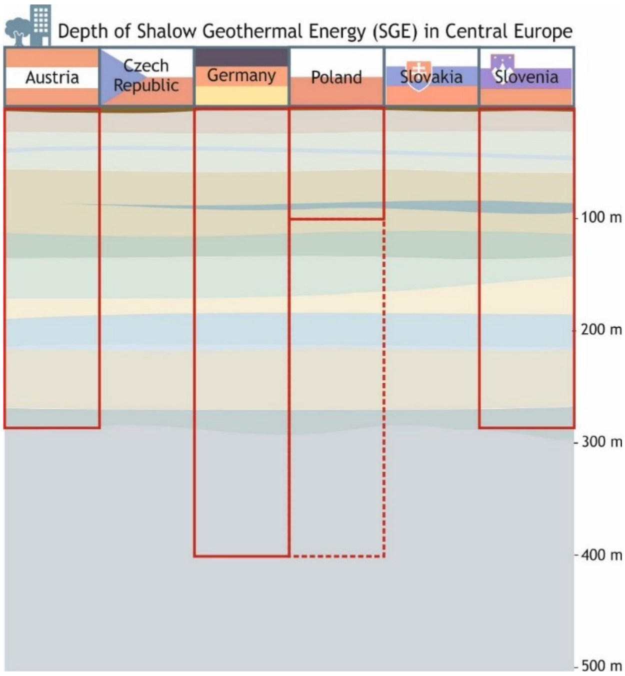

Figure 1: Depth related definition of shallow geothermal energy use in the countries participating in GeoPLASMA-CE.

This article presents the main outputs of GeoPLASMA-CE to support a sustainable and efficient growth of SGE use in Central Europe and intends to disseminate findings, which can be transferred to other regions in Europe and worldwide.

1.2 The current role of shallow geothermal energy in the renewable heating and cooling market in Europe

1.2.1 The renewable heating and cooling market in the European Union

Heating and cooling of building as well as for industrial processes consumed around 50% of the EU's total energy demand in 2017, whereas 79% was consumed for heating and producing hot water and 21% for cooling[1]. Inside the heating and cooling sector, the building sector requires more than half of the final energy demand in 2015 (q.v. Heat Road Map Europe project, Paardekooper et al 2018). In 2017, the average share of renewable energy sources in the heating & cooling market of the EU 28 is at a level of 19.5%[2], which almost meets the EU 2020 target value of 20%. Inside the GeoPLASMA-CE countries, the share of renewables in heating and cooling is above the EU 28 average in Slovenia (33.2%), Austria (32%) and Czech Republic (19,7%), whilst below in Poland (14,5%), Germany (13,4%) and Slovakia (9,8%).

In the EU, the renewable heating and cooling market is still dominated by bioenergy (solid biomass and biogas) covering 87% of the total energy production in 2016. Bioenergy is followed by different types of heat pumps (10%), which also include the use of SGE in terms of ground source heat pumps (European Environmental Agency, 2018). At an estimated share of ground source heat pumps within the heat pump stocks of around 20%, the total share of RES in the heating market is estimated around 2%[3]. In comparison, the

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[1] Source: European Commission (https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling, 24 July 2019).

[2] Source: Eurostat energy statistics 2017 (http://ec.europa.eu/eurostat/web/energy/data/shares, last updated 21 March 2019)

[3] Derived from the statistics of the European Heat Pump Association for the period until 2016 (http://www.stats.ehpa.org).

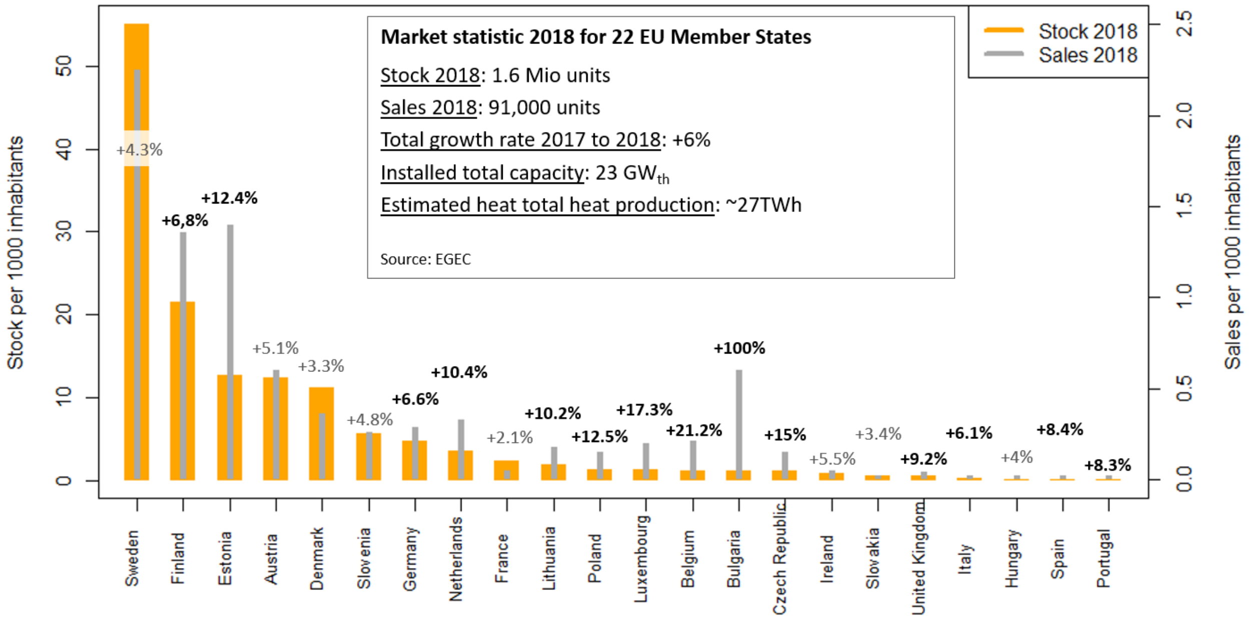
share of direct heating by deep geothermal energy was around 0.8% among the European renewable heating and cooling market in 2016 (European Environmental Agency, 2018). Shallow geothermal energy use still just covers a niche inside the renewable heating and cooling market. Moreover, the exact number of installed shallow geothermal systems in the EU is not exactly known due to the lack of comprehensive registers and as the direct uses without the support of heat pumps in terms of free cooling or free heating (e.g. de-icing) is not entirely covered by statistics.

1.2.2 The shallow geothermal market in Europe in 2018

According to the 2018 EGEC Market Report (Dumas et al 2019), around 1.9 million shallow geothermal systems were installed by the end of 2018 in Europe providing around 27 TWh for heating at installed capacities of around 23 GW_{th}. In average, around 4 shallow geothermal units are installed per 1,000 inhabitants of the EU. From 2017 to 2018, the shallow geothermal market grew around +6%, which is rather moderate compared to the growth of the overall heat pump market of +12% in the same year. The following market topologies can be observed based on the actual market number shown in Figure 2:

The Scandinavians and the Baltic region: Apart of Switzerland, which is not included in the statistic, Sweden is the major role model for a well-developed shallow geothermal market. When it comes to market diffusion, Sweden is the clear winner in the EU having 55 installed units per 1,000 inhabitants. It is followed by Finland, Estonia and Denmark, which seemed to have imported the idea of using shallow geothermal energy from neighboring Sweden in the past. When it comes to growth, the Scandinavian countries indicate effects of a saturating market. Just the Baltic countries Estonia and Lithuania still show growth rates above EU average.

The Benelux countries and the UK: These countries represent emerging markets with significant growth rate way above the EU average. However, apart from the Netherlands, all countries still have a very moderate level of diffusion.


Market statistic 2018 for 22 EU Member States

Stock 2018: 1.6 Mio units

Sales 2018: 91,000 units

Total growth rate 2017 to 2018: +6%

Installed total capacity: 23 GW_{th}

Estimated heat total heat production: ~27TWh

Source: EGEC

Figure 2: Shallow geothermal market 2018 for 22 EU Member States referring to stocks and sales per 1,000 inhabitants as well as to the growth rate (ratio of sales 2018 versus stocks 2017 in %). Derived from the EGEC 2018 Market Report (Dumas et al 2019).

The Southern countries: Due to the lower heating demand, shallow geothermal has not become established so far in Italy, Portugal and Spain. In these countries, applications of ground source heat pumps are reported but the actual situation is not properly recognized due to the lack of registers. However, the latest statistics indicate a growing market above EU average in all mentioned countries.

The GeoPLASMA-CE countries: Like the Scandinavians, shallow geothermal is a well-established technology in Austria and Germany, which is affected by saturation effects in the moment. The same applies to Slovenia having a much younger tradition in using shallow geothermal. In contrast, Poland and Czech Republic indicate emerging markets with strong growth rates. Slovakia represents the only country in the GeoPLASMA-CE region indicating an underdeveloped market so far.

1.2.3 Challenges and future opportunities for a further market diffusion of shallow geothermal in the EU

The transition of the European Union into a low carbon and low greenhouse gas society as well as mitigating climate change and its effects are the most important challenges of the next decade from 2021 to 2030. On the other hand, all Europeans should be able to participate at the process and should be able to benefit from the ambition of the EU in underlining its leading role of providing solutions for a future environmental- and climate friendly society and economy.

In 2019, the European Commission published the "Clean Energy for all Europeans" package, which indicated the strategic roadmap for the transition of the energy system in the EU from 2021 to 2030 (European Union, 2019). The Clean energy package set three main targets by 2030:

- At least 40% cuts in greenhouse gas emissions;

- At least 32% renewables in energy consumption;
- At least 32.5% energy efficiency.

Referring to the Clean Energy package, the revised version of the Renewable Energy Directive (RED II) entered into force in December 2018 (EU 2018/2001). It replaces the Renewable Energy Directive for the period 2011 to 2020 (RED 2009/28/EC) and may play a key role in paving the way forward for increasing shallow geothermal deployment in the next decade. Article 18 of the RED II demands the facilitation of access to information on renewables for actors in the field of energy and consumers. It also enforces harmonized qualification- and certification schemes for installers of renewable energy in the EU. Article 23 promotes the use of renewables in the heating and cooling sector by endeavoring an average increase of their share by 1.3% per year in each Member State. Moreover, it demands measures to raise the share of district heating and cooling grids (average growth of share by 1% per year in each Member State) and provides more flexibility and rights to costumers allowing to disconnect from non-efficient grids and to produce heating and cooling from renewable energy sources by themselves.

The Heat Roadmap Europe (HRE) project created a full decarbonization scenario of the heating and cooling market in 2050 for the 14 largest EU member states, which cover 90% of the overall heating and cooling demand (Paardekooper et al., 2018). The project concluded that a full decarbonization of the EU heating and cooling market can be achieved based on already existing technologies and market ready concepts. Neither will a further increase of the deployment of biomass be needed. The designed HRE 2050 scenario results in a decrease of the overall energy consumption of the heating and cooling market compared to the baseline of 2015 by 10%, a replacement of heat produced by fossil fuels at a level of 10,400 TWh as well as an increase of energy efficiency at both, the supply and demand side by 12%. In that context, HRE concluded that energy efficiency must be shared between consumers by renovation of building and heating and cooling installations (30%) and producers by applying efficient technologies (70%). The HRE 2050 scenario revealed total savings of CO_2 emissions at a level of 4,340 Mt_{oe} compared to 2015 and, in addition, a reduction of the overall costs of the heating and cooling supply in the EU by 67.4 billion Euros per year. The developed HRE 2050 scenario considers a raise of share of district heating and cooling grids from 12% in 2015 to at least 45% in 2050. Up to 50% of the remaining heating and cooling demand will be covered by individual heat pumps, which might be combined with solar thermal or biomass. Small- as well as large scale heat pumps will develop to a major technology as they are able to apply sector coupling to the electricity market and supply the use of excess heat from CHP based electricity production, industrial processes and cooling. This in turn leads to a share of needed investments into electricity- and thermal grids. To avoid high investments into electrical peak load supply and grids, the application of heat pumps requires high efficiencies, expressed by minimum coefficients of performance (COP) of 4 at large scale- and 3.5 at small scale units combined with heat storage facilities. According to the modelled HRE 2050 scenario, installed heat pump capacities (individual and district heating use) need to be increased from 7.26 GW_{th} to 311.02 GW_{th}, whereof 92% is considered for individual heating and cooling.

According to the HRE project cooling supply will increase in all analyzed 14 EU Member states by an average level of +138%, although it will not exceed the heating demand on a national level. The ratio between the cooling and heating demand will raise from 7.3% in 2015 to 24.4% in 2050. In countries with warmer climatic conditions, like Spain, the space and process cooling demand will balance the space heating and hot water production demand. The above outlined decarbonization models and strategies for the European Union for 2030 and 2050 offer promising opportunities for a significant increase of shallow geothermal energy use, such as:

- Providing efficient individual space heating by ground source heat pumps at high seasonal performance factors;
- Supporting low temperature heating and cooling grids by seasonal storage of waste- and excess heat;
- Supplying the future space cooling at a level of at least 438 TWh by 2050 (q.v. Paadekooper et al 2018) for recovery in the heating season and mitigating urban heat island effects by applying underground thermal energy storage.

The European heat pump market is steadily growing in the past years showing sales increase in 2018 of around 12%[3]. However, as indicated in Figure 3, ground source heat pumps could not participate in the market development in the period from 2006 to 2016 as it was the case for air-based heat pump systems. Whilst air-based heat pump systems almost doubled the amount of annually sold units, sales of ground source heat pumps went down by 17% in the same period. This leads to a significant loss of efficiency in the heating sector on a European level by additionally required electric energy. Switching the share of ground source- and air-based heating pumps between 2006 and 2016 would have let to capacity savings for peak load supply in the range of 800 MW_{el}, which corresponds to the saving of up to 2 medium size coal fired power plants without any loss or comfort on the demand side. Moreover, electricity consumption could have been lowered by around 1.4 TWh per year reducing the load of electrical grids.

This unfavorable market development is seen to be caused by primarily non-technological barriers, such as:

- High initial investment costs compared to other renewable heating technologies at a lower level of efficiency;
- Insufficient incentive schemes for supporting the use of ground source heat pumps;
- Non-financial barriers due to an unsuitable legal framework and complex licensing procedures;
- Low visibility and awareness by political decision makers of the technology;
- Lack of access to information and qualified services for consumers.

The most important technological barriers are given by availability of surface space for installing heat transfer systems, the availability of low temperature heating distribution systems (e.g. panel heating), by spatial- and legal restrictions (e.g. water- and environmental protection zones or sensitive geological zones) as well as by overexploitation of the available thermal resources. However, the impact of technological barriers on the market development is significantly lower than the impact of the above-mentioned non-technological barriers.

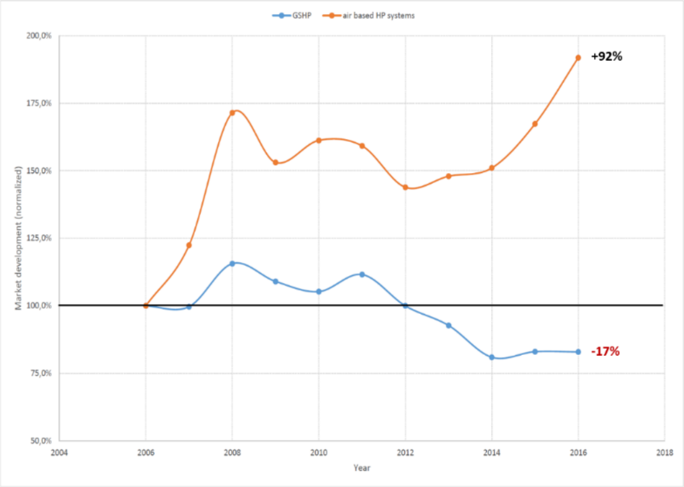


Figure 3: Normalized development of the European heat pump market referring to sold units between 2006 and 2016 with regard to ground source- (blue line) and air based heat pumps (orange line). Data source: statistics of the European Heat Pump Association (http://www.stats.ehpa.org).

As the next decade from 2021 to 2030 will be crucial to foster the inclusion of shallow geothermal energy into the decarbonization process of the heating and cooling market, measures need to be taken right now to overcome the current barriers and capitalize future opportunities. These include a re-design of the market by implying a shift of paradigm from pure heating or cooling supply to rather use the subsurface as a heat storage or the provision of sound information, qualified services and harmonized concepts for an efficient and sustainable use of shallow geothermal.

1.3 The project GeoPLASMA-CE

The EU Interreg Central Europe project GeoPLASMA-CE (2016 – 2019), funded by the European Regional Development Fund (ERDF), aimed at fostering the use of shallow geothermal energy in 6 Central European regions (pilot areas) at different infrastructural and socio-economic boundary conditions. The project covered 3 purely urban areas (Vienna – Austria, Krakow – Poland and Ljubljana – Slovenia), 2 transboundary rural areas (Vogtland / Germany - Western Bohemia / Czech Republic) and 1 combined urban and rural transboundary region (Bratislava / Slovakia – Hainburg-Kittsee / Austria). While Germany and Austria represent mature shallow geothermal markets, Poland, Slovenia and Czech Republic indicate emerging markets. In addition, Slovakia represents an underdeveloped market regarding shallow geothermal energy use.

The GeoPLASMA-CE team consisted of the Geological Survey Organization of all involved countries (national governmental organizations), the AGH University of Krakow (research institute), the German enterprises geoENERGIE Konzept GmbH and GiGa infosystems (SMEs), the German Geothermal Association (NGO) as well as the city administration of Ljubljana (local administration unit). Moreover, 18 local- to international stakeholders representing adapters and multipliers of the project outputs were involved as Associated Partners.

GeoPLASMA-CE addressed the main barriers as mentioned in chapter 1.2.3 by:

- Harmonizing methods for mapping and evaluating resources and limitations of use related to shallow geothermal;
- Demonstrating those methods in the above-mentioned 6 project regions;
- Facilitating access to information by creating state-of-the-art web-based services, which are provided to the addressed project regions;
- Harmonizing quality standards and management procedures for ensuring a secure, efficient and sustainable use of shallow geothermal;
- Comparing and evaluating the current legal framework in the participating regions towards the use of shallow geothermal energy;
- Developing strategies and measures to promote the use of shallow geothermal energy in the project region by involving regional stakeholders.

GeoPLASMA-CE applied a feedback-loop based approach with a strong involvement of stakeholders from the involved regions. At the beginning of most activities, stakeholder surveys were executed to include opinions and requirements outside the project team. Afterwards, concepts and preliminary outputs were created, which were either tested in the 6 project regions or reviewed by the involved stakeholders. The results of this feedback-loop were finally included to complete the outcomes.

GeoPLASMA-CE created the following main outputs:

- *Knowledge repositories* consisting of summary reports and methodological catalogues covering harmonized workflows, management concepts as well as the current legal framework. The joint reports is available at the project website (www.geoplasma-ce.eu) and the GeoPLASMA-CE web portal (see below).
- A *joint web portal* for supporting the knowledge transfer on shallow geothermal between the research sector and actors as well as users of shallow geothermal energy (https://portal.geoplasma-ce.eu/). The web portal furthermore offers state-of the-art spatial information systems for the 6 regions addressed in the project.

- *Regional strategies* for promoting and fostering the inclusion of shallow geothermal in heating and cooling for the regions addressed in the project.
- A *joint position paper* for transferring the key findings of the project to European stakeholders and other regions in Europe.

In the subsequent chapters, we outline the major results achieved referring to the major topics addressed in the project.

2. MAPPING RESOURCES AND LIMITATIONS OF USE

2.1 Overview

Knowing the spatial distribution of available resources and possible limitations like geoenvironmental risks and conflicts related to the use of shallow geothermal energy is a major precondition for developing management concepts and heating and/or cooling supply strategies. There are various qualitative and quantitative ways to describe the suitability of the subsurface to apply shallow geothermal. Unfortunately, resource and limitation of use mapping is still lacking uniform and standardized methods and approaches. In GeoPLASMA-CE, we tried to harmonize approaches used by the project team in previous studies and to fill gap still prevailing.

Based on a stakeholder survey in the beginning of the project we identified relevant parameters describing resources and limitations of use and established a preliminary methodological catalogue. Linked to this catalogue, we set-up a glossary for harmonizing the technical language used in GeoPLASMA-CE. We afterwards tested the preliminary methodological catalogue in the regions addressed by the project and finally created a revised methodological catalogue, which is published at our web portal (Goerz et al 2019). The catalogue also includes specific guidelines how to create GIS based data layers, which afterwards can be shown on web-based information systems. In GeoPLASMA-CE, the partners were free to decide for which parameter data layers will be produced and published on the web information system. The methodological catalogue also considered requirements and adapted approached for urban- and non-urban areas.

All mapping related to the regions addressed in GeoPLASMA-CE referred to geological- and lithological 3D models, which have been created in the framework of the project. The models were created using the software packages Gocad™ and Petrell™ and are displayed in terms of virtual borehole profiles in the project related web information systems.

2.2 Resource mapping

Resource mapping focused on vertical borehole heat exchangers (closed loop systems) and groundwater wells (open loop systems). As shown in Table 1, in total 8 parameters have been chosen to describe resources of which 3 are related to closed loop systems and 5 referring to open loop systems. The harmonized methodologies base on generalized analytical methods and require standard (hydro-) geological input data of the subsurface. We also tried to create output data, which can easily be adapted by planners and installers of shallow geothermal energy use as well as by non-geoscientific land-use or energy planners. However, it has to be pointed out that the resource maps do not intend to replace detailed planning and dimensioning of shallow geothermal installations.

Table 1: Overview of parameters used for describing resources related to shallow geothermal energy use.

Parameter	Category	Unit	Short explanation
Surface temperature	Closed loop systems	degC	Mean annual surface temperature derived from air temperatures measurements (SAT), satellite observation (LST) or soil temperature measurements in shallow depths (<5 meter below surface).
*Bulk thermal conductivity**	Closed loop systems	W/m/K	Average thermal conductivity for a specific depth interval (including the unsaturated zone) but does not account for non-conductive effects caused by groundwater flow.
*Subsurface temperature**	Closed loop systems	degC	Estimated average subsurface temperature for a defined depth interval of a closed-loop system. This parameter considers transient temperature signals caused by long-term changes of the surface temperature.
Groundwater bodies suitable for open loop systems	Open loop systems	none	Outline of shallow aquifers suitable for open- loop systems. The parameter considers a minimum hydraulic productivity required, a maximum overburden thickness and prioritization of uses (e.g. exclude aquifers reserved for drinking water supply).
Hydraulic productivity at peak load	Open loop systems	l/m²/d	Maximum yield available per surface unit and period to tun an open loop system. This parameter delimitates the maximum hydraulic capacity of a well.
*Thermal productivity***	Open loop systems	degC	Groundwater temperatures at a representative day indicating the warmest and coldest condition inside a specific aquifer. The thermal productivity represents the maximum temperature change possible between the production- and injection well and results from the difference between the groundwater temperature and a physical- or legal threshold temperature.
Specific thermal power at peak load	Open loop systems	W/m²	Maximum thermal capacity per surface unit consumed of a groundwater well doublet. This parameter results from the hydraulic productivity and a maximum temperature change possible between the production and injection well.

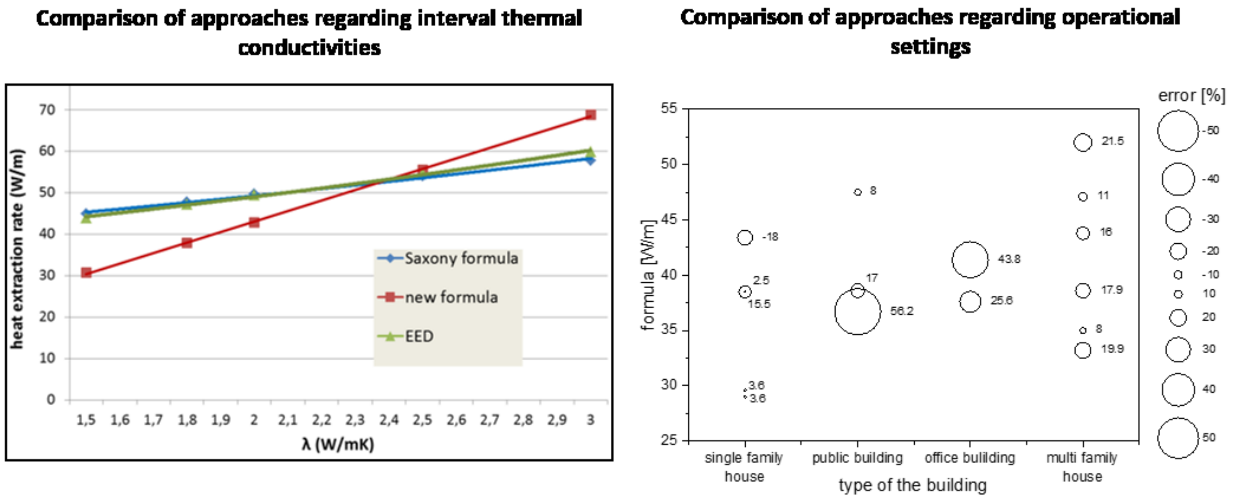
*Energy content***	Open loop systems	kWh/m²/a	The annual amount of thermal energy per surface unit consumed, which can be extracted or injected into an aquifer for heating and/or cooling.

* The parameter represents averaged values for defined depth intervals
**The parameter distinguishes between heating, cooling and an annually balanced use

2.2.1 Closed loop systems

Resource mapping for closed loop systems included the parameters *surface temperature*, interval *subsurface temperature* and interval *bulk thermal conductivities*. These parameters are needed to estimate the specific heat transfer rate of a borehole heat exchanger (W/m).

The heat transfer problem: Initially, we planned to create a workflow for estimating the heat transfer (extraction) rate, a parameter, which was demanded by many stakeholders in the GeoPLASMA-CE regions. The specific heat transfer delimitates the amount of heat transferred by a length unit of the borehole heat exchanger and time and describes the capacity of the system. We applied the infinite line source approach (Reuss 2015), which considers the ambient temperature of a subsurface interval and the duration of the heat transfer as well as the thermal conductivity of the surrounding rock. The major limitation of the infinite line source method is caused by assuming steady state conditions at the heat transfer. The infinite line source method was tested in the region Zwickau Altenburg in Germany by comparing it with (1) an empiric formula created by the Saxon State Office for Environment, Agriculture and Geology as well as with (2) the standard software EED (Hellström and Sanner 2000) for designing borehole heat exchangers. The benchmark test considered the variation of interval bulk thermal conductivities in the test region and different operational settings (single homes, multifamily homes as well as service buildings).



Comparison of approaches regarding interval thermal conductivities

Comparison of approaches regarding operational settings

Created by K. Hofmann (Saxony State Office) in the framework of GeoPLASMA-CE).

Created by K. Zschoke (geoENERGIE Konzept GmbH) in the framework of GeoPLASMA-CE).

Figure 4: Comparison of the infinite line source method with an empiric formula and the standard software EED for estimating the heat transfer rate of a borehole heat exchanger.

As shown in Figure 4, applying the infinite line source method led to lower heat transfer rates at interval thermal conductivities below 2.35 W/m/K and to an overestimation above the before mentioned threshold value. Referring to different operational settings (operational hours per year and total amount of heat transferred), the best fitting between the line source method and the software EED was observed for single family homes, which still represent the major user of ground source heat pumps. The largest differences of up to ±50% of the estimated heat transfer rates were observed for commerical buildings, which are affected by special operational settings, which might include of lower number of annual operational hours and different annual energy balances due to combined heating and cooling. The specific heat transfer rate does not solely depend on the subsurface conditions but also needs to account for operational setting and therefore represents a dynamic parameter. Giving an appropriate estimation of the heat transfer rate requires an interactive input of operational settings in web-based information systems. As such an interface would have exceeded the scope of GeoPLASMA-CE, the project team decided not to include the heat transfer rate in the resource mapping for closed loop systems.

Estimating the subsurface temperature: The effective interval subsurface temperature is a crucial parameter for estimating resources for borehole heat exchangers as it has the same sensitivity on the heat transfer as the interval bulk thermal conductivity. In theory, the subsurface temperature can be derived from the mean annual surface temperature, the seasonal zone of up to 20 meters below surface and the geothermal gradient reflecting the conductive heat flow regime. However, climate change, superposed by anthropogenically induced heating of the subsurface in densely settled areas lead to transient temperature signal, which influences the uppermost tens of meters of the subsurface. This so-called transient zone was observed in all regions addressed in GeoPLASMA-CE and showed thicknesses between 30 and 90 meters below surface.

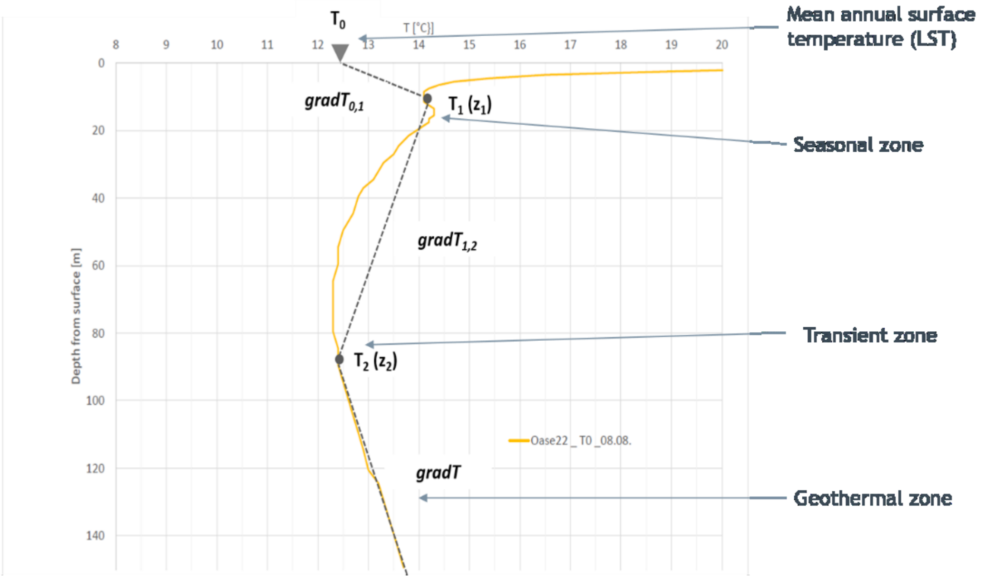


Figure 5: Linear approximation of a transient temperature signal (yellow line), which was recorded in the city of Vienna. The transient signal caused by long-term raise of the surface temperature by climate change superposed by urban heat island effects reaches depths of more than 80 meters below surface.

As shown in Figure 5, we approximate the transient zone by linear thermal gradients for estimating the resulting effective average subsurface temperature for a given depth interval. The mean annual surface temperature was derived from satellite data (LST), which were calibrated by soil temperature observations. The depth levels of the base of the seasonal and transient zones as well as the expected temperatures at these levels were derived from borehole temperature logging, mostly done in the framework of Thermal Response Tests (TRT) or derived from numerical temperature models. The same procedure was applied to estimate the pure conductive geothermal gradients. In areas with a significant influence of groundwater (Ljubljana, Vienna), the annual groundwater temperature, either in terms of an averaged value over the whole vertical groundwater section or calculated for different groundwater depth levels, was used as an additional constraint for approximating the effective interval subsurface temperature.

The effective interval subsurface temperature (T_{mean}) results from weighted averaging of the intervals of the linear approximation:

$$T_{mean}(l) = T_0 + gradT_{0,1} \cdot \frac{z_1^2}{l} + gradT_{1,2} \cdot \frac{(z_2 - z_1)^2}{l} + gradT \quad \cdot \frac{(l - z_2)^2}{l} \tag{1}$$

T_0… Mean annual surface temperature (degC), z_1… depth of the seasonal zone's base (m), z_2… depth of the transient zone's base (m), l… depth interval of the estimated effective subsurface temperature (m), $gradT_{0...2}$… linear temperature gradient for the different intervals shown in Figure 5 (degC/m) and gradT… geothermal gradient (degC/100m).

The effective interval temperature was calculated for individual observation points and later scaled up to a raster covering the GeoPLASMA-CE project regions. The interval bulk thermal conductivity was estimated for the same depth intervals by weighted averaging of individual rock thermal conductivities linked to lithological subsurface models.

Conclusions: The resource maps created for closed loop systems primarily address installers and system designers. It was not possible in the framework of GeoPLASMA-CE to create resource maps referring to closed loop systems, which can directly be adapted by non-geoscientific experts like energy planners.

2.2.2 Open loop systems

In GeoPLASMA-CE, we created and tested workflows to produce resource delimitators, which can be directly used by energy planners not familiar with the geoscientific background of shallow geothermal energy use. For designing an open loop system, both, capacity at peak load and the amount of energy exchanged with a groundwater body in a defined period need to be known. As the thermal regime of shallow groundwater bodies might be anthropogenically influenced in urban areas, we separated between heating-, cooling and balanced alternating heating and cooling use of groundwater bodies.

Outlines of suitable aquifers: In a first step, shallow groundwater bodies suitable for the application of open loop systems were defined. Apart from the presence of groundwater at sufficiently high expected yields, we applied limitations of depth (criteria: uppermost aquifer) to identify suitable aquifers.

Thermal productivity: In a next step, groundwater temperature maps were created for a representative period of warm- and cold groundwater conditions. The maps refer to groundwater temperature observations for the period between 2009 and 2018 and were created either by interpolation of measured groundwater temperatures at specific points in time or by numerical models, which were calibrated by measured groundwater temperatures. In addition, data layers showing the mean annual groundwater temperatures were calculated for estimating the utilizable energy content (see below). The thermal productivity finally refers to the maximum possible temperature shift between the production- and the injection well, which is constrained by physical thresholds (minimum injection temperature >0 degC) but moreover by legal constraints by allowed maximum temperature shifts (e.g. 6 degC in Austria and Germany) and allowed maximum injection temperatures (e.g. 20 degC in Austria and Germany).

Hydraulic productivity: The hydraulic productivity represents the specific yield per surface area and time at peak load conditions. It is derived from the aquifer thickness, the hydraulic conductivity and a given maximum drawdown in the well, which was set to 1/3 of the net aquifer thickness at mean annual conditions. The developed workflows for calculating the hydraulic productivity may include both, unconfined- as well as confined aquifers by applying standard calculations schemes based on the Darcy flow (e.g. Sichardt 1928). The specific yield per surface unit finally accounts the estimated area in the aquifer hydraulically influenced by the thermal groundwater use regarding critical thresholds for the phreatic water levels in neighboring wells (e.g. 0.1 m in Austria).

1. *Specific capacity (thermal power) and utilizable specific energy content*: The specific capacity per surface unit consumed (W/m²) results from combining the hydraulic productivity with the thermal productivity based on the mean annual groundwater temperature and refers to the peak load of the open loop system. In turn, the specific energy content per surface unit consumed (kWh/m²/a) accounts for the annual amount energy exchanged between the aquifer and an open loop system. It differs between pure heating (referring to the temperature distribution at coldest point of the year), pure cooling (warmest point of the year) and thermally balanced use (mean annual groundwater temperature). The energy results from the storage capacity of the aquifer, the heat exchange to its surface and basis and the temperature difference to thresholds for minimum and maximum injection temperatures. It does not account for the heat transferred into a specific volume unit by advection due to groundwater flow. Moreover, we also considered a heat recovery factor, which was derived from numerical benchmark models and was set to 0.75. The specific utilizable energy content by time (unit kWh) refers to the expected operational time, which was set to 20 years for unbalanced use and 1 year for balanced use as the energy stored in the groundwater body will not be affected by the thermal use. **By applying an annually balanced operation setting, the amount of heat exchanged between a groundwater body and an open loop system can be enhanced up to 4 times**.

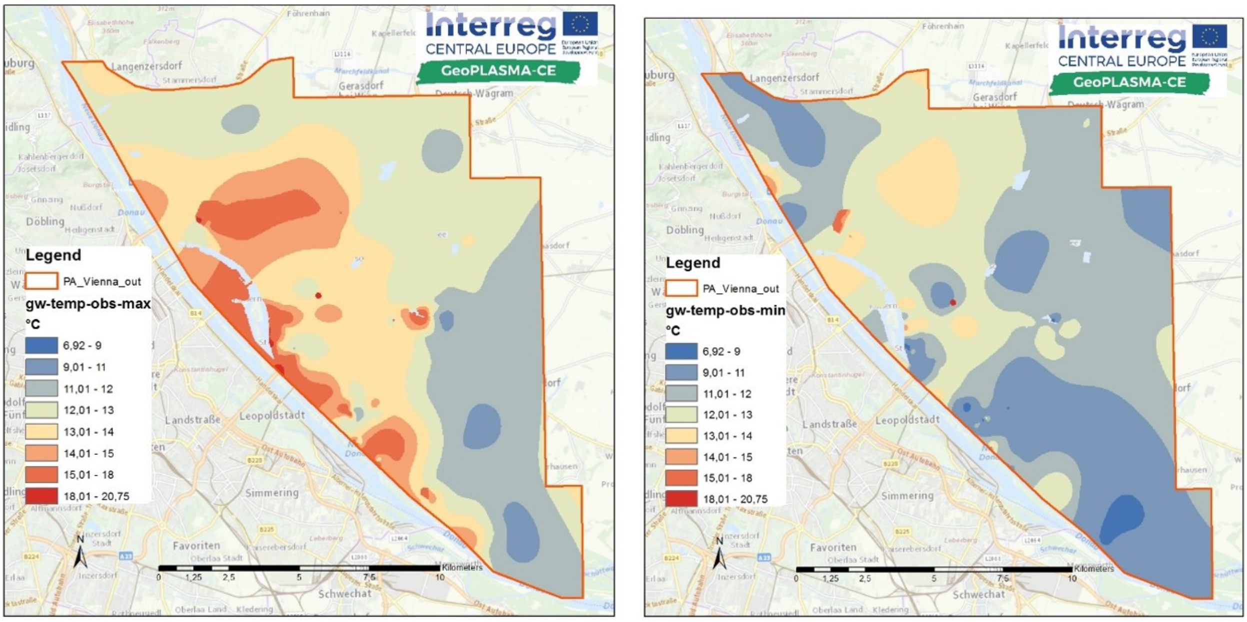


Figure 6: Temperature maps of the uppermost groundwater body below the city of Vienna (Austria) indicating the warmest point- (left) and the coldest point of the season (right). The maps clearly show the impact of urban heat island effects, which raise the groundwater temperature up to 9 degC compared to the natural conditions during the warms season. The excess heat content in the groundwater body was estimated for more than 1,000 GWh/year, which could be used for heating purposes.

Conclusion: The resource maps produced for open loop systems can directly be adapted by both, system designers and energy planners. However, they refer to observations of the thermal- and hydraulic groundwater conditions and do not directly account for capacities consumed by existing open loop systems.

2.3 Mapping limitations of use

2.3.1 Overview

The application of shallow geothermal systems might be limited by legal- and technical constraints, which refer to a prioritization of land-use and technical or environmental risks. Maps showing the limitation of use are primarily political maps referring to legal constraints. Technical constraints rather indicate zones, which require higher quality standards in the planning and installation process of shallow geothermal systems.

In GeoPLASMA-CE, we identified together with stakeholders from the project regions 15 parameters describing possible limitations of shallow geothermal energy use. The project partners were free to select those parameters from a catalogue, shown in

Table 2, which they found relevant for showing at the web-based information systems in their related region.

Table 2: Overview of parameters identified as relevant for delimitating the use of shallow geothermal energy.

Parameter	Short description		Parameter	Short description
Flood risk*	Location of regions which might be flooded seasonally.		Contaminated areas and earthworks*	Abandoned dumps and groundwater contaminated by anthropogenic influences might lead to restrictions in use to prevent the mobilization of contaminants.
Karst areas and caves*	Karst areas may cover vulnerable aquifer systems (high hydraulic conductivity) and may cause technical problems during the drilling process (mud loss).		Tectonics/ faults*	Zone, where rocks have been broken and displaced, may cause technical problems while drilling or problems at cementation jobs for closed loop systems.
Mining areas*	Hollow spaces in the subsurface, which may cause problems with grouting material for closed loop systems. Drilling may be prohibited in such areas.		Landslides*	Ground movement occurring if a slope changes from a stable to an unstable condition. They may cause damage to shallow geothermal applications.
Natural protection areas**	Protected area of importance for wildlife, flora or fauna, or features of geological interest, which are indicated for conservation. Shallow geothermal energy might be limited in natural reserves, such as landscape protection areas, Natura 2000 protection areas due to prohibition of drillings.		Areas restricted for drilling**	Areas with legal limitations to drillings by limitations of drilling depths related to possible technical conflicts or prioritization of use for other purposes (e.g. nuclear waste disposals).
Water protection areas**	Geothermal installations might be limited in water protection areas, which prevent groundwater used for drinking water supply from negative influences.		Shallow geothermal energy systems**	Location of existing geothermal uses, which may lead to negative neighboring influences.
Natural gas emission*	Near surface gas zones, which may cause blow outs during drilling and leads to risk of explosions (methane), intoxication and erosion of the subsurface around the drilling.		Confined or artesian groundwater*	Confined groundwater bodies showing over pressured hydraulic conditions. Drilling might be legally restricted or require high quality standards to prevent hydraulic shortcuts to other groundwater bodies or prevent artesian water flow at the drilling head.
Underground infrastructure*	Existing underground infrastructure (e.g. tunnels, buildings), which need to be avoided by drillings.		Hydraulically separated aquifers*	Interbedded aquifers divided by aquitard. Drilling into hydraulically separated aquifers may shortcut them and influence the hydraulic system (e.g. salinity increase of low mineralized aquifers).
			Problematic groundwater chemistry*	Outline of regions with problematic chemistry (e.g. low oxygen content). Due to the groundwater chemistry scaling of iron, manganese and carbonate in wells and metal corrosion of heat exchangers or wells casings is possible.

* Technical & geoenvironmental constraint

**Legal constraint

2.3.3 Creation of traffic light maps

The parameters listed in

Table 2 were combined to create so called traffic light maps (3 color scheme), which indicate the suitability of a certain location for installing shallow geothermal systems. The traffic light maps were created for closed- and open loop systems individually by applying a harmonized evaluation approach. In a first step, each partner evaluated the implication of a possible conflict by assigning the following scheme:

- Red (“Generally not possible”): The installation of shallow geothermal is not possible by legal limitations
- Yellow (“Additional information required”): Technical constraints are indicated, which requires further investigations and consultations with authorities

The combination of individual aspects to a single traffic light map followed a **precautional principle**, which means **a specific location was marked as a red- or yellow zone as soon as one single parameter was categorized as such**. If no possible limitation was evident the specific zone was marked as green (“Generally possible”). In addition, no data areas were evaluated as yellow zones.

In contrast to resource maps, traffic light maps, which are influenced by legal constraints may differ at political boundaries. As the legal framework may change with time, we recommend creating resource- and traffic light maps independently from each other.

2.4 Assessment of field data including benchmark tests

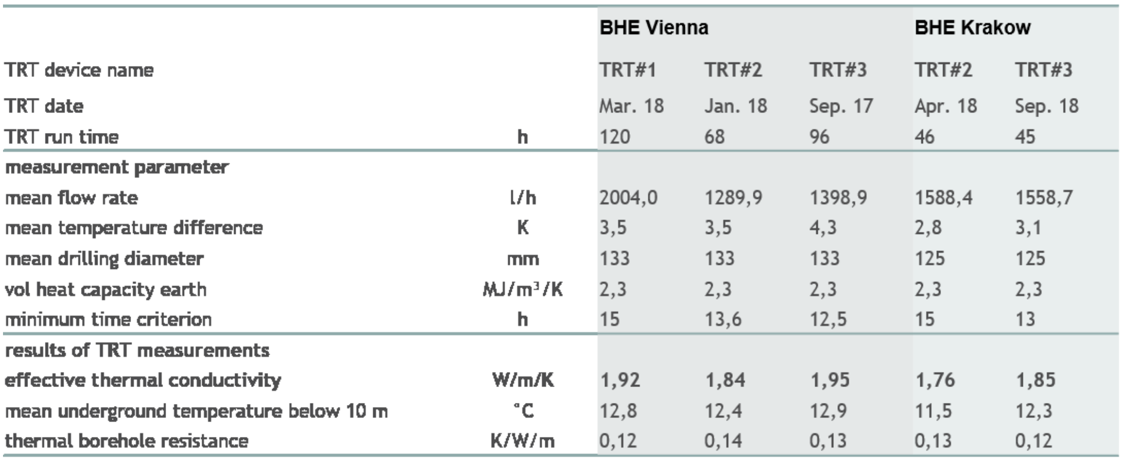
During GeoPLASMA-CE, more than 3,000 individual measurements for assessing the subsurface conditions have been achieved on the 6 project regions. The measurements aimed at calibrating the data models for resources and limitations of use. The field campaigns focused on assessing the following parameters:

- Thermal conductivity (TC) of unconsolidated- and consolidated rocks
- Effective interval thermal conductivities based on Thermal Response Test (TRT) measurements
- Subsurface temperature profiles gained by TRT measurements
- Groundwater temperature profiles by monitoring of observation wells
- Groundwater chemistry by sampling at observation wells and natural springs

The TC measurements at unconsolidated rocks were performed on outcrops like quarries and constructions sites and focused on estimating the influence of the near surface unsaturated zone above the uppermost groundwater body. The achieved results were used to calibrate models of the bulk thermal conductivity at specific rock units (closed loop resource mapping) and the specific energy content (open loop resource mapping). TRT measurements were applied to validate models of the interval thermal conductivity as they allow for estimating the “effective” interval thermal conductivity, which also accounts for non-conductive heat transport effects caused by groundwater flow.

GeoPLASMA-CE also included several TRT benchmark tests at 2 reference sites in Austria and Poland to compare 3 different rigs used in the project. On the one hand, TRT measurements represent the most important method for validating resource maps of closed loop systems. On the other hand, they might be affected by errors linked to the device itself (sensors and thermal insulation), the execution of the test (stability of the boundary conditions during the test) and to the method of processing the achieved results. As shown in the subsequent Table 3, the key parameters effective interval conductivity, average interval temperature and thermal resistivity may significantly vary at the same due to the errors mentioned above. Results from benchmark and comparative tests at well documented and monitored reference borehole heat exchangers (BHEs) are crucial for making individual TRT results comparable to each other. To do so, a network of reference BHEs across Europe is needed.

Table 3: Summary of the TRT benchmark tests performed at two reference sites during the project GeoPLASMA-CE.



		BHE Vienna			BHE Krakow	
TRT device name		TRT#1	TRT#2	TRT#3	TRT#2	TRT#3
TRT date		Mar. 18	Jan. 18	Sep. 17	Apr. 18	Sep. 18
TRT run time	h	120	68	96	46	45
measurement parameter						
mean flow rate	l/h	2004,0	1289,9	1398,9	1588,4	1558,7
mean temperature difference	K	3,5	3,5	4,3	2,8	3,1
mean drilling diameter	mm	133	133	133	125	125
vol heat capacity earth	MJ/m³/K	2,3	2,3	2,3	2,3	2,3
minimum time criterion	h	15	13,6	12,5	15	13
results of TRT measurements						
effective thermal conductivity	**W/m/K**	**1,92**	**1,84**	**1,95**	**1,76**	**1,85**
mean underground temperature below 10 m	°C	12,8	12,4	12,9	11,5	12,3
thermal borehole resistance	K/W/m	0,12	0,14	0,13	0,13	0,12

In GeoPLASMA-CE, we created a guideline on requirements on BHE reference sites and on how to perform TRT benchmark test based on the findings achieved in the project (Zschoke et al 2019). The report is available at the GeoPLASMA-CE web portal.

3. THE GEOPLASMA-CE WEB BASED INFORMATION AND DECISION SUPPORT SYSTEM

3.1 Overview

The GeoPLASMA-CE web portal (https://portal.geoplasma-ce.eu/) represents the major technical output of the project. It aims at creating a role model for facilitating the access to information related to shallow geothermal energy use and aims at interconnecting people interested in this technology in Central Europe. The use of the web portal is free of charge and a full documentation of the source code is available for adapting the portal in other regions. The web portal is available in 6 languages (English and all languages covered by GeoPLASMA-CE) and consists of the following main elements:

- A landing page providing general information on shallow geothermal energy use and on the project GeoPLASMA-CE
- A knowledge and interconnecting platform to facilitate the access to information
- 6 web services for the regions covered by the project to showing spatially distributed information on resources and limitations of use

The web portal was designed to allow an intuitive and interactive use. After registering, external users are allowed to contribute to the knowledge platform.

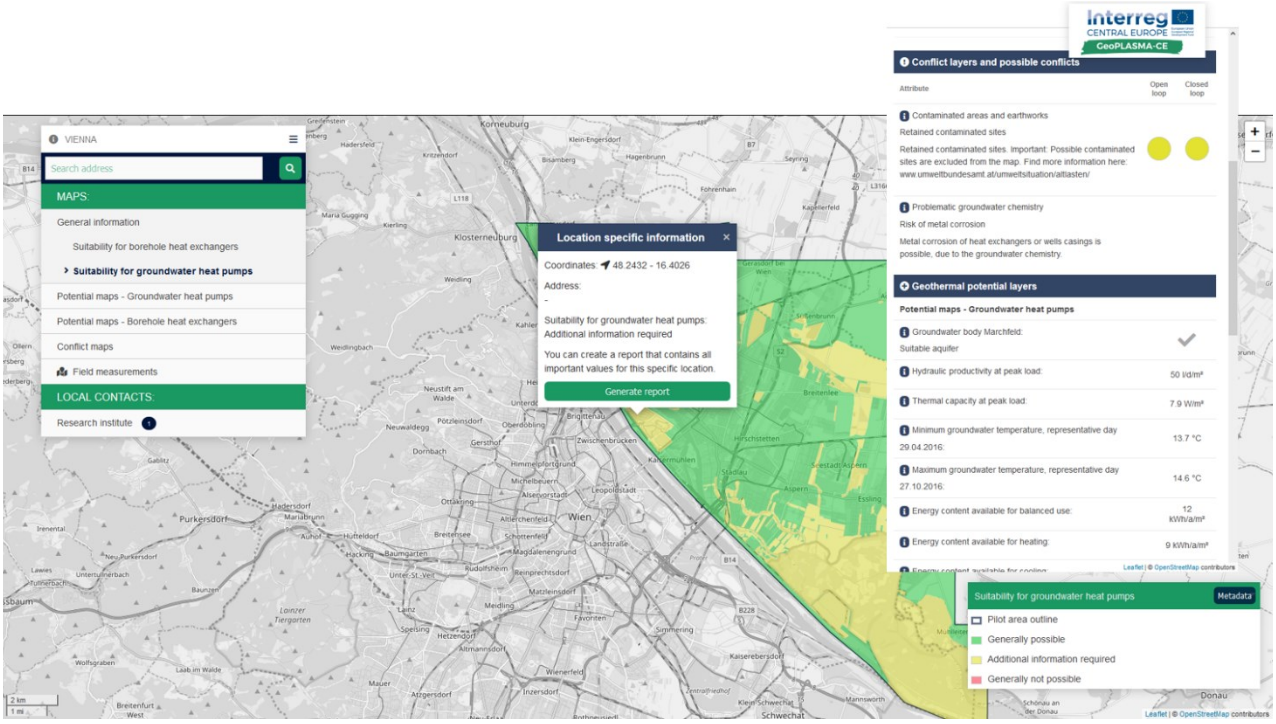
3.2 Landing page and knowledge platform

Apart of a general description of the technology and its advantages, the *landing page* covers all reports published in GeoPLASMA-CE, a joint glossary of technical terms linked to shallow geothermal and a section containing needful links to international policies, initiatives and research projects related to shallow geothermal energy use.

The multi-lingual *knowledge platform* contains 3 major services, which allow an interactive contribution by external users after prior registration. A yellow page application for registering services, a knowledge repository containing publications and an event calendar. The knowledge repository offers a filter search (keywords and language) as well as the opportunity to post English language summaries. However, due to copyright issues, external users are not allowed to upload articles directly on the web portal. Instead, they are offered to enter links to external web-based document storages. In the moment, the knowledge platform is maintained by the Geological Survey of Austria, which was coordinating the project. On the long term, we aim at merging the created communication infrastructure with similar services to enhance the impact of the GeoPLASMA-CE portal by becoming a relevant interface for shallow geothermal energy use in Central Europe.

3.3 The web-based information systems

In GeoPLASMA-CE, we aimed at creating a simple to use, intuitive web-based information system, which allows for creating location related data reports in PDF format in just 3 clicks. After entering the web information systems at one of the 6 project regions a window opens with explanatory notes on the selected region and how to use the system. After closing the message box, the traffic light maps are shown as a default layer. The legend shown at the left-hand side of the GUI allows navigating between the different web maps available for the specific region. Selecting a postal address or clicking on a location inside the map activates the data report. The data report shows the contents of all layers created including those, which are not visible at the map view. The data report can be exported in PDF format for external use. All data layers shown in the services are linked to a metadata description providing further information on the date of creation and the data maintainer as well as on further annotations linked to the shown dataset.



Location specific information

Coordinates: 48.2432 - 16.4026

Address:
-

Suitability for groundwater heat pumps:
Additional information required

You can create a report that contains all important values for this specific location.

Conflict layers and possible conflicts

Attribute	Open loop	Closed loop
Contaminated areas and earthworks Retained contaminated sites Retained contaminated sites. Important: Possible contaminated sites are excluded from the map. Find more information here: www.umweltbundesamt.at/umweltsituation/altlasten/	●	●
Problematic groundwater chemistry Risk of metal corrosion Metal corrosion of heat exchangers or wells casings is possible, due to the groundwater chemistry.		

Geothermal potential layers

Potential maps - Groundwater heat pumps

Groundwater body Marchfeld: Suitable aquifer	✓
Hydraulic productivity at peak load:	50 l/d/m²
Thermal capacity at peak load:	7.9 W/m²
Minimum groundwater temperature, representative day 29.04.2016:	13.7 °C
Maximum groundwater temperature, representative day 27.10.2016:	14.6 °C
Energy content available for balanced use:	12 kWh/a/m²
Energy content available for heating:	9 kWh/a/m²
Energy content available for cooling:	

Figure 7: Example for creating a location specific data report at the GeoPLASMA-CE web portal for the pilot area Vienna.

Apart from the data layers, the GeoPLASMA-CE web service also shows the location and metadata on the field data assessed during the project. Raw data as well as background documentation related to these field data can directly be downloaded from the web services for external use.

4. APPROACHES FOR ENSURING A SUSTAINABLE AND EFFICIENT USE OF SHALLOW GEOTHERMAL ENERGY

4.1 Analyses of the legal framework for the use of shallow geothermal

The legal framework and its linked procedures for licensing and operation of shallow geothermal energy use may on the one hand hinder or support investors decision and on the other hand may ensure a safe and sustainable utilization of the subsurface. In GeoPLASMA-CE, we evaluated the legal framework in the involved regions referring to the following criteria:

- Definition and ownership of shallow geothermal resources;
- Effectiveness of the legal framework (e.g. numbers of acts addressing shallow geothermal or degree of regulation);
- Effectiveness of licensing and commissioning procedures meeting the requirements of the Renewable Energy Directive RED 2009/28/EC.

The evaluation process based on regional stakeholder- and project partner surveys following a questionnaire developed in the EU Interreg Alpine Space project GRETA (Zosseder et al 2017).

4.1.2 Definition and ownership of shallow geothermal resources

As shown in Figure 1, a uniform definition and scoping of shallow geothermal energy is missing in the central European region. All countries except the Czech Republic and Slovakia align the term to the legal scope of mining acts. In contrast, the two mentioned countries lack of any legal constraints regarding maximum depths of utilization.

The heat stored in the subsurface for the use of shallow geothermal is not legally acknowledged in any of the regions involved in GeoPLASMA-CE. In Austria and Germany, ownership of shallow geothermal energy is associated to the ownership of any resources below a land property, which is not affected by public interest. This is valid for shallow geothermal energy including any water resources available at a land property. This in turn hinders the development of joint shallow geothermal utilizations consuming the heat stored in land properties owned by third parties, as these parties have the right to block the licensing procedure. In turn, the use of the subsurface and its resources does not belong to land property owners in the other GeoPLASMA-CE countries.

4.1.3 Effectiveness of the legal frameworks

The effectiveness of the legal framework is determined by a clear jurisdiction, which primarily includes the legal acknowledgment of the resource. In GeoPLASMA-CE, we screened the various acts influencing licensing and operating of shallow geothermal systems. The water act is the main legal instrument for regulating shallow geothermal energy in the 6 investigated central European regions. However, only the Austrian regions are just affected by the water act within the depth limit of shallow geothermal, while other regions, especially those in Poland, are influenced by up to 5 regulating acts during the licensing procedure. This leads to unnecessary long periods for licensing.

4.1.4 Effectiveness of the licensing procedures

The Renewable Energy Directive RED 2009/28/EC (RED) defined a clear set of measures to reduce administrative burdens for promoting the use of renewable energy. In GeoPLASMA-CE, we investigated to which extend these measures have been realized in the project regions (see also Table 4). Poland and Austria show the highest level of compliance with the requirements specified in the RED for facilitating the licensing procedures. In turn, the lowest level of compliance was observed in the Czech Republic and Slovakia, which indicates the lack of awareness and political support towards shallow geothermal energy use. We also observed that all countries clearly prioritize the protection of groundwater towards its use for shallow geothermal purposes, expressed by missing facilitated procedures for open loop systems. The measures required by RED, which are affected by the highest level of missed compliance cover automatic permission after missed deadlines for responses by the licensing authority and the facilitated procedures for small-scale units.

Table 4: Overview of the compliance to the measures defined by the RED in the GeoPLASMA-CE regions.

Closed loop systems *Open loop systems*	**One stop shop**	**Online application**	**Maximum time limit for procedures**	**Automatic permission after deadline**	**Facilitated procedures for small scale producers**
Austria	realized	realized	realized	realized	realized
	realized	realized	missed	missed	missed
Czech Republic	realized	missed	missed	missed	realized
	missed	missed	missed	missed	missed
Germany Vogtland, Saxony)	realized	realized	realized	missed	missed
	missed	realized	realized	missed	missed
Poland	realized	realized	realized	realized	realized
	missed	realized	realized	realized	missed
Slovakia	missed	missed	missed	missed	missed
	missed	missed	missed	missed	missed
Slovenia	missed	realized	realized	missed	realized
	missed	realized	realized	missed	missed

The evaluation of the legal framework revealed that the most favorable present conditions for shallow geothermal energy use are given in Austria. In contrast, the legal boundary conditions clearly need to be improved in Slovakia and the Czech Republic to promote the use of shallow geothermal. This mutually reflects and influences the level of diffusion of shallow geothermal in the respective heating and cooling market. While Austria is one of the leading countries of shallow geothermal use in the EU (rank #4 in 2018), Czech Republic (#15) and Slovakia (#17) clearly lack behind in the EU market statistics.

4.2 Joint quality standards and management approaches for ensuring a sustainable use

Deploying geothermal energy requires activities intruding into the subsurface. This means that geothermal energy installations, such as wells or borehole heat exchangers, become a part of the environment and thus a part of the subsurface infrastructure like underground pipes or cellars are. In addition, the use of thermal energy results in seasonal or permanent temperature changes in the subsurface. These changes can affect economic and social interests and must be considered while planning geothermal installations.

This especially applies to regions with a high density of already existing installations like urban areas. In many countries, the evaluation of permits follows a “first come first served” approach without considering benefits for society and the impact on the subsurface environment. However, **a shift of paradigm towards integrative management approaches** (see also Figure 8) may significantly improve the efficiency and sustainability of the subsurface use.

In GeoPLASMA-CE, we developed harmonized concepts for an integrative management approach on shallow geothermal resources, which were summarized in a catalogue of success criteria (Rupprecht et al 2019). This report is available at the GeoPLASMA-CE website. An integrative management approach may consider following principles:

- Preserve or restore good conditions in the subsurface and avoids negative influences of neighboring installations (sustainability);
- Use the available resources in an efficient manner by evaluating the resulting summation effects or giving priority to highly efficient use (e.g. common uses or alternating heating and cooling use);
- Enable interacting with operators by monitoring and simple electronic interfaces to ensure a continuous updating of contents.

Figure 8: The GeoPLASMA-CE process loop for an integrated approach for the management of shallow geothermal energy systems.

The integrative management approach focusses on the following corner stones of a management cycle providing joint minimum quality standard for each one: *Information system – Planning – Licensing – Installation – Operation – Monitoring*. A web-based information system is the central element acting as an active interface between authorities and investors as well as operators of shallow geothermal installations. Electronic licensing systems linked to electronic information systems could automatically retrieve data for the application procedure. In turn, commissioned installations provide new data by monitoring to keep the information system updated. In addition, the web-based information system may consider summation effects of neighboring uses and might act as a decision support tool for prioritizing shallow geothermal uses. Of course, such approaches are requiring additional costs for assessing and processing new data, received during the licensing procedure and by monitoring. These costs might need to be shared between the community (taxpayers) and investors to avoid additional investment barriers. This might be realized by fees for using the information system during the licensing procedure and by monitoring initiatives of installed systems. Monitoring addresses operational- (system efficiency) as well as environmental aspects (impact and summation effects) and should consider different requirements for small- (capacity $< 12\mathrm{kW_{th}}$) medium- (capacity $<50\ \mathrm{kW_{th}}$) and large-scale systems (capacity $>50\mathrm{kW_{th}}$). While the additional investments in monitoring for medium- and large scale installations are low compared to the overall investment and might be covered by the investor (normative measures), authorities or other public bodies should provide simple to install data loggers to operators of small scale systems (incentive measures).

In GeoPLASMA-CE, we also tried to provide a framework for joint quality standards of each element of the integrative management loop shown in Figure 8. We did not have the mandate to define unified thresholds or standards, but we created a general framework on recommendations how to generate and disseminate them on a regional or national level. In that context, we referred to existing guidelines and norms, which could act as a role model for regions without such standards. Finally, the catalogue of success criteria also includes recommendations how to improve the legal framework regarding the Renewable Energy Directive (RED).

5. JOINT STRATEGIES SUPPORTING THE INCLUSION OF SHALLOW GEOTHERMAL IN EUROPE

In the framework of GeoPLASMA-CE, we were developing strategies and related measures to promote the use of shallow geothermal in the targeted regions of the project. This has been achieved through a regional stakeholder process including joint SWOT analyses and several feedback loops. Moreover, we aimed at upscaling and transferring our key findings to a European level. For that reason, we created a joint position paper, which is disseminated through the GeoPLASMA-CE web portal (Goetzl et al 2019).

As discussed in chapter 1.2 of this article, shallow geothermal currently just covers a niche in the renewable heating and cooling sector but has the potential to become a key technology for efficient low temperature heating, cooling and seasonal heat storage.

Following the Heat Roadmap Europe scenario for the decarbonization of the heating and cooling market in 2050 (Paardekooper et al 2018) we derived the following target indicators for the inclusion of shallow geothermal in the European Union by 2030:

- Overall production of heat by heat pumps (air- and ground source) of 420 Twh;
- Raising the share of shallow geothermal in the EU heat pump market from around 21% in 2018 to at least 50% in 2013;
- Providing heat, partly recovered from geo-cooling or stored waste heat, in the range of at least 210 TWh (2018: 27 TWh).

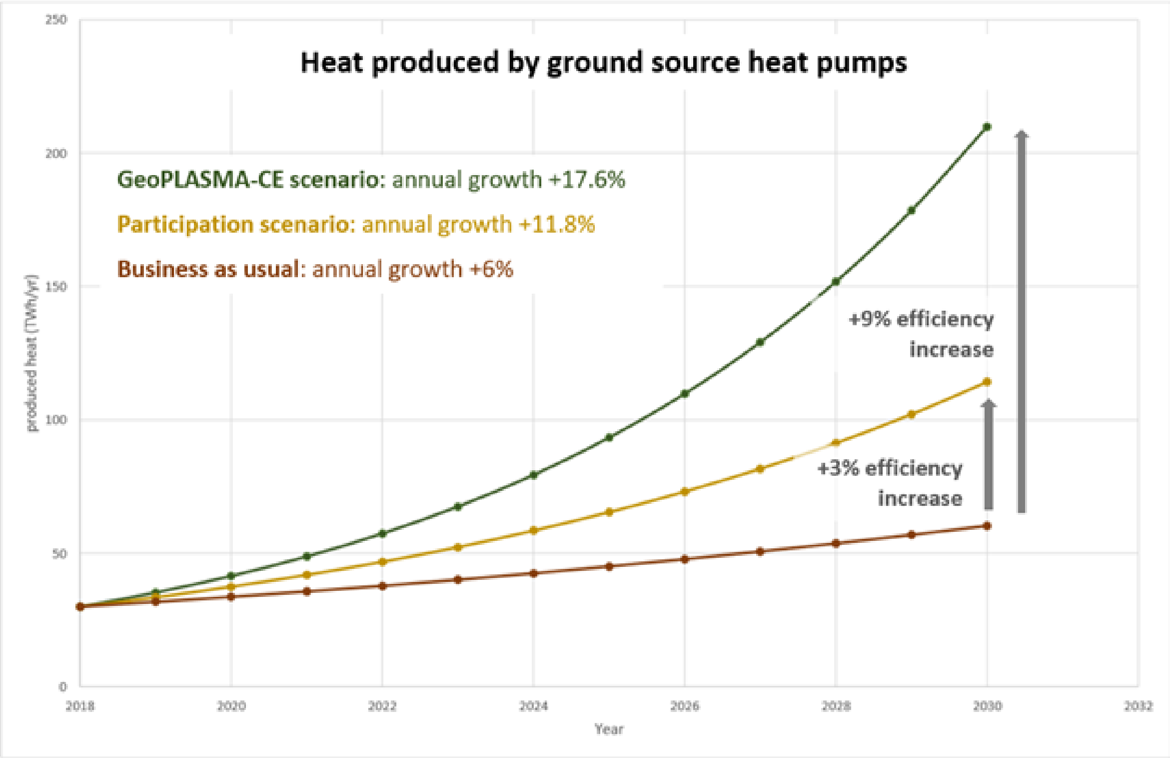


Figure 9: Development pathways for the market inclusion of shallow geothermal until 2030 based on three different scenarios (Mini- business as usual, Midi- participation at the overall heat pump market and Maxi- required to fulfill the defined 2030 target indicators).

We created three roadmap scenarios for the market diffusion: The (1) Business as usual scenario represents the business as usual case by extrapolation the current growth in heat production of 6%. The (2) GeoPLASMA-CE scenario would be needed to achieve the above-mentioned target values and implies a triplication of the current growth to around 18% per year in average. The (3) Participation scenario represents an annual growth of the overall heat pump market at around 12%. The development pathways and their implications regarding the share of shallow geothermal in the heat pump market and possible efficiency gains are shown in Figure 9.

The extrapolation of the current growth of the air source dominated heat pump market indicates an achievement of the overall target indicator of 420 TWh heat produced in 2030. However, the business as usual scenario will clearly miss the target indicator for shallow geothermal in 2030 by achieving a total heat production of only 60 TWh (29% of the target value). This scenario also eventuates in a further loss of share inside the heat pump market down to around 14%, which corresponds to a loss of the overall efficiency of the heating market. Following the participation scenario would already increase the efficiency of the heat pump market by 3%[4] corresponding to electricity savings in the range of 5 TWh/year. The GeoPLASMA-CE scenario would lead to a significant increase of 9% or electricity savings of 8 TWh/year compared to the business as usual scenario[4].

The defined targets are quite ambitious but might be achieved if the right measures would be set on both European as well as national levels. Based on our experiences in the 6 central European target regions, we identified 6 major barriers towards unlocking shallow geothermal resources. Note that these barriers are mainly of non-technological nature. The subsequent

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[4] Assumption: Average seasonal performance factors of 3.0 (air-based systems) and 4.0 (ground source systems).

Table 5 summarizes identified main barriers and proposed countermeasures related to a further market inclusion of shallow geothermal.

Table 5: Barriers and proposed countermeasures related to a further market diffusion of shallow geothermal in the European Union based on the findings of the GeoPLASMA-CE project.

Barrier	Proposed countermeasures
Lack of detailed market knowledge	• Amend statistics on heat pump sales by sound methods to consider replaced heat pumps at existing installations • Implement comprehensive registers on installed shallow geothermal systems linked to licensing procedures • Create statistics considering installed capacities, produced heat and account the share of cooling or storage of waste heat
Low public awareness and missing political support	• Implement interest groups with a clear focus on shallow geothermal • Promote and disseminate demonstrators and lighthouse projects • Implement effective information campaigns for the lay public
Insufficient access to information	• Implement web-based information systems and knowledge platforms • Ensure quick and easy access to information on licensing procedures and funding schemes
Inadequate legal framework and complex licensing procedures	• Realize the requirements of the Renewable Energy Directive (e.g. one-stop-shop or facilitated procedures for small scale units) • Provide E-government procedures linked to web information systems • Include shallow geothermal in spatial energy plans
High investment costs leading to social exclusiveness	• Reduce CAPEX costs through capacity independent low interest loans • Reduce OPEX costs by tax reduction for highly efficient heat pumps • Promote and facilitate collaborative use of shallow geothermal
Missing access to qualified services	• Support standardized qualification schemes and certificates for installers • Support all in one hand services (planning, installation and operation) • Promote business models for decentralized heating and cooling grids

The proposed measures require efforts of interest groups but do not require massive public investments compared to the socio-economic benefits of a highly efficient heat pump market.

6. CONCLUSIONS AND OUTLOOK

6.1 Conclusions

GeoPLASMA-CE could strongly benefit from pooling the experiences and views of the different professional groups (public bodies, academic research, SMEs and one NGO). In addition, involving regions with different boundary conditions and requirements on the use of shallow geothermal energy supported the transferability of key findings and outputs achieved to other European regions. As Interreg projects rather focus on policies and investments than on pure research GeoPLASMA-CE followed a strong user- and stakeholder-oriented approach, which included stakeholder interaction and feedback loop processes. We were able to set importing starting points in harmonizing the language and methodologies linked to the assessment of resources and limitations of shallow geothermal energy use. However, it turned out that there are still methodological approaches missing to provide sound resource indicators, especially for borehole heat exchangers, which directly can be adapted by energy planners (e.g. utilizable amount of energy to be transferred per year). We also recognized that shallow geothermal energy needs measures to be more visible at a European scale. This can be achieved by promoting well-serviced internet platforms offering knowledge exchange and interlinking opportunities. The current legal framework gives another major constraint to the future development of shallow geothermal energy use, which has not been entirely adapted to the requirements of the Renewable Energy Directive of the EU in the investigated regions. Using shallow geothermal energy has hardly been recognized as public interest in jurisdiction, which leads to inefficient and complex procedures (e.g. first come first served). These barriers need to be removed as quickly as possible, as the next decade from 2021 to 2030 will be crucial for the participation of shallow geothermal in the decarbonization process of the heating and cooling market in Europe. The target indicators for 2030, which were set in GeoPLASMA-CE, are rather ambitious but might be achieved if the political will is given. The additional investments needed compared to less efficient or clean energy sources easily pay off on a societal level with exergy savings.

6.2 Outlook

The GeoPLASMA-CE team identified more than 60 measures for fostering the use of shallow geothermal in the project regions. We aim at realizing these measures in collaboration with the involved local stakeholder in the upcoming years. Based on the concept of GeoPLASMA-CE, the EU funded H2020 GeoERA project "MUSE – Managing Urban Shallow Geothermal" (http://geoera.eu/projects/muse3/) started. The project focuses on resource- and limitation of use mapping linked to management concepts in urban areas and involves 14 cities in Europe.

Furthermore, we are aiming to enhance the impact of the created GeoPLASMA-CE web portal for becoming a knowledge exchange- and interlinking platform for shallow geothermal energy use in Central Europe. For that purpose, the web portal might be serviced by European interest groups having a clear interest on promoting shallow geothermal energy use in the future (e.g. EGEC, RHC-ETIP).

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