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Barriers behind the Retarded Shallow Geothermal Deployment in Specific Areas: A Comparative Case Study between Southern Spain and Germany

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Abstract: Shallow Geothermal Energy (SGE) extracted by Ground Source Heat Pump (GSHP) is a proven clean and profitable technology. Although it is available almost everywhere, its market enjoys different maturity levels along with the other EU Members and even those within the same country. In the Murcia region, in Southern Spain, the presence of GSHP is almost nonexistent. Germany, in contrast, has an extensive tradition of exploiting its SGE resources and is an example of a mature GSHP market. In this work, the technical and non-technical barriers were assessed in both countries to identify the site-specific parameters preventing a better deployment of SGE in Southern Spain. In addition, a SWOT analysis was conducted to highlight the parameters positively and negatively influencing the geothermal resource extraction. Results showed that both study cases showed similar and good technical conditions, such as sufficient resource 80 W/m approx. or a similar impact on the environment mainly due to the use of electricity consumed. However, the regulation and legal framework greatly varied from one area to another. In conclusion, the main factors causing a poor deployment are the lack of specific regulation or regional administration support.

Keywords: renewable energy; shallow geothermal potential; barriers; GSHP

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1. Introduction

Heating and cooling consume half of the energy in the EU, and 75% is produced from fossil fuels [1]. To reduce energy consumption and slow down the consequences of climate change, the European Commission approved the European Green Deal in September 2020. Using this document, The EU Commission adopted a new and ambitious Plan of climate objectives to reduce GHG emissions by 55% by 2030, compared with 1990 levels [2]. By 2050, the goal is to achieve climate neutrality.

EU possesses a high dependency on the energy produced outside de EU, with a high increase rate that ranged from 56% in 2000 to 61% in 2019 [3]. Germany's dependence is around 70% and almost 75% in Spain in 2019. In addition, the EU mainly depends on Russia for crude oil, natural gas, and solid fuels [3]. In light of the last events derived from the geopolitical issues, there is more than ever the urgent necessity for the EU-Member countries to become energetically independent from Russia. In 2021, The EU member states imported 155 billion cubic meters of gas from Russia, representing 45% of gas imports and 40% of the total gas consumption [4]. Per country, the situation differs. Due to their location on the Iberian Peninsula, Spain and Portugal remain energy islands that can hardly participate in the energy market [5]. This derives from a low dependency of 10% of the Russian natural gas relative to the other countries such as Algeria or the United States. However, reliance on Russian natural gas rises to 50% [3]. To fight against it, the IEA has recently published a 10-point plan to reduce the European Union´s reliance on Russian Natural Gas [4]. Two proposed actions include gas boilers for heat pumps and using alternative resources.

The way we produce our space Heating and Colling (H&C) is also mainly fossil fuel-oriented. Around 45% comes from natural gas and about 15% from petroleum. Only 25% comes from renewable and waste resources. From this block, 15% comprises biomass, 4% solar thermal, and 1% comes from geothermal.

The shallow geothermal resource is a 24/7 renewable energy resource and can be found almost everywhere [6]. Ground Source Heat Pumps (GSHP) use this energy to provide renewable space Heating and Cooling (H&C) and domestic heat water. Its global installed capacity has more than doubled since 2010, to 75 GWth, and it has been deployed in 88 countries worldwide [7]. The IEA predicted a 2019 increase in direct surface geothermal use of more than 40% (2019–2024), with China, the United States, and the EU responsible for more than 80% of the additional consumption [7].

Despite the GSHP market in the EU having been hit by the COVID-19 pandemic crisis, sales were around 100,000 units, with Sweden, Germany, and The Netherlands accounting for over half of these sales [8]. Considering the number of GSHPs installed, Spain is one of the countries with the lowest deployment of this technology [9]. Among the main barriers preventing a better deployment are the high upfront costs of these systems due to the drilling need to bury the heat exchangers. Therefore, the initial costs make these installations economically less attractive a priori than other renewable H&C systems. Additionally, among the non-technical barriers, the lack of awareness among investors and policymakers and the lack of knowledge about its potential are the leading causes behind its slow deployment. Despite Spain and Germany being subject to the same economic and technical barriers, the number of installed GSHPs is 400 times higher in the latter than in the former [10].

This study aimed at identifying the issues that are slowing down the growth of the shallow geothermal energy in Southern Spain compared with a successful case, Germany. Murcia was placed, using the use of Multi-Criteria Decision Making (MCDM) tools [11], as an area with potential but scarce resource use. Therefore, the assessment of the main parameters that identify the site-specific success or the failure of this technology was carried out. This assessment consists of the resource, technical, and environmental potential and the grade of development of the regulative status to install GSHP in both areas.

The paper is organized as follows. In Section 2, the methodology considered for assessing the site-specific parameters in both case studies is detailed. Section 3 focuses on the study cases details, mainly housing stock building and climatic conditions, and the data used. Section 4 shows the results after applying the methodology to the case studied. Finally, in Section 5, the conclusions are drawn after comparing the results in both study cases.

2. Materials and Methods

The proposed methodology is summarized in Figure 1. The approach was conducted to assess quantitatively and qualitatively the aspects that can define the success or the failure of the GSHP technology in a specific place. The reference technology was a closed-loop GSHP system with a vertical Borehole Heat Exchanger (BHE) to provide H&C for a single house. The methodology for determining the resource and technical potential assessment is in line with ref. [12]. Site-specific resource, technical, environmental, and legal framework characteristics were identified. Afterwards, points were used as input in a SWOT analysis where the strengths, weaknesses, threats, and opportunities for a better deployment of SG in Southern Spain are identified.

This work does not consider the economic study. Notwithstanding that the initial upfront costs are one of the main barriers of SGE, the cost difference of GSHP systems between one country and another is not. However, whether the administration supports these systems or not is of concern, and it is considered in this work.

The methodology is stepwise described in the following sections.

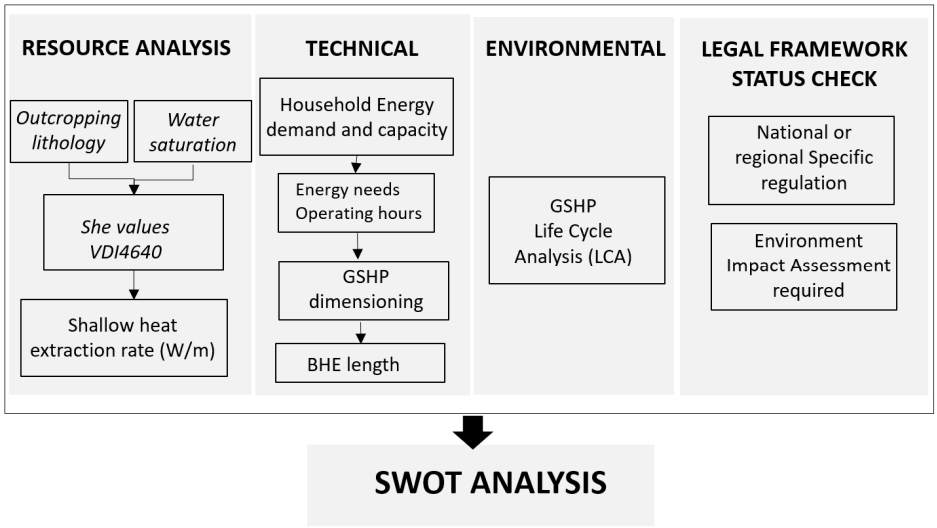


Figure 1. The methodology is applied to measure the success or failure of the GSHP technology in a specific place.

2.1. Resource Potential Assessment

Shallow geothermal resource refers to the energy contained within a certain depth in the underground and varies spatially from one area to another [13]. The methodology to determine the site-specific shallow geothermal resource potential is based on the study of the outcropping lithology, the water saturation degree of the materials, and the direct assignment of extractable heat values from the German VDI4640 standard [14]. This methodology is developed partially with GIS environment support following the steps marked in Figure 1. The VDI4640 regulation establishes, in its annex 2, specific extractable heat values for each type of lithology based on the degree of consolidation of the subsoil material. When it comes to unconsolidated material, such as gravel and sand, the standard establishes ranges of extractable heat values depending on whether the material is water saturated. Therefore, it is first necessary to determine the degree of saturation of the underground. This information can be measured, extracted from the literature, or estimated. For its estimation, a hydrological study must be carried out to assess the height of the water table in the area. Once the water table is known, Equation (1) must be applied [15], where k is the underground lr, Th_{agg} is the overall depth considered, sHE_k is the specific heat extraction rate of the layer k, and th_k is the thickness of the layer k. *Dry* and *sat* refer to the superficial part of the underground where there is no water table and the saturated part where the water table is found up to 100 m deep.

$$the\ sHE = \sum_{k=1}^{n} \frac{\left(sHE_{k\ dry} \cdot th_{k\ dry}\right) + \left(sHE_{k\ sat} \cdot th_{k\ sat}\right)}{Th_{agg}} \quad (1)$$

To associate the extractable heat values of the standard with the existing lithology, firstly, the lithological information must be reclassified and adapted to the lithological classification given by the standard rule. Finally, the lithological and extractable heat information is linked in a GIS environment, and the extractable heat values are obtained in a raster file.

2.2. GSHP System Technical Characteristics

The amount of energy the GSHP system demands to provide the thermal loads and the energy it is capable of delivering determine the design characteristics and the size of the GSHP. For GSHP systems, the energy the installation outputs are determined by the subsoil's specific geothermal potential and the system's performance. The most representative characteristic, at a technical and economic level, is the number of meters

needed of the geothermal exchanger that determines the meters that must be drilled. These data mark the final cost of the installation. The thermal energy that the GSHP system can supply (E_{GSHP}) in (kWh) in a specific area can be determined by applying Equation (2), where qv_{GSHP} is the specific heat extraction rate (W/m) per borehole, t_h is the operating time, L_{BHE} is the length of the borehole heat exchanger, and COP is the Coefficient of Performance of the GSHP.

$$E_{GSHP} = \sum_{i}^{n} qv_{GSHP} \cdot t_h \cdot \frac{L_{BHE}}{\left(1 - \frac{1}{COP}\right)} \quad (2)$$

The length of the BHE required can be estimated based on the GSHP capacity and type of the underground [16] according to Equation (3), where P_{BHE} is the GSHP capacity (W). At the same time, the GSHP capacity can be estimated by dividing the annual energy demand and the operating hours. BHE length is calculated annually for maximum capacity, considering space heating and cooling.

$$L_{BHE} = \frac{P_{BHE}}{sHE} \quad (3)$$

2.3. Environmental Assessment: Life Cycle Analysis

Despite being a profitable technology [17–19], one of the main barriers hampering Shallow Geothermal Energy (SGE) deployment is the high upfront costs of the GSHP systems due to the drilling activities to bury the BHE. Nevertheless, the environmental benefits make GSHP technology a viable option and a great ally to curbing climate change. The LCA for GSHP technology has been previously studied [20] to evaluate mid- and long-term sustainability metric impacts in different locations. In addition, it assesses the technology´s effectiveness while operating with different electricity-generating fuel mixes.

This work conducted the Life Cycle Analysis (LCA) of the GSHP systems for both study cases. The life cycle study performs a complete environmental assessment of the geothermal installation, from its manufacture to its final recycling. The methodology for determining the life cycle is standardized by ISO 14020 of 2006 [21], and its procedure is defined in 4 phases: definition of the study and the product to be studied, inventory of the production processes with an environmental CO_2 quantification, an evaluation of the impact, and finally, an interpretation and assessment of the results and recommendations. Ref. [22] proposed a life cycle analysis for a facility in Germany, among other EU countries, according to ReCiPe [23]. In this work, the same methodology was applied in the Region of Murcia study case and compared with the case of Germany. The ISO 14042 standard establishes the necessity to define the impact categories and determine its indicators. ReCiPe considers three protection areas: resource depletion, human health, and ecosystem quality. In addition, there exist 18 categories that assess the environmental impact of the GSHP utility. Most of them do not affect the GSHP and can be considered negligible. Ref. [22] also established the relative contributions of the impact categories.

2.4. Study of the Regulatory Framework

To identify those measures implemented by the Administration that are facilitating or delaying the implementation and development of geothermal energy in a study area, an evaluation of the laws that rule this resource and its management was conducted. The regulation that manages the geothermal resource is mainly regional [9], so it varies from one region to another and, of course, from one country to another within the EU.

3. Study Case

Two case studies were selected in two countries of the European Union with different climatic characteristics: one in Southern Spain, Cartagena city, the second = biggest city in the Murcia region, and the other in the south of Germany, i.e., the city of Munich (Figure 2). Cartagena city has a population of 200,000 inhabitants and an annual average

temperature of 18.3 °C, while Munich has 1.3 million and an annual temperature of 6.7 °C. These two cities possess very different environmental characteristics in terms of climatic conditions, and the degree of maturation of GSHP technology differs significantly. Within these two cities, two neighborhoods were selected with similar dimensional characteristics and a similar number of houses. Table 1 summarizes the main characteristics of the two study areas.



Figure 2. Location of the study areas. Campo de Cartagena's municipality and the study area's cadastral view are on the lower left. The city of Munich in Germany and the study area are on the right.

Table 1. Study areas characteristics.

Parameters	Cartagena	Munich
Surface (km^2)	1.85	3.57
Houses number	1404	1403
Houses type	Dwellings	Dwellings
Annual average temperature (°)	18.3	6.7

3.1. Housing Stock Characteristics

The current housing stock conditions were consulted to estimate the energy behavior of the typical house in both study areas. The Statistic Institute of Region of Murcia (CREM) classifies the building stock state based on the age of its construction. According to it, Cartagena city possesses around 95% of the building stock in "good condition", whereas more than 60% of the current stock was constructed after the 1970s. On the other side, dwellings are considered the most appropriate housing constructions as they have plenty of space for the BHE and the GSHP accessories system. In the Murcia region, the average building has three floors, although the tendency has varied over the last years (see Figure 3). Nowadays, two-floor buildings are the most frequent construction, although one-floor houses have recently been a leader in the sector for a few years. Indeed, up to the 1990s, Cartagena only accounted for 4% of dwellings among its building stock. However, since 2000, the construction of new buildings has been led by dwellings, up to 80% of the total houses being constructed in 2017. The average surface of the houses in the Murcia region is 107 m^2. Of the housing stock, 87.6% possess a heating system versus 63.9% that have a cooling

system. Among the heating and cooling systems used, the electrical systems and heat pumps are the most frequent [24].

In Bavaria state, the average house surface per capita is 157 m^2. Figure 3 shows the clear and steady tendency over the years concerning the preference of the number of floors in the typical construction, where one-floor buildings are the most frequent. As for the heating systems being used, a significant majority use oil and natural gas, followed by renewable energy resources, district heating, and geothermal in this order [25]. One-hundred percent of the houses possess a heating system, while only one or two per cent have a cooling system. Most heating systems are aged more than 20 years (almost 50% of the total systems), but those younger than five years represent 15% of dwellings.

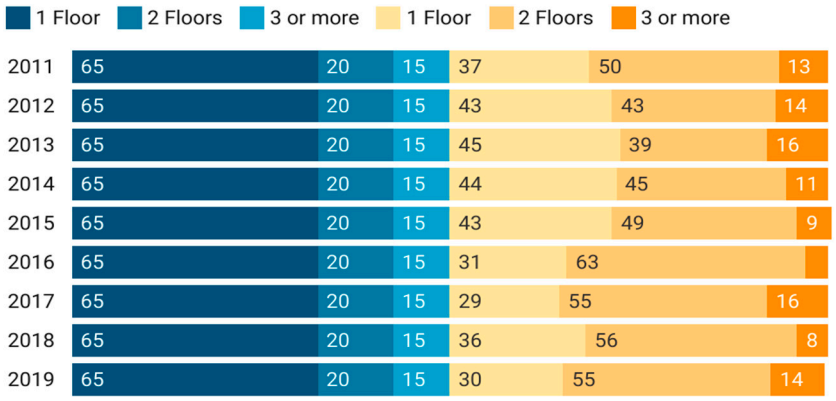


Figure 3. Percentage of residential buildings construction per year and per number of floors. Blue colors represent Bavaria province, and Murcia province in orange colors. Source: refs. [24,26].

3.2. Data Used

For calculating the geothermal potential resource, obtaining the lithological maps and the hydrogeological information of the zones was necessary. For Cartagena, the information was extracted from the Lithological Map of the Murcia Region of the Geological and Mining Institute at a scale of 1:200,000 [27], and the hydrogeological information was obtained from the Official Monitoring Network of the quantitative status: Piezometric Network [28]. As for the Munich area, hydrogeological and lithological information was obtained from the Geological Institute of the German region of Bayern. For the calculation of the geothermal potential resource, it was necessary to obtain the lithological maps and the hydrogeological information of the zones. For Cartagena, the information was extracted from the Lithological Map of the Murcia Region of the Geological and Mining Institute at a scale of 1:200,000 [27], and the hydrogeological information was obtained from the Official Monitoring Network of the quantitative status: Piezometric Network [28]. As for the Munich area, hydrogeological and lithological information was obtained from the Geological Institute of the German region of Bayern (https://www.lfu.bayern.de/index.htm, accessed on 1 February 2022).

4. Results

4.1. Shallow Geothermal Resource Potential

The specific heat extraction rate was determined in both study areas according to the methodology described. For the study case of Cartagena, the data needed to determine the heat extraction values were extracted from ref. [29], and for Munich, the method here described was applied.

Lithologically, the Cartagena area comprises marls, gravels, and sands. According to the water table dataset 10-year series consulted in the piezometers control Network [28], the mean water table in the city is about 50 m deep. On the other hand, Munich´s lithology is composed of gravels and sediments, and the mean water table can be found at a very shallow level. These properties are translated into a geothermal potential of 79 W/m

and 80 W/m for Cartagena and Munich, respectively. Therefore, each geothermal exchanger in this area would obtain 79 W of energy for each meter installed. In addition, the geothermal potential for each study area was calculated by applying the data obtained in Equation (1). Subsequently, the variables that characterize the hypothetical geothermal installation were established.

4.2. Energy Demand of the Residential Buildings

The average energy demand of dwellings has been estimated according to the climatic conditions of each location according to the Technical Building Code [30]. The technical Building code classifies the Spanish territory based on the climatic severity in the summer and winter. It is understood that in cities falling into the same classification, the housing stock account for very similar energy demand for H&C. The Munich area energy demand was set by comparing the city's climatic conditions with similar climatic characteristics in Spain. The city of Burgos turned out to share quite identical climatic conditions with Munich. Therefore, for the Cartagena study case, the demand values of zone B3 were considered as characterized by mild winters and summers. For Munich, the climatic zone E1 was characterized by high heating and no cooling demand. The annual energy demand for space heating and cooling for the study case was conducted (see Figure 4). Every climatic zone [30] offers an average thermal energy demand value making a difference between heating and cooling. The average thermal energy demand of a dwelling in Murcia for heating was 33 kWh/m^2 and 18.5 kWh/m^2 for cooling. For Munich, the average heating demand was 113.1 kWh/m^2 and was null for cooling. The mean H&C values were multiplied by the total number of dwellings to calculate the average annual demand. Results are shown in Table 2.

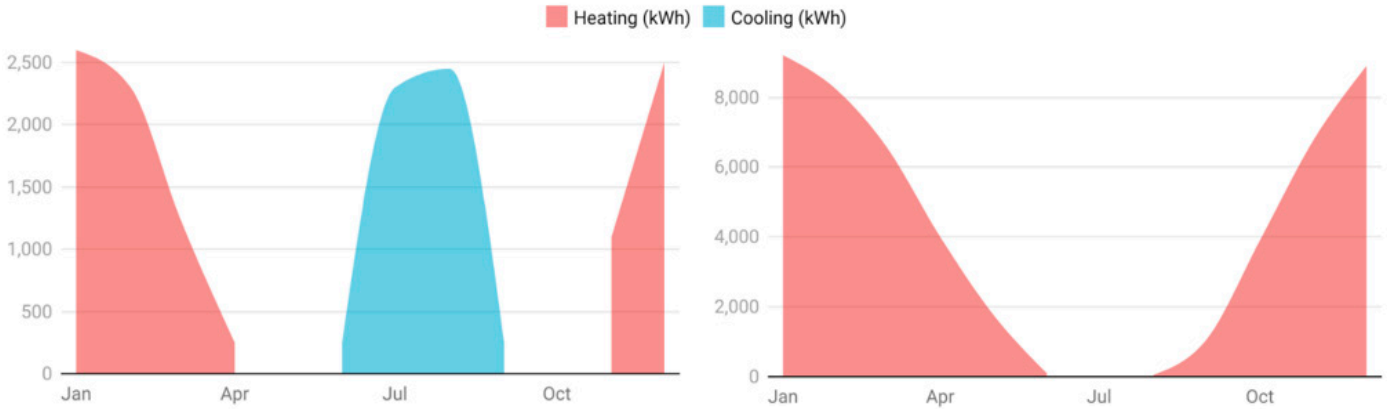


Figure 4. Annual energy demand of the reference dwelling in Cartagena (**left**) and Munich (**right**).

Table 2. Energy demand and characteristics for GSHP.

Parameters	Cartagena	Munich
Space heating demand per dwelling (kWh/m^2)	33 Heat. and 18.5 cool.	113.1 Heating
Annual Space Heating demand (MWh/year)	4000	15,000
COP GSHP	4.6	4.6
Heating Operating hours	969	2000
GHSP capacity (kW)	4.1	7.5
Geothermal energy supplied (kWh/year)	14,845	23,800
BHE length (m)	52	94

4.3. Technical GSHP Assessment

Based on the energy demand calculated in the previous section, the capacity of the GSHP to provide the thermal needs was calculated. For Cartagena, since the energy demand is higher for heating than cooling, the heating values were considered to estimate the GHSP capacity. Results showed that the GHSP capacity needed to cover the energy demand was 4.1 kW for Cartagena and 7.5 kW for Munich. These data and the Specific Heat Extraction (*sHE*) values obtained were used as inputs in Formula (3), resulting in a theoretical BHE length of 52 m in Cartagena and 94 m in Munich. Considering the results obtained so far, thermal energy extracted from the underground to be used as a resource for the GSHP annually was calculated using Formula (2). Results show that around 15 MWh can be obtained in the Cartagena study site and about 24 MWh in Munich.

4.4. Life Cycle Analysis

The analysis includes the manufacture of the heat pump, the preparation of the land and the drilling of the well, the transport of equipment to the site, the installation of the heat exchanger and the pump, and the operation and disposal of the GSHP system. As mentioned in Section 2.2, in the life cycle assessment phase, among the existing characterization factors, three areas of protection were considered, with human health being the most affected (43%), subsequently the contribution to the depletion of resources (34%) and, finally, the quality of the ecosystem (23%). Of the 18 categories stated by ReCiPe, the most influential were fossil resource depletion and climate change accounting for almost 90% of the total impact. These two categories were developed in detail for the region of Murcia.

4.4.1. Inventory Analysis

The main goal of the GSHP system is the production of space heating and cooling. Therefore, the functional unit is the thermal energy produced for the GSHP system throughout the 25-year lifespan. The GSHP is designed for the reference houses described in Table 3. The BHE filling considered is concrete or mortar. The inventory is divided into the following subgroups.

Table 3. Assumed site-specific conditions and technical details for the base case and the case developed in Cartagena for the Life Cycle Analysis (LCA).

Parameters	Cartagena	Munich
GSHP capacity considered (kW)	4.1	10
House surface (m^2)	107	200
COP GSHP	4.6	4
Heating Operating hours	969	1800
Specific heat extraction values (W/m)	79	80
BHE length (m)	100	170
Lifespan (years)	20	25

- Borehole, BHE, and heat transfer liquid. The thermal energy was extracted using a 100 m deep BHE. The BHE was drilled using percussion drilling. The impact of borehole drilling was estimated based on the fuel consumption per lineal meter, estimated at 2.1 L/mL [31]. The refrigerant was considered if a mix of water-nonethylene glycol was concentrated in 25%.
- GSHP and refrigerant gas. The refrigerant gas mainly used was R410A [22]. Its composition is made up of a mix of HFC-32 and HFC-125 in equal parts, and its polluting potential was determined by applying the potentials of each of them. The U.S. Department of Energy, in its 2006 IPCC Guidelines for National Greenhouse Gas Inventories, which is openly available online (https://www.osti.gov/etdeweb/biblio/20880391, accessed on 1 February 2022), indicates that the impact of this gas is 2088 kg of CO_2eq per kg.

- Transport. We assumed that the heat pump and the construction materials (mortar or concrete) were transported by truck over 100 km. A return trip was considered for this transport. In addition, the drilling machine and the as-associated materials were transported in a 16 Tn track over a 100 km distance.
- Electricity. During the operation, the system needs electricity to power the cycle and pump the circulating fluid. It depends on the heating and cooling demand in any case. It is expected that the GSHP would work with 1.98 kW capacity for the heating season and 1.87 kW capacity for the cooling season. The heating and cooling season lengths were considered as 954 h and 456 h, respectively. Therefore, 4.6 was the COP, and 5.2 [32] was the EER estimated for the GSHP for these site-specific conditions. The Spanish electricity impact factor in 2022 ascended to 0.259 kg CO_2eq/kWh (Comisión Nacional de los Mercados y la Competencia).

4.4.2. Life Cycle Technological Elements

In this subsection, the two main ReCiPe categories that impact the environment the most were studied: the contribution to climate change and the contribution to fossil fuel depletion. Relative contributions of Germany and the Murcia Region are shown in Figure 5, and total contributions are shown in Table 4.

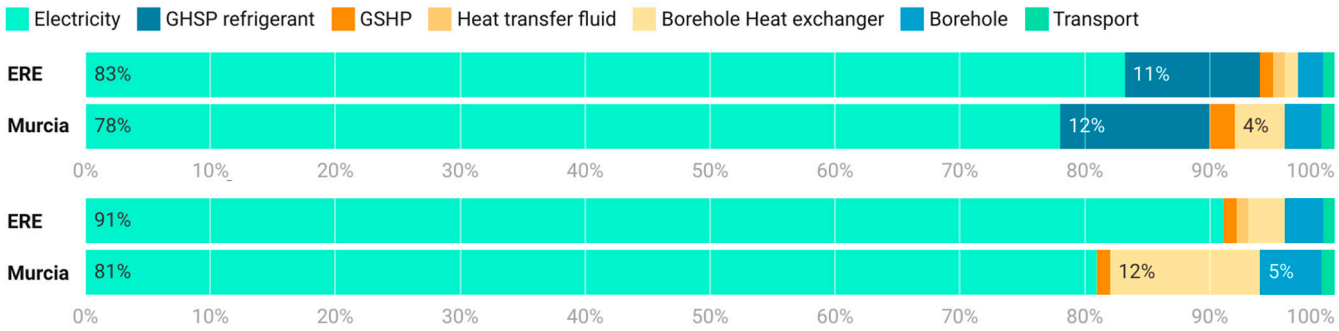


Figure 5. Relative contributions of the technological elements to the contribution to climate change (**above**) and fossil fuel depletion (**down**) ReCiPe category of a GSHP system in Europe (ERE) and Murcia region.

Table 4. The total contribution of CO_2 emissions of the technological component in LCA for the Murcia region and Europe (ERE) (CO_2/year).

	Climate Change Contribution		Fossil Fuel Depletion	
Technological Element	**Murcia**	**ERE**	**Murcia**	**ERE**
Electricity	17,000	53,500	2992	1550
GHSP refrigerant	2698	6800	0	200
GSHP	391	400	330	170
Heat transfer fluid	0	500	0	140
Borehole Heat exchanger	931	600	438	430
Borehole	550	1200	203	440
Transport	122	500	430	190

Climate Change Contribution

Following the data described in the previous section, the electricity consumed and the GHG emissions associated were estimated. Its everyday electricity consumption of 68 MWh in the whole lifespan of the utility represents 17 tons of CO_2 emissions. The drilling process also entails GHG emissions. It is assumed that every meter drilled consumes 2.1 L of diesel. Considering a drilling process of 100 m and an emission factor of the diesel of 2.596 kg CO_2 per L, it supposes a contribution to the climate change of 550 kg of CO_2. As for the transport, two return trips over 100 km were assumed for a conventional track and another

return trip for a 16-ton track. For the former, the associated consumption is 11 L per 100 km and 25 L per 100 km for the latter.

Considering the diesel emission factor, a consumption of 49 L of diesel is expected to impact 122 kg of CO_2. As aforementioned, 0.85 kg of refrigerant is considered the appropriate amount of the refrigerant. Once this utility is dismantled, the refrigerant can be recycled and thus, only the annual leakage is considered, which amounts to 0.051 kg, representing 6% of the total amount. Considering 25 years of lifespan it is 1.28 kg. Besides, an average of 2% is also lost during the manufacturing process, representing 0.017 kg. To sum up, considering the gas the GSHP needs, over its lifespan, 1.3 kg of R410A, translated into 2.1 kg of CO_2. The heat transfer fluid contribution is considered negligible as it has no carbon component. As for the GSHP itself and the heat exchangers, both the manufacturer and recycle stages are considered. That implies the impact of working with 130 kg of steel and copper as well as 273 kg of high-density polyethene. Copper-associated emissions were 2.2 kg CO_2/kg [31]. Supposing a structure composed of half steel and copper, 143 kg of CO_2 were counted.

On the other hand, steel is composed of carbon and iron, whose extraction implies 3.81 kg CO_2 associated [32], despite considering the recycling of this material. Therefore, it supposes an emission of 248 kg of CO_2. The polyethene production process assume 817 kg CO_2 (3 kg of CO_2/kg), and in the recycling process, both 0.6 kWh of electricity and 0.084 kg of diesel are needed [33] per kg of polyethene. This is translated into 55 kg of CO_2 associated with electricity consumption plus 59 kg associated with diesel. The relative contribution of the different elements is shown in Figure 5.

Fossil Fuel Resource Depletion

The heat transfer fluid and refrigerant were considered negligible due to the low carbon content. The electricity mix production in 2021 depended on 27.1% of the natural gas (17.1% combined cycle and 10% cogeneration) and 1.7% of coal use. Therefore, only 28.8% of the 68 MWh contributes to fossil resource depletion. The gas natural calorific value was 10.83 kWh/m^3, and the average performance of the combined cycle was 58% and 90% for cogeneration. Therefore, a natural gas consumption of 1305 m^3 and 1465 m^3 was estimated. This equivalent oil is 1210 kg for the combined cycle and 1359 kg for cogeneration. As for coal power plants, the average performance was 33%, with a calorific value of 9.08 kWh/kg, and the coal demand was 990 kg or 423 Kg_{eq} oil—the elements related to the transport and drilling of the borehole influence due to the use of diesel. As aforementioned, these activities entail the consumption of 231 L and 49 L of diesel, respectively. Considering the diesel density (0.85 kg/L) and its equivalence in Tones Equivalent to Oil (Toe) of diesel, we have 203 kg and 43 kg of Toe, respectively. On the other side, as aforementioned, the manufacture of the heat exchangers consumes 931 km of CO_2. Considering the use of natural gas in the process and the emission factor (0.182 kg of CO_2/kWh) (Inventory Spanish System (SIE)), 5115 kWh were used, which is 473 m^3 or 438 kg Toe. Finally, for the manufacturing of the GSHP, it is assumed that 391 Kg CO_2 were used, translated into 33 kg Toe. For this calculation Formulas (0.9275 Toe per 10,000 m^3 of Natural gas), (0.4267 Toe per Ton coal), and (1.035 Toe per Ton diesel) have been used.

4.5. Market and Legal Framework

There is no explicit EU Directive referring to shallow geothermal energy. Therefore, legal, administrative, and technical issues are dictated by the different national laws and, in some cases, vary from province to province. Furthermore, there is no standard definition of "shallow geothermal energy", referring to the specific depth. For example, in Spain, a typical unofficial depth used is 100 m [34], and in Germany, the depth for "shallow" is up to 400 m [35]. In general, authorization processes and bureaucracy slow down the investments in GSHP technology even more when different entities or governmental authorities are involved. Table 5 reflects the comparison of the both countries.

Table 5. State of the art of the legal framework in every study site country.

Country	National Law	National Standard	Regional	Regulation	Grants	Financial Incentives	Best Practice docs	Free GIS Viewers	Official Database
Spain		✔		✔	✔		✔	✔	
Germany	✔	✔	✔	✔	✔	✔	✔	✔	✔

4.5.1. Spain

While the share of renewable energy to produce electricity is above 40% on some occasions, the decarbonization of heating and cooling is being processed slower; despite energy consumption for thermal representing 50% of the energy sector, the first GSHP application reported dates to 2005 at the Technical University of Valencia concerning a European-funded project which explored the combined use of heating and cooling. With the establishment of the Technical Installations Building (RITE) [36] in 2007, the market of GSHP was favored, which contributed to increasing the renewable energies in buildings by a minimum of 60%, including shallow geothermal energy. Most of the GSHP systems are installed in buildings in the housing sector, although lately, its presence is increasing in tertiary buildings. The presence in Spain of geothermal district heating and cooling systems is still low, with only three in the territory [37]. There are no specific permitting procedures and regulations for GSHP systems in Spain. Likewise, there is no official registration of the renewable heating system, so the exact number of units installed is unknown. Instead, the Energy Institute of the Spanish Government (IDEA) has recently published heat pump statistics by climatic zones, typology (including GSHP), and activity sectors with statistical goals. The lack of national relevant legislation in Spain faces problems for the GSHP systems stakeholders due to low institutional support. In Spain, there are specific regulations for drilling and for the use of water which differ from one province to another. In Murcia, The Segura River basin Authority (Confederación Hidrográfica del Segura) is in charge of the superficial and underground water issues.

Moreover, the Mining and Energy councillorship, which belongs to the Regional Administration, has the competence for drilling and resource use. Since 2013, there is also a Spanish ISO (UNE 100715-1) [34] standard that describes the procedures to design, plan, and install closed-loop vertical systems. In addition, since 2018, there have been new official professional qualifications [38] for SGE installers as described in the RES Directive to overcome the lack of professional expertise. All in all, the 2020 to 2030 period possesses high expectations concerning the deployment of shallow geothermal energy in Spain [39]. In addition, for the first time, the Spanish Government is funding geothermal projects lower than 1 MW capacity in the frame of the Resilience, Recovery, and Transformation Plan derived from the COVID-19 economic crisis. That means that GHSP systems have not had any subsidies so far, considering that the initial upfront costs are one of the main barriers in the GSHP market.

4.5.2. Germany

Germany represents the shallow geothermal energy-mature market. However, despite the widespread GSHP sales (380,000 units installed), the market growth is unsteady, and there is an enormous growth potential for new houses. This could be due to the prices of natural gas and oil being low over the last years, a situation that has changed recently with the dramatically increasing gas prices. Heating and cooling district heating systems using geothermal energy are standard in most federal states. For a decade, the German Federal Administration has offered grants for new heating technologies with excellent conditions for GSHP systems, ranging from 4 to 7 k€, which has been translated into a considerable increase in the units [40]. In North-Rhine-Westfalia federal state, extra grants are offered for installing the buried exchangers for new and existing buildings. The licensing process is quite effective compared with other countries in Europe. Different Administration entities imply that more minor and online applications are available. There is also a maximum

time limit for the procedures, which does not exist in other countries [35]. Concerning GIS-based viewers, the Geothermal Information System GEOTIS [41] was launched in 2014 and concentrated the geothermal potential resource information and maps with plenty of information for end-users.

4.6. Comparative and SWOT Analysis

The main results obtained throughout this work were strategically evaluated to feed a SWOT analysis. This allows us to conduct a situational assessment of both study cases to identify those aspects that must be improved to enhance the use of SGE in the Murcia region (see Figure 6).

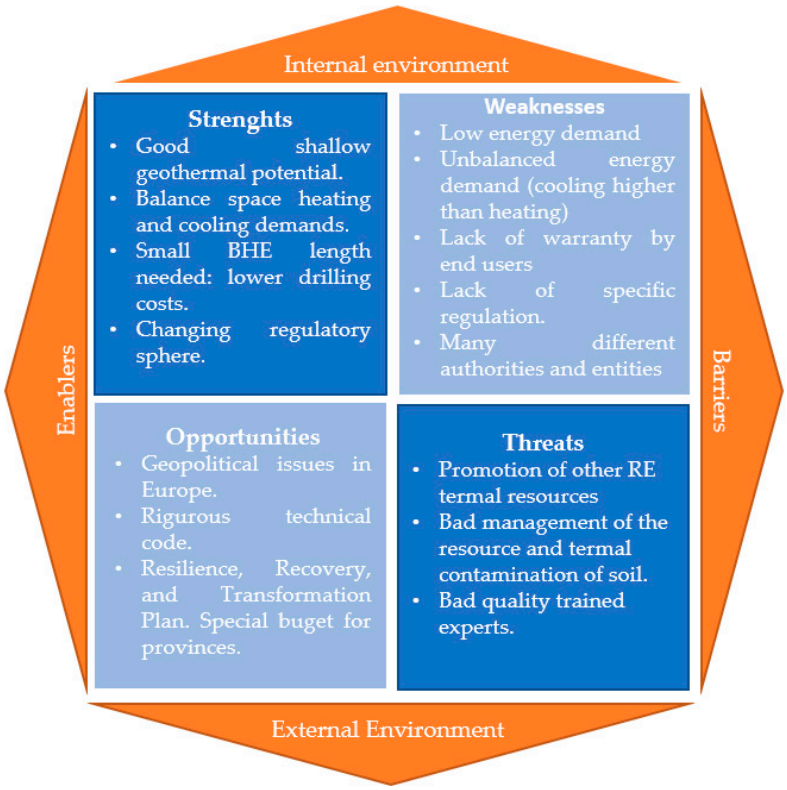


Figure 6. SWOT for the SGE and GSHP system technology in the Region of Murcia, Spain compared to Munich, Germany.

As expected, the resource assessment results showed that SGE resource potential was not a barrier in any case study. On the contrary, both case studies showed good potential, and the thermal energy demanded by the GSHP systems from the soil was always sufficient to cover the building energy demand. However, the climatic conditions differed significantly from one case to another, and they essentially affected the economic and environmental benefits. For example, in Murcia, compared with the case in Munich, the energy demand was relatively lower. This fact has advantages and drawbacks for the Murcia case.

On the one hand, it provokes GSHP systems to have higher payback periods and be less attractive than the German city, so it can be considered a weakness for the Southern region. On the other hand, unlike in Munich, climatic conditions in Murcia make housing stock account for more balanced heating and cooling demands that can be translated into a small thermal plume formation in the underground and the consequent positive influence on the performance of the system. In addition, lower energy demands can be translated into a minor BHE length needed and, consequently, more economical systems. All these statements can be considered a strength.

The LCA analysis showed a similar pattern in both case studies. Contributions of CO_2 in Murcia were slightly lower due to the difference in the electricity consumed by the

GSHP. Electricity CO_2 emission factor in Spain was 62% lower than in Germany. This is positive news for Spain; however, it makes GSHP technology not as attractive in Spain as in Germany as it does not save so many emissions per system installed.

The changing regulatory sphere in Spain can be considered a strength for SGE as the renewable energies range is being broadened, and new resources are being considered for the first time in the subsidies budget, such as the SGE. However, the regulatory system in Spain, compared with Germany, is considered to obstruct the SGE potential to be used. The lack of specific regulation and the complex bureaucratic processes provoke energy decision-makers and stakeholders in the absence of warranty in the systems. Moreover, online processes do not exist, and there are different regional administrations involved in the process. Those facts differ significantly from the German situation and can be considered a weakness. The main opportunities that enable faster deployment of GSE in Murcia are external to this work's results. The most effective measures detected are the gradual disconnection from the Russian gas to produce H&C; the rigorous Spanish Technical Code that obliges constructors dramatically improve the energy efficiency of the new buildings; and the post-pandemic COVID-19 situation and the new budget approved by the EU to promote the energy efficiency. Lastly, compared with the situation in Germany, the main threats detected in Spain are

- poor promotion of the SGE and the technologies associated,
- no management or lousy management system of the geothermal resource, mostly in urban areas, and
- the experts being inadequately or poorly trained with the subsequent low-performance systems installed.

These have dreadful consequences for the field´s reputation and the lack of confidence in the technology.

5. Conclusions

Ground Source Heat Pump is a reputed technology to extract shallow geothermal potential almost everywhere. However, it enjoys a different grade of maturity depending on the country. Within the EU Members, Germany is considered to possess the most mature GSHP market, while Spain is on its way. This paper aimed to identify the main parameters affecting a positive deployment of GSHP. Germany is a reference success case and was compared with the situation in Spain. Two study cases, one in Germany and the other in Spain, were considered. Comparing the results allowed us to identify those aspects on which Spain must improve for a better deployment of the technology.

To this end, for both case studies we conducted a resource, technical, and environmental assessment to study the technical barriers and the regulatory framework to assess the non-technical barriers. Cartagena, located in southeastern Spain, and Munich, a city in southern Germany, were selected. We compared the main results in both areas and examined the differences between both cases. It allowed identification of the positive and negative aspects affecting the deployment of the GSHP technology. The results highlighted that the geothermal potential resource is quite similar in both areas, around 80 W/m, which is considered high; thus, it can be viewed as a barrier. As for the energy consumption, the average house in the study area of Germany consumes between 3 and 4 times more energy than one in Cartagena due to the climatic conditions. In addition, in Cartagena, the energy demand is more or less balanced for heating and cooling, whereas Munich accounts only for heating demand.

Overall, the average GSHP capacity needed is 4.1 kW and 10 kW in Cartagena and Munich, and the theoretical BHE length required to cover the energy demand is 52 and 94 m, respectively. To assess how far this technology can contribute to the site-specific mitigation of CO_2, a Life Cycle Analysis (LCA) was conducted. It showed that the depletion of fossil resources and climate change represent almost 90% of the total environmental impact and that electricity has the most significant environmental influence. Thus, we can conclude that this technology contributes similarly to the local CO_2 mitigation. Spain, though, accounts

for a lower electricity emission factor so that indirectly, in case of the same electricity consumption, Spain emits less GHG. The study of the regulatory framework was carried out both at the national and regional levels. Neither of the countries have a national specific law which, in both cases, affects them negatively, although both have a national standard. The Murcia region has neither any regional standard nor best practices guide. Since very recently, it only accounts for a new line of economic incentives from the national budgets (RD 1124/2021) to promote the use of thermal renewable energies in Spain. Bavaria, though, has a long tradition of subsidies the technologies associated with geothermal energy. The Government of Germany supports the promotion of shallow geothermal energy by creating GeotIS (https://www.geotis.de/homepage/GeotIS-Startpage, accessed on 1 January 2022), a central geothermal information database covering the whole country with the information coming from more than 30,000 boreholes. In Spain, new databases are being launched lately, but, in any case, there is available information for the Murcia region. The lack of official information in Spain regarding geothermal energy is worsened by the fact that there is no registration of installed geothermal pumps in the country, so not even the number of GSHPs in use is known.

All in all, the SWOT analysis showed that the main weakness in the promotion of the shallow geothermal energy in the region of Murcia is the lack of support from the regional administrations along with the historical lack of financing and, among the main threats, the lack of regulation by the authorities. Then, again, the non-technical barriers (versus the technical barriers) hinder the use and promotion of SGE. The current war in Europe is provoking a new worldwide energy market expected to promote the use of local resources, especially those substituting geothermal energy for Russian natural gas. Thus, this is the foremost current opportunity for SGE in Spain and the other EU Member States.

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