Framework for technical and legal assessment of thermal interference and optimised planning of open- and closed loop GHP systems

Deliverable D.3.1

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Abbreviations

ATES – Aquifer Thermal Energy Storage

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

BRL – Beoordelingsrichtlijn

BHE – Borehole heat exchanger

BTES – Borehole Thermal Energy Storage

CAPEX – Capital Expenditure

CLS – Closed loop systems

COP – Coefficient of performance

DIN – Deutschen Institut für Normung

DVGW – Deutsche Verein des Gas- und Wasserfaches

EGEC – European Geothermal Energy Council

GRETA – Geothermal Resources in the Territory of the Alpine Space

GHPs – Geothermal heat pumps

GSHPs – Ground source heat pumps

GWHPs – Groundwater heat pumps

IPCC – Intergovernmental Panel on Climate Change

MUSE – Managing Urban Shallow Geothermal Energy

OLS – Open loop systems

ÖWAV – Österreichische Wasser- und Abfallwirtschaftsverband

PORT PC – Polska Organizacja Rozwoju Technologii Pomp Ciepła

REN21 – Renewables 2021 Global Status Report

TAP – Thermal Aquifer Potential

VDI – Verein Deutscher Ingenieure

1. Introduction

- **Global, European, National, Regional and Local Energy Transition**

Climate change is one of the most urgent challenges of the 21st century. This phenomenon, primarily caused by greenhouse gas emissions, has led to an increase in global temperatures, alterations in climate patterns, and a rise in the frequency and intensity of extreme weather events, such as hurricanes, droughts, and floods (IPCC, 2021). To address climate change and achieve sustainable development worldwide, it is necessary to gradually transform the global energy matrix, shifting from one primarily based on fossil fuels (such as oil, coal, and natural gas) to one supported by renewable and sustainable energy sources (such as solar, wind, hydroelectric, and biomass). In other words, a global energy transition must be undertaken.

The global energy transition is driven by international agreements such as the Paris Agreement (2015), which aims to limit global warming to 1.5°C above pre-industrial levels. This agreement encourages countries to reduce their greenhouse gas emissions and increase the use of renewable energy sources (IPCC, 2021). In Europe, the European Union (EU) energy policy aims to reduce carbon emissions and increase energy efficiency by 2030, and to achieve climate neutrality by 2050 (European Commission, 2020). European countries develop their own unique energy transition strategies based on its geographic characteristics, natural resources and economic needs (World Bank, 2020). Many cities and regions have developed energy initiatives that promote sustainable and clean energy. For example, at the local and regional level there are community renewable energy projects, efficient public transport policies and energy efficiency programs in buildings. Specifically, in the field of geothermal energy, we can find initiatives such as the implementation of shallow geothermal heating networks for intensive agriculture and greenhouses (Geothermal Energy Heating Network – The Netherlands), as well as urban heating systems (Boise Geothermal District Heating System - USA; Cité Descartes Geothermal Project - France) and electricity production plants (Cerro Pabellón - Chile; Wayang Windu Geothermal Power Plant Expansion - Indonesia; Olkaria Geothermal Project - Kenya). These initiatives contribute to the reduction of carbon emissions and promote local resilience (REN21, 2020).

The European Union (EU) has implemented a series of measures to drive the energy transition towards a more sustainable and carbon-free economy. These measures include regulatory policies (European commission, 2019), financing initiatives (European Commission, 2021), and research and innovation programmes (European Commission, 2020). These measures reflect a comprehensive and coordinated EU commitment to address the challenge of climate change and promote an energy transition that is just, inclusive and sustainable.

EU policy support for the Geothermal sector

EU support for the geothermal sector is rooted in the European Green Deal (European commission, 2019). The draft national energy and climate plans submitted to the European Commission show that Member States have promising ideas for geothermal energy. The latest revision of the Renewable Energy Directive increases the overall target for the share of renewable energy sources (RES) by 2030 to 42,5% and set a binding target for an annual percentage point increase in the share of RES for heating and cooling. The revision ensures simpler permits for small and large heat pumps and includes a modified definition of efficient heating and cooling system with the aim of boosting renewable energy sources.
Geothermal energy also features in the Commission's proposal for a net zero industry law as one of eight strategic technologies. The announced heat pump action plan calls for at least 10 million additional hydronic (Both types: geothermal and air-source) heat pumps by 2027 and 30 million by 2030. The plan would encourage the use of small and large geothermal heat pumps (GHPs) in buildings, heating and cooling systems and in industry.

- ## Prospects for European use of GHPs

In recent decades, Shallow Geothermal Applications, specifically Geothermal Heat Pump (GHPs), have garnered increasing attention as a renewable alternative for space heating (Hein et al., 2016) and cooling (Boockmeyer and Bauer, 2016). In Europe, it is estimated that there are over 2 million installed GHPs, underscoring their growing importance in the region's energy landscape. This figure is part of a total of approximately 23 million heat pumps of all types (including air-source and other technologies) installed in the region by 2023 (European Heat Pump Association, 2023). In 2022, the European Union saw its highest sales volume of Geothermal Heat Pump Systems, with over 141,300 new systems installed (EGEC, 2023). This growth has been driven by increasing demands (Cooling and heating energy) for energy-efficient units in residential and commercial sectors, economic incentives, technological advancements, and supportive renewable energy policies (Schnabl, 2024). However, market dynamics vary across countries (GeoERA, 2020).

The European market for GSHPs is projected to experience substantial growth in the coming years. By 2030, this figure is expected to increase significantly due to several driving factors, including the need to enhance energy security, reduce dependence on imported energy sources, and meet greenhouse gas emission reduction targets to comply with international climate commitments (Global Market Insights Inc., 2023).

- ## Robust technical and legal framework for GHPs resource

Geothermal Heat Pump Systems are increasingly recognized for their efficiency and sustainability in heating and cooling applications. However, this constant increase has raised significant concerns regarding the technical sustainability, environmental impact, and long-term economic and social viability of this technology. Existing legal frameworks in European countries have varied regulations (Tsagarakis et al., 2020), and in most countries, legislative conditions do not provide a scientifically based solution (Haehnlein et al., 2010: Prestos et al., 2016; Rupprecht eta al., 2017), leading to scattered and inconsistent legal applications.

To fully harness the potential of GHPs, there is an urgent need for a robust technical and legal framework to facilitate the development and exploitation of geothermal resources sustainably; use geothermal resources in an environmentally friendly manner; and successfully manage shallow geothermal energy (Garcia-Gil et al., 2020). This means that the development of a technical and legal framework for geothermal resources and geothermal heat pumps systems must be approached from a comprehensive and holistic perspective to achieve these goals.

- ## Need for spatial planning of the thermal use of the underground

Two million geothermal heat pump systems have been installed in Europe, and this number is expected to increase over the next few years.

GHPs are often installed in high density, particularly in newly developed and redeveloped residential neighbourhoods, with only tens of meters or less of separation between neighbouring systems (Schelenz et al., 2017). The increasing utilization of Ground source heat pump systems, particularly in urban areas, requires integration into the urban spatial planning processes to optimise deployment and develop thermal land use strategies.

Spatial planning is a key component for the successful implementation of geothermal heat pump systems (Nielsen and Möller, 2013), as it ensures efficient and sustainable use of ground thermal resources, avoiding thermal interferences with other systems (Lund et al., 2021). Such a strategy also mitigates environmental impact (Garcia-Gil et al., 2020), avoids conflicts, with existing infrastructure (Abesser, 2021), improves safety (Banks, 2012), and supports regulatory compliance (Rybach, 2020). As the demand for renewable energy solutions grows, especially in GHPs, the importance of spatial planning for geothermal energy that facilitates the long-term viability and sustainability of this vital resource will continue to increase.

• Overview of deliverable 3.1 framework and objective of the report

The European Green Deal is the EU's main strategy to achieve climate neutrality by 2050. It includes a number of policies and actions. One of them is to reduce its greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels (European Commission, 2019). Accelerating the penetration of cost-effective and energy-efficient renewable heating and cooling technologies (RES HC) will be key to achieving such targets. This is the base of the GeoBOOST project. GeoBOOST seeks to unlock the market barriers for GHPs as the most energy efficient and cost-effective RES HC solution. The main objective of the project is to promote a wider use of the rapidly evolving geothermal heat pump technology. This is being done by addressing the following challenges: lack of awareness, high upfront CAPEX costs, lack of monitoring data and standards, insufficient business models and financing, expansion of the workforce and regulatory harmonisation. The latter is the objective of this work package (WP3).

The main focuses of WP3 are:

i) Analyses the current legal framework and associated procedures and measures to manage and promote the use of GHPs.

ii) Address instruments for energy planning as well as policies on incentive measures.

iii) Assess the current legal and policy framework in terms of shortcomings and good practices, which will provide the basis for proposing instruments, measures and actions to create a supportive framework.

This deliverable addresses the focal aspects of WP3 with the ambition to contribute to the development of a robust technical and legal framework for Geothermal Heat Pump Systems. The integration of planning tools will promote the sustainable management and use of GHPs, in order to support the development of geothermal as a renewable energy source to achieve the renewable energy targets within the EU.

Deliverable D3.1 focuses on the two main configurations; closed loop systems (vertical closed loop and horizontal loop), and open loop system.

The main objectives of the report are the following:

i) Define "thermal interference" and "thermal interaction" for Geothermal Heat Pump Systems.

ii) Identify the technical aspects to be considered in assessing "*thermal interference*" and "*thermal interaction,*" as well as the regulatory elements related to these phenomena in Geothermal Heat Pump Systems.

iii) Present, describe, and analyse the current status of regulation elements in the GeoBOOST partner countries, as well as the geothermal heat pump planning tools from Austria, Germany, and Sweden.

iv) Asses, through a SWOT analysis, the regulation elements that ensure an adequate framework to prevent thermal interference is achieved, optimizing the planning of open-loop and closed-loop systems.

v) Complete a SWOT analysis of existing planning tools covering technical, economic and strategic aspects.

2. Methodology

2.1. Determination of Thermal Interaction and Interferences

A narrative literature review (refer to table 1 definition) thermal interaction in Groundwater heat pump was carried out. The initial assessment highlighted that authors use the terms "*thermal interference*" and "*thermal interaction*" interchangeably to describe the same phenomenon, i.e. one or the other term is used to explain the same process (Annex 1).

In order to establish a definition of both terms, a second literature review - integrative review - was carried out (refer to table 1 definition).

The collected information was analysed to assign a meaning to each term and establish a common definition for both term throughout the GeoBOOST countries. Subsequently, workshops were held to exchange experiences among the project partner to draw guidelines for establishing the definitions of both terms. Finally, through the integrative review, the definitions of the terms *"thermal interaction"* and *"thermal interference"* are established (Section 3.1).

Table 1. Literature review approaches

Literature review approaches

Narrative Review

A narrative review describes existing information. It summarizes some of the existing evidence on relevant topics, offering an overview of the problem being addressed. A narrative review has undefined methods of searching, analysing, and synthesizing the literature (Murphy, 2012). This type of analysis can be useful for detecting various themes, theoretical perspectives, or common issues within a specific discipline or research methodology, or for identifying components of a theoretical concept (Ward, House, & Hamer, 2009).

Integrative Review

An integrative review typically aims to evaluate, critique, and synthesize the literature on a research topic in a way that allows new theoretical frameworks and perspectives to emerge (Torraco, 2005). An integrative review method should result in the advancement of knowledge and theoretical frameworks, rather than a simple overview or description of a research area. That is, it should not be descriptive or historical but should preferably generate a new framework or conceptual theory (Snyder, 2019).

2.2. Correlation between regulation elements and definitions

Establishing the definitions of the terms mentioned in the previous section leads to the identification of key parameters, i.e. technical parameters, when talking about *"thermal interference"* and *"thermal interaction"*.

In order to identify these parameters, the information collected (Annex 1) from the methodologies and recommendations proposed by the different authors for each Geothermal Heat Pump system is analysed.

Then the regulation elements related to the technical parameters (Section 3.2.1) of *thermal interaction* and *thermal interference* for both open and closed systems are identified in Questionnaire 1 of Task 3.3, as well as in the questionnaire used in the GRETA, Geo-PLASMA-CE and MUSE project (Annex 3).

2.3. Comparison of regulation elements

Using the comparative method (Table 2), a comparison of the legislative conditions of the regulation elements of the 7 GeoBOOST countries is made (Section 3.2.2). In addition to considering the information from the GeoBOOST countries, information from the countries that participated in the GRETA (6 countries), Geo-PLASMA-CE (6 countries), and MUSE projects (14 countries) is also incorporated.

Some countries have participated in more than one project. Therefore, the comparison is finally made between 16 European countries: Austria, Germany, Ireland, Spain, Estonia, Slovakia, Poland, the Netherlands, France, Italy, Switzerland, the Czech Republic, the United Kingdom, Croatia, Belgium and Denmark.

Table 2. Comparative Method

Comparative Method
This method involves looking at a subject of study in relation to another. The subject of study is usually compared across space and/or time. The comparative method is often applied when seeking patterns of similarities and differences, explaining continuity and change. Comparative methods can be qualitative and quantitative (Bolbakov et al., 2020)

2.4. Technical Assessment of regulation elements

Information gathered from research reports, case studies and scientific publications on GHPs is analysed to assess the impact of regulation elements from a technical point of view (3.2.1). The impact assessment of the regulation elements is done only for the parameters considered for thermal interference, as it is the main objective of this report.

The analysis focuses on:

i. Recognising the importance of defining boundary parameters for some regulation elements, which can benefit the installation and operation of a Geothermal Heat Pump System.

ii. Identify the impact of the regulation element on the operation of the GHPs.

iii. Evaluate the recommendations made by the different authors on the legal status for each regulation element.

2.5. SWOT analysis of regulation elements

A SWOT analysis (Table 3) was carried out only on the regulation elements of thermal interference, as this is the main focus of this report.

The SWOT analysis provides an initial qualitative overview. Then, to obtain a more complete, structured and accurate view of the regulation elements and their capabilities, a qualitative analysis is performed, through an Internal Factor Evaluation Matrix (IFEM) and an External Factor Evaluation Matrix (EFEM). This allows for a more detailed and structured assessment of the factors identified in the SWOT analysis, helping to prioritise and focus strategic efforts on legal and technical aspects.

This analysis is performed on the groups of regulatory elements:

- Distance
- Temperature
- Extraction and discharge,
- Size and layout of the Groundwater heat pump installation
- Subsurface conditions
- Seasonal performance of installation

Table 3. Quantitative and qualitative analysis methods

SWOT analysis It is a tool that can be used to identify specific strengths and weaknesses that impact an organization. The analysis facilitates decision making and helps to anticipate different situations, i.e. SWOT analysis provides a clear and structured view of the current situation to determine strategic decision making (Gurl, 2017). Although it was initially designed for the industry sector, it is increasingly being used in different areas (e.g. Harrison, 2016). SWOT analysis uses a two-by-two grid. Each quadrant provides an overview of the strengths, weaknesses, opportunities and threats of the subject (Sammut-Bonnici and Galea, 2015). ○ Strengths: Internal capabilities and resources that the organization manages well. ○ Weaknesses: Internal areas where the organization is less competent or has problems. ○ Opportunities: External factors that the organization can leverage to its advantage. ○ Threats: External factors that could cause problems or difficulties.
External Factors Evaluation (EFEM) It is a strategic analysis tool that helps an organization to identify, evaluate and weigh external factors that can affect its performance, seize opportunities and mitigate threats (David, 2011). The EFE Matrix analysis involves taking all the criteria for weaknesses and threats of a situation and then assigning factors and weights to them. This structured approach helps organizations systematically assess external influences and prioritize their strategic responses. ○ Steps in EFE Matrix Analysis

- Identify Key External Factors
- Assign Weights
- Rate the Factors
- Calculate the Weighted Score
- Sum the Weighted Scores

Internal Factor Evaluation (IFEM)

This is a strategic analysis tool that allows an organization to identify, evaluate and weigh the internal factors that affect its performance, providing a solid basis for the formulation of effective strategies and the development of sustainable competitive advantages (David, 2011).

The IFE Matrix provides a clear and quantitative means of evaluating an organization's internal environment. By systematically analysing and weighting these factors, organizations can develop more informed and effective strategic plans, leading to sustainable competitive advantages.

- Steps in IFE Matrix Analysis
- Identify Key External Factors
- Assign Weights
- Rate the Factors
- Calculate the Weighted Score
- Sum the Weighted Scores

Figure 1. The basic SWOT diagram

The results obtained are analysed and combined with those obtained from the assessment of the regulation elements' impact.

2.6. SWOT analysis of Good Practices

A SWOT analysis (Table 3) is performed on the planning tools from the following countries:

- Austria: *"ÖWAV Publications"*
- Germany: *"GeoKW app"*
- The Netherlands: "Interference Tool Closed Loop Ground Energy Systems"
- Sweden: "*Temperature reduction 3000 Programme*"

To obtain a more complete, structured, and accurate perspective of geothermal heat pump planning tools an Internal Factor Evaluation Matrix (IFEM) and an External Factor Evaluation Matrix (EFEM). The results of this analysis help prioritize and focus strategic efforts on the Geothermal heat pump planning tool.

3. Thermal Interference and interaction

In this section, the results obtained from the analyses described in the previous section are presented. The first two subsections consider the analysis of the terms "thermal interference" and "thermal interaction." However, based on the definitions obtained for both terms, the following sections will focus solely on presenting the results for the term "thermal interaction." This is because the definition established for this term in this work addresses the main objective of this report, which is to promote the management and use of geothermal heat pump systems while avoiding thermal interaction between systems.

3.1. Definitions

Clear definitions must be established when discussing the interaction and interference processes of the geothermal system in order to provide the essential data (key parameters) or the most important ones. These definitions help to distinguish the processes involved and to determine the limits of their extent from the content analysis. This ensures legal certainty and a clear regulatory framework (Pasquali and O'Neill, 2015), in this case a clear definition for GHPs regulatory framework.

The relevance of the definitions in the Regulatory Framework are:

- Performance optimization: it allows systems to be designed to maximise energy efficiency (Rezaie and Rosen, 2012) and to avoid thermal effect between geothermal heat pump systems（Witte and Van Gelder, 2006)

- Environmental protection: it minimises negative impacts on aquifers and geological stability, ensuring that heat extraction does not cause environmental imbalances（Banks, 2012）.

- Providing safety and reliability: it helps to establish monitoring and maintenance protocols that ensure the safe operation of GHPs in the long term（Lund et al., 2010).

- Planning: it avoids over-installation of systems in areas that cannot support thermal demand（Rybach and Sanner, 2000).

- Technological Development: it promotes research and development of new technologies that optimise thermal interaction and minimise thermal interference, improving efficiency and reducing long-term operating costs（Goldstein and Sanner, 2010）.

- Regulations and Standards: it promotes the incorporation of clear guidelines to avoid harmful interference. This will ensure equitable and sustainable use of geothermal resources.

In addition, defining the terms “thermal interaction” and “thermal inference” provides a common definition among GeoBOOST countries.

The literature analysis (in section 2.1) (Annex 1. List of articles), including reports and guidelines from previous projects (Annex 2. List of projects), allows definitions for the terms (Table 4).

Table 4. Definition of terms

Terms	Definition option
Thermal interaction	Refers to the thermal effect that occurs between wells within the same Shallow Geothermal System (Geothermal heat pump system), which affects the efficiency of the system. This effect arises due to prolonged interaction between wells or boreholes, for example in a: i) Closed system: Thermal effect between heat exchangers located in nearby boreholes, ii) Open system: Thermal effect of an injection well on the reinjection well.

Thermal interference	Refers to the thermal influence between two or more nearby Shallow Geothermal Systems (Geothermal Heat Pump System: open and closed loop systems) or between a shallow geothermal system and a nearby groundwater users (e.g. a drinking water well). This influence between systems can be allowed, as long as it does not exceed the thresholds/limits set by each country, maintaining the subsurface or system conditions, maintaining the efficiency of the system during its operating time ("long term ") without any negative effects or modifications to such conditions. If this thermal influence exceeds the established thresholds, it is referred to as *negative thermal interference.*

3.2. Regulation elements and thermal interaction - Thermal interferences

3.2.1. Technical Aspects and regulations elements

The establishment of definitions on i) "*thermal interaction*"; and ii) "*thermal interference*" (Table 4) guided the identification of technical aspects to be considered in the study as the essential data to be considered.

Evaluating *thermal interaction* and *interference* for open and closed-loop systems is essential to developing technical solutions that ensure the sustainable and optimal operation of individual geothermal systems, as well as the interactions between neighbouring ones. The technical solutions derived from these assessments can help to set technical limits within legislation and regulations. The technical parameters (Table 5 and 6 – right column) obtained from the analysis performed for the term *"thermal interference"* and "*thermal interaction"* are related to the regulation elements (Table 5 and 6 – left column) consulted in questionnaire 1 of Task 3.1, as well as in the questionnaire used in the GRETA project, Geo-PLASMA-CE, and MUSE (Annex 3. Questionnaires). These regulation elements were selected as critical to guaranteeing, from a legal point of view, the correct operation of Geothermal Heat Pump Systems.

Tables 5 and 6 list, group and present all the technical parameters recognised in the literature review (left-hand columns), which are used in the different methods proposed by the different authors. These technical parameters must be considered to avoid influences between systems that affect the efficiency, sustainability, environmental impact, design, costs and safety of the system. The research, conclusions and recommendations of the different authors highlight the essential need to consider a detailed analysis and proper management of these parameters for the success of geothermal projects.

Tables 5 and 6 show that some of the groups of regulation elements will be composed of only one element. An example of this can be found in Table 6, in the group of elements related to

subsurface conditions and **seasonal performance of the installation/thermal displacement**. This is because the regulation element encompasses all the technical parameters outlined in the same group corresponding to the technical parameters. It is also observed in some cases that technical parameters (table 6) are included within a regulation element of another group. For example, **flow rate of extraction well** and **limitation Volume of reinjection water** are included within the regulation element **pumping test report** and **register of Groundwater extraction.**

Table 5. Technical parameters and regulation elements for thermal interaction

Thermal Interaction – Technical parameters			
Technical parameters		**Regulation elements**	
OLS	**CLS**	**OLS**	**CLS**
1) Distance - Distance between reinjection and extraction well - Distance to the property line - Distance from next building	**1) Distance** - Distance between boreholes - Distance to the property line - Distance from next building	**1) Distance** - Distance between reinjection and extraction well - Distance to the property line - Distance from next building	**1) Distance** - Distance to the property line - Distance from next building
2)Temperature - Temperature difference between extracted and reinjected water ΔT [°C] - Outlet temperature [°C] of each pumping well - Absolute minimum temperature of reinjected groundwater Tmin [°C] - Absolute maximum temperature of reinjected groundwater Tmax [°C] - Undisturbed ambient temperature (groundwater or subsurface) [°C]	**2)Temperature** - Temperature difference between outlet and inlet pipe ΔT [°C] - Outlet temperature [°C] of each extraction pipe - Absolute minimum temperature of inlet heat carrier fluid Tmin [°C] - Absolute maximum temperature of inlet heat carrier fluid Tmax [°C] - Undisturbed ambient temperature (groundwater or subsurface) [°C]	**2)Temperature** -Temperature difference of the reinjected water -Absolute allowed Tmin of groundwater -Absolute allowed Tmax of groundwater -ΔT Between disturbed and ambient undisturbed temperature	**2)Temperature** -Absolute allowed Tmin of inlet pipe -Absolute allowed Tmax of inlet pipe -ΔT Between disturbed and ambient undisturbed temperature
3) Extraction and discharge -Flow rate of extraction well (l/s) -Flow rate of injection well (l/s) -Limitation Volume of reinjection water (l/s)	**3) Preventive technical measures** - Backfilling material (Cement / Mixture) - Type of refrigerant or heat carrier fluid - Flow rate of heat carrier fluid	**3) Extraction and discharge** -Limitation Volume of reinjection water -Reinjection for Groundwater heat pump	**3)Preventive technical measures** - Backfilling material (Cement / Mixture) - Type of refrigerant or heat carrier fluid
4) Seasonal performance of installation -Seasonal performance factor -Heat and cooling energy supplied from geothermal heat pump system - Number of heat pump - Rated power of heat pump	**4) Seasonal performance of installation** -Seasonal performance factor -Heat and cooling energy supplied from Ground source heat pump system - Number of heat pump - Rated power of heat pump	**4) Seasonal performance of installation** -Evidence/register of heat pumps -Evidence/register of Geothermal heat pump production	**4) Seasonal performance of installation** -Evidence/register of heat pumps -Evidence/register of geothermal heat pump production
5) Size and layout of geothermal heat pump installation - Number of extraction and injection wells - Length of the wells in the geothermal field (extraction and injection wells) - Distribution between wells in the geothermal field (extraction and injection wells)	**5) Size and layout of geothermal heat pump installation** - Number of boreholes - Length of the boreholes in the geothermal field - Distribution between boreholes in the geothermal field	**5) Size and layout of geothermal heat pump installation** -Borehole drilling report	**5) Size and layout of geothermal heat pump installation** -Borehole drilling report
6) Subsurface conditions - Groundwater flow velocity (hydraulic gradient) - Groundwater flow direction - Groundwater analysis - Aquifer thickness	**6) Subsurface conditions** - Thermal parameters of the soil (thermal conductivity and heat capacity) - Groundwater table and head (just in case), - Groundwater flow and direction (just in case) - Soil temperature (depth-dependent).	**6) Subsurface conditions** -Pumping test report -Evidence/register of groundwater abstraction	**6) Subsurface conditions** - Thermal response test report

Table 6. Technical parameters and regulation elements for thermal interference

Thermal Interference – Technical parameters			
Technical parameters		**Regulation elements**	
OLS	**CLS**	**OLS**	**CLS**
1) Distance - Distance to neighbouring plot (property line) - Distance from next building - Distance from drinking water well - Distance from other uses well - Distance from other public installations - Minimum distance to neighbouring Ground source heat pump installation - Minimum distance to neighbouring Groundwater heat pump installation - Distance between reinjections and extraction wells	**1) Distance** - Distance to neighbouring plot (property line) - Distance from next building - Distance from drinking water well - Distance from other uses well - Distance from other public installations - Minimum distance to neighbouring Ground source heat pump installation - Minimum distance to neighbouring Groundwater heat pump installation	**1) Distance** - Distance to neighbouring plot (property line) - Distance from next building - Distance from drinking water well - Distance from other uses well - Distance from other public installations - Minimum distance to neighbouring Ground source heat pump installation - Minimum distance to neighbouring Groundwater heat pump installation	**1) Distance** - Distance to neighbouring plot (property line) - Distance from next building - Distance from drinking water well - Distance from other uses well - Distance from other public installations - Minimum distance to neighbouring Ground source heat pump installation - Minimum distance to neighbouring Groundwater heat pump installation
2) Temperature - Maximum/minimum operation temperature restrictions in GWHP systems - Temperature change restrictions in exploitation regimes of GWHP systems - Undisturbed ambient temperature (groundwater or subsurface) [°C] - Absolute minimum temperature of reinjected groundwater Tmin [°C] - Absolute maximum temperature of reinjected groundwater Tmax [°C] - Outlet groundwater temperature [°C]	**2) Temperature** - Temperature difference between outlet and inlet pipe ΔT [°C] - Outlet temperature [°C] of each extraction pipe - Absolute minimum temperature of inlet heat carrier fluid Tmin [°C] - Absolute maximum temperature of inlet heat carrier fluid Tmax [°C] - Undisturbed ambient temperature (groundwater or subsurface) [°C]	**2) Temperature** -Temperature difference of the reinjected water (Groundwater heat pump) -Absolute allowed Tmin of groundwater -Absolute allowed Tmax of groundwater -ΔT Between disturbed and ambient undisturbed temperature	**2) Temperature** -Absolute allowed Tmin of inlet pipe -Absolute allowed Tmax of inlet pipe -ΔT Between disturbed and ambient undisturbed temperature
3) Extraction and discharge -Flow rate of extraction well -Flow rate of injection well -Limitation Volume of reinjection water -Difference in the discharge between extracted and reinjected water	**3) Flow rate of outlet and inlet pipes**	**3) Extraction and discharge** - Reinjection for Groundwater heat pump	**3) Flow rate of outlet and inlet pipes**
4) Seasonal performance of installation / Heat displacement - Heat and cooling energy supplied from Ground source heat pump system - Seasonal performance factor - Minimum COP eligible - Maximise COPs of GHP systems	**4) Seasonal performance of installation / Heat displacement** - Heat and cooling energy supplied from Ground source heat pump system - Seasonal performance factor - Minimum COP eligible - Maximise COPs of GHP systems - Seasonal space heating and cooling energy efficiency	**4) Seasonal performance of installation / Heat displacement** - Evidence of GHPs production	**4) Seasonal performance of installation / Heat displacement** - Evidence/register of GHPs production

- Seasonal space heating and cooling energy efficiency - Heat extraction rate - Rated power of heat pump - Number of heat pump **5) Size and layout of geothermal heat pump installation** - Number of wells in the geothermal field - Length of wells in the geothermal field - Correct emplacement or distribution of GHP systems **6) Subsurface conditions** - Groundwater flow velocity (hydraulic gradient) - Groundwater flow direction - Thermal properties of the subsurface (thermal conductivity and heat capacity - Groundwater analysis - Aquifer thickness - Groundwater level and head	- Heat extraction rate - Rated power of heat pump - Number of heat pump **5) Size and layout of geothermal heat pump installation** - Number of boreholes in the geothermal field - Length of Boreholes in the geothermal field - Correct emplacement or distribution of GHP systems **6) Subsurface conditions** - Thermal properties of the subsurface (thermal conductivity and heat capacity In case the boreholes are submerged in groundwater, should also be considered: - Groundwater level and head - Groundwater flow velocity (hydraulic gradient) - Groundwater flow direction	**5) Size and layout of geothermal heat pump installation** - Evidence/register of drilling data - Borehole drilling report **6) Subsurface conditions** - Evidence/register of geothermal data - Evidence/register of groundwater Extraction	**5) Size and layout of geothermal heat pump installation** - Evidence/register of drilling data - Borehole drilling report **6) Subsurface conditions** - Evidence/register of geothermal data - Evidence/register of heat exchanger

3.2.2. Status of regulation elements identified in the GeoBOOST countries

The comparison of the regulation elements allows to observe the regulatory status of each country, as well as to find a convergence and/or range of values of the legal conditions of each element.

Tables 8, 9, 10 and 11 provide an overview of the regulation situation in the GeoBOOST countries, as well as the countries participating in the GRETA, Geo-PLASMA-CE and MUSE projects. In the first column of the tables, the regulation elements are presented. In columns 2, 3, 4, and 5, the legal status of the regulatory elements in each country is shown. In the 6th column, a summary of the legislative conditions of the regulatory elements is described. Based on the information obtained about the legislative conditions, ranges of values and considerations for each regulatory element are provided in the last column of Table 7.

Main results:

Legal status

- The legal status and legislative conditions of regulatory elements vary across countries.
- In some countries, the legal status is "Obligatory" but there are no written regulations or known management practices for the elements.
- In some countries, the legal status is "not regulated" under specific regulations for GHPs. However, other existing regulations apply to the elements.

Legislative conditions

- It can be observed that in some countries, the legislative conditions of regulation elements related to temperature and distance can be established through an assessment. In other countries, a specific value is established.
- The legislative condition for elements in the extraction and reinjection group (*thermal interaction and interference*) does not have established values except in Ireland.
- The legislative condition for the limit groundwater extraction does not present established (e.g. analytical simulation) values by European countries.

Other

- Some parameters of elements within the groups: Seasonal performance of installation / Heat displacement, Size and layout of the geothermal heat pump installation, and Subsurface, are obligatory depending on the size and capacity of the installation.

Table 7a. Country participation in projects

Country	Austria	Czech Republic	Ireland	Germany	Poland	Spain	Sweden	The Netherland	Francia	Italy	Switzerland	Slovenia	Slovakia	United Kingdom	Croatia	Belgium	Denmark
GeoBOOST Project	x		x	x	x	x	x	x									
GRETA Project	x			x					x	x	x	x					
Geo-PLASMA-CE Project	x	x		x	x							x	x				
MUSE Project	x	x	x		x	x	x	x	x			x	x	x	x	x	x

Table 7.b Used Abbreviations

Country	Austria	Czech Republic	Ireland	Germany	Poland	Spain	Sweden	The Netherland	Francia	Italy	Switzerland	Slovenia	Slovakia	United Kingdom	Croatia	Belgium	Denmark
ISO 3166-1 Alpha2	AT	CZ	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	SK	UK	HR	BE	DK

Table 7.c Legend

Legal regulation	**Not allowed**	**Allowed**	**Not required**	**Obligatory**	**Not regulated**	**Recommended**	**No information**

Table 8. Regulation elements for OLS in thermal interaction

Regulation Element		GeoBOOST Partner Countries							GRETA Countries				GeoPLASMA-CE Countries		MUSE Countries				Summary	Value range
		AT	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	CZ	SK	UK	HR	BE	DK	~	
1) Distance	Distance between pumping and reinjection site																		8 countries do not have legal regulations for this element (Spain, Czeck republic, Ireland, Poland, Slovakia, Croatia, Italy, and Denmark). However, in Ireland, a decision on this element is made based on an evaluation by a competent hydrogeologist to define the specific site requirements. In Slovakia, the distance depends on the design and is authorized by the water authority. In Czeck republic, Reinjection of the water is not common practice. The water is mostly disposed into the nearest stream. In Sweden and Austria, the legal status of this element is a recommendation. In Sweden, it is decided by the institution Mark och miljödomstol, while in Austria, a simplified analytical estimate is required for small-scale systems and a numerical model for multiple large-scale wells or complex hydrogeological environments. In the rest of the countries, it is Obligatory. In some, a distance is established based on an environmental and hydrogeological assessment (Switzerland), while in others, specific values are set as Germany: **10m** distance and Slovenia: **25m distance, UK is 50m**	10-50m Assessment
	Minimum distance to neighbouring plot (property line)																		7 countries do not have legal regulations for this element (Spain, Czeck republic, Ireland, Slovakia, Croatia, the United Kingdom, and Denmark). In Slovakia, when the drilling is up to 30 m, a minimum distance of **2 m** must be respected, while for drillings over 30 m, the GSHE must not affect the temperature of the neighbouring property. In Czech Republic, according to the building act should not be closer than 2m. but it is prohibited to drill under the neighbouring property. In Austria, Sweden, Belgium, and Poland, the legal status of this element is a recommendation. In Sweden is **10 m**. In Poland, a distance of **5 m** is accepted. In the rest of the countries, it is obligatory. In some, a distance is established based on an environmental and hydrogeological assessment (France), while in others, a national value or ranges of values depending on the region are established; Slovenia: **0.5-4 m**; Switzerland: **2.5-3 m**; and Germany: **1.5-5 m,** Austria 2**,5m**	0.5-10m Assessment
	Distance to next building																		7 countries do not have legal regulations for this element (Spain, Czech Republic, Slovakia, Croatia, the United Kingdom, Ireland and Denmark). In Slovakia, it is decided by the authority. In Czech Republic, the distance is not defined, but it must not interact with the building**.** In Austria, Poland, and Italy, the legal status of this element is a recommendation. In Poland, a distance of **5 m** is accepted, while in Italy there is a range of **4.5-5 m**. In Austria, a distance of 1 **m** is accepted, and in Ireland, it depends on the amount of groundwater extracted and discharged. In the rest of the countries, it is obligatory. In some, a distance is established based on an environmental and hydrogeological assessment (France), while in others, a national value or ranges of values depending on the region are established (Slovenia); Germany: **1.5-3 m**, and Slovenia requires an agreement with the competent authority.	1.5-5m Assessment Decided by authority
2)Temperature	Temperature difference of the reinjected water																		6 countries do not have legal regulations for this element (Slovenia, Czech Republic, Slovakia, Croatia, the United Kingdom, and Denmark). In Slovakia, the temperature is regulated by water legislation, with a difference of **6°K**. In Czeck Republic, it is decided by hydrogeologic and water authorities, **6°c**. In Austria, Ireland, Poland, Spain and Sweden, the legal status of this element is a recommendation. In Sweden, it is decided by the institution Mark och miljödomstol, while in Austria, a maximum temperature of 6°C is indicated. In Poland, a range of **3-5 K** is suggested, and in Ireland, a thermal contamination assessment is required. For the rest of the countries, it is obligatory. In some, a temperature is established based on an environmental and hydrogeological assessment, while in others, specific values are set: Germany: **4-6 °K** (with a maximum groundwater temperature of 20°C); United Kingdom: **8°C** in England; Italy: **3-5 °K, in France 4° and Switzerland is 3°C**	3-8°C/K Assessment
	Absolute allowed Tmin of reinjected groundwater																		7 countries do not have legal regulations for this element (Ireland, Sweden, Slovenia, Czech Republic, Poland, Croatia, and Denmark). In Czeck Republic, it is decided by hydrogeologic and water authorities. In Belgium, Spain, Slovakia, the United Kingdom, Spain, and Germany, it is obligatory. In Slovakia is **4 °C**. In some countries, a temperature is established based on an environmental and hydrogeological assessment, while in others, a national value or ranges of values depending on the region are set Austria: **5°C**; Germany: **4-5°C**; Belgium, UK and Slovakia**: 4°C,**	4-5°C Assessment
	Absolute allowed Tmax of reinjected groundwater																		6 countries do not have legal regulations for this element (Sweden, Poland, Ireland, Slovenia, Czech Republic, and Croatia). In Czeck Republic, it is decided by hydrogeologic and water authorities, **max 20°c.** In Poland cannot exceed 35°C. In Denmark, Spain, Belgium, the United Kingdom, Slovakia, France, Spain, and Germany, it is obligatory. In some countries, a temperature is established based on an environmental and hydrogeological assessment, while in others, a national value or ranges of values depending on the region are set Austria: **20°C**; Germany: maximum groundwater temperature of **20°C**; France: **32°C**; Slovakia: **23-25°C**; Belgium: **25°C**; and Denmark: **20-25°C**. It is recommended to have a maximum temperature between **20-25°C**. In Austris it is recommended: 20°C	20-32°C Assessment
	Relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature.																		8 countries do not have legal regulations for this element (Spain, Croatia, Poland, Ireland, Slovakia, Czech Republic, Slovenia, and Sweden). In Czeck Republic, it is decided by hydrogeologic and water authorities, max **6°C.** In Poland the range is 3-5^K In Slovakia, the limit is **6°C**. In Belgium, the United Kingdom, Spain, and Germany, it is obligatory. In Belgium, Italy, and Austria, it is recommended. In Italy, the range is 3-5°C, and in Austria, it **is 6°C**. In Denmark, the United Kingdom, France, Spain, and Germany, it is obligatory. In some countries, a distance is established based on an environmental and hydrogeological assessment (Spain), while in others, a national value or ranges of values depending on the region are established: Germany: **4-5°C**, in the United Kingdom: **8°C. and France is 3°C.**	4-8°C Assessment
3) Extraction and discharge	Reinjection for GWHP (SGS-W)																		Only two countries do not regulate this element: Denmark and the Czech Republic. In Czech Republic, reinjection into the ground or into the river is decided by Water authorities. Discharges into the surface waters is preferred over the reinjection into the underground In Italy, Spain and Sweden reinjection is allowed. In Italy for only geothermal plants (allowed under agreement of the competent authority). In Sweden it is allowed by Mark och miljödomstolen. In Italy it is only allowed for geothermal plants. In all other countries it is obligatory (Belgium, Croatia, United Kingdom, Slovenia, Slovakia, Switzerland, Poland, Germany, Ireland and Austria). In Ireland it is obligatory when Discharges to surface water or groundwater when **greater than 5m3/day.** In Slovakia it is authorised by the competent authority. In Slovenia is If only heat is abstracted from abstracted water. In Switzerland is evaluated.	Greater than 5m3/day Groundwater abstraction limit Authority decision Assessment
	Limit of groundwater extraction																		In 5 countries an extraction limit is obligatory (Ireland, Germany, Sweden, Slovakia, and Spain). In Ireland it depends on the extraction limit. In Germany **only one third of the groundwater** body can be extracted. In Spain a hydrogeological assessment is made and in Sweden it is approved by the Mark och miljödomstolen. In Slovakia it is regulated, in small plants it is approved by the local authority and in plants with extraction above **15000 m3** annually or **1250 m3** monthly it is approved by the environmental authority. Three countries are not regulated: Austria, Czech Republic, and Poland. However, in these countries it may be allowed if an assessment is made.	Assessment Above 15000 m3 annually or 1250 m3 monthly
4) Seasonal performance of installation	Evidence/register of heat pumps																		In Denmark the status is recommended. In the UK, Croatia, France, Czeck republic, Sweden, and Spain it is not regulated. In Czeck republic, the building authorities has to be informed during a change of the kind of heating system. In Spain there is a basic IDAE registration of heat pumps: In other countries the element is obligatory (Slovenia, Sweden, Italy, Poland, Germany, Ireland, and Austria). In Slovenia, Slovakia, and Germany there is only evidence for subsidised heat pumps. In Ireland and Slovakia, it is obligatory for new buildings and renovated buildings.	Required for subsidised heat pumps New buildings and renovated buildings
	Evidence/register of geothermal heat pump production																		In 8 countries this element is not regulated (Belgium, Croatia, Czeck republic, France, Sweden, Spain, Poland, and Ireland). In Czeck republic, it is not required by, except measurement of water discharge over monthly extraction of 500m3. In Denmark this element has the status of recommendation. In other countries it is obligatory (UK, Slovenia, Switzerland, Italy, Germany, and Austria). In Slovenia the sum of geothermal energy from the heat pump is stored. In Germany a report is required for **>30 to 50 kW**. In Slovakia it is required for multi-family houses according to the thermal energy law.	>30 to 50 kW. Required for multi-family houses
5) Size and layout of the geothermal heat pump installation	Borehole drilling report																		In Croatia, Czeck republic and the UK there is no regulation. In Czeck republic, obligatory greater than 30m. In Ireland it is recommended when applying for an environmental assessment. In other countries it is obligatory (Belgium, Denmark, Slovenia, Switzerland, Italy, France, Sweden, Spain, Poland, Germany, Austria). In Spain it is requested as part of the environmental assessment required by the Spanish hydrogeological confederation, but not especially for heat pumps. In Slovakia and Italy it is requested for boreholes larger than 30m.	Required for drilling deeper than 30m. Assessment
6) Subsurface conditions	Pumping test report																		In the UK, Croatia and Ireland legal status is recommended. In Ireland it can be requested by the licensing authority. In Austria, Czeck republic, Sweden, and France it is not regulated. In Austria it can be requested for large systems and in Sweden it can be requested by customers. In other countries it is obligatory (Germany, Poland, Spain, Italy, Switzerland, Slovenia, Slovakia, Belgium, and Denmark). In Slovakia in systems, it is requested when there is an **extraction of 0.5 l/**s. In the other countries it is a requirement for obtaining authorisation.	Extraction of 0.5 l/s Assessment
	Evidence /register of groundwater Extraction																		In Poland, Czeck republic, and France this element is not regulated. In Czeck republic, Water meter is necessary to install and the report the water withdrawal is required. In other countries it is obligatory (Denmark, Belgium, Croatia, United Kingdom, Slovenia, Italy, Spain, Germany, Ireland, and Austria). Italy as well as Slovenia and Spain are obligatory for registration. In Germany and Ireland, it is obligatory for an extraction volume **of > 100,000 m3 per** year and >**25m3/day**, respectively. In Slovakia it is reported when there is extraction of **15 000 m3 annually** or **1250 m3 monthly. In Sweden is recommended and decides by Mark och Miljödomstol**	> 100,000 m3 per year >15 000 m3 annually or 1250 m3 monthly

Table 9. Regulation elements for CLS in thermal interaction

Regulation Element		GeoBOOST Partner Countries							GRETA Countries				GeoPLASMA-CE Countries		MUSE Countries				Summary	Value range
		AT	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	CZ	SK	UK	HR	BE	DK		
1) Distance	Distance to Next building,																		This element is not regulated in 8 elements (Denmark, Belgium, Croatia, United Kingdom, United Kingdom, Slovakia, Switzerland, Spain and Ireland). In Italy, Poland, Czeck republic and Austria a distance of **1,5m** is recommended. In the case of Austria a distance of **1m** is recommended, in Poland 1.5m and in Italy there is a range of **4.5-5m** distance. In Czeck republic, the system must not interact with the building. In other countries it is obligatory (Slovenia, Switzerland, France, Sweden and Germany). In some countries a distance is set on the basis of an environmental assessment and in agreement with the competent authority (Switzerland, France and Slovenia), while in other values are set, such as Germany which sets a distance of **1.5m.**	1-5m Assessment
	Minimum distance to neighbouring plot (property line)																		8 countries do not regulate this element (Denmark, Belgium, Croatia, United Kingdom, Slovakia, Switzerland, Spain and Ireland). In Poland and Austria, a distance **of 2.5m** is recommended. In the Czech Republic it is recommended the distance between the GSHE and the boundary with the neighbouring property is usually 5% of the drilling depth. In other countries it is obligatory (Slovenia, Switzerland, France, Sweden, Germany and Italy). In Slovenia the recommended distance is between **0.5-5m**; in Switzerland it is **2.5m**; in Italy it is over **2m;** in France it is **5m**; in Sweden it is **10m** and in Germany it is **5m.**	0.5-10m. Assessment
2)Temperature	Absolute allowed Tmin of reinjected heat carrier fluid																		6 countries do not regulate this element. In Spain, it is noted that there are no design guidelines for closed or open loop systems. In Slovakia and Czeck republic, there is no regulation but VDI4640 is used. In Austria a minimum injection temperature is recommended. In Austria it is **> -1,5°C**. In Poland and Ireland and. In Ireland temperature not below 0oC at year 50 defined in NSAI S.R. 40-1 and prEN1752. In Poland the temperature **is 0 °C** in baseload, **-3 °C** in peak load. In other countries it is obligatory (Switzerland, Italy, France and Germany). In Switzerland the minimum temperature is **1.5°C**. In Italy it is 1°C (4°C if the heat carried fluid is pure water). In France it is -**3°C**. In Germany it is : **0 °C** in baseload, **-3** °C in peak load.	-3°-4C
	Absolute allowed Tmax of reinjected heat carrier fluid																		4 countries do not regulate this element. In Spain, it is noted that there are no design guidelines for closed or open loop systems. In Austria a maximum injection temperature is recommended. In Austria it is Tmax **< 30°C**. In Slovakia, there is no regulation but VDI4640 (**max. 20°C**) is used. In Poland, recommended and Ireland it recommended. In Poland and Czeck republic, it is **20°C** in the underground. In other countries it is obligatory (Switzerland, France, Slovakia and Germany). In Germany it is 20 °C in the underground; in France the Tmax is **40 °C, in Slovakia is 26°C** and in Italy the Tmax is **28 °C** and the Tmax **is 40 °C**, if demonstrated that the structural function of the energy piles is not compromised.	20-40°C Assessment
	Relative value describing the accepted ∆T between disturbed and ambient undisturbed temperature.																		5 countries do not regulate this element (Slovenia, Italy, France, Sweden and Spain). In Slovakia is **6 °k**. In Spain it is noted that there are no design guidelines for closed or open loop systems. In Poland, Slovakia, Ireland and Austria the status of this element is recommended. In Poland, Slovakia, Czeck republic, and in Austria the ∆T is max. **6°C**. It is obligatory in Germany and Switzerland. In Germany and Austria, the ∆T is max. 6°C. In Switzerland is 3-4 °k in 50 years of operation.	6°C- 6°k
3)Preventive technical measures	Backfilling material (Cement / Mixture)																		In 4 countries this element is not regulated. In Slovenia and the Czech Republic, it is not regulated specifically for heat pumps, but it is part of the building plan. This element is recommended in Italy, Austria, Poland and Ireland. In Italy they recommend Water, cement or bentonite mixture, while in Austria a density >**1.3 g/cm³** is recommended for cement mixtures. In 4 countries it is obligatory (Germany, Sweden, France and Switzerland).	With a density >1.3 g/cm³ Cement
	Type of refrigerant or heat carrier fluid																		In 7 countries this element is not regulated (Denmark, Croatia, United Kingdom, Slovenia, Czech Republic, Sweden, and Spain). In the Czech Republic it is under construction regulation and in Sweden it is not to be used as a poisonous product. In Austria, Ireland, Poland, and Italy this regulatory element is recommended. In Poland Propylene or ethylene glycol is recommended. According to F-gas regulation. In Austria must be low impact on the environment. In Italy is necessary a natural refrigerant; content of lubricating oil as low as possible.	Low impact on the environment
4) Seasonal performance of installation	Evidence/register of heat pumps																		5 countries do not regulate this element (Belgium, Croatia, France, Sweden, and Spain). Denmark and Czeck republic have the status of 'recommended' regulation. In Czeck republic, the building authorities has to be informed during a change of the kind of heating system. In 8 countries evidence of heat pump production is obligatory (Austria, Germany, Italy, Switzerland, Slovenia, and the United Kingdom). In Germany, only subsidised applications are registered. In Ireland and Slovakia, it is only registered for new and renovated systems.	Obligatory For new and renovated systems
	Evidence/register of geothermal heat pump production																		7 countries do not regulate this element (Belgium, Croatia, France, Sweden, Spain, Poland, and Ireland). Denmark and Czeck republic have the status of 'recommended' regulation. In 7 countries evidence of heat pump production is obligatory (Austria, Germany, Italy, Switzerland, Slovenia, Ireland and the UK). In Germany there is only registration for subsidised applications. In Ireland it is only registered for new and renovated systems. In Slovakia, it is provided at the time of an environmental assessment for wells over 400 m or long systems. In Slovenia Only sum of geothermal energyfrom heat pumps – 2-yearsprogress on national level.	Assessment Obligatory for subsidised applications
5) Size and layout of the geothermal heat pump installation	Borehole drilling report																		In 4 countries a borehole drilling report is not regulated (Croatia, UK, Slovakia, and Spain). In Slovakia it is required for boreholes over 30m. In Ireland the status is recommended, as it will only be required if an environmental assessment is requested for the permit application. In Czeck republic, it is required for boreholes over 30m. In other countries it is obligatory (Denmark, Belgium, Slovenia, Switzerland, Italy, France, Slovakia, Poland, Germany, and Austria). In Slovakia and Italy, it is required in case of **depth >30m.**	Depth >30m Obligatory
6) Subsurface conditions	Thermal response test report																		In Spain a thermal response test report is allowed, which is not associated with a heat pump regulation. In France, Czeck republic and Ireland, it is recommended. In Ireland it is only requested for large systems, but it is not obligatory. In Poland it is recommended for plants **bigger than 30 KW**. In Czeck republic is recommended for plant bigger than :50 KW In Italy, Austria and Germany it is obligatory. In Germany it is obligatory for **large plants 30 to 50 KW and in Austria may be required for large systems.** In Italy it is obligatory for small plants (< 30 kW): TRT on 1 boring at least; Large plants (> 50 kW): 1 TRT each 10 boring at least; Plants with more than 100 boreholes: lab test on grouting. In Austria long systems can be applied for. In 8 countries it is not regulated (Denmark, Croatia, United Kingdom, Slovenia, Czech Republic, Slovakia, Switzerland, and Poland). In Slovakia it can be applied for by the local authority.	Small and large plants Decided by local authority.

Table 10. Regulation elements for OLP in thermal interference

Regulation Element		GeoBOOST Partner Countries							GRETA Countries				GeoPLASMA-CE Countries		MUSE Countries				Summary	Value range
		AT	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	CZ	SK	UK	HR	BE	DK		
1) Distance	Distance to next building	See Regulation elements for OLP in thermal interaction																		
	Minimum distance to neighbouring plot (property line)	See Regulation elements for OLP in thermal interaction																		
	Distance between reinjection and extraction well	See Regulation elements for OLP in thermal interaction																		
	Distance to other uses wells																		In three countries, it is not regulated (Slovakia, Czeck republic, and Ireland). In Ireland, it is only defined for systems with groundwater abstraction >25m3/day. Additionally, the EIA requirement is decided on a case-by-case basis to demonstrate no negative impact. In Slovakia, the water, mining, or construction authority defines the distance. In Czeck republic, Pre-existing groundwater wells are not allowed to be affected. In Austria, Poland, Spain, Sweden, and Italy, the legal status is "recommendation". In Austria, it must not affect pre-existing groundwater wells **(5m).** In Poland, groundwater wells must not be affected. In water protection zones, drilling is not permitted. In Sweden, it is approved and decided by the Kommun, miljöförvaltning. In Italy, a distance **greater than 10m** is recommended. In five countries, it is obligatory to maintain a distance from other wells (Germany, Spain, France, Switzerland, and Slovenia). In France, environmental impact results must be submitted. In Slovenia, the responsible authority indicates this distance.	Greater than 10m 5m Assessment systems with groundwater abstraction >25m3/day
	Distance from drinking water well																		In three countries, it is not regulated (Slovakia, the Czech Republic, and Ireland). In Ireland, it is only defined for systems with groundwater abstraction >25m3/day. Additionally, the EIA requirement is decided on a case-by-case basis to demonstrate no negative impact. In the Czech Republic, old wells cannot be affected. In Slovakia, an evaluation must be conducted. In Austria, Poland, Spain, Sweden, and Italy, the legal status is "recommendation". In Austria, pre-existing groundwater wells must not be affected **(1,5m).** In Poland, groundwater wells must not be affected. In water protection zones, drilling is not permitted. In Sweden, it is approved and decided by the Kommun, miljöförvaltning. In Italy, it is not permitted. In five countries, it is obligatory to maintain a distance from other wells (Germany, France, Switzerland, and Slovenia). In France, environmental impact results must be submitted. In Slovenia, the responsible authority indicates this distance.	Assessment Existing wells should not be affected 1,5m
	Distance to other public installations																		In Ireland, it is not regulated and is only defined for systems with groundwater abstraction >25m3/day. Additionally, the EIA requirement is decided on a case-by-case basis to demonstrate no negative impact. In Slovakia is also not regulated. This have to be approved by the building or mining authorities. In Austria, Spain, and Poland, the legal status is "recommendation". In Austria, pre-existing groundwater wells must not be affected **(2.5m**). In Poland, groundwater wells must not be affected. In water protection zones, drilling is not permitted. In Sweden, it is approved and decided by the Kommun, miljöförvaltning. In Italy, a distance greater than **10m** is recommended. In five countries, it is obligatory to maintain a distance from other wells (Germany, France, Switzerland, and Slovenia). In Spain and France, environmental impact results must be submitted. In Slovenia, the responsible authority indicates this distance. In Slovakia, it must not affect neighbouring constructions. The installation approval depends on the mining or construction authority. In Czeck republic it is not regulated. The GSHE should not be installed inside the water or mineral water source protection zone.	Evaluation 2,5m – 10m systems with groundwater abstraction >25m3/day
	Minimum distance between neighbouring Ground source heat pump installations to heat exchanger																		in four countries, the status of this element is recommended (Austria, Spain, Poland, Slovenia). In Austria, a distance **of 5 meters** is recommended, with an influence limit for existing wells of **dT < 1°C, dH < 0.1 m.** In Poland, a distance of 5 meters is recommended. In seven countries, it is not regulated. In France, it is decided based on an environmental assessment. In six countries, it is obligatory (Belgium, Switzerland, Italy, Sweden, Spain, UK and Germany). In some, a distance is established based on an environmental and hydrogeological assessment, while in others, specific values are set; in Germany, the distance is between **5-10 meters**; in Switzerland, it **is 5 meters**; in Italy, the distance ranges from **8-10** meters; and in Sweden, the distance **is 20 meters** and **200m**. In seven countries, it is not regulated. In Slovakia, an evaluation is conducted to demonstrate that it will not affect a neighbouring system. In Czeck republic, according to the building act should not be closer than **2m.**	5-200m evaluation
	Minimum distance between neighbouring GWHP installations a groundwater well																		In two countries, the status of this element is recommended (Poland and Slovenia). In Poland, a distance of **10 meters** is recommended. In six countries, it is not regulated (Denmark, Croatia, the Czech Republic, Slovenia, France, and Ireland). In France, it is decided based on an environmental assessment. In Croatia is **10m**. In eight countries, it is obligatory (Belgium, Switzerland, Italy, Sweden, Spain, Germany, and Austria). In some, a distance is established based on an environmental and hydrogeological assessment (Spain and Switzerland), while in others, specific values are set; in Germany, the distance is **between 5-10 meters**; in Austria, an influence limit for existing wells is set **at dT < 1°C, dH < 0.1** m; in Italy, the distance ranges from 8-10 meters; in Sweden, the distance is **30 meters**; and in Italy, there is a range of **30-100 meters**. In six countries, it is not regulated. In Slovakia, it is indicated that it must not affect groundwater quality. In Czeck republic, new installation must not interact with the previous one.	5-100m Evaluation dT < 1°C, dH < 0.1 m
2) Temperature	Temperature difference of the reinjected water	See Regulation elements for OLS in thermal interaction																		
	Absolute allowed Tmin of reinjected groundwater	See Regulation elements for OLS in thermal interaction																		
	Absolute allowed Tmax of reinjected groundwater	See Regulation elements for OLS in thermal interaction																		
	Relative value describing the accepted ∆T between disturbed and ambient undisturbed temperature.	See Regulation elements for OLS in thermal interaction																		
3) Extraction and discharge	Reinjection for GWHP (SGS-W)	See Regulation elements for OLS in thermal interaction																		
4) Seasonal performance of installation / Heat displacement	Evidence/register of geothermal heat pump production																		7 countries do not regulate this element (Belgium, Croatia, France, Sweden, Czeck republic, Spain, Poland, and Ireland).). In Czeck republic, it is not required by, except measurement of water discharge over monthly extraction of 500m3 Denmark is the only country that has the status of 'recommended' regulation. In 7 countries evidence of heat pump production is obligatory (Austria, Germany, Italy, Switzerland, Slovenia, and the UK). In Germany there is only registration for subsidised applications. In Ireland it is only registered for new and renovated systems. In Slovakia, it is provided at the time of an environmental assessment for wells over 400 m or long systems.	
5) Size and layout of the geothermal heat pump installation	Evidence/register of drilling data																		In the United Kingdom and Croatia, it is recommended to have evidence of drilling data. In nine countries, this element is not regulated (Denmark, Belgium, Slovenia, France, Spain, and Ireland). In Slovakia, the mining authority requires it. In six countries, it is obligatory (Austria, Germany, Poland, Italy, Slovakia and Switzerland). In Italy, it depends on the canton or region. In Austria if it is necessary. In Slovakia the evidence is required.	If an authority requires
	Borehole drilling report																		In five countries, a well drilling report is not regulated (Croatia, the United Kingdom, Slovakia, the Czech Republic, and Spain). In Ireland, the status is a recommendation, as it is only required if an environmental assessment is requested for the permit application. In Czeck republic. It is no regulated until 30m depth. In other countries, it is obligatory (Denmark, Belgium, Slovenia, Switzerland, Italy, France, Slovakia, Poland, Germany, and Austria). In Italy, it is required if the depth is greater **than 30 meters**.	Greater than 30 meters. Obligatory assessment
6) Subsurface conditions	Evidence/register of geothermal data																		In Denmark, the status is recommended. In five countries, it is obligatory (Croatia, Belgium, France, Sweden, and Spain). in Switzerland is necessary an assessment. In eight countries, it is not regulated (Austria, Ireland, Germany, Poland, Italy, Switzerland, Slovenia, and the United Kingdom). In Ireland, it is required for new and renovated buildings. In Germany, it is required for subsidized systems.	Obligatory assessment
	Evidence/register of groundwater Extraction																		In 3 countries it is not regulated (France, Czeck republic, and Spain). 8 countries are obligatory (Germany, Ireland, Italy, Sweden, and Slovenia). In 10 countries it is obligatory (Austria, Ireland, Germany, Sweden, Italy, and Slovenia). In Germany it is for extraction volumes > 100,000 m3 per year. In Iceland it is obligatory for abstraction volumes >25m3/day. In Sweden it is decided by Mark och Miljödomstol. In Switzerland it depends on the canton or region. In Slovakia, the reporting of ground water extraction is required above 15 000 m3 anually or 1 250 m3 monthy.	Obligatory Assessment > 100,000 m3 per year.

Table 11. Regulation elements for CLP in thermal interference

Regulation Element		GeoBOOST Partner Countries							GRETA Countries				GeoPLASMA-CE Countries		MUSE Countries				Summary	Value range
		AT	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	CZ	SK	UK	HR	BE	DK		
1) Distance	Minimum distance to neighbouring plot (property line)	See Regulation elements for CLP in thermal interaction																		
	Distance to next building	See Regulation elements for CLP in thermal interaction																		
	Distance to drinking water well.																		In three countries, it is not regulated (Slovakia, Ireland, and Spain). In Ireland, it is only defined for systems with abstraction and discharge above **>25m3/day**, and the EIA requirement is decided on a case-by-case basis. In Slovakia, it is established that it must not affect pre-existing wells. In three countries, this element is recommended (Austria, the Czech Republic, and Poland). In Austria, a distance **of 5 meters** is recommended. In Poland, it is not allowed in protected areas. In Czeck republic, distance from the small personal water well is on the decision of the projecting hydrogeologist. In six countries, it is obligatory (Germany, Sweden, France, Switzerland, Slovenia, and Slovakia). In Germany, it depends on the water catchment area; in Sweden, it is approved by the Kommun, miljöförvaltning. In France and Switzerland, it depends on an environmental and hydrogeological assessment. In Italy, in WPA and if L < 200 m. In Slovakia, it may not be in protection water zone.	Assessment 5m-200m
	Distance to other public installations																		In Austria, a distance of **2.5 meters** is recommended. In two countries, there is no regulation (Ireland and Spain). In six countries, it is obligatory (Germany, Sweden, France, Switzerland, and Slovenia). In Germany, a range between **5-10 meters** is specified. In Switzerland, it is indicated that other users should not be affected. In France, an environmental impact assessment is required, and in Slovenia, authorization must be obtained from the competent authority. In Slovekia, it is not permitted to affect other installations. In Slovakia is not allowed. In Sweden, Poland and Czeck republic it is recommended.	2.5-10m Assessment
	Distance to other uses wells																		In 3 countries, recommendations are made (Austria, Czeck republic, and Poland). In Austria, a distance of **5 meters** is recommended. In Poland, drilling is not allowed in protected water areas. In Czeck republic, distance from the small personal water well is on the decision of the projecting hydrogeologist. No impact on the quality and the amount of water in the neighbours' wells is. In four countries, there is no regulation. In Slovakia, construction regulations are used. In six countries, it is obligatory (Germany, Sweden, France, Italy, Switzerland, Slovenia). In Switzerland and France, an assessment is conducted to ensure that other users are not impacted. In Germany, it is the responsibility of the private individual. In Italy, the distance must be greater than **10 meters.**	Greater than 10m 5 m Austria Assessment
	Minimum distance between neighbouring Ground source heat pump installations to heat exchanger																		In Austria and Poland, a distance of **5 meters** is recommended. In Austria, there is a limit on the influence on existing wells with **dT<1°C, dH<0.1m**. In 10 countries, it is not regulated. In France, an environmental impact assessment must be conducted. In 4 countries, it is obligatory. In Germany, the distance range is between **5-10 meters**. In Sweden, it is 20 meters. In Italy, the distance is between **8-10 meters**. In Switzerland, it is set **at 5 meters**. In 10 countries, it is not regulated (Ireland, Spain, France, Slovenia, the Czech Republic, Slovakia, the United Kingdom, Croatia, Belgium, and Denmark). In Slovakia, the recommended distance is **5 meters:**	5-20m Assessment
	Minimum distance between neighbouring Ground source heat pump installations a groundwater well																		In Austria and Poland, it is recommended: In Poland, a distance of **10 meters** is recommended. In Austria, the existing well should not be affected with **dT<1°C, dH<0.1m**. In 5 countries, it is obligatory. In Switzerland, there must be a distance of **30 meters**. In Germany, the heat extraction must be within the area of the plant. In Switzerland, it is evaluated through simulations and research. In Italy, different permissible distances are allowed, ranging between **30-100 meters**. In **10** countries, it is not regulated (Ireland, Spain, France, Slovenia, the Czech Republic, Slovakia, the United Kingdom, Croatia, and Belgium). In Slovakia and the Czech Republic, the distance is determined by the authority issuing the permit.	10-100m Assessment
2) Temperature	Absolute allowed Tmin of reinjected heat carrier fluid	See Regulation elements for CLP in thermal interaction																		
	Absolute allowed Tmax of reinjected heat carrier fluid	See Regulation elements for CLP in thermal interaction																		
	Relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature.	See Regulation elements for CLP in thermal interaction																		
4) Seasonal performance of installation / Heat displacement	Evidence/register of geothermal heat pump production																		7 countries do not regulate this element (Belgium, Croatia, France, Sweden, Spain, Poland, and Ireland). Denmark and Czeck republic have the status of 'recommended' regulation. In 7 countries evidence of heat pump production is obligatory (Austria, Germany, Italy, Switzerland, Slovenia, and the UK). In Germany there is only registration for subsidised applications. In Ireland it is only registered for new and renovated systems. In Slovakia, it is provided at the time of an environmental assessment for wells over 400 m or long systems. In Czeck republic it is recommended.	Decision of the local authorities
5) Size and layout of the geothermal heat pump installation	Evidence/register of drilling data																		Two countries recommend a drilling data registry. Six countries have no regulation. In six countries, it is obligatory. In Switzerland, it is sometimes available on the internet.	obligatory
	Borehole drilling report																		It is recommended for Czeck republic and Ireland when an environmental assessment is requested. Four countries have no regulation. In 10 countries, it is obligatory. In Slovakia and Italy, it applies to drillings greater than 30 meters.	Greater than 30 meters. Requirement Evaluation
6) Subsurface conditions	Evidence/register of geothermal data																		It is obligatory in only two countries. In Slovakia, it is recommended and can be requested by the authority.	Obligatory Required if it is necessary
	Evidence/register of heat exchanger																		It is obligatory in only two countries. In Ireland, renovated buildings are registered. In the Czech Republic, it can be requested by the authority and in Slovakia depend on the length of the borehole. Both are recommended	Decided by the relevant authority Obligatory

3.2.3 Remarks on the regulation elements of GHPs in the context of thermal interference

This section, focuses exclusively on thermal interference, leaving aside thermal interaction. This decision aligns the main objective of this report, which is to delve into the specific aspects of thermal interference, and its relevance in the context studied.

Legal Status

In the European countries participating in various projects, it is observed that the legal status of regulatory elements for open and closed systems differs from one country to another (section 3.2.2), both for *thermal interaction* and *thermal interference*.

In particular, the situation regarding thermal interference is as follows for the GeoBOOST countries:

- Austria

In Austria, the regulatory elements for open and closed systems have a similar legal status. Most elements concerning distance and temperature have a recommended status, while other elements are mandatory. The legal framework for all types of uses associated with shallow geothermal methods is governed by the Federal Water Act (WRG 1959, BGBL. I 54/2014 id.g.F.), which is the responsibility of the Federal Ministry for the Environment (FME). Therefore, all regulatory elements associated with them will have a "obligatory" regulatory status. This is the same situation for the guidelines issued by state governments, which are not legally binding. However, the guidelines summarize all the legally binding points of the procedure.

The Austrian Association for Water and Waste Management (ÖWAV) provides guidelines for thermal interaction. The ÖWAV guidelines are not legally binding but are generally considered by the administrative authorities. Since they are not legally binding, most regulatory elements are in a legal status of recommendation.

- Ireland

In Ireland, regulations elements are only applicable to open loop system at present. The legal framework for open loop shallow geothermal systems is governed by the Water Supplies Act 1942 (Guidance on the Authorisation of Direct Discharges to Groundwater, 2014) and governed by Environment Protection Agency (EPA). No regulations currently apply to closed loop systems. Other regulations such as Regulations 2018 (S.I. No. 261/2018) and Building Control (Amendment) Regulations 2014 (S.I. No. 9 of 2014) are specific to all types of heat pump (and other technologies) deployed in the built environment and all these regulations are mandatory.

Regulation elements are included in the NSAI (National Standards Authority of Ireland) SR 50-1 Part 4 (Standard Recommendation (S.R. 50-4:2021- Building Services-Part 4: Heat pump systems for dwellings)

- Germany

In Germany, most regulation elements have an obligatory legal status for both open and closed systems. The established requirements in the guidelines are legally binding. Exceptions include guidelines such as VDI, DVGW, BAU-Cert W 120 – 1 or W 120 -2, DIN 4023, and DIN EN ISO 22282-4, while are not legally binding, but they are highly regarded when discussing standards that ensure the high quality and safety of Ground source heat pump installations. Other elements are governed by the Federal Mining Act (BBergG), the Water Resources Act (WHG), and the Water Framework Directive (WFD). The only regulatory element that is not regulated is the registration/evidence of geothermal data.

- Netherlands

In the Netherlands, regulatory elements for open loop systems have mandatory legal status. The legal framework for these systems is primarily governed by the Water Act (Wet Milieubeheer). However, it is also encompassed within the framework of the Drinking Water Act (Drinkwaterwet), the guidelines from the RIVM (National Institute for Public Health and the Environment), the Mining Act (Mijnbouwwet), the Soil Energy Systems Decree, the Technical Guidelines from the Water Boards (legally binding), and local regulations. For closed loop systems, the regulatory elements also have mandatory legal status. These elements are governed by the Building Decree (Bouwbesluit), the Drinking Water Act (Drinkwaterwet), the guidelines from the RIVM, the Water Act (Wet Milieubeheer), the Soil Energy Systems Decree (Besluit bodemenergie), and the Mining Act (Mijnbouwwet). Just like with open loop systems, in closed loop systems some regulatory elements are governed by the Technical Guidelines from the Water Boards (legally binding), and local regulations.

- Poland

In Poland, regulation elements have a legal status for both open and closed systems for thermal interference. Most regulation elements are in a recommended status because they are governed by the PORT PC guidelines, which are not legally binding. Other regulation elements with an obligatory status are governed by Geological, Water, Construction, and Environmental laws.

- Spain

In Spain, there is a significant difference in the legal status of regulatory elements between open and closed systems. In the case of open systems, there are more elements with an obligatory status. This is because the Spanish Water Confederation requires by obligation an environmental impact study. So, all regulation elements are governed by this. However, there is no specific regulation for GHPs. For closed systems, there is no regulation. Only the element "well drilling report" is mandatory.

- Sweden

In Sweden, regulation elements are very similar for open and closed systems. The elements are governed by the Guideline Vägledning för att borra brunn - Normbrunn 016, which is legally binding. For some elements, there is no determined value in the guideline. However, the relevant authority can determine this value.

In general, it can be inferred that the regulation elements delimiting thermal interference in GeoBOOST countries are governed by different national, local, or regional regulations (mining, water, environment, etc.). When elements are governed by these regulations, their status has been classified for the purpose of this deliverable as "obligatory" or "allowed." Meanwhile, when a regulatory element is governed by a non-binding guideline, it has been classified as "recommended." Additionally, it can be observed that regulations for closed systems appear to be less stringent than those for open systems, likely due to the lack of binding legislation or the lower complexity of installation. This situation may also apply to other European countries.

The legal variation indicates that significant work is required in the legal framework of GeoBOOST countries to ensure the efficiency of GHPs, prevent the occurrence of thermal interference between systems, and ensure their safe use.

Legal condition - technical status.

In the “summary” column of tables 8, 9, 10, and 11, it can be seen that different countries have varying thresholds, parameters, or quality of regulation elements, i.e., different legal conditions. Based on the information provided, table 12 has been constructed to illustrate the possible factors influencing this variability. The first column of the table shows the groups of technical parameters, while the second column lists the identified factors. Columns 3, 4, 5, and 6 present the factors influencing the technical status (legal condition) in each participating country for the different projects.

Table 12. Factors influencing the legal conditions of the Regulation Element Groups. X corresponds to both systems, closed-loop and open-loop systems. C – closed loop systems and O – open loop systems.

Project		GeoBOOST Partner Countries							GRETA Countries				Geo-PLASMA-CE Countries		MUSE Countries			
Countries		AT	IE	DE	PL	ES	SE	NL	FR	IT	CH	SI	CZ	SK	UK	HR	BE	DK
Technical parameter groups	**Factors**																	
1) Distance	Legal and Regulatory Context[1]		O	X	X	X	X											
	Geological, hydrogeologic and Environmental Characteristics[2]	X				X	X		X	X	X							
	Health and Safety Requirements[3]	X	O		X		X					X						
	Infrastructure and Land Use Considerations[44]	X							X			X					X	
	Historical Standards and Practices[5]			X			X		X	X								
2) Temperature	Environmental and Ecological Conditions[6]	O C	O	C		O C	O C		C	C								
	Geological and Climatic Characteristics[7]	C	O	C			O			C								
	Health and Safety Requirements[8]		O						O									
	Technical and Engineering Considerations[9]			O C						O C								
	Legal and Regulatory Framework[10]		O	C	C					O C								
	Protection of water resource[11]		O	C					C	C								
3) Extraction and discharge	European Directives[12]			O	O				O									
	Geological Conditions[13]					O				O	O							
	Permitting and EIA[14]						O			O								

[1] Each country has a different legal and regulatory framework, which affects how geothermal projects are managed. These legal frameworks can be influenced by history, government structure and national priorities
[2] Each country has different hydrogeological conditions that may require specific regulations. Geological and environmental conditions influence how geothermal systems are designed and managed.
[3] Regulations are also established to protect public health and safety. The protection of drinking water sources is a priority in many jurisdictions.
[4] Population density, land use and existing infrastructure play an important role in the regulations.
[5] Previous experience and historical practices also influence regulations. Countries may have more detailed and specific regulations
[6] Each country has different environmental and ecological concerns that influence heat transfer fluid temperature regulations.
[7] Geological and climatic conditions vary significantly between countries, which affects the temperature regulations of the geothermal fluid.
[8] Temperature regulations to prevent damage to infrastructure and ensure system safety.
[9] Technological capabilities and engineering practices also influence regulations.
[10] Each country has a different legal and regulatory framework that affects temperature regulations
[11] The protection of groundwater resources is a priority that affects regulations
[12] EU member countries implement the Water Framework Directive, but implementation may vary.
[13] Countries with specific geological and environmental conditions may have stricter regulations
[14] Permitting requirements and stringent environmental assessments influence the regulation of reinjection

	Resource Protection[15]		O				O			O		O						
	National and local regulation[16]	O								O		O		O				
4) Size and layout of GHP installations	European Union Directives and Regulations[17]		X	X	X	X												
	Geological and Environmental Conditions[18]		X			X	X			X								
	National and Local Regulations[19]	X	X	X						X	X		X	X	X			
	Permitting requirements and Environmental Impact Assessments[20]	X	X		X		X		X	X	X	X						
	Availability and Accessibility of Geothermal Data[21]	X			X		X				X							
5) Subsurface conditions	Geological and Hydrogeological Context[22]			X	X					X	X	X						
	Data Availability and Accessibility[23]					X	X			X		X						
	Environmental Regulations and Policies[24]		O								X							
	Infrastructure and Technical Capacities[25]			X						X								
	Decentralisation and Regional Autonomy[26]			X		X					X							
6) Seasonal performance of GHP systems	Geological condition			X														
	Data Availability and Accessibility									X	X							
	Infrastructure and Technical Capabilities[27]									X	X							
	Legal and Policy Frameworks[28]	X		X														
	Environmental and Energy Priorities[29]									X								

[15] Different approaches to water resource protection are reflected in legislative variations
[16] National and local legislation reflects country-specific priorities and contexts.
[17] The European Union sets directives that its member states must comply with, but the specific implementation may vary.
[18] Geological and environmental characteristics of each country can influence regulations. Soil properties, availability of water resources and environmental sensitivity vary widely.
[19] Each country has its own legal structure and local regulations that can influence how geothermal activities are managed.
[20] The requirements for obtaining permits and conducting environmental impact assessments vary, which can lead to differences in legislative requirements.
[21] Geothermal and drilling data are available and accessible to the public and authorities differs between countries.
[22] Each country has unique geological and hydrogeological characteristics that affect the availability and management of groundwater resources.
[23] The infrastructure for collecting, recording and accessing geothermal and groundwater data varies between countries.
[24] National and international environmental policies influence regulations.
[25] The technical capacity to implement and enforce regulations varies, i.e. resources and technical capacity to carry out and supervise regulated activities.
[26] The administrative structure of a country can give autonomy to regions to adapt regulations.
[27] The availability of technology and trained personnel to monitor and report geothermal production may vary.
[28] Each country has a different legal and regulatory framework that affects temperature regulations
[29] Some countries may prioritise the promotion of renewable energies, including geothermal

Differences in legal conditions between countries may be due to a combination of factors. Some of the are:

- Geological conditions
- Climatic conditions
- History of geothermal development in the country
- Technical infrastructure and regional autonomy
- Availability and access to data
- Public health and safety.
- Protecting water resources
- Infrastructure and land use
- European, National and Local regulatory framework

Each country may have adapted their regulations to their specific needs and legal contexts to address their specific challenges, in particular, to optimise the sustainable management of shallow geothermal systems (specifically GHPs) and geothermal resources, promoting the efficient and safe use of geothermal energy.

3.3. Technical requirements elements for thermal interferences assessment

3.3.1 Assessment of the Impact of regulatory elements from a technical point of view

Results of the comparative analysis presented in the previous section show clear differences in the legal situation and legislative conditions across European countries. Therefore, it is important to highlight the impact of regulation aspects on the prevention of thermal interference (our focus). For this purpose, an analysis is carried out with a technical approach.

Analysing a regulation from a technical point of view is not only important for complying with legal and technical standards but also for optimizing operations and minimising risks. This ensures that regulated activities are performed in a safe, efficient and responsible manner, while promoting innovation and continuous improvement.

The results of this analysis (Table 13) indicate that certain regulation elements impact the operation of one or more open or closed loop systems from a technical standpoint by ensuring system functionality and efficiency, thereby preventing "thermal interference." Other elements are important because they promote strategies for the sustainable management of geothermal resources, environmental protection, cumulative impact assessment, regional planning, and the overall efficiency of geothermal heat pump systems.

Based on these findings, it follows that each identified regulation element is relevant to ensure that geothermal installations are safe, efficient and sustainable. Therefore, the regulatory framework must be robust and comprehensive to ensure the long-term viability of geothermal technology and to optimise the use of geothermal resources.

Table 13. Impact of regulation elements from a technical point of view on System Design and Operation as well as on the Planning of Geothermal Heat pump Systems Installations (Thermal interference).

Thermal interference	**Systems**	
Regulation elements	**OLS**	**CLS**
1) Distance		
Distance to the property line	Determining a minimum acceptable or recommended distance between a GHP system and the property boundary will help prevent aquifer contamination, maintain land stability, and ensure system efficiency.	Determining a minimum acceptable or recommended distance between a GHP system and the property boundary maintain land stability and ensure system efficiency.
Distance from next building	Defining a minimum acceptable or recommended distance between a GHP system and the next building will prevent aquifer contamination, maintain ground stability, ensure system efficiency, ensure safety of building and help manage safety measures.	Defining a minimum acceptable or recommended distance between a GHP system and the next building will maintain ground stability, ensure system efficiency, ensure safety of building and help manage safety measures.
Distance from drinking water well	Establishing a minimum acceptable or recommended distance between a geothermal heat pump system and the nearest potable water well helps **prevent contamination of drinking water,** avoids undesired	Establishing a minimum acceptable or recommended distance between a geothermal heat pump system and the nearest potable water well helps **prevent contamination of drinking water**, avoids changes in the

	changes in the temperature of the resource, protects public health, ensures the sustainability of the public resource, protects ecosystems, and guarantee the efficiency of the system.	temperature of the drinking water, protects public health, ensures the sustainability of the public resource, protects ecosystems, and guarantee the efficiency of the system.
Distance from other uses well	Considering a minimum acceptable or recommended distance to a well for other uses will prevent possible accidents or incidents between the different infrastructure systems, reduce the risk of technical interference between the different systems, protect the structural integrity of the wells and other equipment used in each system and minimize environmental risks.	Considering a minimum acceptable or recommended distance to a well for other uses will prevent possible accidents or incidents between the different infrastructure systems, reduce the risk of technical interference between the different systems, protect the structural integrity of the wells and other equipment used in each system and minimize environmental risks.
Distance from other uses well	Defining a minimum acceptable or recommended distance between a GHP system and other public facilities enables the safety of the infrastructure, prevents risks for users of public institutions, promotes operational continuity, protects the environment and promotes a sustainable and harmonious development of the city.	Defining a minimum acceptable or recommended distance between a GHP system and other public facilities allows guaranteeing the safety of the infrastructure, promoting operational continuity, protecting the environment, promoting the prevention of contamination of drinking water, managing risks and promoting development. sustainable and harmonious of the city.
Minimum distance to neighbouring Ground source heat pump installation	Determining a minimum distance between boreholes of a BHE system and GWHP wells prevents thermal interference between systems, optimizes system performance, protects the environment, maintains operational efficiency and helps identify and mitigate risks associated with the operation.	Defining the minimum acceptable or recommended distance between wells at different facilities makes it possible to improve the installation planning process, guarantee operational efficiency, prevent technical interference, protect the environment, mitigate risks and optimize the overall performance of both systems.
Minimum distance to neighbouring GWHP installation	Define the minimum acceptable or recommended distance between wells from different facilities, optimize system performance, protect the water resource, prevent contamination, and facilitate the operational efficiency of both systems.	Determining a minimum distance between perforations of a BHE system and GWHP wells allows improving the installation planning process, preventing thermal interference between systems, optimizing system performance, protecting the environment, maintaining operational efficiency and identifying and mitigating risks associated with the operation.
2) Temperature		
Temperature difference of the reinjected water	Establishing a maximum injected temperature difference helps prevent mutual interference between neighbouring geothermal systems, ensure better operation and performance of each geothermal system separately, benefiting cooling effects of already warmed groundwater zones and protect the geothermal resource.	
Absolute allowed Tmin of groundwater/ inlet pipe	Defining the minimum acceptable or recommended absolute temperature in an area with two or more systems helps protect the environment, preserve the resource, and prevent technical issues when there are multiple open-loop heat pump systems in a geothermal zone.	Defining the minimum acceptable or recommended absolute temperature in an area with two or more systems helps prevent freezing of the ground around the heat exchanger and prevent systems from influencing each other through heat exchange.
Absolute allowed Tmax of groundwater/ inlet pipe	Establishing the maximum acceptable or recommended absolute temperature between systems allows for avoiding interference between systems, protecting the resource, conserving the resource, and maintaining efficiency for both systems.	Defining the minimum acceptable or recommended absolute temperature between systems allows for avoiding thermal influence between systems, minimising the negative effect on groundwater quality. preventing heat accumulation in the ground and long-term alteration of thermal properties and promoting energy efficiency and operational cost effectiveness of the systems.
ΔT Between disturbed and ambient undisturbed temperature	Determining a temperature difference value between disturbed and undisturbed ambient temperatures at a specific time, distance, and depth from injection points in densely populated settlements within the aquifer zone ensures energy balance and energy efficiency of the systems.	Determining a temperature difference value between disturbed and undisturbed ambient temperatures at a specific time, distance, and depth from wells in densely populated settlements allows for avoiding soil temperature disturbance, ensuring energy balance, and efficiency of the systems.
3) Extraction and discharge		
Reinjection for Groundwater heat pump	The reinjection of a geothermal heat pump in an area with multiple similar systems requires careful and coordinated management to control water levels, manage aquifer pressure during reinjection, and ensure that cumulative effects do not degrade aquifer performance or the long-term efficiency of heating and cooling systems.	
4) Seasonal performance of installation		
Evidence/register of geothermal heat pump production	The evidence/register of heat pump production enables market supervision and control, sustainable development of the country's shallow geothermal energy, fostering innovation, promoting a fair and competitive market that meets standards, ensuring energy efficiency, evaluating environmental impact, and encouraging research and development of geothermal heat pump systems.	The evidence/register of heat pump production allows for market supervision and control, sustainable development of the country's shallow geothermal energy, fostering innovation, promoting a fair and competitive market that meets standards, ensuring energy efficiency, evaluating environmental impact, and encouraging research and development of geothermal heat pump systems.
5) Size and layout of the geothermal heat pump installation		
Borehole drilling report	Requiring a drilling report when installing a geothermal heat pump in areas with many similar installations is decisive for obtaining information that enables the management and protection of underground resources, ensuring the safety and efficiency of the installations, and ensuring environmental sustainability. This	Requiring a drilling report when installing a geothermal heat pump in areas with many similar installations is essential for obtaining information (location, installation type, etc.) that enables the management and protection of underground resources, ensuring the safety and efficiency of the installations, and ensuring environmental

	requirement also facilitates the planning and management of public policies, ensuring responsible and effective geothermal development.	sustainability. This requirement also facilitates the planning and management of public policies, ensuring responsible and effective geothermal development.
Evidence/register of drilling data	A drilling data register for open-loop geothermal heat pump systems allows for protecting water resources, sustainably managing resources, providing geological information of the site, facilitating accurate data for future installation designs, ensuring long-term system performance, establishing a database for authorities, facilitating planning and management of public policies, and promoting responsible and effective geothermal development.	A drilling data register for closed-loop geothermal heat pump systems allows for protecting soil integrity, ensuring sustainability through life cycle simulations for system temperature development, designing systems that maximize thermal and operational efficiency, ensuring efficient system operation, monitoring and controlling environmental impact, preventing interferences, protecting existing infrastructure (e.g., potable water wells), managing energy and geothermal resources, and guaranteeing the sustainability and safety of geothermal resources.
6) Subsurface conditions		
Evidence/register of groundwater abstraction	The groundwater extraction register from several open-loop geothermal heat pump systems in an area enables the prevention of overexploitation, maintenance of water balance (ensuring equilibrium between extraction and natural aquifer recharge), protection of ecosystems, prevention of aquifer contamination, storage of hydrogeological data, assessment of cumulative impacts from multiple systems, planning of mitigation measures, promotion of land management, facilitation of water infrastructure planning, optimisation and planning of system improvements, and ensuring long-term sustainable use.	
Evidence/register of geothermal data	The register of geothermal data from various open-loop heat pump systems in an area enables monitoring of heat extraction and reinjection, sustainable management of geothermal resources, environmental protection, assessment of cumulative impacts, regional planning, research, and regulatory compliance. Maintaining detailed and accurate registers allows for informed and proactive management, ensuring that geothermal activities are conducted efficiently, sustainably, and responsibly, benefiting both society and the environment.	The register of geothermal data from various closed-loop geothermal heat pump systems in an area enables optimising of system design and operation, monitoring of subsurface thermal balance, sustainable management of geothermal resources, environmental protection, assessment of cumulative impacts, and regional planning, and encouraging research and development of geothermal heat pump systems.
Evidence/register of heat exchanger		The register of heat exchanger data in a closed-loop geothermal heat pump systems allows for storing technical information (exchanger models, capacity, and technical specifications), sharing installations location and date, registering fluid inlet and outlet temperatures within the exchangers, monitoring system pressures, documenting maintenance and repairs, evaluating long-term system performance, and monitoring for leaks or emissions. Registration of the heat exchangers in a closed geothermal heat pump system is essential to ensure efficiency, safety, reliability and regulatory compliance, encourage research and development of geothermal heat pump systems, as well as contributing to reducing operating costs and minimising environmental impact.

3.3.2 SWOT analysis and evaluation of external and internal factors of regulation elements groups.

The SWOT analysis and the Evaluation of External and Internal Factors allows the role of regulation elements in optimizing geothermal heat pump systems to be assessed. This approach helps to identify and prioritize the key elements to be included in the regulatory framework (Dzonzi-Undi and Li, 2015). By assessing and prioritizing factors according to their relevance and impact, an effective and sustainable implementation of regulations is ensured.

The focus of SWOT analysis has been on assessing the relevance of regulation elements within the groups to prevent "*Thermal Interference*" between geothermal heat pump systems. This approach ensures the effective implementation and operation of geothermal systems, as well as their long-term viability. The analysis also considers broader objectives, such as promoting the sustainable and efficient use of geothermal resources and planning of geothermal heat pump installations. It highlights the strengths, weaknesses, opportunities, and threats of these groups of regulatory elements for both open and closed systems, in the context of their current and future implementation.

For the analysis, 25 criteria (Annex 6) were determined (Table 14) based on strengths, weaknesses, opportunities, and threats for regulation element groups. The criteria were weighted out 100, and the applicability of each was assessed based on information gathered regarding *"Thermal Interference"* from GHPs in various projects and studies.

Table 14. SWOT analysis; criteria and weights

	STRENGTHS	**Weight**		**WEAKNESSES**	**Weight**
1	Storage of geological and technical data	12	**1**	Thermal changes in the subsurface and/or groundwater	20
2	Sustainable geothermal resource use	20	**2**	Subsurface interference impact on the ability to deliver heating & cooling power	20
3	Prevention of unfavourable interference between systems	18	**3**	Special legal obligations, restrictions, or technical requirements.	15
4	Efficiency Operation of systems	15	**4**	Higher energy consumption (Maintenance and Repair Costs, Control and Monitoring Equipment, Fuel or Auxiliary Energy Costs, etc)	10
5	Ensure Energy balance of GHP systems	15	**5**	Groundwater thermal short circuit or thermal breakthrough between systems	20
6	Optimization of heat exchange distribution of the systems over time.	10	**6**	Space and availability for systems in different environments	15
7	Optimization of cost of the systems	10			
	OPPORTUNITIES	**Weight**		**THREATS**	**Weight**
1	Improved monitoring techniques	15	**1**	Regulatory instability	25
2	Develop optimized planning software	15	**2**	High costs associated with complying with regulations	20
3	Development of future installations and/or heating districts	20	**3**	High operation costs	15
4	Encouraging and promoting research and development	15	**4**	Unknown Environmental Impacts	20
5	Protecting ecosystems	15	**5**	Conflict with other subsurface users (subsurface infrastructure) causing possible damage (e.g., physical) between users.	20
6	Long term resource management	20			
7	Optimise consumption of the heat pump	15			

The results of the analysis (Annex 9) are depicted in figure 2. It shows that most regulation element groups are in the relevance zone, indicating a strong opportunity that should be exploited. This means that all groups in this zone play a relevant role to ensure the long-term efficiency of neighbouring geothermal heat pump systems. Therefore, these regulation element groups should be prioritized and included in the development of the technical and legal (regulatory) framework for effective and balanced regulation.

The graph shows that groups such as **temperature, extraction and discharge, and subsurface conditions** are highly relevant to both opportunities and threats.

- The graph shows that **subsurface conditions group and Temperature** present strengths and opportunities that outweigh weaknesses and threats. This indicates a significant potential to exploit the advantages of subsurface conditions within the regulatory framework. In the case of subsoil conditions groups, it ensures the storage of geological and technical data, promotes long-term resource management and facilitates the development of planning tools. The **size and layout of geothermal heat pumps** group ensure the storage of geological and technical data and ensuring operational efficiency. The "**temperature**" regulation group holds relevance for the sustainable use of resources and preventing unfavourable interactions between systems, protecting ecosystems, promoting long-term resource utilization and future development of installations. The absence of these regulation elements could leave weaknesses vulnerable to threats, affecting the ability to extract necessary heat and cold in systems and resulting in high operational costs.

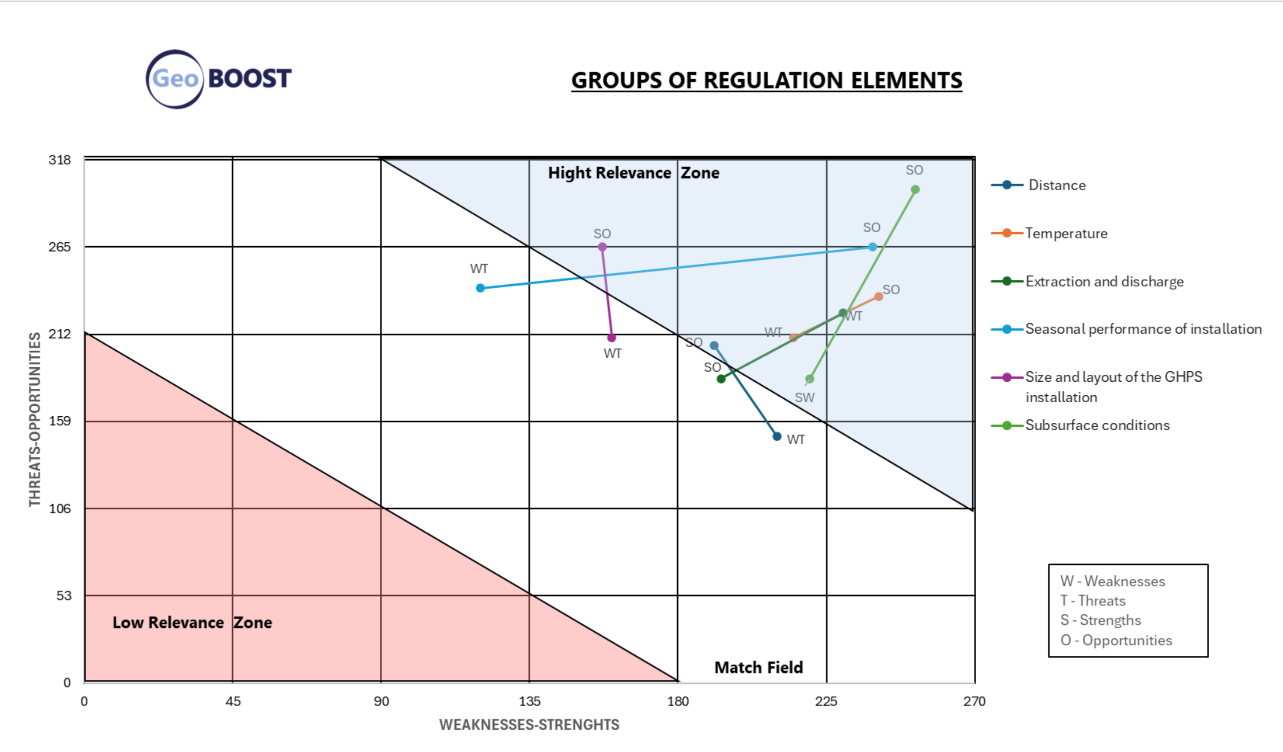
- In the case of the **"extraction and discharge"** groups the weaknesses and threats elements have a higher combined score than the strengths and opportunities, indicating that there are more significant challenges or problems and that therefore, strategies to mitigate the weaknesses and threats need to be strategically addressed in the regulation framework. The **extraction and discharge** group highlights its relevance due to its potential to ensure resource sustainability and prevent unfavourable system interactions. The absence of these regulation elements could lead to thermal resource interactions and conflicts with other subsurface users.

The graph shows that the groups such as "**seasonal performance of the installation", "size and layout of ground source heat pumps" and "distance"** have moderate relevance.

- In the group "**seasonal performance of the installation", "size and design of ground source heat pumps"** and **"distance"** present strengths and opportunities that outweigh the weaknesses and threats. This indicates a significant potential to exploit the advantages of the subsurface conditions within the regulatory framework. However, weaknesses and threats are found in the "*Match zone*". This implies that the regulation groups have factors to consider and present certain challenges, these are not critical and can be handled with proper planning and management in the regulatory context, i.e., these regulation groups are still potentially beneficial/relevant in regulating the system. Considering the "**subsurface conditions"** group promotes long-term resource management and facilitates the development of planning tools. On the other hand, the "**size and design of geothermal heat pumps"** group is important for ensuring both the storage of geological and technical data and operational efficiency.

The "**seasonal Performance"** of the Installation group is relevant for ensuring the storage of geological and technical data and the operational efficiency of the systems, which allows for improved monitoring techniques, the development of optimized planning software, the creation of future installations and/or heating districts, and the promotion of research and development. Meanwhile, the "**distance"** group elements ensure the sustainable use of resources and prevent adverse interactions between systems, thereby protecting the ecosystem and long-term resource management.

Figure 2. SWOT Analysis for Regulation element groups



4. Good Practices Examples

Geothermal heat pump system planning tools have the capacity to optimize design and sizing (Sanner et al., 2003), analyse hydrogeological behaviour (Banks, 2012), perform energy simulations (ASHRAE, 2019), integrate with energy management systems (Rees, 2016), assess economic feasibility (Kavanaugh, 2014), and manage system performance (Gehlin and Spitler, 2019). The application of these tools impacts the efficiency, sustainability, economic viability, and regulatory compliance of these systems (European Union, 2018). Integrating these tools within a solid legal and technical framework ensures regulatory compliance, energy efficiency, safety, economic viability, and effective integration into construction and urban development projects. This integration allows geothermal systems to be implemented and operated efficiently, safely, and sustainably.

Describing a GHPs planning tool can be useful for those interested in the installation and optimization of these heating and cooling systems. Below, example planning tools from the GeoBOOST countries; are described with the aim and providing an overview of these tools and their relevance the planning tools used by GeoBOOST countries**.**

- **Austria:** ÖWAV RB 207 freely calculation sheets used in the entire country
- **Germany:** GEO:KW Web App, used by the city of Munich
- **The Netherlands:** Interference Tool Closed Loop Ground Energy Systems (ITGBES) freely calculation sheets and the "pro" version web app used in the entire country.
- **Sweden (Stockholm City)**: Temperature Reduction 3000 calculation programme, used by the city of Stockholm

4.1. Example from Austria

4.1.1. Framework

The use of geothermal heat pumps (GHPs) in Austria gained traction after the 1970s oil crises. Initially, direct evaporation systems with horizontal ground collectors were used. Between 2000 and 2010, GHPs were the most popular heat pump type. However, after 2010, air-source heat pumps dominated the market due to easier installation and fewer regulatory requirements (Goldbrunner and Goetzl, 2022). Between the start of market diffusion and 2022, an estimated total of 604,569 heat pump systems were sold in the Austrian domestic market. Based on the assumption of a 20-year lifespan for these systems, it has been estimated that there were 441,068 heat pumps in operation across various applications in Austria by 2022 (Biermayr and

Prem, 2023). In 2022, air-water heat pumps had an 86.2% market share. Brine-to-water heat pumps were second with a 9.9% share, while water-to-water heat pumps held 1%. Thus, GHPs accounted for about 11% of the market.

GHPs in Austria are predominantly found in smaller-scale installations, with most systems being used for space heating in the residential sector (Biermayr and Prem, 2023). For 2021, ~ 92,000 GHPs were estimated to be operational in Austria, with a total net capacity (excluding electricity consumption of the heat pumps) of around 1,100 MWTh. The total gross heat supply was estimated at 2.3 GWTh for that year (Goldbrunner and Goetzl, 2022).

The development and acceptance of GHPs in Austria results from a combination of factors such as supportive political frameworks, financial mechanisms, and educational initiatives. From a general technical point of view, the most important initial constraints for GHPs deployment are the presence of near-surface groundwater bodies for open systems (groundwater heat pumps) as wells as land availability and access to it for drilling or digging of closed systems (borehole heat exchangers and horizontal collectors).

Legislation and regulatory framework

The federal Water Act (WRG 1959, and amendments) establishes the legal framework governing all uses associated with shallow geothermal methods in Austria.

The Austrian Water and Waste Management Association (ÖWAV), which represents service providers in water supply, and waste management, has issued the following guidelines relevant to thermal interactions:

- ÖWAV RB 207: Addresses the thermal use of groundwater and subsurface areas for heating and cooling.
- ÖWAV RB 208: Relates to drilling procedures for groundwater exploration.

Though the ÖWAV guidelines are not legally binding, the administrative bodies consider them as state of the art. In particular, the ÖWAV RB 207 is considered the most important guideline for the use of shallow geothermal energy in Austria. Nevertheless, some federal provinces have established stricter rules than in ÖWAV RB 207.

Austria has two main licensing procedures in place for shallow geothermal energy systems: *Permitting Procedure* and *Simplified Notification Procedure*. Factors determining which one should be enforced are the geological setting, water protection areas and interactions with other water rights and public installations (including thermal interaction and negative thermal interference) (Rupprecht et al., 2017).

Main governmental institutions involved in fostering GHPs in Austria

- **Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology (BMK):** Oversees the implementation of renewable energy policies and provides funding and regulatory support for geothermal energy projects.
- **Climate and Energy Fund:** Provides financial support for geothermal research and development projects.
- **Geothermal Association of Austria (GTÖ):** Promotes geothermal energy through advocacy, research, and public education. It also organises events and provides resources for stakeholders in the geothermal sector.
- **GeoSphere Austria:** Implements technical and research projects related to geothermal energy, generates hydro-geological data and resource maps. Hosts the recently launched "Geothermie-Atlas", an online information platform displaying geodata and interactive potential calculations for individual borehole heat exchanger installations as basis for the planning procedure.
- **Kommunalkredit Public Consulting:** Handles for example the subsidy programme for heat pumps.

4.1.2. Planning tools for the optimisation of geothermal heat pump system installations.

While Austria does not have specific legal requirements for the installation and operation of GHPs, compliance with the state-of-the-art practices is required (Annex 5). As introduced before, the ÖWAV RB 207 is a recognised nationwide guideline that provides the state of the art. It covers operational criteria like working temperatures and placement procedures such as minimum distance to neighbouring properties. These requirements apply uniformly to both urban and non-urban areas, with no distinctions at the legal level (Rupprecht et al., 2017).

A key point is that pre-existing water rights must remain unaffected. For example, to safeguard drinking water supplies and public interests, restrictions are imposed on constructing and operating geothermal systems. Installations within water protection areas I and II (§ 34, WRG 1959) are typically prohibited.

It should be emphasised that in Austria there is currently no specific "optimisation method" available to assess potential thermal interactions between closed systems, between open systems, or between open and closed systems. The assessment of thermal interactions is based on pre-existing water rights as previously mentioned. This means, that not only other geothermal systems, but all water rights, e.g. groundwater abstractions must be considered in the planning. Groundwater heat pumps are always considered a water right. Closed systems like borehole heat exchangers (BHEs) do not extract groundwater, but they require water law permits under certain conditions (§31c Abs. 5, WRG 1959).

For practical assistance, the ÖWAV RB 207 freely available calculation sheets for open (based on the analytical equations - Annex 4). and closed systems (based on SIA 384/6) can be accessed at: ÖWAV Publications".

- Optimisation method between open and closed loop geothermal heat pump systems

In Austria, thermal interactions between open and closed systems are not explicitly mandated by specific methodologies or integrated regulations. Instead, the ÖWAV RB 207 guideline provides a framework for the individual assessment of open and closed systems, in order to protect pre-existing water rights.

  - Optimisation method between open geothermal heat pump systems

For the planning of geothermal heat pumps with groundwater systems, as mentioned in the ÖWAV RB 207 guideline, hydraulic calculations must be performed, and thermal behaviour should be evaluated through thermal plume simulations. The input data and parameters obtained from the calculations vary according to the methodology employed, but generally include the parameters set out in the table 15.

Table 15. Input and output data

Input data	Output data
Pumping/injection flow rate	Size of the thermal plume
Extracted water temperature	Velocity of the thermal plume
Reinjection temperature	Thermal interference
Groundwater flow velocity	Injected water temperature
Thermal conductivity of the soil and water	Maximum allowable temperature change in reinjection
Thermal dispersion coefficient:	Transit time of the water
Distance between extraction and injection wells	
Local climatic conditions	

Some assumptions of certain parameters must be considered in the calculation. In the case of the injection temperature, this must be between 5 °C and 20 °C, with exceptions for seasonal cooling (it can temporarily drop below 5 °C). The maximum admissible temperature change at re-injection must not exceed 6 K with respect to the original value of the groundwater. The temperature change along the thermal plume must be a maximum of 1 K. If this change is exceeded, it is considered thermal interference which may adversely affect the environment.

- Optimisation method between closed loop geothermal heat pump systems

Borehole heat exchangers

For vertical geothermal heat exchangers (BHEs, Borehole Heat Exchangers) and horizontal collector systems, the ÖWAV RB 207 guideline provides clear instructions on the input data and the parameters (Table 16) obtained from the calculations.

Table 16. Input and output data

Input data	Output data
Distance between BHEs or horizontal collectors	Size of the thermal plume
Temperatures of the heat transfer medium	Thermal interference
Temperatures of the heat transfer medium	Soil and groundwater temperature
Soil properties	Duration of thermal equilibrium
Geological and aquifer data	Energy performance
Thermal loads	
Distance to horizontal collectors	

Some assumptions of certain parameters must be considered in the calculation. The minimum distance between BHEs is 10 m for small heating systems, 5 m is applicable for large BHEs. The inlet temperature of the heat transfer fluid in heating mode must be -3 °C and the outlet temperature must be 0 °C, with an average temperature of -1.5 °C. Finally, the temperature of the heat transfer fluid in cooling mode must not exceed 30 °C and the minimum distance for horizontal collectors must be 1 m from supply lines and structures and 1.5 m from well structures.

4.2. Example from Germany

4.2.1. Framework

Germany's commitment to reducing carbon emissions and promoting renewable energy has been a significant driver in adopting new technologies. GSHPs have seen significant development and growing acceptance in Germany, driven by various factors across political, economic, social, and educational domains.

These main documents built the political and legislative framework.

- **Renewable Energies Heat Act (EEWärmeG)** mandates the use of renewable energy in new buildings.
- **Energy Saving Ordinance (EnEV)** sets standards for energy efficiency in buildings, impacting Ground source heat pump installations.
- **Renewable Energy Sources Act (EEG)** supports the integration of renewable energy sources, including GSHPs, into the national energy portfolio.
- The **Federal Emission Control Act (BImSchG)** and **Building Energy Act (GEG)** also support the implementation of GSHPs by providing guidelines and incentives for sustainable building practices.

The main regulatory body that provides and administers economic incentives for Ground source heat pump installations, such as:

i) Grants and subsidies are mainly the **Federal Office for Economic Affairs and Export Control (BAFA).**

ii) On the other hand, **the Federal Ministry for Economic Affairs and Energy (BMWi)** oversees the implementation of energy policies.

iii) Several other institutions such a **German Heat Pump Association (BWP), German Institute for Standardization (DIN)** and the **Association of German Engineers (VDI)** play important role in Ground source heat pump implementation. **BWP** advocates for the industry, provides information and support to stakeholders, and participates in policy development. While **DIN** and **VDI** develop and maintain standards that ensure the high quality and safety of Ground source heat pump installations.

Germany's experience with Ground source heat pump offers insights into how a combination of supportive legislation, financial incentives, public awareness, and technical standards can drive the adoption of renewable energy technologies.

4.2.2. Planning tools for the optimisation of geothermal heat pump system installations.

- Optimisation method between open geothermal heat pump systems

Introduction and background

Within the framework of the 'Decision in principle II Climate-neutral Munich', the Chair of Hydrogeology of TUM, SWM and City of Munich developed a planning tool that enables a more efficient thermal use of groundwater as a decentralised energy source for heating and cooling as part of the collaborative project "Geo.KW" (2019-2022, project funded by BMWK). The aim of this tool is to enable optimised planning that facilitates the implementation of systems for the thermal use of groundwater and optimises the management of this energy resource, ensuring that the various city-specific consumers are connected to the dynamics and storage potential of groundwater. This makes it possible to cover a higher proportion of the city's cooling and heating needs through the thermal use of groundwater than before and to reduce primary energy needs.

The web application **"Geo.KW"** was designed in such a way that the results can be used in three overarching subject areas:

- Basis for the development of energy strategies
- Information basis for authorisation practice and facilitation of assessment
- Provision of planning principles for specialist planners and urban land-use planning

About programme calculation

The planning tool is available (https://geokw.dyn.mwn.de); but it is necessary to have access to it. The construction of the tool is based on Thermal Aquifer Potential (TAP) method (Böttcher et al., 2019) und Optimised method (Halilovic et al., 2023) (Annex 4).

The planning tool already incorporates information (Table 17) about the area to perform calculations and evaluations.

Table 17. Incorporated information

Assumptions
Well planning map (with available information)
Existing thermal uses (other existing groundwater heat pump systems)
Average annual groundwater temperature
Average groundwater levels

Average distance between the ground and the water table
Average thickness of groundwater
Hydraulic permeability
Groundwater flow velocity

The integrated spatial availability map will allow the visualization of existing wells in order to avoid thermal interference between nearby geothermal heat pump systems. In the availability map, the system (extraction and injection wells) that is intended to be installed can be located. To start calculating, it is necessary to provide the programme with information about the **system's capacity**, the **type of building** and the **required function** (heating and/or cooling).

The programme will calculate the **minimum distance that the extraction and re-injection wells can be positioned**, the **extraction rate per month**, **extraction rate and re-injection rate**, the **temperature difference between the extracted and injected water temperature**, the influence on the system itself, the influence on another system and the influence of the urban heat islands. It will also provide information about the **drilling depth** and whether it is recommended to install a system at that location.

4.3. Example from Sweden

4.3.1. Framework

Sweden has about 1.7 million heat pumps installed. In 2022, about 508,000 of them are geothermal (liquid-to-liquid) heat pumps. Geothermal heat pumps produce about 28 TWh of thermal energy, covering 24 % of the heating energy.

In the 1970s Sweden relied heavily on oil to heat buildings. The huge increase in the price of oil in the years 1974 and 1978 hit Sweden hard and triggered a series of actions. One was to build nuclear power plants. Together with a large amount of hydroelectric power, this kept electricity prices in Sweden low for a long time. Another action was to build district heating systems. Today practically every municipality in Sweden has one - in total there are about 580. For these, sources such as waste, peat, biofuels and waste heat from industrial production are used. CO_2 emissions from district heating are still not negligible at 51.4 g/kWh, most of which comes from burning waste. Looking at primary energy alone, about 60% of total heating comes from district heating, but this drops to 40% when the "free" energy from heat pumps is added. The third major action triggered by the oil price increase was to stimulate research and development of heat pump technology. Public funding supported academic research.

The first geothermal heat pumps (GWHPs) were already in use in the 1980s. However, these were not very efficient, and the solution acquired a bad reputation. At the same time theoretical analysis tools and software for simulating effect of extracting and injecting heat in the bedrocks were developed at a few Universities in Sweden, Germany and USA. Public financing supported the academic research. Effective GHPs were developed in the 1990s and were used with closed loop systems that are easier to install and maintain compared to open-source systems. At the turn of the century, driven by high oil prices, government subsidies (there are still some subsidies for private homeowners) and cheap electricity, the number of systems really started to skyrocket.

Several factors contributed to the strong development of GHPs in Sweden (Annex 4). Factors such as i) early advanced development of heat pump technologies and drilling equipment, ii) favourable geology and climate, iii) early academic development (Methods and software, E.g. Earth Energy Designer), iv) cheap electricity, v) timely government subsidies, and vi) simple permitting procedures.

Legislation and regulatory framework: Simple permit management

All municipalities in Sweden have an environmental department (sometimes together with other municipalities). The environmental department is the entity that issues the permit to install a geothermal heat pump, including drilling (or excavation). The process is simple, a simple form needs to be filled out and sent to the department. Provided there is no problem with neighbours being too close (at least 20 meters from adjacent wells), water protection issues or the need to drill on contaminated land, permission is almost always granted. And usually within a few weeks. Each drill must be reported on a simple form, can be done interactively and sent to the Swedish Geological Survey; it is a quick procedure. This light bureaucracy also facilitates the spread of GHPs.

4.3.2. Planning tools for the optimisation of geothermal heat pump system installations.

- Optimisation method between closed loop geothermal heat pump systems

Introduction and background

The increased interest in heat pumps has meant that even small house owners in densely built-up areas want to install geothermal heating. Many municipalities require that the distance between two energy wells must be at least 20 metres. If the distance is to be less than 20 metres, you should therefore be able to show how the impact on the ground and nearby energy wells must be reduced.

The Swedish Energy and Heat Pump Association (SEV) in collaboration with The City of Stockholm's environmental centre for companies has drawn up a proposal for how energy wells should be dimensioned with long-term (25 years) consideration of thermal impact between nearby energy wells. Based on this proposal, a calculation programme has been developed (Annex 5). The calculation programme, called **Temperature Reduction 3000**, is based on simulations by Göran Hellström, LTH. The purpose of the calculation programme is to in a uniform, authoritative and relatively simple way, make possible for heat pump installers, well drillers and municipalities to assess the appropriate dimensioning and placement of energy wells in densely built-up, residential areas.

About the calculation programme

The planning tool is available online and can be downloaded https://boende.stockholm/energi-uppvarmning/varmepump/borra-i-innerstad-eller-radhusomrade/ .

The planning tool is based on the following assumptions (Table 18) to perform calculations and evaluations.

Table 18. Programme Assumptions

Assumptions
Distance between ground level and groundwater surface is 5 metres
The heating demand is the same every year and the heating factor is 3.3 (annual average)
Normal active drilling depth for heat pump 5 kW is 90 metres
Normal active drilling depth for heat pump 7 kW is 125 meters
Normal active drilling depth for heat pump 9 kW is 160 meters
Normal active drilling depth for heat pump 11 kW is 195 meters
Drill hole diameter 115 mm
Normal power and energy consumption is 39 W resp. 165 kWh/year per meter borehole
Energy coverage space heating demand has been assumed to be 90%
The space heating requirement is 20,000, 28,000, 36,000 and 44,000 kWh/year for heat pump 5, 7, 9 and 11 kW respectively
Energy requirement for domestic hot water is 3,500 kWh (energy coverage 100%) for VP 5 kW
Energy demand for domestic hot water is 5,000 kWh (energy coverage 100%) for VP 7, 9 and 11 kW respectively
Thermal conductivity rock Low = 3.0 Medium = 3.5 High = 4.0 W/m,°K
The result applies to the impact after 25 years

When dimensioning energy wells in densely built-up areas, it is suggested that consideration be taken to both existing and possibly additional wells within a radius of 50 metres. For the verification of the wells, this page can be used https://etjanster.stockholm.se/Varmepump/hur-har-grannarna-borrat (The calculation programme can handle up to 16 neighbours).

To start the calculation, the size of the heat pump in kW (active borehole depth) for the energy well to be sized must be entered. The thermal conductivity of the source rock must also be entered. In addition, the information of the neighbouring wells must be included.

The program calculates how much you need to increase the drilling depth at the densest placement of energy wells to counteract the temperature drop in the ground affecting existing and future energy wells nearby.

4.4. Example from The Netherlands

4.4.1. Framework

The development of geothermal heat pumps (GSHP) in the Netherlands has been on an upward trajectory, driven by the growing need for sustainable heating and cooling solutions. As the country has moved forward in its energy transition towards a carbon-neutral future, GSHPs have gained popularity as a key technology to reduce greenhouse gas emissions and decrease dependence on fossil fuels, especially natural gas.

The political context in the Netherlands has played a key role in the uptake of GSHPs. The country's commitment to the Paris Agreement and its own 'Energy Strategy 2050' have set ambitious targets for reducing CO2 emissions and improving energy efficiency. In this framework, geothermal heat pumps present themselves as a viable and sustainable option for heating homes and commercial buildings, especially considering the decision to phase out natural gas as a heating source, following the crisis related to gas extraction in Groningen.

The economic acceptance of GSHPs has been facilitated by a number of government incentives and subsidies. The Investeringssubsidie Duurzame Energie en Energiebesparing (ISDE) is one of the key programmes offering financial support for households and businesses to invest in renewable technologies, including geothermal heat pumps. As the price of fossil fuels increases, ground source heat pumps become more competitive, cementing their place in the Dutch energy market.

From a societal perspective, growing environmental awareness among the population has favoured the adoption of GSHPs. Concerns about climate change and the environmental impacts associated with traditional forms of heating have driven the preference for sustainable alternatives. The development of new residential and commercial areas with high energy efficiency standards has been an additional catalyst for the implementation of geothermal systems.

However, the economic factor has also been accompanied by an effort to educate and train professionals in the design and installation of these systems. Institutions such as BodemenergieNL, the Dutch Association for Geothermal Energy, have played a crucial role in creating training and certification programmes to improve the quality standards of installations and ensure their efficiency.

Institutions involved in promotion and regulation

- BodemenergieNL: The Dutch Association for Soil Energy is a key player in the promotion of GSHP technology.
- Dutch Ministry of Economic Affairs and Climate Policy is responsible for setting overall climate and energy targets, overseeing policies that promote the uptake of renewable energy, including subsidies and financial incentives for GSHPs.
- Rijkswaterstaat oversees the sustainable management of water resources.
- Regional water authorities (Waterschappen) are responsible for granting permits for open-loop GSHP systems, ensuring that they do not adversely affect groundwater levels or quality.
- Municipalities responsible for granting building permits, especially for closed-loop GSHP installations in urban areas.
- Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO), managing financial incentives and programmes, such as ISDE, aimed at promoting sustainable energy technologies, including GSHPs.

Legislation and regulatory framework

In the Netherlands both open loop and closed loop systems are regulated by national, regional and (closed loop systems) municipal laws. Before 2013 only open loop systems were regulated under the "water law", all systems with a capacity over 10 m3/hr required a permit that was issued by the regional authority. This changed in 2013 with an amendment to the law also requiring a registration for small (< 70 kW ground thermal capacity systems) and permit for large, closed loop systems where the municipality is the authority. Also, rules were defined in law with regard to e.g. injection temperatures and monitoring. A national registration system was implemented (www.wkotool.nl) that provides basic information on all systems and indicates zones of special interest (ground water protection areas, interference zones).

One of the legal requirements is that all companies are certified to work on ground source energy systems according to the BRL 2100 (drilling), BRL 11000 (underground aspects of ground source energy) and RL 6000-21 (aboveground aspects of ground source energy).

In January 2014 a new law came into effect (the "omgevingswet"), in principle this only changes the legal framework, the technical procedures and requirements have not been changed. Only in this new law the municipalities are allowed to define more detailed and specific rules also outside the zones of interference.

4.4.2. Planning tools for the optimisation of geothermal heat pump system installations.

- Optimisation method between closed loop geothermal heat pump systems

Introduction and background

In the Netherlands currently about 120.000 closed loop systems and 2000 open loop systems have been installed, with a growth of about 20.000 per year (situation 2023). Regulations regarding design and installation of ground source heat pumps systems are in effect for all systems since 2013. As e Netherlands is a very densely built country (distance between houses are usually small, between the centroid of neighbouring plots a distance of 6 – 8 meters is common) in addition to the design there were concerns about possible negative thermal interactions (negative thermal interference) between systems that cannot be taken into account during the design of the system (e.g. because parameters of the neighbouring systems are not known).

Therefore, Groenholland Geo-energy systems was commissioned in 2011 by the Dutch government to develop a general methodology and simplified tool to assess thermal interference between closed loop systems (SIKB 2013; SIKB 2020; Witte, 2011; Witte 2018). This tool, called ITGBES (Interferentie Tool Gesloten Bodem Energie Systemen or Interference Tool Closed Loop Ground Energy Systems, Groenholland 2020), is now in use since 2013 and a free automated (excel) version has been developed in 2020.

Other methods are used as well. The software MLU (developed for evaluation of pumping tests) is used to calculate thermal influence zones of closed loop systems. When interactions with open loop systems or natural ground water flow needs to be considered codes that allow the calculation of combined hydro-thermal effects such as Feflow are used.

About the calculation programme

The tool is based on the well-known Finite Line Source method (also used for the calculation of the so-called G-functions for many design calculation tools). The free excel tool (https://www.sikb.nl/doc/ITGBES_v0211.xlsm) has a simple approach, thus calculating the thermal interactions as a function of the net heat extraction rate per meter depth per year (kWh/m2/year) and where a maximum of 20 systems can be evaluated. There is a 'pro' version (www.itgbespro.nl), which does not have these limitations.

The WKO Tool and the local authority must be consulted to start the calculation. Information on all open loop systems within a search radius of about 750 meters is requested as well as information on large (> 70 kW ground thermal capacity) closed loop systems within a search radius of 350 meters and all other closed loop systems within a search radius of 120 meters.

Data must be entered in the free excel tool ITGBES (Table 19) (https://www.sikb.nl/doc/ITGBES_v0211.xlsm) for the calculation.

Table 19. Input data

Data
Thermal conductivity of the soil (W/mK)
Number of systems in the evaluation (n)
Coordinates of the system (Dutch RD or Cartesian X- and Y- in meters)
Total length of the borehole heat exchangers (m)
End-depth of the borehole heat exchangers (m)
Thermal capacity on the ground of the system (kW)
Total heating demand (MWh)
Total cooling demand (MWh)
Cooling system SPF (default: 20)

With the information entered, the thermal interactions between closed-loop systems and the distance between them are calculated as a function of drilling depth, total heat and total cooling supplied to the user and overall system efficiency (SPF). The tool calculates the net heat extraction rate (kWh/m/year) and a thermal interference map to show the spatial distribution of assigned net heat extractions or temperature effects.

4.5 SWOT analyses of planning tools

The SWOT analysis and the Evaluation of External and Internal Factors allow for understanding and continuously improving planning tools for open and closed loop systems. This approach helps to identify and prioritise the key aspects to be considered in the development of planning tools. By assessing and prioritising factors in terms of their competitiveness, it ensures that tools are effective and adaptable to a constantly changing environment. Additionally, the SWOT analysis considers broader objectives such as promoting the sustainable and efficient use of geothermal resources.

SWOT highlights the strengths, weaknesses, threats, and opportunities of the plannings tools of Austria, Germany (Munich City), Sweden (Stockholm city) and The Netherland for geothermal heat pump systems in the context of their current and future implementation. It is important to mention that although there is currently no specific "optimization method" in Austria to evaluate potential thermal interactions between systems, the ÖWAV RB 207 spreadsheets available for open systems (based on the analytical equations that will be described below) and closed systems (based on SIA 384/6) in: ÖWAV Publications. These spreadsheets serve as a constraint tool for the construction and operation of geothermal heat pump systems.

For the analysis, 29 (Annex 7) criteria were determined (Table 20) based on strengths, weaknesses, opportunities, and threats for planning tools. The criteria were weighted on a scale of 100, and the applicability of each was assessed based on planning tool development information provided by each country.

Table 20. SWOT analysis; criteria and weights

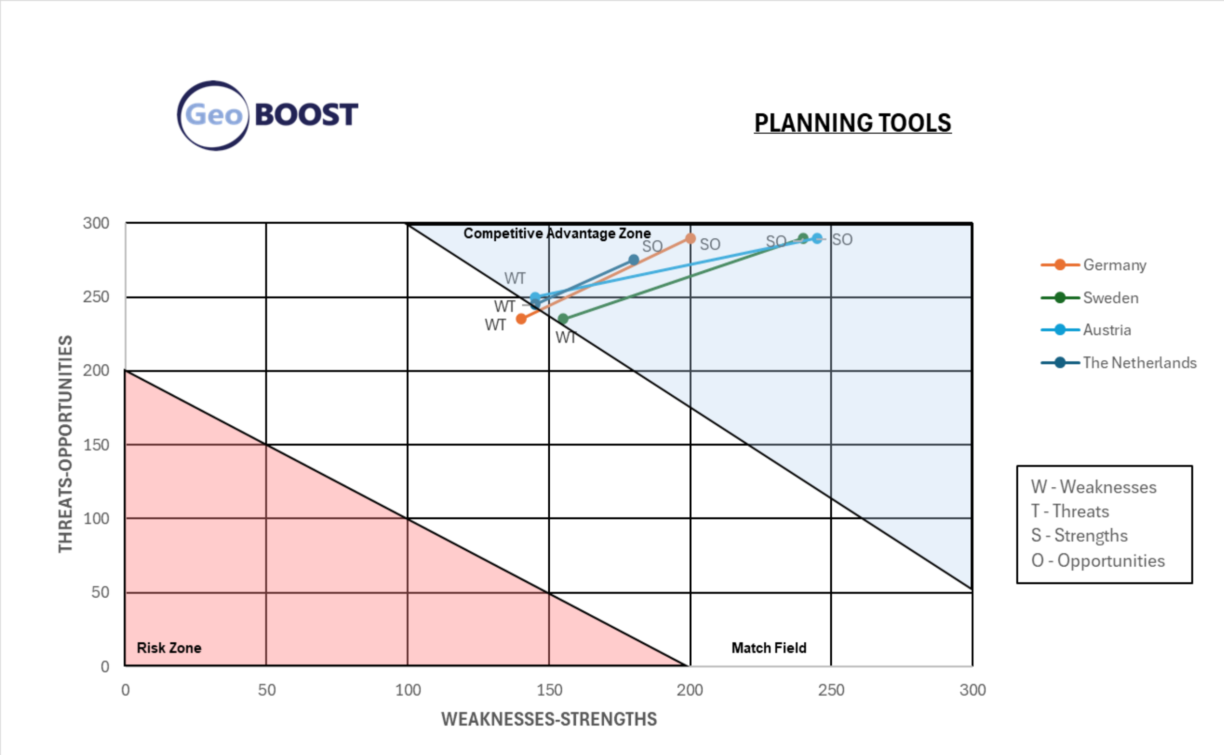
	STRENGTHS	Weight		WEAKNESSES	Weight
1	Adaptability to urban and rural areas	15	**1**	Difficult tool to understand and execute	20
2	Application for different GHP systems (open and closed systems)	10	**2**	Operational problems of the tool	15
3	Free access	20	**3**	Require advanced hardware	10
4	Performance measurement	10	**4**	Large amount of required data for the calculations	15
5	Detailed modelling results	15	**5**	Restrictive calculation results for future installation	10
6	Clear information on calculation results	10	**6**	Constraints and restrictions to upgrade and innovate	10
7	Functionality for handling calculation or modelling errors	5	**7**	Limited handling/processing of information for large-scale or complex projects	20
8	Incorporation of local norms and standards	5			

9	Integrated geothermal databases	10			
	OPPORTUNITIES	**Weight**		**THREATS**	**Weight**
1	Consolidation of the planning tool to be used in mature markets	15	**1**	Changes in European policies	15
2	Transfer of tool usage to other regions/jurisdictions	15	**2**	Expensive regulatory requirements	15
3	Facilitates decision-making	20	**3**	Changing energy needs	10
4	Use of local and regional resources	10	**4**	New planning tools emerge	20
5	Integration into energy action plans	15	**5**	Requirement for constant updating and maintenance of planning tool	20
6	Map and plan heating and cooling energy demand based on sub-surface resource data	15	**6**	Lack of data availability in the area of future installation	20
7	Development of long-term energy supply	10			

The analysis results are represented in the "**PLANNING TOOLS"** graph (Figure 3). It shows that all the plannings tools are in the high competitiveness zone, indicating a significant opportunity that should be seized. This means that all the tools play an essential role in ensuring the long-term efficiency of neighbouring geothermal heat pump systems and geothermal resource management, as well as minimizing risks. Therefore, the development of planning tools should be prioritized to be integrated into a robust and solid regulatory framework.

The graph shows that the planning tools of the three countries are in the "Competitive Advantage Zone," indicating that they have more strengths and opportunities compared to their weaknesses and threats. All countries have high scores in opportunities, indicating a favourable environment for development. Strengths are higher for Austria, Sweden and The Netherland compared to Germany, which may be because the German planning tool is not **free access**. Weaknesses are higher for Sweden, Austria and The Netherland indicating areas for improvement. This may be due to the **large amount of data required for calculation**. Germany has the fewest threats, suggesting a safer and more stable environment.

Figure 3. SWOT Analysis for Planning Tools



As mentioned, the analysis reveals that the three countries are well-positioned in terms of strategic planning for geothermal heat pump systems. The development of planning tools has been based on the energy, economic, social, geological, and financial context of each country. This has enabled the enhancement and safeguarding of an energy alternative, shallow geothermal energy, as well as the development of solutions and innovations to meet the needs of society.

5. Recommendations

5.1. Thermal interferences and interactions

Understanding *thermal interaction* and *thermal interference* is essential in the design and operation of Geothermal Heat pump Systems. These two variables affect the efficiency, sustainability and long-term performance of these systems. Therefore, defining the terms thermal interference and thermal interaction clearly is critical, as it is a key issue to enable sustainable regulation and licensing of resources. It is also relevant in the regulatory framework of each country (Pasquali and O'Neill, 2015).

While a clear legal definition of the above terms is essential for an effective regulatory regime, formulating such a definition can be challenging. Therefore, definitions for the terms thermal interface and thermal interaction (section 3.2.1) are proposed in this report. Depending on the different studies carried out in each country, threshold values can be added to determine the degree of tolerance of both phenomena. Therefore, this definition is flexible and adaptable to the reality of each region.

5.2. Technical and legal aspects

Geothermal heat pump systems are a highly efficient and versatile technological solution for heating and cooling buildings, reducing reliance on fossil fuels. In recent years, the number of installations has increased, especially in urban areas. Therefore, measures must be taken to ensure the efficiency and sustainability of these systems. This is why the consideration of a robust legal and technical framework is essential to prevent and avoid thermal interference between systems in an area.

From a technical perspective, proper design and planning (Lund and Sanner, 2019) are essential to maximise system efficiency (Flach, 2020) and ensure long-term performance (Megies, 2021). From a legal standpoint, relevant regulations and norms (Flach, 2020) are vital to protect the rights of all involved parties (Megies, 2021) and avoid costly litigation (Lund and Sanner, 2019). Therefore, both legal and technical aspects are relevant for the proper management of *thermal interference*, significantly contributing to the success and viability of geothermal heat pump systems.

As a result of the analysis conducted in section 3.2, and thanks to the key points identified regarding thermal interference, a range of requirements or allowed margin is proposed for legislative conditions, as well as the legal status of regulation elements for the proper management and planning of GHP systems.

Table 21. Range of requirements or allowed margin for regulation elements of open-loop systems

Regulation Element	Range of requirements or allowed margin
1) Distance	
Minimum distance to neighbouring plot (property line)	Each jurisdiction must establish a specific minimum distance for neighbouring properties, considering relevant legal and regulatory factors (local) in each location and the characteristics of the environment.
Distance to next building	For the safety of the driller, it must be established a distance. This distance should be specifically determined in each jurisdiction, considering local legal and regulatory requirements regarding developments close to property boundaries.
Distance to drinking water well.	A specific minimum distance must be determined through a detailed assessment of hydrogeological conditions and by consulting the applicable regulations in each area, especially in relation to existing extraction licenses.
Distance to other public installations	The distance to consider to public installation must be determined to protect installations. considering relevant legal and regulatory factors (local) in each location and the characteristics of the environment.
Distance to other uses wells	A specific minimum distance must be established by consulting the applicable regulations in each area, especially in relation to existing licenses.
Minimum distance to neighbouring Ground source heat pump installation	A minimum distance between an open-loop and a closed-loop system must be established through a careful assessment based on local soil conditions and considering the temperature to protect current installations.
Minimum distance to neighbouring Groundwater heat pump installation	A minimum distance must be considered. However, this should be evaluated considering the draw down of the neighbouring well to avoid affecting its functionality.
2) Temperature	
Temperature difference of the reinjected water	It is relevant to establish a temperature difference. In the studied countries, a recommended temperature difference of 5°K-8°K is observed. It is recommended to set this measure through an evaluation of the temperature difference between the extracted water and the reinjected water (injection point/position).
Absolute allowed Tmin of reinjected groundwater	The minimum reinjection temperature to consider is 3°C to avoid freezing. However, this may increase depending on an assessment of local hydrogeological conditions and regulatory requirements.

Absolute allowed Tmax of reinjected groundwater	The maximum reinjection temperature is 18°C to avoid cooling and heating in urban areas. However, this may increase or decrease depending on an assessment on hydrogeological conditions and regulatory requirements.
Relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature.	The relative value describing the accepted ΔT to consider is 4°C. However, the difference between the area disturbed by the system's operation and the undisturbed natural temperature can be determined through assessment.
3) Extraction and discharge	
Reinjection for GWHP (SGS-W)	Reinjection should be allowed to maintain the water balance. However, this can be evaluated if conditions are adverse, and the pertinent authorities make the decision. A reinjection volume limit threshold should be established by assessment.
4) Seasonal performance of installation	
Evidence/register of Geothermal heat pump production	The register or evidence of geothermal heat pump production must be submitted or made available to the authority. A data collection structure is proposed in deliverable 2.1 of the GeoBOOST project.
5) Size and layout of the Geothermal heat pump installation	
Evidence/register of drilling data	The register or evidence of drilling data must be submitted or made available to the corresponding authority. A data collection structure is proposed in deliverable 2.1 of the GeoBOOST project.
Borehole drilling report	The Borehole drilling report of wells must be submitted or made available to the authority.
6) Subsurface conditions	
Evidence/register of geothermal data	The record or evidence of geothermal data must be submitted or made available to the authority.
Evidence/register of Groundwater extraction	The record or evidence of groundwater extraction must be submitted or made available to the authority. Allowing authorities to set a threshold for minimum monitoring and reporting requirements.

The regulation elements for Geothermal heat pump systems are applicable to ATES systems. However, criteria o value range applicable to both GHPs and ATES systems may require specific adaptations due to their interaction with the aquifer and their larger scale and thermal storage capacity. Therefore, an assessment is recommended to determine specific values or emphasize their mandatory nature. For example:

- Distance between reinjection and extraction well: It is very important to avoid thermal interference between the injection and extraction wells, with distances that may be greater than in GHP systems due to the scale of the system.

- Minimum distance to neighbouring GWHP installation: This is important for similar reasons but with a greater focus on aquifer management.
- Temperature Difference of the Reinjected Water: The ΔT limits may be stricter compared to OLS due to the larger scale of the system.
- Relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature: This is very relevant due to the greater thermal influence on the aquifer. The limits may be stricter to maintain the thermal stability of the aquifer.
- Reinjection for GWHP (SGS-W): This is important to ensure the efficiency and sustainability of the system.
- Evidence/register of drilling data: This is essential due to the larger scale of drilling operations.
- Evidence/register of groundwater extraction: This is fundamental for the sustainable management of the aquifer.

It is important that regulations are adapted to the characteristics of each type of system to ensure their safe and efficient operation.

Table 22. Range of requirements or allowed margin for regulation elements of closed-loop systems

Regulation Element	**Range of requirements or allowed margin**
1) Distance	
Distance to Next building,	For the safety of the driller, it must be established a distance. This distance should be specifically determined in each jurisdiction, considering local legal and regulatory requirements regarding developments close to property boundaries.
Minimum distance to neighbouring plot (property line)	Each jurisdiction must establish a specific minimum distance for neighbouring properties, considering relevant legal and regulatory factors (local) in each location and the characteristics of the environment.
Distance to drinking water well.	A specific minimum distance must be determined through a detailed assessment of hydrogeological conditions and by consulting the applicable regulations in each area, especially in relation to existing extraction licenses.
Distance to other public installations	The distance to consider to public installation must be determined to protect installations. considering relevant legal and regulatory factors (local) in each location and the characteristics of the environment.

Distance to other uses wells	A specific minimum distance must be established by consulting the applicable regulations in each area, especially in relation to existing licenses.
Minimum distance to neighbouring Ground source heat pump installation	The minimum distance must be established through an assessment to avoid impacting neighbouring systems, that is, to prevent thermal interference between the systems.
Minimum distance to neighbouring Groundwater heat pump installation	The distance between systems must be established through an assessment to prevent interference between the systems.
2) Temperature	
Absolute allowed Tmin of reinjected heat carrier fluid	The minimum reinjection temperature to be considered to prevent soil cooling can be established through an assessment of local hydrogeological conditions and regulatory requirements.
Absolute allowed Tmax of reinjected heat carrier fluid	The average maximum temperature to be considered in the studied countries is 30°C. However, this may vary depending on the geology (groundwater or rock type) or the type of system (closed loop or BTES). Therefore, it is recommended to conduct an assessment to establish or determine the value of this parameter.
Relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature.	The minimum temperature difference should be established trough assessment so as not to affect neighbouring systems.
4) Seasonal performance of installation	
Evidence/register of Geothermal heat pump production	The record or evidence of heat pump production must be submitted or provided to the corresponding authority. A data collection structure is proposed in deliverable 2.1 of the GeoBOOST project.
5) Size and layout of the Geothermal heat pump installation	
Evidence/register of drilling data	The evidence or record of drilling data must be submitted or provided to the corresponding authority. A data collection structure is proposed in deliverable 2.1 of the GeoBOOST project.
Borehole drilling report	The Boreholes drilling report of wells must be submitted or provided to the authority.
6) Subsurface conditions	
Evidence/register of geothermal data	The evidence or record of geothermal data must be submitted or provided to the corresponding authority. However, this may be subject to the system's capacity
Evidence/register of heat exchanger	The evidence or record of heat exchangers must be submitted or provided to the authority.

The regulation elements of closed-loop systems can be similar to those of BTES. However, they may require specific adjustments in regulations due to their larger scale, storage capacity, and potential thermal impacts. Therefore, an evaluation is recommended to determine specific values or emphasize their mandatory nature. For example, for regulation elements:

- Minimum distance to neighbouring Ground source heat pump installation. The distance can be critical due to the larger scale and thermal accumulation in BTES.
- Minimum distance to neighbouring GWHP installation: This value is especially important for large storage volumes.
- Relative value describing the accepted ΔT between disturbed temperature and undisturbed ambient temperature: This is a more critical value due to the greater thermal variability in large storage systems.
- Evidence/register of drilling data: It is decisive due to the larger scale and potential depth of the drillings.

It is important that regulations are adapted to the characteristics of each type of system to ensure their safe and efficient operation.

Legal Framework

Based on the results provided by the regulatory impact analysis and the relevance of these elements in the planning of open and closed loop systems, it is proposed that all regulation elements identified to prevent thermal interference should have mandatory legal status. The obligatory legal status of regulation elements in geothermal heat pump systems is essential to prevent thermal interference between systems and ensure their long-term efficiency, sustainability, and safety. These regulations not only protect individual users but also contribute to research development and environmental protection, fostering confidence in this technology and promoting its widespread adoption.

Obligatory requirements may make geothermal heat pump installations less attractive. However, complementary measures and compensatory strategies can be implemented:

- Financial and Tax Incentives

Provide i) grants and tax credits to homeowners installing geothermal heat pump systems, significantly reducing the initial cost, ii) low-interest loans tailored for geothermal heat pump installation projects, helping to spread costs over time, and iii) reduced energy tariffs for geothermal system users, offering ongoing savings to offset regulatory compliance costs.

- Certifications

Provide sustainability and energy efficiency certifications that enhance property value.

- Technical Support

Offer free or subsidized consultancy and technical assistance services to help homeowners and developers plan, design, and implement geothermal heat pump systems that comply with regulations.

- Simplification of Processes

Ensure i) clear and simplified regulations, meaning they are clear, coherent, and easy to understand. Simplifying bureaucratic and administrative requirements can reduce the burden on property owners and developers, and ii) centralize the management of all necessary permits and licenses through a single office to streamline the process and reduce the time and effort required.

- Promotion of Sustainability and Long-Term Benefits

Highlight successful case studies and pilot projects that demonstrate the economic and environmental benefits of geothermal systems, encouraging others to follow their example.

- Engagement and Commitment

Involve the community and stakeholders in the development and review of regulations through consultations and workshops, which can increase acceptance and support.

5.3. Planning tools

Planning tools enable informed decision making in the selection and design of systems that consider local conditions, maximise energy efficiency (Lund et al., 2021), facilitate implementation and maintenance, reduce operating costs and ensure return on investment. On the other hand, the use of the tool promotes the reduction of CO_2 emissions and ensures the sustainability of the resource (Bayer et al., 2019). In summary, the planning of open and closed heat pump systems is important for the continued development of geothermal heat pumps system, as they maximise energy efficiency, reduce environmental impact, improve economic viability and facilitate the implementation and maintenance of these systems.

Based on the SWOT analysis, some recommendations can be made to countries that need to develop their own planning tools for open and closed systems of GHPs.

1) The planning tools should be adaptable to rural and urban areas, considering local factors (e.g., climate) to maximise their applicability and use.

2) It is important that this tool has the capability to measure its performance and provide detailed, clear, and actionable results, thus facilitating decision-making based on precise data.

3) The tool should integrate geothermal databases for more efficient use of resources.

4) The current context of technological infrastructure should be considered in the development of the tool, to avoid limitations in accessibility and difficulties in understanding and execution.

5) The planning tool to be developed should be designed for future adoption in different regions and jurisdictions, facilitating standardization and international cooperation.

6) It is essential to invest in continuous research and development of the tool, ensuring it stays at the forefront of technology and market needs.

Implementing these recommendations can facilitate the effective and successful development of planning tools for open and closed systems of GHPs.

6. Conclusion

This document highlights the importance of developing a robust legal and technical framework in Europe, a significant advancement in the European Union's determined path towards the integration of renewable energies and the achievement of carbon neutrality. The results of the analysis have underscored the importance of understanding thermal interactions and thermal interferences, crucial factors that affect the efficiency, sustainability, and long-term performance of these systems. Clearly defining these terms is essential not only for the regulatory framework but also to avoid legal conflicts and optimize system design.

The report proposes relevant regulation elements for better design and management of geothermal heat pumps (GHPs), minimizing thermal interferences and maximizing energy efficiency. Through individual analysis and cross-country comparison of these regulation elements, a significant gap has been identified between the legal and technical status of these elements. Therefore, recommendations on the legal and technical status of each are proposed. These recommendations will ensure the successful management of shallow geothermal energy, the strategic deployment of new geothermal heat pump installations, and the visibility, trust, and investment in the technology.

Finally, the analysis of best practices and the recommendations presented in this document highlight the need for a robust technical and legal framework that integrates the management of geothermal resources in both open and closed systems. This will promote greater awareness and adoption of geothermal heat pump systems as a viable and efficient renewable energy source, significantly contributing to the energy transition and environmental sustainability.

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Annex 1. Literature review checklist

Authors using the term "thermal interaction"

Thermal interaction in a closed system

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Annex 2. List of projects

REGEOCITIES (2012-2015)

This project was focused on the achievement of the National Renewable Energy Action Plans (NREAP) geothermal targets 2020 marked by countries with ambitious objectives regarding Shallow Geothermal (SGE) systems by means of the removal and clarification of the non-technical administrative/ regulatory barriers at local and regional level. The ReGeoCities project worked on the integration of shallow Geothermal Energy at a local and regional level. It examined and promoted best practices and an intelligent regulatory framework, supporting cities to reach their SEAPS and the 2020 climate and energy goals. It developed the Heat Under Your Feet campaign that promotes greater awareness about the ground source heat pump industry in Europe.	
Key objectives - Develop the use of the common methodology for regulating the implementation of SGE systems at European scale. - Develop local competencies on SGE systems with the help of the training program defined during the project. - Increase and enhance the GSHP market in the European regions by the elimination of current regulative barriers and the dissemination of SGE systems to European key actors. - Integrate the SGE technologies into the SMART CITIES concept in order to obtain implementation of sustainable and high efficient systems into public and family buildings.	**Results relevant to GeoBOOST** - General report of the current situation of the regulative framework for the SGE systems[1] - Developing geothermal heat pumps in smart cities and communities - Recommendation guidelines for a common European regulatory framework[2]

[1] D2.2: General Report of the current situation of the regulative framework for the SGE systems
[2] Recommendation guidelines for a common European regulatory framework

GRETA 2015 – 2019

The GRETA project studied the opportunities, technical issues and economic viability of applying near shallow geothermal energy to villages, public buildings with specific constraints and isolated Alpine huts. The project elaborated geothermal potential maps as decision support tools for the integration of SGE into policy instruments, e.g. energy plans and strategies. The strategies for the inclusion of SGE in policy instruments were also formulated, contributing to increase of SGE utilization. Thanks to GRETA, people can learn about the potential for shallow geothermal energy in their area; administrators can take advantage of policy guidelines; and everyone can better understand how long it takes for the initial investment to pay back. With this knowledge, a new heating system can be developed.	
Key objectives - Increasing knowledge on the spatial distribution of SGE potential in the area - Exchanging knowledge and best practices on a transnational base	**Results relevant to GeoBOOST** - Overview and analysis of regulation criteria and guidelines[1] -Harmonized guidelines for legal and technological procedures[2]

GeoPLASMA-CE 2016 – 2019

The project aimed to foster the share of shallow geothermal use in heating and cooling strategies in central Europe. The project created a web-based interface between geoscientific experts and public as well as private stakeholders to make the existing know-how about resources and risks associated to geothermal use accessible for territorial energy planning and management strategies in Central Europe. The project is supported by the Interreg Central Europe Program, which is funded by the European Regional Development Fund.	
Key objectives - Fostering the share of SGE use in H&C strategies in Central Europe entities - Transferring knowledge from scientific experts to public authorities and related entities in the participating countries.	**Results relevant to GeoBOOST** - Catalogue of success criteria for a sustainable management of SGE use[3] - Summary of national legal requirements, current policies, and regulations of shallow geothermal use[4] - Catalogue of reviewed quality standards, current policies and regulations5

[1] D2.1.1 – Overview and analysis of regulation criteria and guidelines for NSGE applications in the Alpine region
[2] D2.3.1 – Definition of the guidelines for legal and technological procedures
[3] D.T. 2.5.1. Catalogue of success criteria for a sustainable management of Shallow geothermal energy use
[4] D.T2.4.1. Summary of national legal requirements, current policies, and regulations of shallow geothermal use
[5] D.T2.4.2 Catalogue of reviewed quality standards, current policies, and regulation

GEO4CIVHIC 2018- 2022

The main goal of GEO4CIVHIC is to develop and demonstrate easier to install and more efficient GSHEs, using innovative compact drilling machines tailored for the built environment & developing or adapting HPs and other hybrid solutions in combination with RES for retrofits through a holistic engineering and controls approach improving the return of investments. GEO4CIVHIC's target is to accelerate the deployment of shallow geothermal systems for heating and cooling in retrofitting existing and historical buildings. It is based on innovative solutions investigated by an international expert group of companies and research centres.	
Key objectives - Identify and where missing develop building blocks solutions in drilling (machines and methods), GSHE types, heat pumps and other renewable energy/storage technologies, heating, and cooling terminals with the focus on every type of built environment, civil and historical - Generate and demonstrate the easiest to install and cost-effective geothermal energy solutions using and improving existing and new tools.	**Results relevant to GeoBOOST** - Regulatory analysis overview guide on the implementation of renewables and GSHP in retrofit scenarios and historical buildings[1] - Environmental Impact of GEO4CIVHIC technologies at case study sites - Recommendations for the planning and implementation of new GSHP systems in dense urban environments and related too

Managing Urban Shallow Geothermal Energy 2018 –2021.

MUSE was one of the GeoERA projects under the GeoEnergy theme. It investigated resources and possible conflicts of use associated with the use of shallow geothermal energy (SGE) in European urban areas and delivered key geoscientific subsurface data to stakeholders via a user-friendly web based GeoERA information platform (GIP). The assessment of geothermal resources and conflicts of use lead to the development of management strategies considering both efficient planning and monitoring of environmental impacts to feed into general framework strategies of cities like Sustainable Energy Action Plans (SEAPs). The overall aim of the MUSE project is to support methodologies and concepts for an efficient and sustainable use of SGE in the urban areas for heating, cooling and seasonal heat storage that can be implemented across Europe	
Key objectives - Develop strategies for efficient and sustainable use of SGE in European urban areas. - Transferring knowledge from scientific experts to public authorities and related entities in the participating countries. - Identifying, summarising, and developing state-of-the-art methods	**Results relevant to GeoBOOST** - Evaluated currently existing regulation measures and provided a sound basis for tailored management strategies - Management guidelines and specific measures and actions to integrate SGE use into urban energy supply

[1] D6.3. Recommendations for the planning and implementation of new GSHP systems in dense urban environments and related tool.

[2] D3.1. Report on the current legal framework, procedures and policies on SGE use in selected European cities

Annex 3. List of questionnaires

Questionnaire used by GeoPLASMA-CE for D.T2.4.1

D. REGULATION ELEMENTS FOR THE INSTALLATIONS, IMPLEMENTATION AND OPERATION OF SHALLOW GEOTHERMAL ENERGY SYSTEMS

D. Regulation elements for the installations, implementation and operation of shallow geothermal energy systems (SGES)							
		PILOT AREA				GENERAL	
	Regulation element	Requirements				National regulation	Other regulations
ALL SYSTEMS	Drilling below groundwater table allowed						
	Minimum distance to neighboring plot [m]	GWHP:		BHE:			
	Minimum distance to buildings [m]	GWHP:		BHE:			
	Minimum distance neighboring wells [m]	GWHP:		BHE:			
	Minimum distance to neighboring closed loop systems [m]	GWHP:		BHE:			
	Groundwater investigations necessary (Hydrochemistry)	GWHP:		BHE:			
	Certification for drilling companies needed						
	Certification for planners or installers needed						
	Numerical simulations required						
OPEN LOOP SYSTEMS	Minimum distance between pumping and reinjection site [m]						
	Reinjection of used groundwater						
	Temperature difference between extracted and reinjected water [°C, K]						
	Absolute allowed temperature range of the reinjected water [°C]						
	Allowed temperature change [°C]						
	Accepted drawdown [cm]						
	Pumping test obligatory						
CLOSEDLOOP SYSTEMS	Minimum distance to other heat exchangers of the same installation [m]						
	Target value for the average inital and input temperature of the heat carrier fluid [°C]	Heating:		Cooling:			
	Regulations for heat carrier fluid type						
	Regulations for refrigerant type						
	Regulations for the backfilling of BHE						
	Leakage test of ground loop and refrigerant tubing required						
	Borehole drilling report required						
	Taking core samples required						
	Thermal response test required						
	Calculation of drilling depth required						

Questionnaire used by MUSE for D.3.1.

Questionnaire Part D

Part D comprises a series of questions referring to the selected regulation elements on SGES operation in the following manner:

- both OLS and CLS together: 4 questions.
- OLS: 13 questions.
- CLS: 16 questions.

The possible replies are yes, no, case to case decision and decision up to regional regulations. In addition, a special place for comments to each question is provided.

#	Questions / regulation elements*
	OLS and CLS
D.1	Is the drilling below the groundwater table allowed?
D.2	Is the certification for the designers, planners and installers mandatory?
D.3	Is the certification for drilling companies mandatory?
D.4	Are the numerical simulations/ models required?
	OLS
D.5	Is the minimum distance (m) to the neighboring ground plot defined?

#	Questions / regulation elements*
D.6	Is the minimum distance (m) to the neighboring buildings defined?
D.7	Is the minimum distance (m) to the neighboring groundwater wells defined?
D.8	Is the minimum distance (m) between the wells defined?
D.9	Is the minimum distance (m) between the pumping and reinjection wells defined?
D.10	Is the minimum distance (m) to the neighboring closed loop systems defined?
D.11	Is the reinjection of used groundwater allowed?
D.12	Is the maximum allowed temperature difference (°C, K) between extracted and reinjected water defined?
D.13	Is the absolute allowed temperature range (°C, K) of the reinjected water defined?
D.14	Is the allowed temperature change (°C, K) defined?
D.15	Is the groundwater table drawdown (m) defined?
D.16	Are the groundwater investigations (dynamics, hydrochemistry, etc.) mandatory?
D.17	Is the pumping test mandatory?

	CLS
D.18	Is the minimum distance (m) to the neighboring ground plot defined?
D.19	Is the minimum distance (m) to the neighboring buildings defined?
D.20	Is the minimum distance (m) to the neighboring groundwater wells defined?
D.21	Is the minimum distance (m, % of well depth) between the borehole heat exchangers defined?
D.22	Is the target value for the average initial and input temperature (°C, K) of the heat carrier fluid defined?
D.23	Are there any specific regulations on the heat carrier fluid type?
D.24	Are there any specific regulations on the refrigerant type?
D.25	Are there any regulations for the grouting of the borehole heat exchanger?
D.26	Is the flow test of the closed-loop and refrigerant tubing mandatory?
D.27	Is the tightness test of the closed-loop and refrigerant tubing mandatory?
D.28	Is the borehole drilling report mandatory?
D.29	Is the sampling of the cuttings mandatory?
D.30	Is the sampling of the drilling core mandatory?
D.31	Is the thermal response test (TRT) mandatory?
D.32	Is the exact measurement of the borehole depth mandatory?
D.33	Are the groundwater investigations (dynamics, hydrochemistry, etc.) mandatory?

*partner questionnaire run in 2019-2020

Questionnaire Part E

Part E contains 34 questions aiming at gathering new information and providing more precision to the selected thematic areas in the following manner:

- Comprehensive register of SGE installations and/or systems: 5 questions.
- Monitoring of SGE installations and/or systems: 18 questions.
- Environmental monitoring of SGE installations and/or systems: 11 questions.

The possible replies are yes, no, case to case decision and decision up to regional regulations.

#	Questions*
E.1	**Comprehensive register of SGE installations / systems**
E.1.1	Do you have in your country a register of SGE installations?
E.1.2	If yes, is it comprehensive and regularly updated?
E.1.3	If yes, is your GSO involved in running the register?
E.1.4	If yes, is the register publically available?
E.1.5	If no, is the lack of the register a barrier for development of SGE market?
E.2	**Monitoring of SGE installations / systems**
E.2.1	Is monitoring of SGE installations (system efficiency and/or environmental) compulsory in your country?
E.2.2	If yes, do the authorities enforce monitoring?
E.2.3	If yes, is monitoring applied to all installations independently of the installed capacity or only to large capacity installations? If yes, what is the minimum capacity for obligatory monitoring (write the threshold value in comments)?
E.2.4	If yes, do the authorities run a general digital database in which the monitoring data of the individual installations is stored?
E.2.5	If yes, are the monitoring results of the public buildings publically available?
E.2.6	If yes, is your GSO involved in monitoring of SGE installations?
E.2.7	If yes, are there any recommendations on monitoring of efficiency of SGE installations available?
	If yes, which parameters are monitored:
E.2.8	Heating/cooling installed capacity
E.2.9	Operating hours
E.2.10	Electricity consumption
E.2.11	Water extraction volume
E.2.12	Water injection volume
E.2.13	Temperature of extracted water
E.2.14	Temperature of injected water
E.2.15	Ground temperature
E.2.16	Heating/cooling medium temperature
E.2.17	Thermal energy production
E.2.18	Other
E.3	**Environmental monitoring of SGE installations / systems**
E.3.1	Are there any recommendations on environmental monitoring related to SGE installations (during all phases, e.g. construction, operation)?
E.3.2	If yes, is environmental monitoring required in relation to SGE construction phase (e.g. drilling, testing, etc.)?
E.3.3	If yes, is your GSO involved in environmental monitoring of SGE installations?
E.3.4	If yes, is installation of monitoring wells and/or piezometers for environmental monitoring of SGE installations required?
	If yes, which parameters are monitored:
E.3.5	Groundwater head
E.3.6	Groundwater temperature
E.3.7	Physiochemical parameters of groundwater, e.g. EC, TDS, pH, Eh, O2 conc., etc.
E.3.8	Chemical composition of groundwater
E.3.9	Contamination of groundwater, rocks and soils
E.3.10	Microbiota in groundwater, rocks and soils
E.3.11	Other

*partner questionnaire run in June 2020

Questionnaire used by GRETA for D.2.1.1.

Levels of regulations in the Country

Regulation level	1	2	3	4
NATIONAL				
Legal instrument				
REGIONAL				
Legal instrument				
LOCAL				
Legal instrument				

Tables of regulation elements

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Regulation level
1. Drilling /excavating below groundwater table				
2. Reinjection for NSGE-W				
3. Minimum distance to installations a. next building, b. drinking water well, c. other uses wells d. other public installations				
4. Minimum distance between neighboring NSGE installations a. heat exchanger or b. groundwater well				
5. Minimum distance to neighboring plot (property line)				
6. Minimum distance between pumping and reinjection site				
7. Temperature difference of the reinjected water (W)				

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Regulation level
8. Temperature drop (H, V) a. absolute allowed T_{min}, b. absolute allowed T_{max}, c. relative value describing the accepted ΔT between disturbed and ambient undisturbed temperature.				
9. Heat carrier fluid type				
10. Refrigerant type				
11. Tightness – ground loop and refrigerant tubing				
12. Backfilling of BHE				
13. Liquidation procedure after abandonment of NSGE installation a. heat pump b. heat exchanger				
14. Monitoring				

Installation of NSGE in special geological conditions

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Level
15. Artesian aquifers				
16. Very shallow water table where reinjection can be problematic				
17. Perched groundwater layers				
18. Two or multiple aquifer layers				
19. Mineral water resources				
20. Thermal water resources				
21. Gas occurrences				

22. Unstable ground a. compressible soil b. landslide c. evaporate (with the risk of swelling / dissolution)				
23. Contaminated soil				
24. Karst area				

Installation of NSGE on protected areas or natural risk zones

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Level
25. Water protection area (WPA)				
26. Natura 2000 area				
27. Nature protected ecosystem area				
28. Flood and erosion areas				
29. Landslide area				
30. Riparian / coastal zone				
31. Other areas a. ... b. ...				

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Level
32. NSGE (GSHP) objectives a. national (NREAP) b. regional c. local (LEC...)				
33. Subsidies				
34. Insurance system				
35. Certification a. professionals b. organization				
36. Borehole drilling report				
37. Pumping test report				
38. Thermal response test report				
39. Reception of borehole by the investor				
40. Water pumping data periodic report				
41. Heat energy production data periodic report from NSGE				
42. Register of heat pumps				
43. Register of heat exchanger				
44. Register of NSGE production				
45. Register of drilling data				
46. Register of geothermal data				
47. Register of groundwater abstraction				

Regulation element	Legal regulation	Legislative conditions	Legal instrument	Level
48. Research/drilling permit				
49. Declaration / Recorded special use of water				
50. Water consent				
51. Water permit				
52. Water fee				
53. Concession				
54. Royalty / concession fee				
55. Energy fee				

Annex 4. Planning tool methods

Planning tool methods- Germany

Methods used to develop the planning tool

This section describes the methodical procedure and the relevant methods for calculating the results and is based on the requirements of the municipal heating planning. In detail, the description of the methodology is divided into, the assessment of the technical potential for plots and building blocks (a), the comparison of the potential with the needs b) and finally the optimisation and determination of the spatial potential are explained c).

a) Assessment of the technical potential for plots and building blocks

In a first step, the aspects of the legal framework affecting the exclusion of contiguous zones will be examined. These exclusion zones* will form a map of blank spaces for the location of wells. These zones are excluded from the quantitative analysis of sites, as they will not be authorised.

Exclusion zones*
Drinking water protection areas
Nature conservation areas
Landscape conservation areas
Natura 2000 areas
Biotopes
bodies of water
Ground monuments
Natural monuments
Floodplains
Trees
Underground tunnels
Suburban railway tunnels
Road tunnels
Underground car parks

In the following, the three relevant technical restrictions of the approval practice are calculated in the potential analysis based on the Bavarian regulations for the use of near-surface geothermal energy (VDI 4640, BayWG and WHG) (3 m to buildings and plot boundaries. In addition, a minimum distance between the two wells of 10 m is required).

The calculation of the thermal use potential of groundwater is based on the TAP (Thermal Aquifer Potential) method. This is briefly described below.

The corresponding equations for quantifying the technically feasible extraction volume are summarised in the following sections.

i) Drawdown in the extraction well: Equation (1) calculates the abstraction rate in the extraction well at a maximum drawdown of one third of the thickness of the saturated aquifer and the locally prevailing hydraulic conductivity within.

$$V_1 = 0{,}195\, k_f\, M^2 \qquad (1)$$

where

V_1	m3 s -1	Pumping rate for the drawdown limit value of M/3
k_f	ms -1	Permeability coefficient
M	m	Groundwater saturated thickness

ii) Accumulation in the injection well: The reintroduction of groundwater must not lead to an excessive rise in the groundwater level that could result in surface or basement flooding. The groundwater level may rise to a maximum of 0.5 m below ground level (no surface flooding). The maximum injection rate is determined by the hydraulic conductivity, the hydraulic gradient, and the thickness of the saturated aquifer.

$$V_2 = (s - 0{,}5)\, k_f\, M^{0{,}798}\, e^{(29{,}9\, i)} \qquad (2)$$

Where,

V_2	$m^3 s^{-1}$	Discharge rate for the accumulation limit (s-0.5)
k_f	ms^{-1}	Permeability coefficient
M	m	Groundwater saturated thickness
s	m	Distance between the ground surface and the water level
i	-	hydraulic gradient

iii) Hydraulic short circuit (or breakthrough): The extraction well, which is connected downstream of the extraction well, returns the thermally altered water to the aquifer. For efficient utilisation of groundwater heat pumps, it is essential that there is no thermal-hydraulic breakthrough between extraction and reinjection, as this would prevent sustainable and efficient operation of thermal groundwater utilisation. The extraction rate is therefore limited and depends on the well spacing. The maximum extraction rate of a pair of wells without hydraulic breakthrough is also determined by the Darcy velocity and the groundwater saturated thickness.

$$V_3 = \frac{\pi}{1{,}96} v_D \, M \, x_w \qquad (3)$$

Where,

V_3	$m^3 s^{-1}$	Extraction rate without hydraulic breakthrough
v_D	ms^{-1}	Darcy velocity
M	m	Groundwater saturated thickness
x_w	m	Distance between production and injection wells

The Darcy velocity of the groundwater is defined as

$$v_D = k_f \, i \qquad (4)$$

Where,

k_f	ms^{-1}	Permeability coefficient
i	-	Hydraulic gradient

iv) *Estimation of the technically feasible extraction rate*: The three calculated volume flows in the well pair are combined in a final step in the technically feasible extraction rate. The minimum volume flow is the dominant limiting factor that determines the technically feasible extraction rate. The following applies:

$$V_{max} = \min(V_1, V_2, V_3) \qquad (5)$$

Where,

V_{max}	$m^3 s^{-1}$	Technically feasible extraction rate
V_1	$m^3 s^{-1}$	Pumping rate for the drawdown limit value of M/3

V_2	$m^3 s^{-1}$	Discharge rate for the accumulation limit (s-0.5)
V_3	$m^3 s^{-1}$	Discharge rate without hydraulic breakthrough

v) Calculation of the thermal extraction rate and heating capacity:

The technically feasible extraction rate was then used to calculate thermal output within the legally permissible temperature range for thermal groundwater utilisation, which generally corresponds to 5 K in Bavaria. In addition, the absolute minimum, and maximum temperatures of 4°C and 20°C must be considered. The following applies:

$$P_{th} = V_{max} \ c_{pw} \, \rho_w \, T \qquad (6)$$

Where,

P_{th}	W	Thermal extraction capacity
V_{max}	$m^3 s^{-1}$	Technically feasible extraction rate
c_{pw}	$J\, kg^{-1} K^{-1}$	Specific heat capacity of water
ρ_w	$kg\, m^{-3}$	Water density
T	K	Maximum temperature range

According to VDI 4640 Sheet 2, equation (6) and a specific heat capacity of 4.187 (water at constant pressure and 10°C) can also be used to estimate the evaporator capacity of a water/water heat pump. This means that only an approximate estimate of the average efficiency is required to calculate the final heat output that a heat pump can provide in the heating circuit. This results in the average heating output:

$$P_h = \frac{P_{th}}{1-\frac{1}{SPF}} \qquad (7)$$

Where,

P_{th}	W	Thermal extraction power
P_t	W	Average heat output

SPF - annual performance factor of the heat pump

Determination of the plot-specific potential

The spatial hydrogeological basic data from previous projects are used as the basis for the potential analysis for thermal groundwater use. For this purpose, the plot distance, groundwater-filled thickness, flow direction and gradient as well as the hydraulic permeability of the aquifer are used to calculate the quantitative potential. For this purpose, the median of all input parameters is determined for each plot and the calculations are used to determine the technically feasible potential on a plot-by-plot basis. The extraction rate and the discharge rate can be derived directly from the aggregated hydrogeological data using equations (1) and (2). To calculate equation (3), the well spacing that can be realised on the plot is also required.

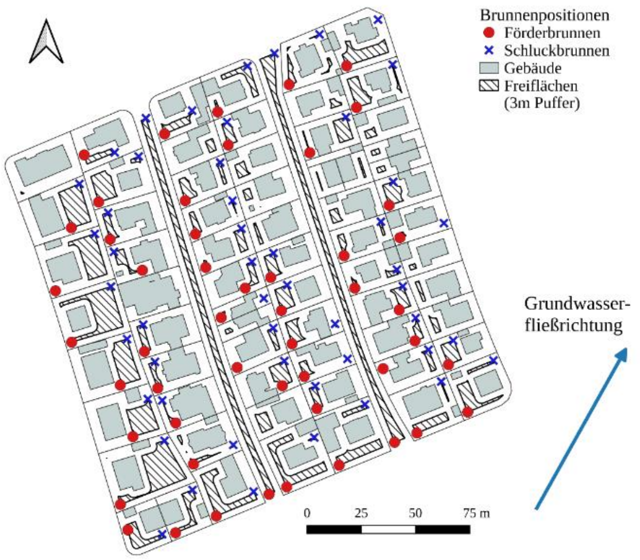

Figure 1: Exemplary arrangement of extraction and injection wells on plots of land, considering the groundwater flow direction and the 3 m minimum distance to buildings and the plot boundary.

To calculate the maximum possible distance between extraction and injection wells, both the groundwater flow direction for aligning the wells and the compliance with distance areas are considered. To designate appropriate open spaces for well construction, the minimum distance of 3 metres to existing buildings and property boundaries prescribed in Bavaria is first considered. The remaining open spaces are then used to place the production well at the point furthest upstream and the injection well at the point furthest downstream. If the resulting well spacing is less than 10 metres, the pair of wells is no longer taken into account. All values for the calculation of equation (3) are now available and the technically feasible extraction rate and the thermal output for each plot can be calculated.

Determination of the building block-specific potential
Similar to the plot approach, the hydrogeological parameters are determined as a median for each building block and the calculations are then used to determine the technically feasible potential. The open space available in the building block is also mapped for the positioning of the wells. In contrast to the plot approach, only the 3 m minimum distance to buildings is considered here. The decision not to include any distance to building block boundaries was made in consultation with SWM, since as a municipal energy supplier they are also authorised to drill wells on public land or on traffic areas. The potential on building blocks is used to assess the feasibility of interconnected solutions such as cold local heating networks, which are typically operated by an energy supplier.

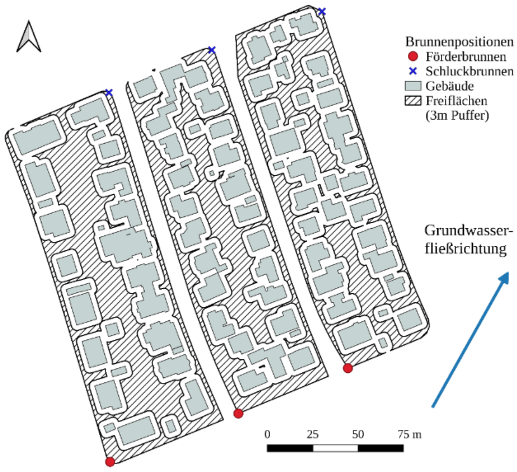

Figure 2: Exemplary arrangement of extraction and injection wells on building blocks, considering the groundwater flow direction and the 3 m minimum distance to buildings

Since the wells can generally be located further apart from each other than with the plot approach, the hydraulic breakthrough becomes less and less of a limiting factor for the technically feasible withdrawal rate. Limit states are more frequently reached in which the maximum drawdown or the maximum accumulation are decisive for the feasible extraction rate.

After calculating the potentials from the two aggregation levels, i.e. plot and building block, the next step is to compare them with the building's heat demand.

b) Comparison of potential and heat demand.

In order to check the possible coverage of the heating demand by the locally available potential, a detailed comparison of the technically possible heating output with the heating demand on the respective plot or building block is necessary. The technically possible heating output is calculated using equation (7). For this purpose, an average annual performance factor of 4 is assumed to be constant for groundwater heat pumps. In contrast to other shallow geothermal extraction systems, the decisive factor for thermal groundwater utilisation is not the annual energy quantity, but the output. Since no thermal short circuit occurs during extraction and injection in a pair of wells, even at the maximum operating point, continuous operation is ensured by a conservative design of the method. Consequently, it is not the duration of operation, i.e. extraction power, but the intensity, i.e. maximum extraction capacity, that is decisive.

The conservative assumption is always that the heat pump will operate monovalently and that the heat demand of the building will be fully covered. If the needs of one building can be met, it will be supplied, and the next smaller building will be considered. The supply of buildings accumulates until the potential is spent or all buildings are supplied. If the next smallest building cannot be supplied, but there are other buildings in the area, the test is continued, thus ensuring that the remaining potential is 'filled'. The result of the possible adjustment is an identification of the buildings that can be supplied and an indication of the possible coverage of the needs in plots and building blocks. Particularly important here is the total installed heating capacity of the zones, as this is used to optimise the spatial potential.

In addition to checking whether the available potential on a plot can meet the demand, in a second step, the economic feasibility of the construction of wells is considered. Depending on the depth of the water table (distance from the ground), the well construction costs for a system can vary greatly from place to place, whereas, for example, the costs for construction equipment, well pumps, permits, etc. are fixed. costs tend to fluctuate little for the same system size.

In practice, such high costs for developing the heat source are not economical, so a limit on the maximum final depth (expansion depth) of the well pair was introduced depending on the heating capacity of a groundwater heat pump. The larger the heat pump, the deeper the wells can be built. To determine the current costs for 2023, an expert survey was carried out among drilling companies, geo-offices and heat pump manufacturers. Based on the usual services for the installation of a groundwater heat pump, the variable items of well construction, such as linear metres of drilling and well construction, including risers and down pipes, were evaluated to adapt a cost function.

The function for calculating the cost key figure is

$$c_{limit} = \frac{5,6\,z + 6,9\,(2,25\,p_{hp})^{0,47}}{15\,p_{hp}^{0,7}} \qquad (8)$$

Where,

c_{limit}	-	Ratio of the variable investment costs of the well construction to the costs of the heat pump unit
p_{hp}	kW	Heat output of the heat pump
z	m	Depth of the well pair (extraction and injection wells)

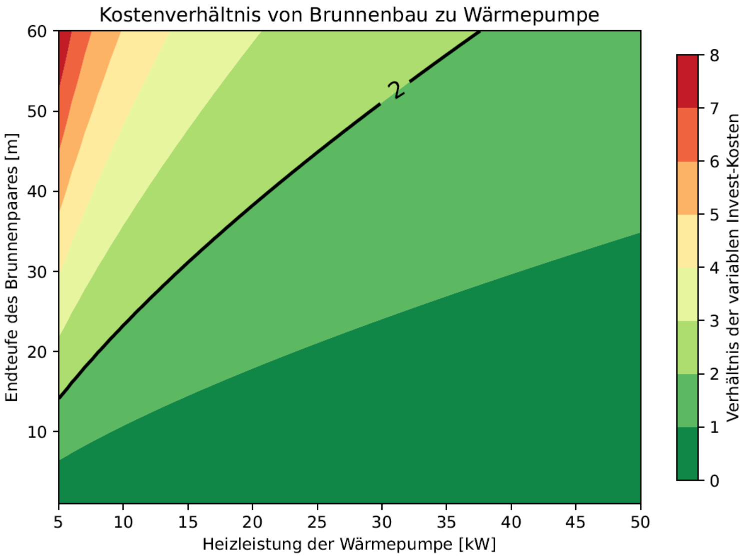

Figure 3: Development of the ratio of the variable well construction costs as a function of the final depth of the well pair to the costs of the heat pump as a function of the installed heating capacity with the defined economic limit of 2 (black contour line = well construction twice as expensive as the heat pump).

The limit of the cost factor (c_limit) in equation (8) was set at 2. This value was determined empirically in consultation with drilling companies.

It should be noted that the function given in equation (8) is the calculation of the cost factor (c_limit) is represented graphically by equation (8) for defined ranges of well depth (final depth) and heat pump heat output.

c) Methodology for spatial optimisation in model coupling

The central element in the optimisation is the temperature field calculation using spatial and temporal superposition.

Analytical temperature field calculation

The Linear Advective Heat Model (LAHM) is used for the analytical calculation of the temperature field. This type of temperature field calculation has proven itself in licensing practice for the assessment of thermal uses and is particularly suitable for the hydrogeological conditions in the Munich gravel plain with high flow velocities. The LAHM method tends to overestimate the thermal propagation of cold plumes and can therefore be regarded as conservative. The model describes the heat transport starting from an absorption well under the assumption of homogeneous hydrogeological parameters. LAHM is defined as

$$\Delta T(\Delta x, \Delta y, t) = \frac{q \cdot \Delta T_{inj}}{4 \varepsilon B v_a \sqrt{\pi \beta_T}} \exp\left(\frac{\Delta x - r}{2\beta_L}\right) \frac{1}{\sqrt{r}} erfc\left(\frac{r - \frac{v_a t}{R}}{2\sqrt{\frac{v_a \beta_L t}{R}}}\right) \quad (9)$$

and

$$r = \sqrt{\Delta x^2 + \Delta y^2 \frac{\beta_L}{\beta_T}} \quad (10)$$

Where,

ΔT	K	Change in groundwater temperature
$\Delta x, \Delta y$	m	Spatial distance in x and y direction
t	s	Time
q	m 3s -1	Discharge rate at the injection well
T_{inj}	K	Difference between natural and discharged water
ε	-	Porosity
B	m	Groundwater-saturated thickness
v_a	$m\, s^{-1}$	Distance velocity
$\beta_{L/T}$	m	Longitudinal and transverse dispersity
r	m	Radial spacing factor
R	-	Retardance factor

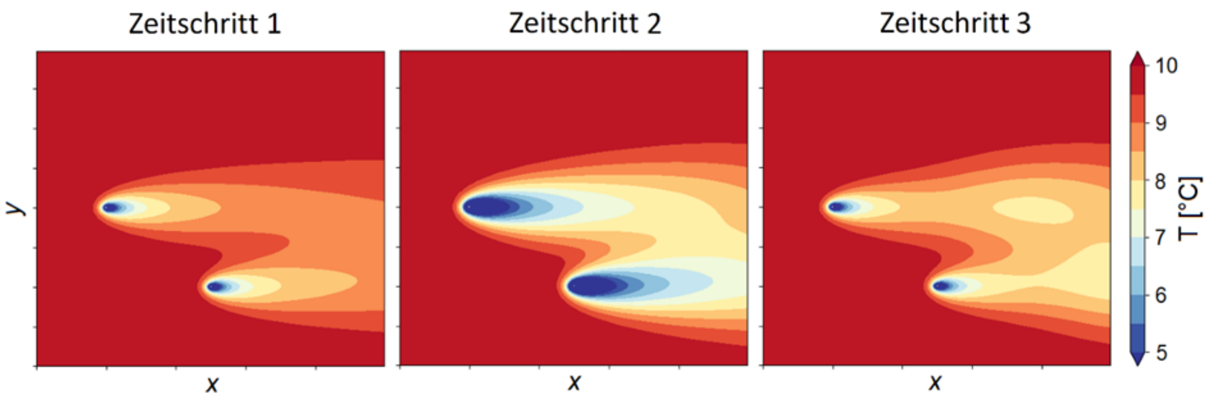

Figure 4: Extension of the LAHM model by a combined spatial and temporal superposition in which the temperature anomalies of two injection wells propagate over 3 time steps in the aquifer in the x-direction (after Halilovic et al. 2023).

In its original definition in equation (9), however, LAHM can only be used for an injection well with a constant discharge rate. Therefore, the model was extended by two different principles of superposition. Spatial superposition makes it possible to calculate many temperature anomalies on a temperature field and thus also to map the joint influence of several absorption wells. The temporal superposition offers the possibility of calculating temperature anomalies that are formed by variable discharge rates. In this way, the seasonally varying loads of thermal utilisation can be considered.

The temperature field calculation with LAHM can now be used for larger areas with a large number of potential groundwater heat pumps in order to identify and exclude possible negative thermal interactions between neighbouring wells. The aim here is to arrange the wells in an area in such a way that, in addition to excluding negative interaction, the maximum thermal output is also installed.

Optimisation of the spatial expansion

The optimisation objective is to maximise the thermal potential in the aquifer. This is achieved by positioning the wells of potential groundwater heat pumps in such a way that they can utilise the maximum energy within a defined area without negatively affecting each other within the legal regulations.

For the definition of potential well locations, legal framework conditions such as nature and drinking water protection areas and the existing building structure with distance areas are considered in a white area mapping. The open areas are then divided into inflow and outflow areas in their centroid at right angles to the groundwater flow direction. Finally, potential well locations are generated at the outer edges of the sub-areas at a regular distance of 5 metres from each other. Production wells are located on the inflow areas and absorption wells on the outflow areas. This ensures that a hydrogeological probe selection of possible locations is available for optimisation.

Heat pumps are set in such a way that there is no negative thermal impact and only those systems are installed that lead to optimum utilisation of the limited groundwater resource.

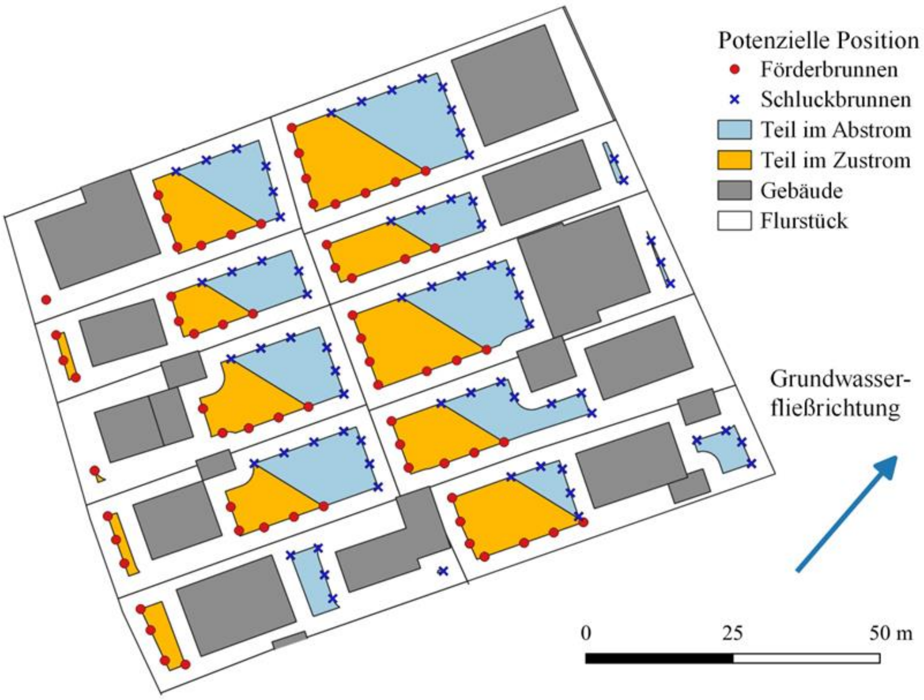

Figure 5: Possible well positions in the spatial optimisation with legally prescribed distance areas

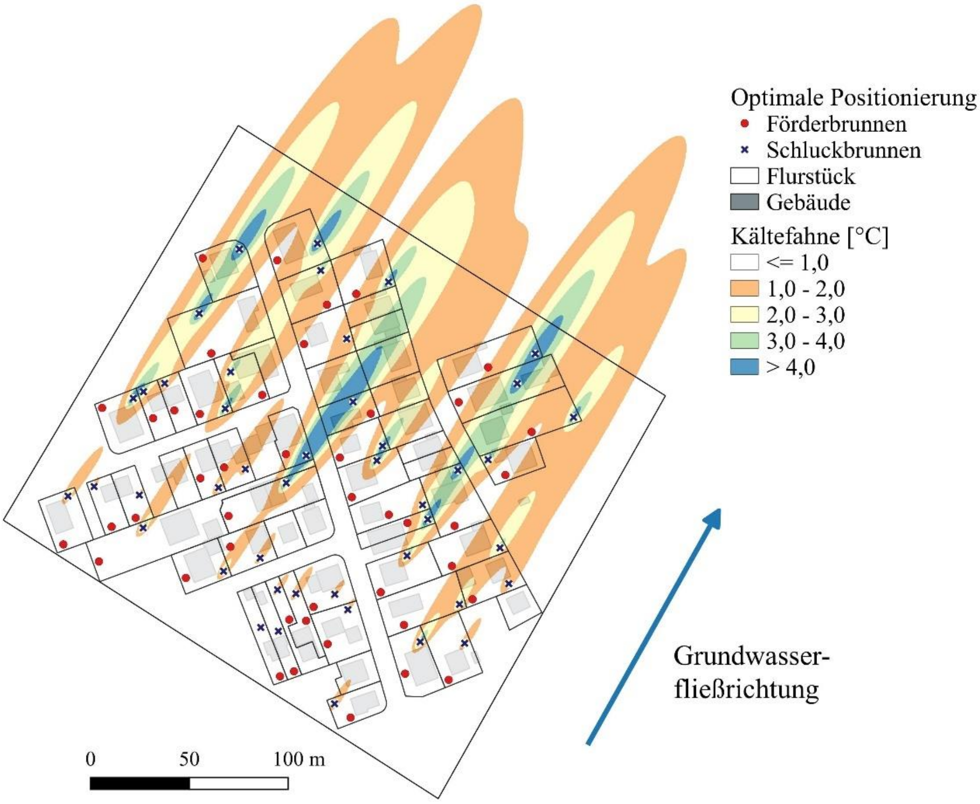

Figure 6: Exemplary temperature field of the cold anomalies in a neighbourhood that represents an optimal well positioning under exclusion of a negative thermal influence.

Figure 6 shows the temperature field after optimisation in an exemplary neighbourhood. Individual parcels could not be supplied, especially downstream, as the 1-K temperature anomaly (orange area) of upstream injection wells completely influences the properties. As the difficulty and therefore the computational effort of the optimisation problem increases exponentially with the number of optimisation variables, the size of the area per optimisation process is limited.

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Planning tool methods- Austria

- Optimisation method between open and closed loop geothermal heat pump systems

In Austria, thermal interactions between open and closed systems are not explicitly mandated by specific methodologies or integrated regulations. Instead, the ÖWAV RB 207 guideline provides a framework for the individual assessment of open and closed systems, in order to protect pre-existing water rights.

- Optimisation method between open geothermal heat pump systems

When thermally altered water is introduced into groundwater systems, the resulting thermal front30 moves at approximately half the speed of groundwater flow due to the influence of the rock matrix. Consequently, the degree of temperature change diminishes along the flow path. The end of the thermal front is defined by a temperature difference of 1 K. This means that if the temperature difference exceeds 1 K, it is considered negative thermal interference. Specific temperature thresholds have been established in the ÖWAV RB 207 with the goal to prevent ecological harm. The injection well has to maintain temperatures above 5 °C and below 20 °C31 for thermally used groundwater. Seasonal variations, such as significant cooling from surface water, may allow temperatures to drop below 5 °C. The guideline also stipulates the maximum permissible temperature increase or decrease at the injection side. This value should not exceed 6 K32 from the given groundwater temperature at the location of the installation.

The methodology in the planning phase of groundwater heat pumps involves hydraulic calculations, appropriate well placement, and consideration of thermal plumes. ÖWAV RB 207 recommends using their practical analytical tools for the preliminary assessment of small single installations and multiple systems. Numerical models are recommended for more precise simulations in complex scenarios and for large installations. The methods are summarised below.

Hydraulic aspect

[30] A thermal front is the boundary between areas of different temperatures within the groundwater system. When warm or cool water is introduced into groundwater, this front delineates the zone where the temperature difference begins to spread.
[31] In Vienna, the range is stricter, being set as 5 °C to 18 °C.
[32] For example, if the natural groundwater temperature is 10 °C, the reintroduced water should be between 4 °C and 16 °C.

Groundwater extraction and injection influence the local water table. When groundwater is extracted, the water level drops around the extraction well (drawdown), while it rises around the injection well (mounding). The balance between extraction and injection is crucial to confining the flow influence locally. Keeping this balance is in general mandatory for groundwater heat pumps in Austria. The drawdown (s) can be calculated using the following equation for an ideal, homogeneous, isotropic aquifer with a free surface:

$$(2H - s) \cdot s = \frac{Q}{k_f \cdot \pi \cdot ln\frac{R}{r_0}}$$

Where:

Q is the extraction rate [m^3/s]

kf is the hydraulic conductivity [m/s]

r0 is the well radius [m]

R is the extent of drawdown [m]

H is the saturated aquifer thickness [m]

Thus, this formula relates the drawdown to the extraction rate, hydraulic conductivity, well radius, and aquifer thickness. The guideline says that it is important to prevent a hydraulic short-circuit, where the returned water quickly reaches the extraction well without adequate thermal exchange, thus preventing thermal interaction. This can be achieved by ensuring adequate separation between extraction and return wells and considering the groundwater flow direction.

Minimum distance between wells

For aquifers with low thickness, the minimum distance between extraction and return wells to prevent thermal interference is given by:

$$a = 0.6 \cdot (\frac{Q}{(J \cdot kf \cdot H)})$$

Where:

J is the groundwater gradient [-]

For aquifers with *large thickness*, the returned water tends to stratify in the upper part of the aquifer. The guideline remarks that ensuring a vertical separation of at least 8 m between the lower groundwater level and the top of the filter screen in the extraction well can prevent thermal short-circuiting, provided the system runs under continuous, steady-state conditions.

Analytical solutions for thermal plumes

For single small installations, the spread of temperature changes in the groundwater can be estimated using simplified analytical methods. These methods consider heat exchange, dispersion, and changes in groundwater flow direction. The method used in the ÖWAV RB 207 guideline is based on an iterative calculation, which balances energy flows in a trapezoidal control volume. This method assumes that a temperature anomaly, differing by ΔT from the unaffected groundwater temperature, begins at the reinjection well. The anomaly diminishes exponentially along the groundwater flow direction. The extent of the anomaly is considered to end when its calculated value drops below 1 K. The end of the thermal front must have a ΔT of less than 1 K to avoid negative thermal interference. The solution assumes steady-state conditions, ideal well behaviour, and homogeneous, isotropic soil, providing a rough approximation of the thermal plume spread:

$$T\_\{i+1\} = \frac{Q(\mathrm{T\_i} \cdot (\mathrm{B\_i} - \mathrm{B}) + \mathrm{T\_0} \cdot (2 \cdot \Delta \mathrm{x} \cdot \tan(\alpha) + \mathrm{w\_i}))}{(B\_\{i+1\} + w\_i)}$$

With:

$$B\_\{i+1\} = B\_i + 2 \cdot \Delta x \cdot tan(\alpha)$$

$$w\_i = (\frac{\lambda D}{(A + \frac{H}{4}))} \cdot (B_i + \Delta x \cdot tan(\alpha)) \cdot \Delta x \cdot \frac{Q}{(B \cdot c\_vw)}$$

Where,

- T_i is the temperature at point i [°C]
- T_0 is the average extraction temperature [°C]
- α is the lateral spread angle (5° to 15°)
- c_vw is the specific heat capacity of water (4.2 x 10^6 J/(m^3·K))
- λD is the thermal conductivity of the cover layer [W/(m·K)]

For regions with multiple systems, the cumulative thermal load is assessed using a heat balance equation:

$$(2H - s) \cdot s = \frac{Q}{k_f \cdot \pi \cdot ln\frac{R}{r_0}}$$

Where,

T_E is the return water temperature in the groundwater body [°C]

F is the horizontal area of the considered region [m^2]

ΔT is the average change in groundwater temperature

When analytical methods are insufficient due to simplifying assumptions, e.g. for large installations, numerical modeling should be employed. These models optimise system operation based on local hydrogeological and thermophysical parameters, consider variable heat/cold supply and demand, and provide legally relevant impact forecasts. Adequate data for model calibration and verification is decisive.

Final remarks

For considering the admissibility of further systems for the thermal use of groundwater in already heavily used aquifers, the creation of "heat load plans" is mentioned as a useful tool. These can represent all thermal measures, usually simplified analytical calculation formulas, graphically based on databases. Heavily used or overused areas can thus be identified in GIS systems. In order to be able to create "heat load plans" knowledge about already in place groundwater heat pumps, including their heat and cold production – at best from monitoring data – is essential.

In Austria, licensing procedures follow the "first-come, first-served" principle, meaning that typically, each system is treated independently in the licensing process. This can be hindering for an efficient thermal use of the underground, especially for groundwater heat pumps, as the thermal impact of open systems is in general larger than of closed systems. Small installations might therefore impede the use of large systems with a larger heat or cold production. This might be especially the case in densely populated areas with already a high number of neighbouring systems and limited space for wells, which increases the possibilities of negative thermal interference. In order to still enable an efficient and sustainable use of groundwater for heating and cooling – avoiding thermal interaction and negative interference, an integrative management system become inevitable. An integrative groundwater management requires the combination of knowledge about the resources, existing water rights and the heating and cooling demand.

Resource maps are available for Vienna online at the "Geothermie-Atlas" (geothermieatlas.geosphere.at). This platform is intended to grow and cover the entire Austria. As of now, geothermal flow direction and existing water rights are not yet included in the resource maps. The resource maps serve as input in the planning phase. A first step towards an integrative management system was done as well in Vienna, where in the GeoPLASMA-CE project a numerical model of the districts 21 and 22 of Vienna was set-up as preparation for a general model, where all existing groundwater heat pumps could be implemented. A numerical model covering the entire aquifer could serve as input basis for the individual simulations during planning. This would be one-step towards an integrative management system. In the city neighbourhood Oberes Hausfeld in Vienna, the authority is already going into this direction, by requiring one joint simulation, that includes multiple new and old systems to investigate possible negative thermal interferences. With these numerical simulations the planning will be optimized.

- Optimisation method between closed loop geothermal heat pump systems

For BHEs, the guideline recommends that a minimum distance of 2.5 m should be kept from property boundaries. However, the Austrian Federal Provinces may set different values; for example, in Salzburg the minimum distance is specified as 5 m. For systems running in heating mode, the average temperature of the heat transfer medium should not fall below -1.5 °C after stabilisation (new thermal equilibrium), which typically takes 5 to 50 years. This the case for an inlet temperature of -3 °C and an outline temperature of 0 °C. In cooling mode, the temperature of the heat transfer medium must not exceed +30 °C. The guideline further notes that large BHE fields might influence the overall groundwater temperature significantly. The guideline considers that heat extraction mainly takes place within a 10-m radius around the probe. This would be a typical distance between BHEs in small systems, mainly used for heating. Closer probe spacing increases mutual thermal influence, so correction factors according to SIA 384/6 are used. In practice, a closer spacing of around 5 m is applied for larger BHE systems used as storage (borehole thermal energy storage).

For horizontal collector systems, a distance of at least 1 m must be maintained from supply and disposal lines as well as to building structures. From well structures, a distance of at least 1.5 m must be maintained. For systems operating in heating mode, the temperature of the heat transfer medium should be selected to prevent freezing of the surrounding area. In cooling mode, the temperature of the heat transfer medium should not exceed 30 °C. The ÖWAV RB 207 guideline mentions that effects on the subsoil and groundwater are minimal. Empirical measurements indicate that any cooling or heating effects are transient, with temperatures returning to normal after a regeneration phase. This is due to the dominant effects of solar radiation and the return flow of infiltration water.

Below, an outline of the methods set out in the ÖWAV RB 207 guideline for designing and installing both horizontal collectors and borehole heat exchangers (BHEs) are given.

Horizontal collectors

Horizontal collectors are laid horizontally at a depth of 1.2 to 1.5 m. The collector area can be sized based on specific extraction rates, which depend on soil type and operating hours (1,800 or 2,400 hours per year):

Dry, non-cohesive soil: 10 W/m² at 1,800 hours/year and 8 W/m² at 2,400 hours/year.

Cohesive, moist soil: 20–30 W/m² at 1,800 hours/year and 16–24 W/m² at 2,400 hours/year.

Water-saturated sand/gravel: 40 W/m² at 1,800 hours/year and 32 W/m² at 2,400 hours/year.

For higher operating hours (e.g., hot water preparation or extreme climate zones), the extraction rates should be reduced to prevent exceeding the maximum permissible annual extraction rate, which could lead to frost damage and reduced heat pump efficiency. Installation involves laying the pipes carefully, ensuring proper bedding to avoid damage. Specific distances must be maintained:

From building structures: At least 1 m.

From well structures: At least 1.5 m.

Frost-free depth: Between 1.2 to 1.5 m.

Connections must be made using sleeve welding, and circuits must be balanced and well-vented. Pipes should be laid frost-free, with warning tapes placed 0.5 meters above the collector pipes.

Borehole heat exchangers

Proper sizing of boreholes (typically 70-150 m deep) needs to ensure the required power and energy without causing freezing or excessive heating. Methods include:

Using operating data from existing systems: Comparable site conditions can guide sizing if temperature limits are maintained, with data covering at least two years.

VDI 4640 standard: Provides specific extraction rates for different subsurface types.

SIA 384/6 standard: Probe sizing can be conducted in accordance with the Swiss standard SIA 384/6 when there is precise information about the thermal conductivity of the subsurface at the probe location, with guidelines for probe spacing and correction factors.

Numerical modelling.

For BHEs, the "Geothermie-Atlas" (geothermieatlas.geosphere.at) provides a tool to estimate the resources of selected properties. With this tool it is possible to arrange the BHE fields individually and get a first estimation of heat and cold production, and the coverage of demand. The "Geothermie-Atlas" also provides spatial data for planning, such as thermal conductivity and underground temperature for Vienna.

Specific extraction rates for various subsurface mentioned for VDI 4640 include for example:

- Poor subsurface: 25 W/m at 1,800 hours/year, 20 W/m at 2,400 hours/year.
- Water-bearing gravel/sand: 65-80 W/m at 1,800 hours/year, 55-65 W/m at 2,400 hours/year.
- High thermal conductivity rock: 65-85 W/m at 1,800 hours/year, 55-70 W/m at 2,400 hours/year.

The guidelines mention that the heat extraction primarily occurs within a radius of 10 m around the probe. Smaller probe spacing increases mutual thermal influence, requiring adjustments based on the SIA 384/6 correction factors. A minimum distance of 2.5 m from property boundaries should be maintained. The heat transfer medium should have an average temperature that does not fall below -1.5 °C when heating at maximum load and does not exceed 30°C when cooling at maximum load. Alternating between heating and cooling is recommended for thermal regeneration of the geothermal field.

Numerical modelling

For larger systems like BHE fields, numerical modelling is the recommended approach. The guideline advises to perform a pilot borehole to explore thermal properties of the site. The data obtained form the basis for the modelling. The guidelines states that for larger, complex systems for heating and cooling (e.g., shopping centres), sizing can only be done by numerical modelling. This allows for the estimation of mutual influence between adjacent systems and the consideration of thermal effects of groundwater flow. Moreover, for heating and cooling with a reversible heat pump or cooling machine, modelling should always be carried out according to the guideline. Numerical modelling studies should simulate the system over 5 to 50 years.

Final remarks

Exceeding the maximum permissible extraction rate should be avoided. Numerical modelling is the only reliable way to design large or complex systems to ensure long-term efficiency and stability. The ÖWAV RB 207 guideline advocates for alternating between heating and cooling as this helps maintain the geothermal field's thermal balance.

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Annex 5. Additional information on good practices in GeoBOOST countries

Sweden

Introduction

The total heated area in Sweden 2022 was 704 million m2.

The year 2002 it was 574 million m2.

In spite of this increase the primary energy used for heating and tap water decreased from 2002, when it was 89,2 TWh, to 74,2 TWh in 2022.

Some reasons for this are more efficient building technology, refurbishments like more efficient windows, attic isolations and a general awareness focused on energy savings. But the most important reason is the vastly increased usage of heat pumps during this period. An estimation based on number of sold heat pumps gives “free” heat energy produced from air/soil/lake/bedrock to about 40 TWh. Thus about 114 TWh is really used for heating and hot water production.

Sweden has some 1,7 million heat pumps installed. As of 2022 about 508 000 of those is ground source heat pumps (liquid to liquid), 458 000 exhaust air to air or liquid heat pumps and 754 000 air to air heat pumps. (1)

The ground source heat pumps produce around 28 TWh of heat energy. Extrapolated from (2) and based on verbal communication with ground source heat pump expert Ph D Signhild Gehlin, head of Svensk Geoenergicentrum, who closely monitor this and is a coauthor of (2). Thus, about 24 percent of heating energy is provided by ground source heat pumps.

This figure is somewhat contested, and other estimates is that about 20 % of the total heating energy comes from ground source heat pumps.

Main drivers

What are the main drivers for this?

In the 70-ties Sweden was heavily dependent on oil for heating buildings. Since the 50ties Sweden had systematically switched most heating system from coal to oil. Most individual houses had oil burners and larger buildings in urban areas were often served by decentralized plants producing heat using large oil burners and disposing of hot gases through high chimneys.

The heat produced were provided by pipes to buildings nearby. For buildings erected on public lands it was mandatory to connect to this decentralized heat production plants.

The vastly increased oil price the years1974 and 1978 hit Sweden very hard and triggered several actions. One was to build nuclear power-plants. In a few years at the end of the 70ties Sweden built and commissioned 12 reactors. Together with lots of hydropower this kept

Swedish electricity prices low for a long time. Six of the nuclear plants are still running as of today. The decommissioning of the other six has been based on political decisions.

Another action was to build district heating systems. The first in Sweden was built already 1948 but by the time of the oil crises, it was still not widely spread. But the oil price crises spurred a fast buildup of district heating networks. Today virtually every township in Sweden has one, all in all there is about 580 of them. Originally many of them used fossil fuels like oil and coal and even electricity which was very cheap at the time.

But fossil fuels are nowadays mainly out phased for heat production in District heating plants, only about 1,9 % of the fuel is fossil. Instead, sources like waste, peat, biofuel and waste heat from industrial production are used. The CO2-emission from district heating is still a not negligible 51,4 g/kWh, most of it from burning waste. (3)

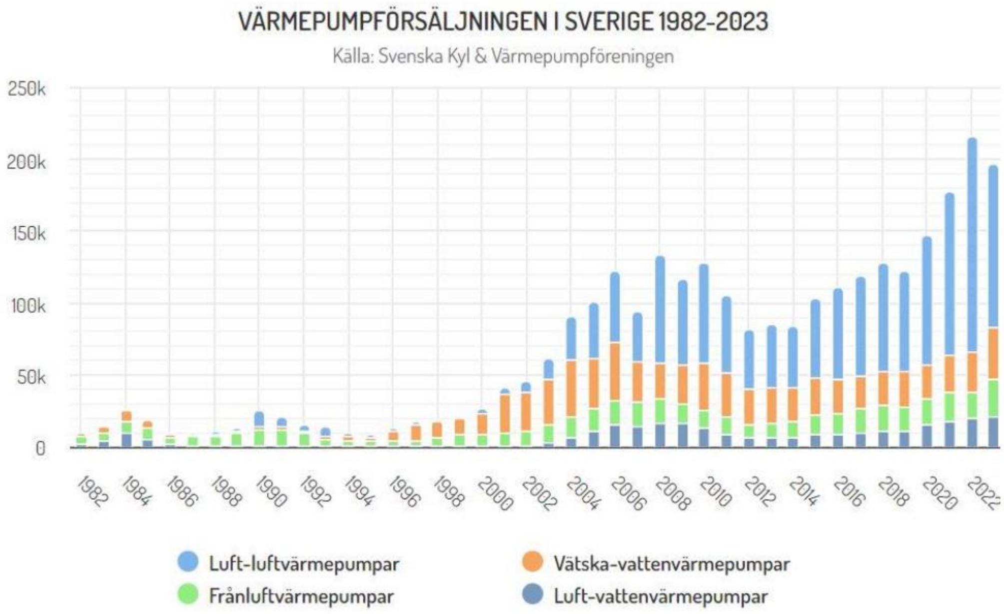
If we look only at primary energy about 60 % of total heating is provided by District heating but it shrinks to 40 % when the "free" energy from the heat pumps is added. Penetration for larger buildings in urban areas is about 90 %.

Also, in individual small buildings oil is mainly out phased, less than 1 % still uses oil, the oil burners are mainly replaced by heat pumps.

Gas has never been a major source for heating in Sweden, and nowadays, less than 1 percent of the building area are using gas for heating.

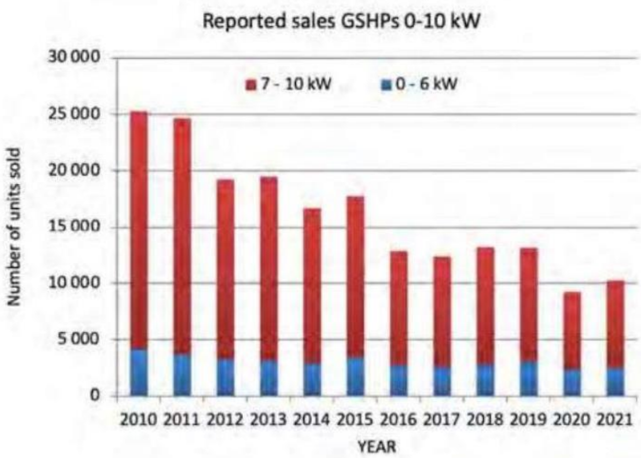
The third major actions caused by the oil price increases was to stimulate research and development of heat pump technology. Sweden already had a strong industrial sector and regarding heat pump technology Sweden was a pioneer developing the modern refrigerator based on an invention made by Munters and von Platen. A refrigerator is a heat pump though the purpose is the reverse. A heat pump/refrigerator is moving heat from one place to another. Decreasing the temperature on one side, increasing it at another.

The first heat pumps for buildings were developed by pioneering companies like NIBE and IVT in the 80ties. But effective ground source heat pumps were first developed in the 90ties. At the same time theoretical analysis tools and software for simulating effect of extracting and injecting heat in the bedrocks were developed at a few Universities in Sweden, Germany and USA. Public financing supported the academic research.



Above can be seen sales statistics for heat pumps in Sweden. (4) The first ground source heat pumps (light brown) were deployed already in the 80ties. They were open source based, using ground water directly. They were not very efficient, and the solution got a bad reputation, effectively stopping all sales. As mentioned, effective ground source heat pumps were developed in the 90ties and used with close loop systems which are easier to install and maintain compared to open-source systems. In the beginning of the century, driven by high oil prices, government subsidies (there is still some subsidies for private house-owners) and cheap electricity the number of systems really started to soar as can be seen in the diagram.

In the segment small houses, the ground source heat pumps soon were meeting stiff competition from air based heat pumps (blue colours in graph above, and also illustrated here.



But it was compensated by a fast growth of larger heat pumps (which means more drilling) as can be seen from graph below. (2).

A perfect storm

Several factors contributed to the strong development for ground source heat pumps in Sweden.

Four factors are already mentioned above:

A strong industrial and technological base, with basic knowledge about heat pumps already around.

Academic research publicly funded. Methods and software developed puts calculating borehole fields on a more accurate base, ensuring sustainable solutions. E.g. Earth Energy Designer is and easy to use software tool for simulating bore hole fields with a proven accuracy. It was developed in the 90ties through a collaboration between Lund Institute of Technology (Sweden) and Giessen University (Germany)

Government subsidies in the beginning of the century. Cheap electricity.

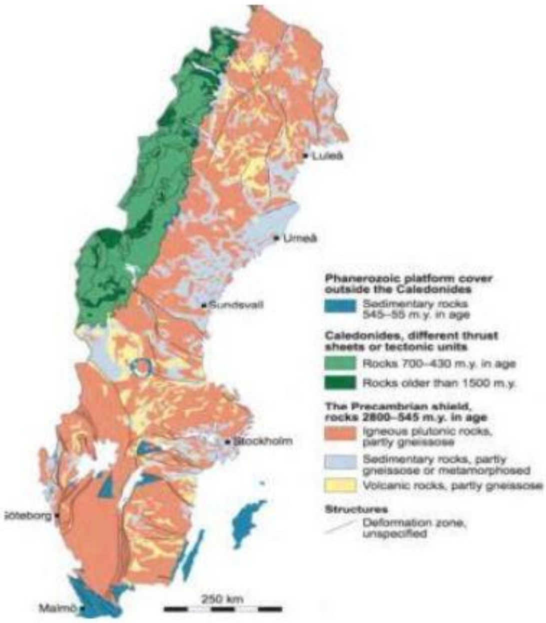
Geology and drilling
A large part of Sweden the bedrock consists of the so-called Baltic shield. The Baltic shield consists of old (pre-Cambrian), predominantly crystalline igneous and metamorphic rocks suitable for drilling and as a heat source and sink since it is giving stable holes for mounting collectors and with good heat conductivity due to high quartz content. The most common diameter for the holes is 114 mm, even if 139 mm is sometimes used for deeper boreholes.

Government subsidies in the beginning of the century. Cheap electricity.

Geology and drilling

A large part of Sweden the bedrock consists of the so-called Baltic shield. The Baltic shield consists of old (pre-Cambrian), predominantly crystalline igneous and metamorphic rocks suitable for drilling and as a heat source and sink since it is giving stable holes for mounting collectors and with good heat conductivity due to high quartz content. The most common diameter for the holes is 114 mm, even if 139 mm is sometimes used for deeper boreholes and the collector is normally a single U-collector 40-50 mm in outer diameter with SDR 17. Material is PolyEthylene (PE100 is common) Sometimes double-U collectors are used, and the pipes then are 32 mm, SDR 17 mm. Boreholes with less diameter is cheaper to drill since less energy is needed for smashing the rocks and for transporting the crushed rock to the surface.

The high conductivity normally found in Swedish rocks means less amount of drilling meter per produced heat unit, which of course also keeps the cost down. Overview of the geology below by Swedish Geological Survey. From (2).



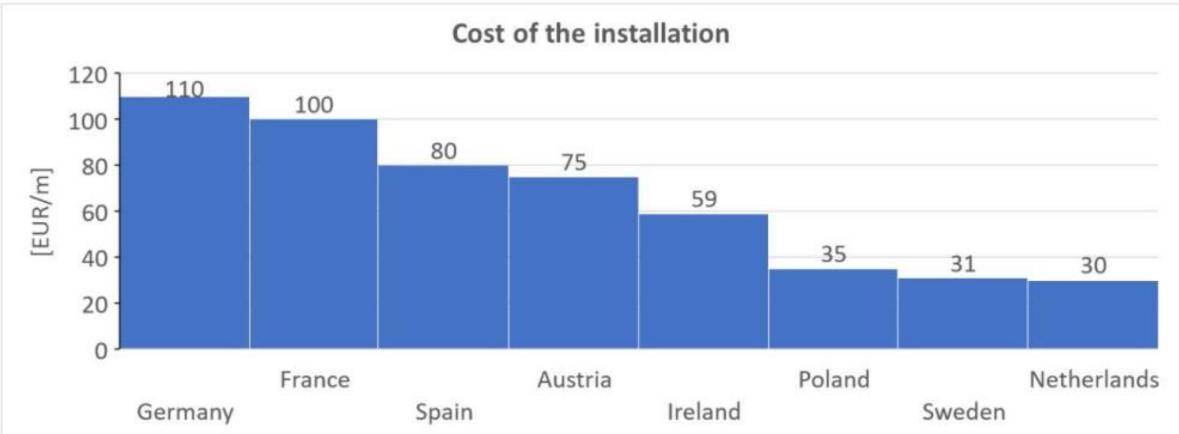
An important contributor to the fast spread of borehole-based ground source heat pumps were efficient, therefore relatively cheap, drilling methods. Sweden has a long history of mining in hard rocks. Due to that efficient drilling methods and machinery; rigs, tools and compressors already were developed by companies like Sandvik and Atlas Copco. And could be used for drilling for ground source heating. Cost comparison in (5) shows that Sweden drilling methods are efficient and therefore cheap, compared to other countries.

In Swedeen there is usually no demand for grouting, since there is plenty of ground water almost everywhere and this keeps the cost down. Ground water level is usually found at depths between 4 and 6 meters. The protection of the ground water is regulated in several (strong) recommendations how to drill to protect the ground water, as stated in the document Normbrunn 16 (translated to English it can be found at (6)) by the Swedish Geological Survey.

High ground water levels mean grouting is not necessary since heat is transferred between the bedrock and the collector through the ground water.

Finally, another factor keeping the cost down, is that the soil (sand, moraine, etc) overburden covering the bedrock is usually quite shallow keeping the need to drill with steel pipes to a minimum. It is rarely thicker than 6 meters. And drilling with pipes is much more expensive compared to drilling in solid rocks.

From (5)



Since heat pumps is a commoditized market, the price does not differ much between EU countries and labour-cost are also quite equal (except for Poland) the cost in the above graph (5) is mainly reflecting drilling cost.

Serving the ground source heat pumps in Sweden is some 670 000 drilled bore holes (vertical and closed loop), 150 000 soil/lake based (horizontal and closed loop) heat pumps and around 12 000 open-source (direct usage of ground water) systems. Extrapolated from (2).

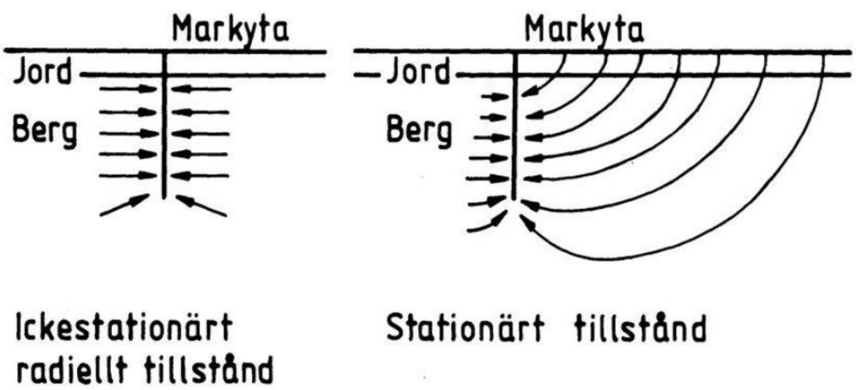
Drilled boreholes with closed loop system is thus by far the biggest heat source for liquid-based heat pumps in Sweden. The reason is that in urban area there is no space for soil-based system and even if some 13 percent of Swedish ground holds enough water for open loop systems (2) it is a complicated process to get permission to drill there, since it is often used for freshwater extraction and thus highly protected. The permission procedure is also more complicated compared to drilling for closed systems.

Drilling 114 mm borehole and mounting a single-U collector is a standardized routine and therefore efficient and cost-effective, and together with an abundance of drilling companies that makes it a highly competitive sector, are factors keeping the cost for drilling and mounting collectors and pipes, down.

Climate

Sweden has a continental climate with cold to very cold winters and warm summers, this means there is a great need for efficient warming solutions to handle the winter cold and that there is some need for cooling in the summer and the bedrock can be used as a source and sink for both needs.

Since most of the heat energy stored in the upper crust derives from the sun, warm summers is favourable for long term extraction of heat energy as illustrated below (from 7). The heat from the interior of the earth is very negligible in Sweden due to thick continental crust (the Baltic Shield) that isolates the upper crust from the hot mantle.



Right part of the picture illustrates the situation when you have a steady temperature around the borehole(s) and thus a sustainable ground source heat installation. To the left is the initial situation when temperature is dropping in the bedrock.

Simple permission management

All municipalities in Sweden have an environmental department (sometimes together with other municipalities). The environmental department is the entity that gives the permission of installing a ground source heat pump, including drilling (or digging).

The process is simple, a simple form needs to be filled in and sent to the department. Provided there is no issue with neighbours' being too close (at least 20 meters from adjacent boreholes), water protection issues or drilling has to be done on contaminated ground the permission is practically always granted. And normally within a few weeks' time.

Every drill must be reported on a simple form, it can be done interactively, and sent to the Swedish Geological Survey, it is a quick procedure.

This light bureaucracy also facilitates the spread of ground source heat pumps.

Conclusion

Factors like advanced and early development of technologies for heat pumps and drilling equipment, a favourable geology and climate, early development in academia, cheap electricity, timely government subsidies and simple permission procedures all created a "perfect storm" for the fast and thorough spread of ground base heat pumps in Sweden.

In absolute numbers Sweden (the most recent figure is 560 000, from (9)) is only surpassed by China and USA when it comes to number of ground source heat pumps installations. The only country in Europe near the number of installations that Sweden has, is Germany (410 000 units installed (9)). When it comes to number of ground source heat pumps installations per capita and share of heating used for buildings there is no country even close to Sweden. A country like Iceland, a volcanic island sitting on top of the mid Atlantic ridge is having a whooping amount of 90 percent of heating from buildings coming directly from warm and hot ground water but mostly without the need for a heat pump. In contrast, and unlike most European countries one cannot even find any warm water reservoir, within a reasonable depth, in Sweden with a temperature above 25 °C.

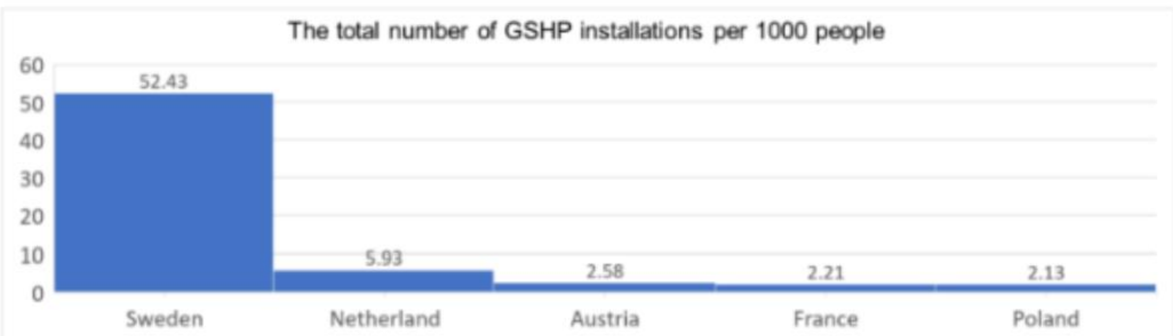
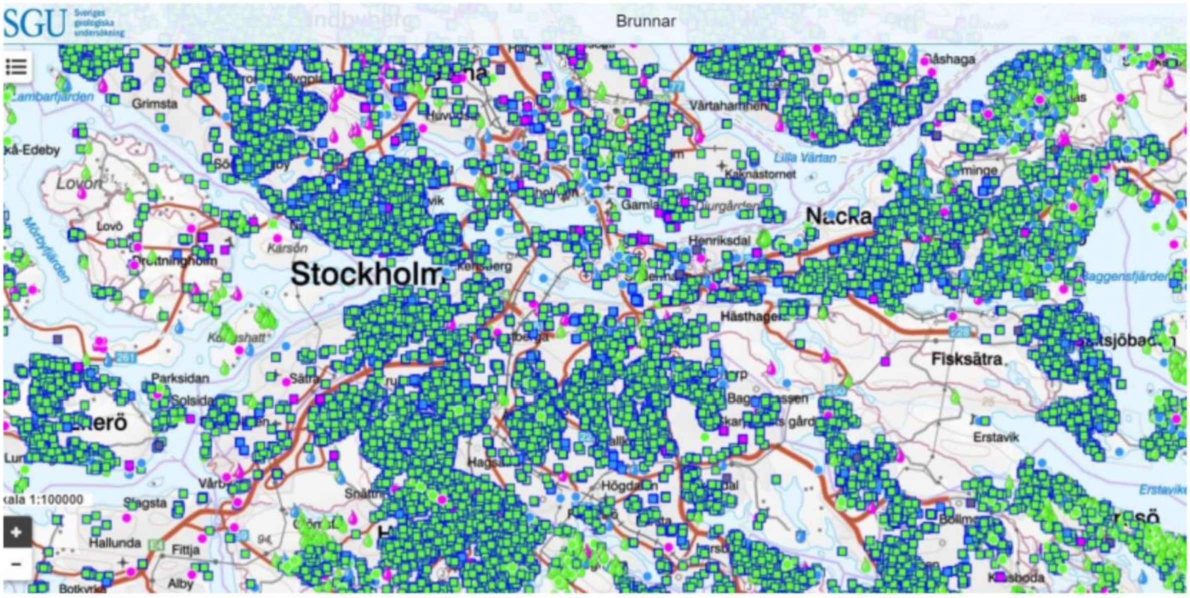


Figure 4. Total number of GSHP installations per 1000 people

Graph above from (4)

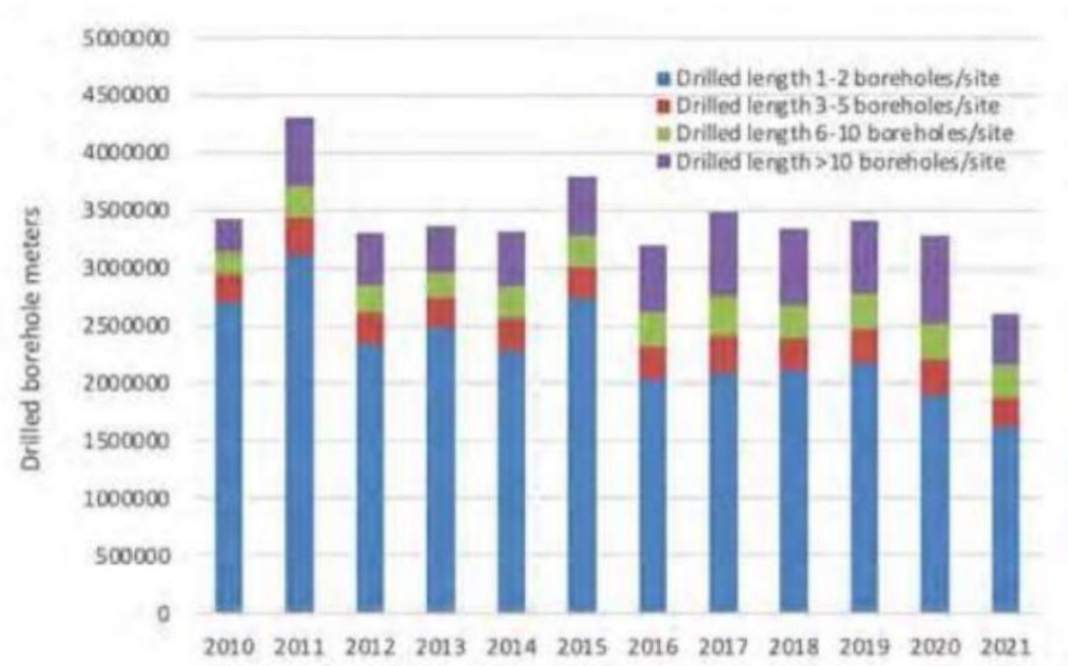
Below is an excerpt from “Databsen brunnar” (generally referred to as Brunnsarkivet. (8). Every green square is one or several borehole(s). As can be seen the penetration is indeed high!

This is a great tool since each borehole is documented with distance to bedrock, distance to ground water, abundance of groundwater, bigger cracks and generally gives some information about the bedrock. It facilitates planning and cost estimation for drilling.

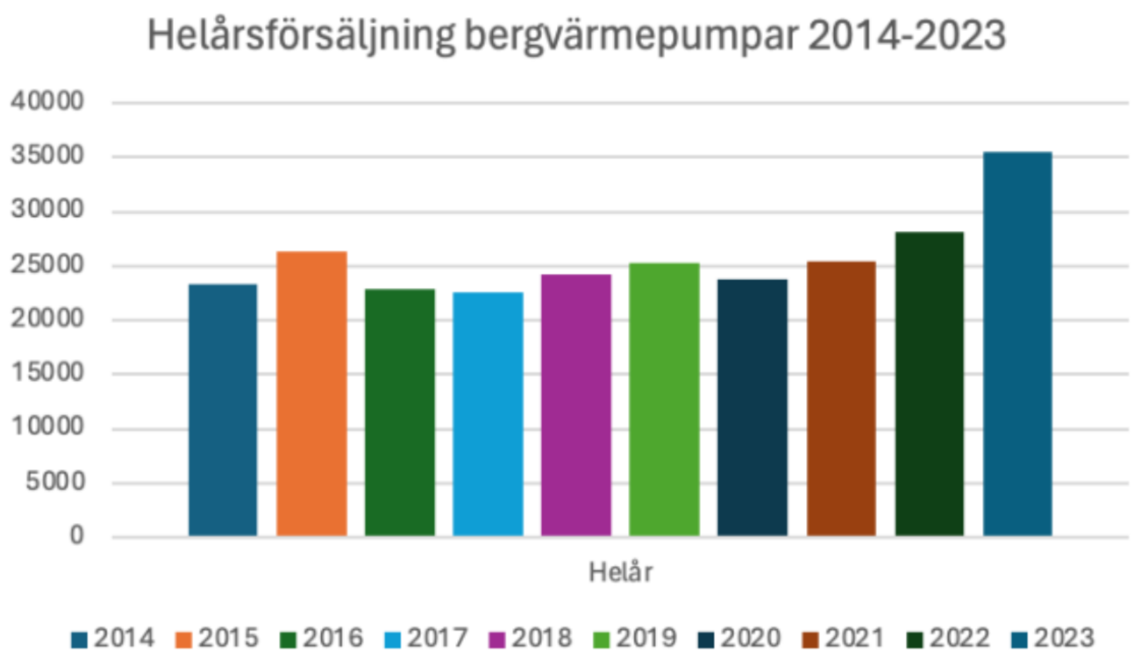


Future

The market for ground source heat pumps has been quite stable for many years. The decrease in sales towards the small house segment is offset by an increase of larger systems. Thus, the drilling has been quite stable, about 3,3 million drilled meters per year as can be seen in the graph below. Not even the pandemic changed that. (2) 2021 is underreported due to lag in the reporting.



This graph also shows a stable market. Ground source heat pumps sales in Sweden. (4)



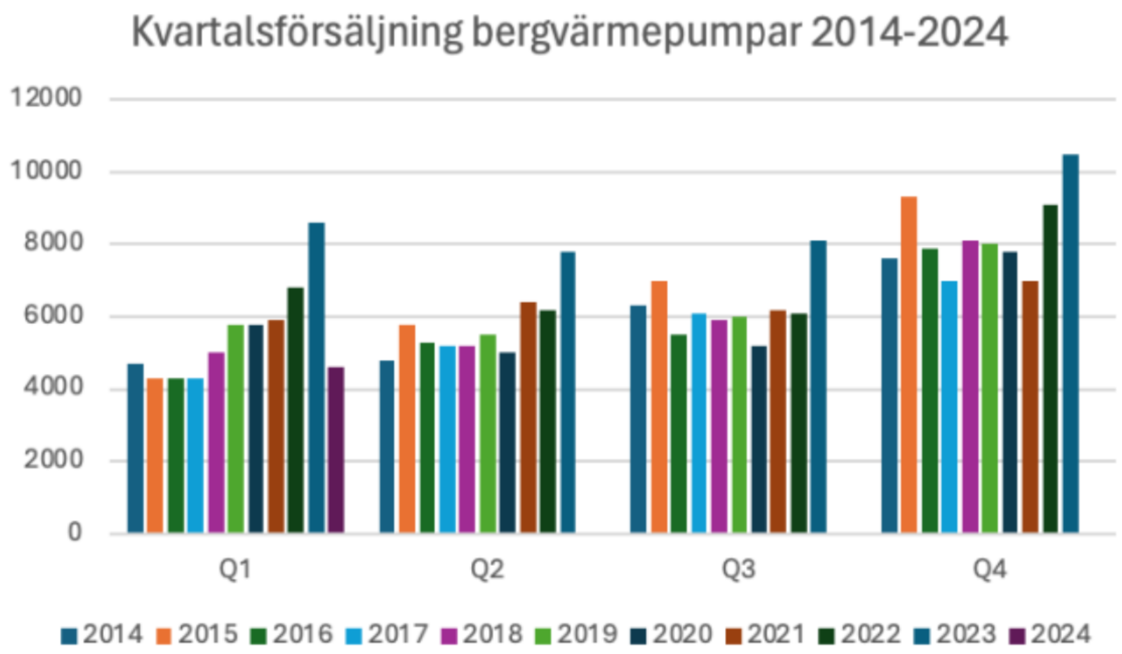
However, the Russian invasion of Ukraine and all the effect and actions it causes created problems for the market.

The increase of the interest rate made it more expensive to invest in a ground source solution due to its high capex. The electricity price increased more than the District heating prices making comparisons with district heating less favourable. For larger installations in urban areas district heating is always an alternative to ground source heat pumps.

The increase in sales for ground source heat pumps the year 2023 is a little hard to explain since it was not followed by an increase in drilling demand. On the contrary the drilling market shrunk in size 2023.

An explanation is the very optimistic forecast from EU (9) regarding sales of heat pumps in Europe and the need for weaning of gas boilers somehow spilled over to the Swedish installers and they invested in increasing their inventories, anticipating a surge in sales. A surge that never came.

And, predictably, in Q1 2024 the sales took a sharp dip as can be seen in this graph (4).



It is a fact that Sweden is in a recession now and most larger building projects has been cancelled or put on hold, and that of course reflects as a shrinkage of the ground source heat market.

However, there is light in the tunnel since Sweden is soon coming out of the recession, interest rates are on its way down and the building market will rebound. And for larger buildings with need for both heating and cooling an LCC will most of the time show that ground source heat solutions, most of the times, are less expensive in the long run compared to the alternative, district heating. And, also more sustainable, with less CO2-emission if certified electricity is used.

(1) https://pxexternal.energimyndigheten.se/pxweb/sv/Bost%c3%a4der%20och%20lokaler/Bost%c3%a4der%20och%20lokaler__Samlingsrapport/EN0112_6_ts.px/table/tableViewLayout2/?rxid=b1ada2ab-5fc9-4c72-a2e1-f429a1644466
(2) Geothermal energy use, Country update for Sweden. Gehlin, Andersson, Rosberg 2022
(3) https://www.energiforetagen.se/statistik/fjarrvarmestatistik/miljovardering-avfjarrvarme/
(4) https://skvp.se/nyheter-o-statistik/statistik/varmepumpforsaljningen
(5) Geoboost- Deliverable D2.1 Ground Source Heat Pumps in Euro
(6) https://www.sgu.se/globalassets/grundvatten/publikationer/well-standard--16guidelines for-well-drilling.pdf
(7) Prof. Bo Nordell / Göran Hellström, Avd. för förnyelsebar energi, Luleå tekniska universitet. Lecture material extract.
(8) https://apps.sgu.se/kartvisare/kartvisare-brunnar.html
(9) https://setis.ec.europa.eu/heat-pumps-european-union_en

Austria

The use of geothermal heat pumps (GHPs) in Austria gained traction after the 1970s oil crises. Initially, direct evaporation systems with horizontal ground collectors were used. Between 2000 and 2010, GHPs were the most popular heat pump type. However, after 2010, air-source heat pumps dominated the market due to easier installation and fewer regulatory requirements (Goldbrunner and Goetzl, 2022). Between the start of market diffusion and 2022, an estimated total of 604,569 heat pump systems were sold in the Austrian domestic market. Based on the assumption of a 20-year lifespan for these systems, it has been estimated that there were 441,068 heat pumps in operation across various applications in Austria by 2022 (Biermayr and Prem, 2023). In 2022, air-water heat pumps had an 86.2% market share. Brine-to-water heat pumps were second with a 9.9% share, while water-to-water heat pumps held 1%. Thus, GHPs accounted for about 11% of the market.

GHPs in Austria are predominantly found in smaller-scale installations, with most systems being used for space heating in the residential sector (Biermayr and Prem, 2023). For 2021, ~ 92,000 GHPs were estimated to be operational in Austria, with a total net capacity (excluding electricity consumption of the heat pumps) of around 1,100 MWh. The total gross heat supply was estimated at 2.3 GWh for that year (Goldbrunner and Goetzl, 2022).

The development and acceptance of GHPs in Austria results from a combination of factors such as supportive political frameworks, financial mechanisms, and educational initiatives. From a general technical point of view, the most important initial constraints for GHP deployment are the presence of near-surface groundwater bodies for open systems (groundwater heat pumps) as wells as land availability and access to it for drilling or digging of closed systems (borehole heat exchangers and horizontal collectors).

Austria has made great progress in promoting renewable energy, with specific policies and funding aimed at advancing geothermal energy. These efforts are primarily realised by the Federal Ministry for Climate Action and the Climate and Energy Fund. These policy initiatives are part of Austria's broader goal to achieve 100% renewable electricity by 2030 and climate neutrality by 2040. The Austrian government demonstrated its commitment to renewable energy by publishing the first "FTI-Roadmap Geothermie" in 2022. This document serves not only to further support Austria's advocacy for renewables, but also more directly highlights the importance of geothermal energy in the country's renewable energy strategy.

Economic incentives play a major role in the adoption of GHPs in many European countries, and Austria is no exception. Direct funding by means of non-repayable funds (e.g., grants) has been the main financial mechanism used by Austria to support GHPs. Financial incentives have been decisive in offsetting the high initial costs associated with these installations. Austria currently actively supports households to replace oil and gas heating with more sustainable heating including heat pumps. Federal and state subsidies are available for heat pump systems in Austria. Federal programs included "*Raus aus Öl und Gas*", "*Sauber Heizen für Alle*", and a commercial heat pump promotion program, all offering non-repayable investment grants as already mentioned. In 2022, 14,256 heat pump systems (out of which 1,246 were GHPs received EUR 98.2 million under "*Raus aus Öl und Gas*". Also, 200 systems (out of which 16 were GHPs received EUR 1.5 million under "*Sauber Heizen für Alle*" (Biermayr and Prem, 2023).

The electricity-to-gas price ratio is an important factor that influences heat pump adoption, especially in countries with extensive gas grids. In the EU, electricity prices are on average double those of gas. In 2021, a proposed revision of the Energy Taxation Directive aimed to balance taxes between electricity and gas. Since 2022, Member States can apply reduced VAT rates to energy-efficient heating systems like heat pumps (Lyons et al., 2022). In Austria, Eurostat data showed the electricity-to-gas price ratio for households fell to 1.7 in early 2023, the lowest since 2007 (Brancher and Steiner, 2024). However, it rose to about 2.0 in the second half of 2023.

At both Austrian EU levels, main obstacles to GHP deployment are high initial costs, limited product availability due to pandemic-related shortages and the semiconductor scarcity, and a lack of skilled labour (Lyons et al., 2022). Macroeconomic factors, such as import/export tariffs on raw materials and rising interest rates affecting financing (notably for GHPs), also pose challenges. The shortage of planners, architects, engineers, and qualified installers causes installation delays. However, advancements in heat pump technology, transition from F-gases to natural refrigerants, and increased retrofit rates are alleviating some of these issues (Lyons et al., 2022).

Public awareness and acceptance of geothermal energy have been growing in Austria, driven by educational initiatives and public information campaigns. However, this point is still considered problematic by experts (Goldbrunner and Goetzl, 2022). For instance, the share of geothermal energy in Austria's installed renewables for heating remains very low at ~ 2%, and for renewable electricity production, it is insignificant at less than 0.1%. These residual numbers have been attributed not only to a lack of political will and an unfavourable legal framework, but also to a generally low level of public awareness of geothermal technologies (Goldbrunner and Goetzl, 2022).

Main governmental institutions involved in fostering GHPs in Austria

- Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology (BMK): Oversees the implementation of renewable energy policies and provides funding and regulatory support for geothermal energy projects.
- Climate and Energy Fund: Provides financial support for geothermal research and development projects.
- Geothermal Association of Austria (GTÖ): Promotes geothermal energy through advocacy, research, and public education. It also organises events and provides resources for stakeholders in the geothermal sector.
- GeoSphere Austria: Implements technical and research projects related to geothermal energy, generates hydro-geological data and resource maps. Hosts the recently launched "Geothermie-Atlas", an online information platform displaying geodata and interactive potential calculations for individual borehole heat exchanger installations as basis for the planning procedure.
- Kommunalkredit Public Consulting: Handles for example the subsidy programme for heat pumps.

Legislation and regulatory framework

The federal Water Act (WRG 1959, and amendments) establishes the legal framework governing all uses associated with shallow geothermal methods in Austria. This Act falls under the jurisdiction of the Federal Ministry of Agriculture, Forestry, Environment, and Water Management (BML). Concerning regulatory procedures, the BML's authority is primarily concentrated on transnational regulation aspects (§100, WRG 1959). The execution of the federal Water Act is delegated to the governors of Austria's nine autonomous provinces, represented by their administrative offices (*Ämter der Landesregierungen*).

The Water Act regulates groundwater heat pump systems in terms of groundwater abstraction and reinjection. For groundwater uses not exceeding 300 l min–1, in addition to closed systems, the regulatory responsibilities are managed by the district offices (Bezirkshauptmannschaften) of the Austrian provinces. In contrast, groundwater uses yielding more than 300 l min–1 and broader planning and management issues, such as defining water protection areas, are overseen by the administrative offices of the federal provinces. For BHEs and horizontal collectors, the Water Act specifies situations requiring a submission and outlines the submission process. The Water Act defines the regulation and application for geothermal systems broadly and stipulates that the state of the art is to be upheld for all water utilisations, and installations and measures subject to this Federal Act.

The Austrian Water and Waste Management Association (ÖWAV), which represents service providers in water supply, and waste management, has issued the following guidelines relevant to thermal interactions:

- ÖWAV RB 207: Addresses the thermal use of groundwater and subsurface areas for heating and cooling.
- ÖWAV RB 208: Relates to drilling procedures for groundwater exploration.

Though the ÖWAV guidelines are not legally binding, the administrative bodies consider them as state of the art. In particular, the ÖWAV RB 207 is considered the most important guideline for the use of shallow geothermal energy in Austria. Nevertheless, some federal provinces have established stricter rules than in ÖWAV RB 207.

Austria has two main licensing procedures in place for shallow geothermal energy systems: Permitting Procedure and Simplified Notification Procedure. Factors determining which one should be enforced are the geological setting, water protection areas and interactions with other water rights and public installations (including thermal interaction and negative thermal interference). Table 1 provides a comparison of the two procedures, showing their main aspects and requirements (Rupprecht et al., 2017).

Table 1. Comparison between the permitting and notification procedures for shallow geothermal energy systems in Austria (Rupprecht et al., 2017).

Aspect	Permitting Procedure	Notification Procedure
Negotiations	Includes building negotiations with neighbours	No building negotiations required
Decision time frame	No specified duration	Decision within 2 months
Requirements	Mandatory building and operating requirements set by the water agency	Self-regulated compliance
Mandatory for	All open systems and closed systems affecting other installations or water rights	Certain closed systems unless in water protection areas or sensitive locations
Authority discretion	Water authority can change the procedure if necessary	Not applicable
Validity period	Set individually for each system	Valid for 25 years
Extensions	Request required upon expiry	Request required upon expiry
Sensitive locations	Defined by federal states; include karst areas, contaminated sites, unstable ground, confined groundwater areas, gas occurrences, thermal or mineral water resources, evaporites	Not applicable, in sensitive locations the permitting procedure is enforced
Information resources	Online platforms, GIS applications, telephone consultation	Online platforms, GIS applications, telephone consultation
Submission point	Local departments of the water authorities	Local departments of the water authorities
Review process	Documents forwarded to federal state water agencies for additional review	Documents forwarded to federal state water agencies for additional review
Post-approval requirement	Users must maintain an operating diary	Users must maintain an operating diary

Annex 6. SWOT Analysis criteria – Regulation elements

Explanation of each category for SWOT and what they represent in the context of geothermal heat pump systems

Strengths

Storage of geological and technical data: detailed and accurate records of geological and technical data aids in the design, operation and maintenance of geothermal systems.

Sustainable geothermal resource use: efficient and responsible use of geothermal resources, ensuring long-term sustainability.

Prevention of unfavourable interactions between systems: measures to avoid negative interference between geothermal systems, improving efficiency and operational safety.

Efficiency operation of systems: Maximise operational efficiency to reduce costs and improve overall performance.

Ensuring Energy balance of GHP systems: appropriate balance between energy extracted and energy injected to optimise performance.

Optimization of heat exchange distribution of the systems over time: heat distribution over time to maximise efficiency.

Optimization of cost of the systems: Reduce costs through efficient design, operation and maintenance.

Weaknesses

Thermal Changes in the Subsurface and/or Groundwater: Temperature variations in the subsurface or groundwater that can negatively impact system performance.

Subsurface Interference Impact on the Ability to Deliver Heating & Cooling Power: Subsurface interactions that may reduce the effectiveness of systems in providing heating and cooling.

Special Legal Obligations, Restrictions, or Technical Requirements: Regulations and restrictions that may complicate the installation and operation of systems.

Higher Energy Consumption: Additional energy needed to operate (Maintenance and Repair Costs, Control and Monitoring Equipment, Fuel or Auxiliary Energy Costs, etc) the system, which can increase operating costs.

Groundwater Thermal Short Circuit or Thermal Breakthrough Between Systems: Issues where heat transfer between geothermal systems negatively affects each system's performance.

Space and Availability for Systems in Different Environments: Space limitations and availability constraints that may restrict geothermal system implementation.

Opportunities

Improved Monitoring Techniques: Development of advanced monitoring techniques that can enhance system management and performance.

Develop Optimized Planning Software: Creation of planning and optimization software that can improve design and operation efficiency.

Development of Future Installations and/or Heating Districts: Expansion of geothermal system infrastructure into new areas or heating districts.

Encouraging and Promoting Research and Development: Support for research that could lead to innovations and improvements in geothermal systems.

Protecting Ecosystems: Implementation of practices to ensure ecosystem protection while developing geothermal energy. An ecosystem is a more specific and delimited unit within the environment, consisting of a biological community of living organisms interacting with each other and their abiotic environment (physical and chemical factors).

Long Term Resource Management: Sustainable management of geothermal resources in the long term.

Optimize Consumption of the Heat Pump: Improvements in heat pump efficiency to reduce energy consumption and operating costs.

Threats

Regulatory Instability: Changes in regulations that could negatively affect the feasibility and operation of geothermal systems.

High Costs Associated with Complying with Regulations: Additional costs required to comply with regulations that may impact system profitability.

High Operation Costs: High costs associated with operating and maintaining geothermal systems that could reduce their economic viability.

Unknown Environmental Impacts: Risks of environmental impacts that are not fully understood and could emerge over time.

Conflict with Other Subsurface Users Causing Possible Damage (e.g., physical) Between Users: Conflicts with other subsurface users that could result in physical damage or operational issues.

Annex 7. SWOT analysis criteria – Planning Tools

Strengths

Adaptability to urban and rural areas: The tool's ability to be used in both urban and rural areas make it versatile.

Application for different GHP systems (open and closed systems): the tool is applicable to different types of geothermal heat pump (GHP) systems.

Free access: the tool is free to the public access and at no cost associated with it.

Performance measurement: It allows measuring the performance of the implemented systems.

Detailed modelling results: The tool provides detailed and accurate results of modelling that can be useful for analysis and planning.

Clear information on calculation results: The calculation results are presented in a clear and comprehensible manner.

Functionality for handling calculation or modelling errors: The tool can manage and correct errors in calculations or modelling.

Incorporation of local norms and standards: It integrates specific norms and standards from different localities.

Integrated geothermal databases: It includes geothermal databases that can be used in calculations and modelling.

Weaknesses

Difficult tool to understand and execute: It can be complex to use for users unfamiliar with the technology.

Operational problems of the tool: It may face recurring operational problems in the operation or functioning of the software.

Require advanced hardware: The tool needs advanced equipment to work properly.

Large amount of required data for the calculations: the tool requires a large amount of data to be entered or delivered to perform the calculations.

Restrictive calculation results for future installation: The results may limit options for future installations.

Constraints and restrictions to upgrade and innovate: The tool can be difficult to update and innovate due to inherent constraints.

Limited handling/processing of information for large-scale or complex projects: the tool has limitations in handling or processing information in large-scale or complex projects.

Opportunities

Consolidation of the planning tool to be used in mature markets: opportunity to consolidate the planning tool in mature markets, improving its adoption and use.

Transfer of tool usage to other regions/jurisdictions: Expansion of its use in different regions and jurisdictions.

Facilitates decision-making: The tool assists decision-makers in making informed decisions.

Use of local and regional resources: The tool promotes the efficient use of local and regional resources in energy planning processes.

Integration into energy action plans: the tool can be incorporated into energy action plans.

Map and plan heating and cooling energy demand based on sub-surface resource data: the tool allows for detailed energy mapping and planning based on geothermal data.

Development of long-term energy supply: the tool contributes to the development of long-term energy supply strategies.

Threats

Changes in European policies: the threat posed by changes in European policies that could affect the implementation and use of the tool.

Expensive regulatory requirements: Costly regulatory requirements can limit the adoption and use of spreadsheets, especially if they involve high compliance costs.

Changing energy needs: the threat of changes in energy needs that could affect the relevance and usefulness of the tool.

New planning tools emerge: The appearance of more advanced tools may reduce their use.

Requirement for constant updating and maintenance of planning tool: The continuous need to update and maintain the planning tool may require significant resources, which could be a burden for users.

Lack of data availability in the area of future installation: Lack of available data in the area of future installation may limit effectiveness in new areas.

Annex 8. SWOT Analysis - Scoring of Regulatory Elements

Strengths	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Storage of geological and technical data	12	1	12	1	12	2	24	3	36	3	36	3	36
Sustainable geothermal resource use	20	3	60	3	60	2	40	3	60	1	20	3	60
Prevention of unfavourable interaction between systems	18	3	54	3	54	3	54	1	18	2	36	2	36
Efficiency operation of systems	15	2	30	2	30	2	30	2	30	2	30	3	45
Ensure Energy balance of GHP systems	15	1	15	3	45	1	15	3	45	1	15	3	45
Optimization of heat exchange distribution of the systems over time.	10	1	10	3	30	2	20	3	30	1	10	1	10
Optimization of cost of the GHP systems	10	1	10	1	10	1	10	2	20	1	10	2	20
Total	100		191		241		193		239		157		252

Weaknesses	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Thermal changes in the subsurface and/or groundwater	20	1	20	3	60	3	60	1	20	1	20	2	40
Subsurface interference impact on the ability to deliver heating & cooling power	20	3	60	3	60	2	40	3	60	3	60	3	60
Special legal obligations, restrictions, or technical requirements.	15	1	15	2	30	2	30	2	30	2	30	2	30
Higher energy consumption (Maintenance and Repair Costs, Control and Monito	10	1	10	1	10	1	10	1	10	0	0	2	20
Groundwater thermal short circuit or thermal breakthrough between systems	20	3	60	2	40	3	60	0	0	1	20	2	40
Space and availability for systems in different environments	15	3	45	1	15	2	30	0	0	2	30	2	30
	100		210		215		230		120		160		220

Opportunities	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Improved monitoring techniques	15	1	15	3	45	1	15	3	45	2	30	2	30
Develop optimized planning software.	15	2	30	2	30	2	30	1	15	3	45	3	45
Development of future installations and/or heating districts	20	2	40	2	40	2	40	3	60	3	60	3	60
Encouraging and promoting research and development	15	0	0	0	0	1	15	3	45	2	30	3	45
Protecting ecosystems	15	2	30	2	30	2	30	1	15	2	30	1	15
Long term resource management	20	3	60	3	60	2	40	2	40	2	40	3	60
Optimise consumption of the heat pump	15	2	30	2	30	1	15	3	45	2	30	3	45
	100		205		235		185		265		265		300

Threats	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Regulatory instability	20	1	20	1	20	3	60	3	60	1	20	1	20
High costs associated with complying with regulations	20	1	20	2	40	3	60	3	60	3	60	2	40
High operation costs	15	1	15	1	15	1	15	2	30	1	15	1	15
Unknown Environmental Impacts	20	1	20	3	60	2	40	2	40	2	40	3	60
Conflict with other subsurface users (subsurface infraestructure) causing possi	25	3	75	3	75	2	50	2	50	3	75	2	50
	100		150		210		225		240		210		185

AXIS				Distance		Temperature		Extraction and discharge		Seasonal performance of installation		Size and layout of the GHPS installation		Subsurface conditions		
100		0	200	210	191	215	241	230	193	120	239	160	157	220	252	WS
400	100	200	0	150	205	210	235	225	185	240	265	210	265	185	300	TO
				WT	SO	WT	SO	WT	SO	WT	SO	WT	SO	WT	SO	

Annex 9. SWOT Analysis - Scoring of Planning tools

Strengths	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Adaptability to urban and rural areas	15	2	30	3	45	3	45	3	45
Application for different GHP systems (open and closed systems)	10	3	30	1	10	1	10	3	30
Free access	20	3	60	1	20	3	60	3	60
Performance measurement	10	2	20	2	20	2	20	2	20
Detailed modelling results	15	2	30	2	30	2	30	2	30
Clear information on calculation results	10	3	30	3	30	2	20	2	20
Functionality for handling calculation or modelling errors	5	2	10	2	10	2	10	1	5
Incorporation of local norms and standards	5	3	15	3	15	3	15	3	15
Integrated geothermal databases	10	2	20	2	20	3	30	2	20
Total	100		245		200		240		245

Weaknesses	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Difficult tool to understand and execute	20	1	20	1	20	1	20	1	20
Operational problems of the tool	15	1	15	1	15	1	15	1	15
Require advanced hardware	10	1	10	2	20	1	10	1	10
Large amount of required data for the calculations	15	2	30	1	15	2	30	2	30
Restrictive calculation results for future installation	10	1	10	1	10	2	20	2	20
Constraints and restrictions to upgrade and innovate	10	2	20	2	20	2	20	1	10
Limited handling/processing of information for large-scale or complex projects	20	2	40	2	40	2	40	2	40
Total	100		145		140		155		145

Opportunities	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Consolidation of the planning tool to be used in mature markets	15	3	45	3	45	3	45	3	45
Transfer of tool usage to other regions/jurisdictions	15	3	45	3	45	3	45	2	30
Facilitates decision-making	20	3	60	3	60	3	60	3	60
Use of local and regional resources	10	2	20	2	20	2	20	2	20
Integration into energy action plans	15	3	45	3	45	3	45	3	45
Map and plan heating and cooling energy demand based on sub-surface resource data	15	3	45	3	45	3	45	3	45
Development of long-term energy supply	10	3	30	3	30	3	30	3	30
Total	100		290		290		290		275

Threats	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Changes in European policies	15	2	30	2	30	2	30	2	30
Expensive regulatory requirements	15	2	30	3	45	3	45	2	30
Changing energy needs	10	3	30	2	20	2	20	2	20
New planning tools emerge	20	2	40	2	40	2	40	2	40
Requirement for constant updating and maintenance of planning tool	20	3	60	3	60	3	60	1	20
Lack of data availability in the area of future installation	20	3	60	2	40	2	40	2	40
Total	100		250		235		235		180

AXIS				Austria		Germany		Sweden		The Netherlands		
100		0	200	145	245	140	200	155	240	145	245	WS
300	100	200	0	250	290	235	290	235	290	180	275	TO
				WT	SO	WT	SO	WT	SO	WT	SO	