

Geothermal Energy Use in Germany, Country Update 2019-2021

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Keywords: Geothermal development, power production, direct use, ground source heat pumps, Germany.

ABSTRACT

This country report update gives an overview of the geothermal energy use in Germany. It covers geothermal power production, direct use applications as well as geothermal heat pump units for heating and cooling.

At the end of 2021, about 190 geothermal installations for direct use of geothermal energy were in operation in Germany. This number includes facilities for district heating and thermal spas, the latter often in combination with space heating.

The installed geothermal capacity of these facilities amounted to 406.9 MW_{th} with a geothermal heat production of 6183.7 TJ in 2020. District heating plants accounted for the largest portion of the geothermal capacity with 345.8 MW_{th} and a heat production of 4439.2 TJ.

Geothermal electricity generation in Germany is based on the use of binary systems (Kalina cycle or ORC). This allows power production even at temperatures of 100 °C. At the end of 2021, eleven geothermal plants with an installed capacity of 47.6 MW_{el} fed electricity into the German grid. The geothermal power production in 2020 summed up to a total of 190.6 GWh.

Due to favourable geological conditions, geothermal district heating and power plants are mainly located in the Molasse Basin in Southern Germany, in the North German Basin, or along the Upper Rhine Graben.

In addition to installations using “deep” geothermal energy, numerous small- and medium-sized decentralised geothermal heat pump units are in use for heating and cooling of individual houses and office buildings. In the last years, the sales figures of heat pumps have

increased again. Over 150'000 heat pumps were sold in 2021, with a share of about 18 % (27'000) for geothermal systems (brine and water systems). At the end of 2021, 435'000 geothermal heat pumps were running successfully in Germany and supply renewable heat mostly for residential buildings. All installed geothermal heat pumps had a thermal output of about 4930 MW_{th} in total and provided 25'704 TJ of renewable heat in 2021.

1. INTRODUCTION

The majority of geothermal projects worldwide is located in geological systems with convection dominated heat transport such as magmatic arcs or large scale active faults (e.g. plate boundaries) (Moeck, 2014). Germany, with its conduction dominated heat transport systems, lacks natural steam reservoirs which can be used for a direct drive of turbines. Thus, geothermal power generation is based on the use of binary systems, which use a working fluid in a secondary cycle (ORC or Kalina cycle). Hydrothermal reservoirs with temperatures and hydraulic conductivities suitable for power generation can be expected and are already utilised particularly in the Upper Rhine Graben as an active, deeply rooting fault system, and the Alpine Molasse Basin as an orogenic foreland basin (Agemar et al., 2014a, b; Moeck, 2014).

However, the necessary implementation of the heat transition (referred to as *Wärmewende*) in Germany shifts the focus to geothermal heat production. In contrast to fossil fuels, geothermal heat in place can be used over a large depth and temperature range by a whole variety of technologies. Due to this scalability of geothermal applications, depending on the heat demand there is a huge potential for the development of geothermal utilisation. With the *Wärmewende* in Germany, we recognize the scalability of geothermal technology as the potential of geothermal use rather than individual geologic formations. Effectively, a broad range of the geothermal gradient from shallow to

medium deep account for the installed geothermal capacity in Germany.

At the end of 2021, 30 geothermal plants for district heating and/or power generation were in operation in Germany and several new plants are under construction or in the planning phase. The discovery of deep hot aquifers has led to a vivid project development especially in Southern Germany. Current projects focus on the Bavarian part of the Alpine Molasse Basin, where karstified Upper Jurassic carbonates provide a suitable aquifer of several hundred meters thickness (Figure 1). Some projects are also in operation or under development in the Upper Rhine Graben, which is another region of elevated hydrothermal potential. Above-average geothermal gradients make this region especially interesting for the development of electricity projects.

This paper describes geothermal reservoirs and probable resources followed by the status of geothermal energy use in Germany. Different use categories such as district and space heating or thermal spas, as well as heat pumps and their contribution to the geothermal heat supply are allocated.

2. GEOTHERMAL RESOURCES

Geothermal resources applicable for geothermal power production and heat use in Germany were investigated in several studies and contributions to European geothermal atlases (Haenel and Staroste, 1988; Hurter and Haenel, 2002; Jung et al., 2002; Paschen et al., 2003).

In order to better understand the range of geologic settings hosting geothermal resources, subsurface data are collected, analysed, interpreted and provided by the Leibniz Institute for Applied Geophysics (LIAG) through the Geothermal Information System (GeotIS) since 2005 (Agemar et al., 2014a). GeotIS was funded by the German Government and the LIAG realised the project in close collaboration with several research partners.

The information system provides a variety of data collections on deep aquifers suitable for commercial geothermal exploitation. Furthermore, map and data compilations of regions with indicated hydrothermal resources and with inferred resources for enhanced geothermal systems (EGS) were published by Suchi et al. (2014) in a study about the competing use of the subsurface for geothermal energy and CO₂ storage. The resulting maps of that study are also available in GeotIS.

Besides the research focus, the practical relevance of GeotIS is to minimize the exploration risk of geothermal wells and to improve the quality of planning data for geothermal projects. GeotIS is designed as a digital information system which is available free of charge as an open-access data base (<http://www.geotis.de>).

Although a great theoretical potential for geothermal power generation is attributed to EGS (Paschen et al., 2003), the commercial project development to date focuses on hydrothermal resources in sedimentary systems. The most important geologic systems hosting proven geothermal reservoirs in a depth greater than 1000 m in Germany are the North German Basin, the South German Molasse Basin, and the Upper Rhine Graben (Figure 1).

More detailed information on this systems can be found in previous publications associated with earlier European or World Geothermal Congresses (e.g. Weber et al., 2019; Weber et al., 2020+1).

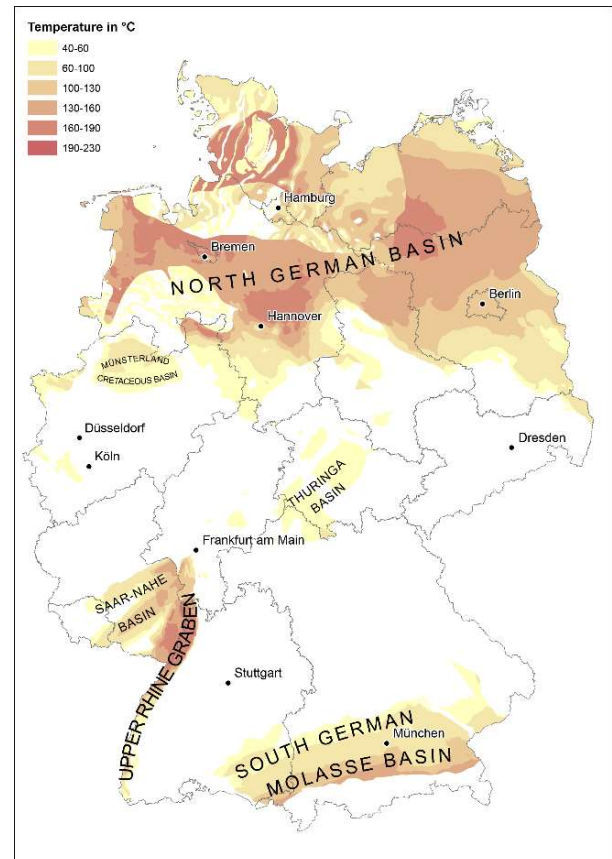


Figure 1: Regions with hydrothermal resources in Germany (inferred and indicated) and associated temperature ranges (map adapted from Suchi et al., 2014).

3. CURRENT TRENDS AT MEDIUM AND DEEP GEOTHERMAL PROJECTS

Before having a closer look on the installed geothermal capacities in Germany as described in Chapter 4, the following section provides a short summary about recent developments and trends for medium and deep geothermal projects being recently installed, currently under construction or are in the planning.

3.1 Large-scale high temperature heat pumps

The increasing availability of commercial high temperature heat pumps (HTPHs) with a deployable possible temperature level of up to 100 °C (Arpagus et al., 2018) is of high interest regarding medium and deep

geothermal projects. Such HTHPs can play two potential roles regarding geothermal heating projects. Firstly, increasing the available thermal capacity of the geothermal project in case its capacity is (temporarily) lower than the heat demand of the district heating system (DHS). If this is the case, the HTHP can further cool down the return temperature of the DHS while providing additional heat to the DHS supply side. Due to the lowered DHS return temperature, the geothermal brine can now be further cooled down, resulting in a higher thermal load provided by the geothermal project. Secondly, enabling the integration of geothermal sources, even if the brine temperature is significantly lower than the required DHS supply temperature. Thus, by lifting the temperature of the heat source by e.g. 30 to 60 K, HTHPs enable the utilization of geothermal reservoirs with temperatures below the required DHS supply temperature (Schäfer et al., 2019).

A current commercial example for the application of such a large-scale HTHP system can be found in the geothermal heating project in Schwerin in the Northeast of Germany. The geothermal project utilizes a reservoir in a depth of 1200 m. The geothermal brine temperature of 55 °C is not feasible to supply the existing local DHS, which is characterized by an average supply and return temperature of 80 °C and 55 °C, respectively. The planned HTHP system cools down the geothermal brine from 55 °C to 20 °C, while heating up the DHS from 55 °C to 80 °C with an overall thermal capacity of 6.9 MW_{th}. A special technical feature of the project in Schwerin is the number of heat pumps installed. Instead of having one single heat pump with a high temperature lift, the overall temperature increase takes place in four serial heat pumps. Due to the lower temperature lifts in each of these heat pumps, a higher overall Coefficient of Performance (COP) can be achieved. While this solution increases the investment costs and plant complexity, the significant reduction of the required electrical power demand compared to one single HTHP is favourable considering the long-term operational costs (Mathes, 2022).

The Stadtwerke München (SWM) plan to install a large HTHP system with a capacity of 21–30 MW_{th} at their envisaged project *Michaelibad* in the East of Munich in order to increase the thermal capacity of the geothermal heating plant with a conventional capacity of 45 to 107 MW_{th} (SWM Services GmbH, 2021). Furthermore, future HTHPs may also be able to provide both process heat up to 200 °C and process steam for industrial consumers (Bracke et al., 2022). While such high temperature ranges cannot be supplied by commercially available HTHP systems today, there is a strong research activity in this area. For example, the current *Kabel ZERO* project investigates the supply of process steam for a paper factory by a geothermal reservoir with 130 °C and a HTHP.

3.2 Long-distance heat transmission pipelines

Regarding the utilization of geologically attractive regions, one limiting factor is that these regions are not always spatially overlapping with urban areas that have

a high heat demand density. Thus, without heat transportation systems, rural geothermal heating projects might not be economic due to the low local heat demand. While transporting heat from geothermal sources over a long distance is currently not applied in Germany, such concepts can be found for example in Iceland (Erlingsson and Porhallsson, 2008). However, it has gained also increasing interest in the German geothermal sector during the last years. E.g. in 2020, a study by the Geothermal Alliance Bavaria demonstrated the high potential of large-scale heat transmission systems in the Southeast of Germany. By installing long distance heat transmission pipelines, a high share of the biggest heat demand clusters in the region (Munich, Augsburg, Rosenheim, etc.) could be supplied by geothermal projects in geological attractive (but rural) regions in the South and Southeast of Munich (Loewer et al., 2020). The SWM plan to install a heat transmission pipeline from their central DHS to three existing geothermal power plants (Kirchstockach, Dürnhhaar and Sauerlach) in order to have their thermal capacity of around 120 MW_{th} available for heating purposes if required (Cröniger, 2020; Kleinertz et al., 2021).

3.3 Cooling with deep geothermal energy by thermally driven absorption chillers

Against the background of the expected increasing cooling demand especially in urban areas, providing cooling will be a further relevant application case for geothermal energy next to heating and power generation. Currently, some buildings or district cooling systems (DCS) utilize shallow geothermal systems for this purpose (Epting et al., 2020). A further promising alternative are thermally driven absorption chillers for cooling. Such sorption chillers can provide cooling by using heat as a main driving source for the cooling system, resulting in a significantly lower electricity demand compared to a conventional vapour compression cycle, which is currently the most common cooling technology. Depending on the required cooling temperature and the exact cycle configuration, sorption chillers can operate from a heat source level between 60 and 80 °C on. Thus, medium and deep geothermal energy might be utilized for cooling in two ways: Using the heat of a geothermally driven DHS at the consumer with cold demand or by driving a DCS supplied by a central geothermal driven sorption chiller.

In Unterföhring, the heat of the DHS is used to drive an absorption chiller with a cooling capacity of 200 kW in order to cool a large office building with more than 4500 m² since 2015 (Geovol, 2015). In Munich, the SWM are installing a large-scale absorption chiller at their geothermal project in Sendling. If the geothermal heat is not required completely for supplying the DHS during the summer months, it can be used for cooling purposes resulting in a higher overall annual utilization of the geothermal project. The cold will be transported to a DCS in the city centre by a 5 km long pipeline (SWM 2021). Thus, the current projects in Unterföhring and Munich highlight the technical

feasibility and growth potential of environmentally friendly cooling. The recently published roadmap on deep geothermal energy in Germany by Bracke et al. (2022) suggests an installed capacity of 1 GW for cooling systems driven by deep geothermal energy after 2040.

3.4 Current trends in recently installed and planned power generation projects

During the last years, only a low number of geothermal power plants have been installed. The two main projects were both located in the South German Molasse Basin: Holzkirchen and Garching a.d. Alz. The combined heat and power generation (CHP) project in Holzkirchen utilizes a geothermal brine temperature of 155 °C, which is the highest temperature of all projects in the South German Molasse Basin so far. For power generation, a two-staged Organic Rankine Cycle (ORC) is installed. According to the manufacturer, their new two-staged ORC systems are utilizing an advanced four-staged turbine with two injection points on different pressure levels. Thus, the power generation of the two-staged ORC system can be realized within one turbine, resulting in a high efficiency also for low ORC mass flow rates during times with a high DHS heating demand (Duvia, 2020).

Also in Garching a.d. Alz, a CHP project is installed. In this project, the condensation system is a special feature. While the majority of the existing power plants are using air-cooled condensers, the project in Garching can use the cold water of an industrial channel next to the side for a water-cooled condenser (Friedlaender, 2020). Thus, especially during the summer period, higher ORC efficiencies can be achieved due to the lower condensation temperatures compared with air-cooled condenser systems. In addition, the water-cooled system reduces the required investment costs and auxiliary power demand and displays lower noise emissions. However, such cooling solutions are limited to very few potential locations due to strong ecological restriction in case of using water from natural rivers. In summary, both recently installed power projects are CHP projects and have an installed capacity of a few MW_{el}, following the main characteristics of the already existing geothermal power generation projects in Germany (Eyerer et al., 2020).

The geothermal project in Kirchweidach provides heat to local DHS and a greenhouse since several years. Currently, a large-scale ORC with around 4 MW_{el} is under construction (Duvia, 2020). In addition, several standardized modular ORC systems by the German ORC manufacturer Orcan Energy have been installed. Six modules with a capacity of up to 200 kW_{el} are installed, resulting in an overall capacity of around 1 MW_{el} (ITG, 2021). Thus, for the first time in Germany, such modular ORC systems have been installed at a geothermal project. While these modular systems display higher specific investment costs compared to an individually engineered large-scale ORC, they might enable an earlier starting of the power

generation due to the significantly lower planning and construction times.

Regarding currently planned geothermal projects in the South German Molasse Basin, there is a certain trend towards larger projects consisting of four wells, instead of the currently common doublets. E.g. all three planned projects in Tengling, Palling and Traunstein want to realize four wells. Thus, these projects would have an installed power plant capacity of 10–15 MW_{el} each, while still planning to provide heat to local municipalities. Furthermore, around 10 projects are currently in a planning phase in the Upper Rhine Graben. Next to power generation and heat supply, some of these projects are focusing also on the extraction of Lithium from the geothermal brine. According to Sanjuan et al. (2022), the Upper Rhine Graben is the most promising area for geothermal Lithium extraction in Europe.

Another novel development is the current plan for the geothermal project in Geretsried, Bavaria. In 2018, the drilling for a conventional hydrothermal project was not successful due to a too low achievable brine flow rate. Currently it is planned to use the already existing well as a basis for realizing a deep closed-loop concept by a Canadian company, the so-called Eavor Loop concept. In Geretsried four such systems could be realized, resulting in a power capacity of around 9 MW_{el} (Gahr, 2022). The drilling might start in 2023. Realizing such a large-scale deep closed-loop system for the first time in Europe might be an interesting and promising development regarding the utilization of the tremendous geothermal potential not only in geologically favourable hydrothermal hotspot regions.

4. STATUS OF GEOTHERMAL ENERGY USE

The German Government supports the development of geothermal energy by project funding, market incentives, credit offers as well as offering a feed-in tariff for geothermal electricity. However, progress in the development of geothermal energy lags behind the development of other renewables although there are good conditions for heating plants and also for power production at several locations (Figure 1). For example, especially in southern Germany, a number of new projects have been realised and further developments are being planned.

Geothermal heat is utilised in about 190 larger installations using hydrothermal resources. Thermal spas are the most widespread form of deep geothermal heat utilisation. However, the number of larger district heating plants is growing continuously. They presently account for about 68 % of the deep geothermal heat production, with an upward tendency.

Besides deep geothermal utilisations, numerous geothermal heat pumps for heating and cooling office buildings and private houses contribute the major portion to geothermal heat use in Germany.

4.1 Geothermal Power Production

Since the last WGC country update in 2020 two new geothermal power plants were commissioned in Germany: the 4.9 MW_{el} plant in Garching a. d. Alz and the modular ORC systems in Kirchweidach (for details see paragraph 3.4). The installed geothermal capacity in Germany reached 47.6 MW_{el} end of 2021 (Tables A & B) and the electricity production amounted to 190.6 GWh in 2020.

4.2 Centralised Installations for Direct Use

In Germany, common deep geothermal utilisations for direct use are district heating plants or combined heat and power plants (CHP), thermal spas, and space heating. At present, about 190 geothermal installations of these types are in operation in Germany (Figure 2, Tables D1 & D2).

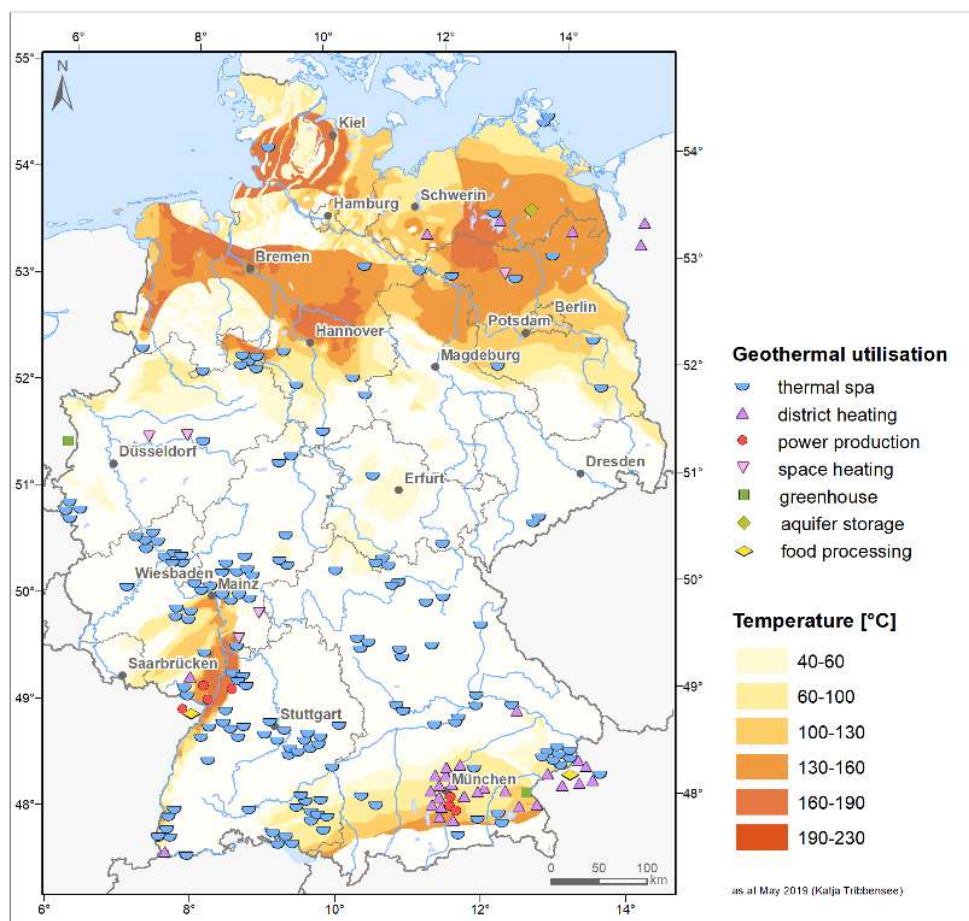


Figure 2: Sites of deep geothermal utilization in Germany and neighboring countries. The background colors represent predicted temperature ranges of the respectively deepest identified geothermal resources in sedimentary or volcanic rocks (map generated in GeotIS, 2019).

Furthermore, five deep borehole heat exchangers are in operation in Germany: Arnsberg with a total depth of 2835 m heating a spa, Prenzlau (2786 m, used for district heating), Heubach (773 m, providing heat for industry), Landau (800 m, for space heating) and Marl (700 m, for local heating). Also the use of mine water is becoming more and more interesting with regard to the heat transition in Germany.

At end of 2020, the geothermal installed capacity of direct heat use applications was 406.9 MW_{th} with a heat production of 6183.7 TJ in 2020. 26 district heating and combined heat and power plants accounted for the largest portion of the geothermal capacity with about 345.8 MW_{th} and a heat production of 4439.2 TJ (Tables C, D1 & D2). There was not much change since the last

country report, however installed capacity as well as heat production will increase with the new heating plant of the Stadtwerke München at the Schäftlarnstraße being in full operation in 2022.

4.3 Geothermal Heat Pumps

Heat pumps are a technology that has been established and ready for the market for decades for the sustainable provision of heating and cooling in residential and non-residential buildings in Germany. After an initial small boom at the beginning of the 1980s, heat pumps have become increasingly established in the German heating market since the turn of the millennium. As Figure 3 shows, 2006 was the first year where more than 30'000 units were sold per year. Thereafter the sales and installation numbers rose to around 80'000 heat pumps

annually in the mid-2010s and to over 150'000 heat pumps last year. There is a clear trend that the share of heat pumps sold is shifting from geothermal heat pumps to air-source heat pumps. While the percentage share of ground-source heat pumps was still more than 50 % until 2016, the sales figures for air-source heat

pumps have increased significantly in the recent past, so that the share of ground-source heat pumps fell to below 20 %. These geothermal heat pumps use well systems, geothermal borehole heat exchangers (BHE) as well as geothermal collectors as a heat source.

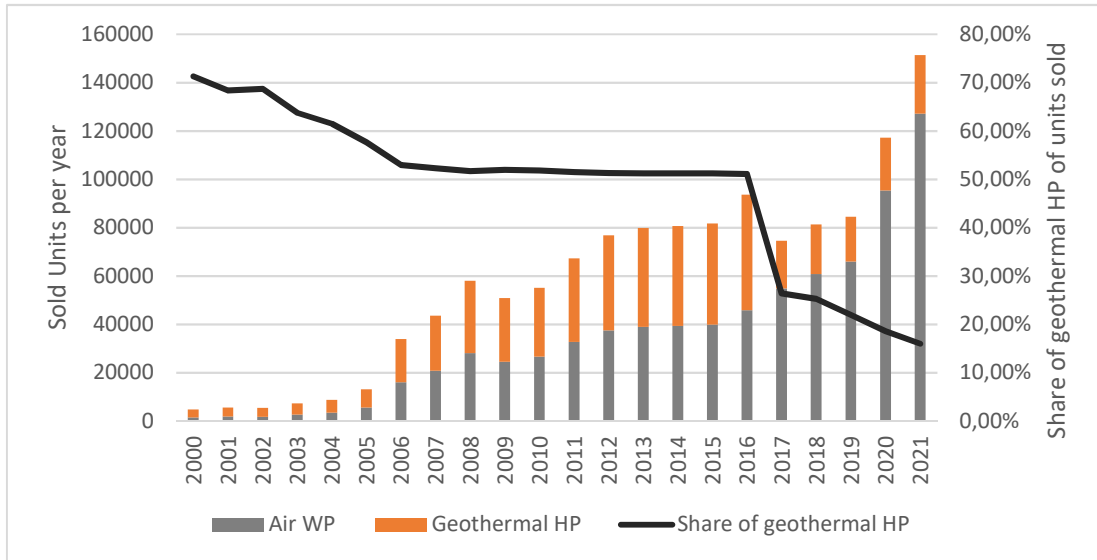


Figure 3: Development of sales figures for heat pumps in Germany (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

Figure 4 shows the share of different heat sources - wells and BHEs/collectors - with geothermal BHEs being the dominant technology (Jensen and Pester, 2019). Well systems in particular have been declining in importance in the past, with a share of less than 5 % of systems sold in 2021. Nevertheless, well systems in hydrogeologically suitable areas make a contribution to the heating and cooling supply.

in figure 5. This is mainly due to the fact that heat pumps are currently mainly used in smaller residential buildings, and here mainly in new buildings.

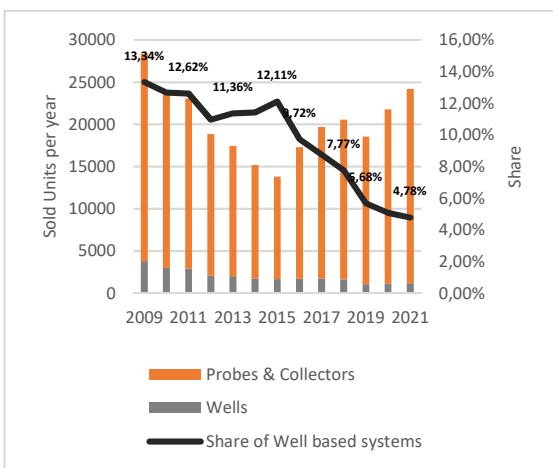


Figure 4: Share of different heat sources (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

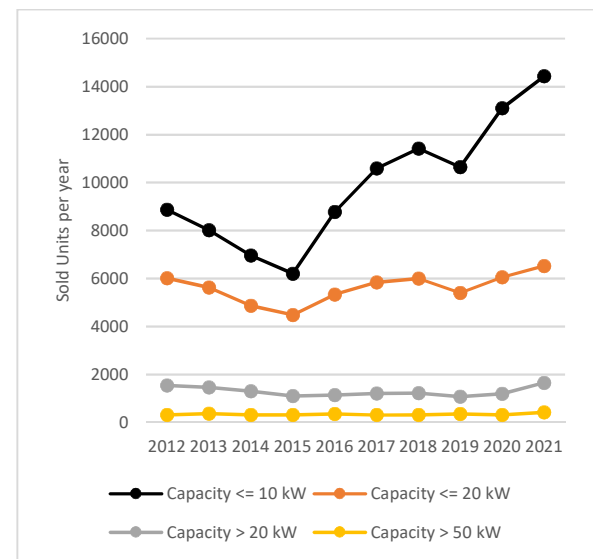


Figure 5: Capacity of sold geothermal heat pumps per year (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

Furthermore, the trend can be observed that mainly geothermal heat pumps of relatively small output classes are sold (outputs of less than 20 kW), as shown

In 2020, heat pumps were installed in more than 50 % of new buildings (55'544 air-source heat pumps and 10'257 ground-source heat pumps) (Statistisches Bundesamt, 2021). In the same year, only 30'000 heat

pumps were subsidised in existing buildings (BAFA, 2021). Nevertheless, much larger systems (several hundred kW) represent the top of the market. In sum there was a field inventory of 435'000 successfully installed geothermal heat pumps in Germany end of 2021, see table 1.

Table 1: Field inventory of geothermal heat pumps

Year	Geothermal heat pumps
2016	340.000
2017	362.000
2018	382.000
2021	435.000

4.3.1 Calculation of Capacity, Usable Heat and Renewable Energy

The renewable heat that is provided by geothermal heat pumps in Germany based on the number of heat pump systems in operation (the field inventory), the average seasonal performance factor (SPF) of the heat pumps (in correlation of the year on installation), the average full load hours per year and the average capacity. The derivation of the data is methodologically based on the study "Analysis of the German heat pump market" (Born et al., 2017). The methodology was described in detail in the last Country Update 2018 (Weber et al., 2019). A continuation to 31.12.2021 was made.

In result, the renewable heat that is provided by geothermal heat pumps in Germany is calculated in the following way.

The usable heat of all installed heat pumps is the product of the number of installed heat pumps multiplied by the average capacity and multiplied by the full load hours.

$$Q_{usable} = H_{HP} \cdot P_{rated}$$

where Q_{usable} is the estimated total usable heat delivered by heat pumps [GWh], H_{HP} are the equivalent full-load hours of operation [h] and P_{rated} is the capacity of heat pumps installed [GW]

$$P_{rated} = n_{hp} \cdot P_{avg}$$

where n_{hp} is the number of installed heat pumps and P_{avg} is the average capacity of all heat pumps [kW]

The renewable energy (E_{RES} , pure geothermal contribution) is the total useable heat minus the operating energy for the heat pump (electric energy) according to the average SPF.

$$E_{RES} = Q_{usable} \cdot \left(1 - \frac{1}{SPF}\right)$$

Table 2 shows the calculated values for the total installed capacity of all heat pumps P_{rated} , the total usable heat Q_{usable} and the pure geothermal contribution E_{RES} for the years 2016 to 2018 and 2021.

Table 2: Installed capacity, usable heat and renewable energy provided by geothermal heat pumps

	2016	2017	2018	2021
P_{rated} [GW]	3,88	4,09	4,40	4,93
Q_{usable} [TWh]	7,95	8,38	9,03	9,83
E_{RES} [TWh]	5,80	6,15	6,60	7,14

435,000 geothermal heat pump systems in Germany provide around 10 TWh of heat annually, which corresponds to approx. 1.3% of Germany's energy demand for space heating and domestic hot water in 2021.

4.3.2 Outlook – Future market development

A large number of studies describe scenarios of how the stock of heat generators must change by 2030 or 2045 / 2050 in order to achieve Germany's climate policy goals. The unanimous tenor of the studies is that the heat pumps must play a central role in the future provision of heat.

The various scenarios, as shown in Figure 6, postulate an average (target path for expansion) of 6 million heat pumps in 2030 and 16 million in 2050 (Agora Energiewende, 2021; BDI, 2021; BWP, 2021, dena, 2017, Greenpeace, 2022). The most recent publication by Greenpeace (Greenpeace, 2022) even concludes that 12 million installed heat pumps are already possible in 2035. If these targets are compared with the trend scenario, which assumes a constant growth in the number of new installations as in the average from 2016 to 2021, it becomes clear that in just eight years there will be a shortfall of almost 5 million heat pumps, and in 2050 more than 8 million. In order to achieve the goals of the heat transition for society as a whole, enormous efforts are therefore necessary in the short and medium term to support change on the German heat generator market.

The decision for a geothermal heat pump systems in comparison to alternative fossil fuel heat generators is always also an economic decision. While the investment costs, especially for the drilling for heat source development, are still higher than for fossil heating systems, the developments for the operating costs, the electricity and gas prices, have been positive in the recent past. For the end customer, a kWh of electrical energy will only be ~3 times as expensive as a kWh of natural gas at the beginning of 2022, see Figure 7. Heat pumps with a seasonal performance factor of three are just as economical in operation as fossil heating systems.

In order to compensate for the higher investment costs, there is a nationwide subsidy for the installation of heat pumps in Germany via the Federal Subsidy for Efficient Buildings (BEG). The scope of the current subsidy range is 35% to 50% of the total investment costs (BAFA 2022).

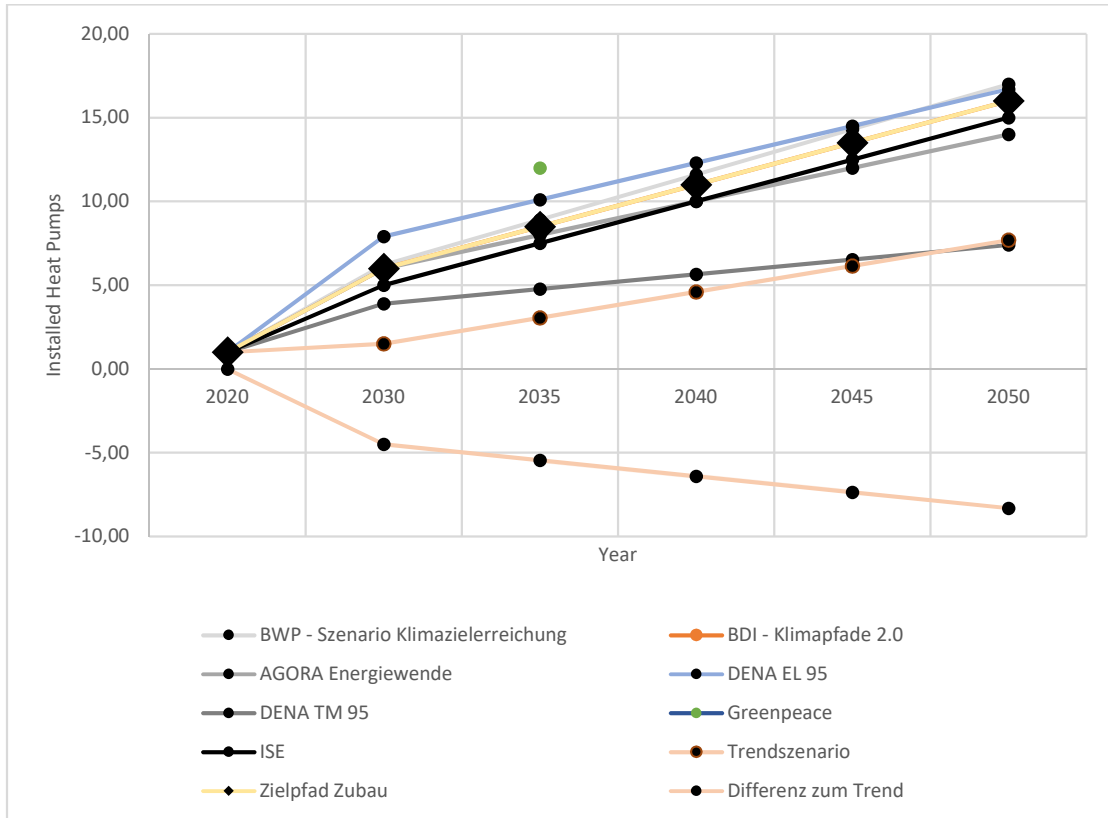


Figure 6: Scenarios for the Heat Pump field inventory by 2050 (Agora Energiewende 2021; BDI 2021; BWP 2021, dena 2017, Greenpeace 2022 and own calculations)

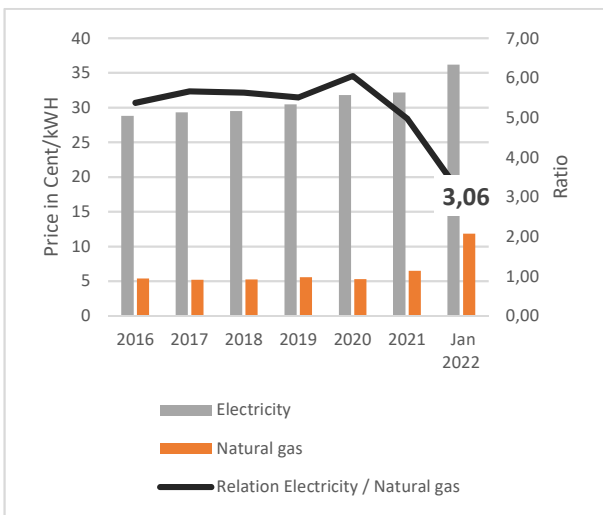


Figure 7: End customer price for electricity and natural gas in Germany (BDEW, 2022)

4.3.3 Data Collection on Shallow Geothermal Energy Utilization in Lower Saxony

Rather than depending on market sales of the heat pump producing industry, Lower Saxony, a federal state in Northwest Germany, is developing a database with the completed geothermal projects.

According to German law (Federal Mining Act, Geological Data Act and Federal Water Act) every drilling irrespective of its purpose has to be announced. Lower Saxony developed an online drilling-notification many years ago for the notification under mining law. The notifications required under water law were made in an analogous way at each water authority (53 in total in Lower Saxony). Since almost 100 % of the drillings are registered with this online application, the State Authority for Mining, Energy and Geology decided in 2012 to expand it to registering geothermal projects according to water law. Thus, the notification under mining law and water law were combined in one online tool for geothermal projects.

Up to now, data from about 14'400 of the known 21'400 installations in Lower Saxony are stored in this database. So now, not only the data of the drilling itself like location, depth and drilling method is collected, but also data about the geothermal project that are relevant for the license under water law. This includes the following data:

- Type of geothermal system (borehole heat exchanger, horizontal heat exchanger, open well systems, exploration well, thermally activated foundation pile)
- Depth of project
- Planned beginning

- Total number (e.g. total number of borehole heat exchangers)
- Heat output of the installation (output of the heat pump)
- Cooling output (in case of cooling)
- Seasonal performance factor
- Full load hours
- Further information on the geothermal system, e.g. borehole heat exchanger:
 - Total meters of borehole heat exchangers
 - Type of borehole heat exchanger (e.g. U-type)
 - Type of heat carrier fluid
 - Type of grouting material

These data allow the state authority and the water authorities easy access to statistics for the federal state

and its administrative districts. Figure 8 shows an example of one of the different statistics available from the database for a larger administrative district in Lower Saxony. Here, the new geothermal installations broken down to the type of system are plotted for each year. In this case, the local authority can see a successive growth of the market, that borehole heat exchangers have a dominant market share and open well systems are rarely used.

It is not only possible to see the development of the market for shallow geothermal systems in Lower Saxony but also to detect trends in installation configuration. Furthermore, it allows an overview on used materials (heat carrier fluid and grouting material) and the possibility to select installations with specific properties.

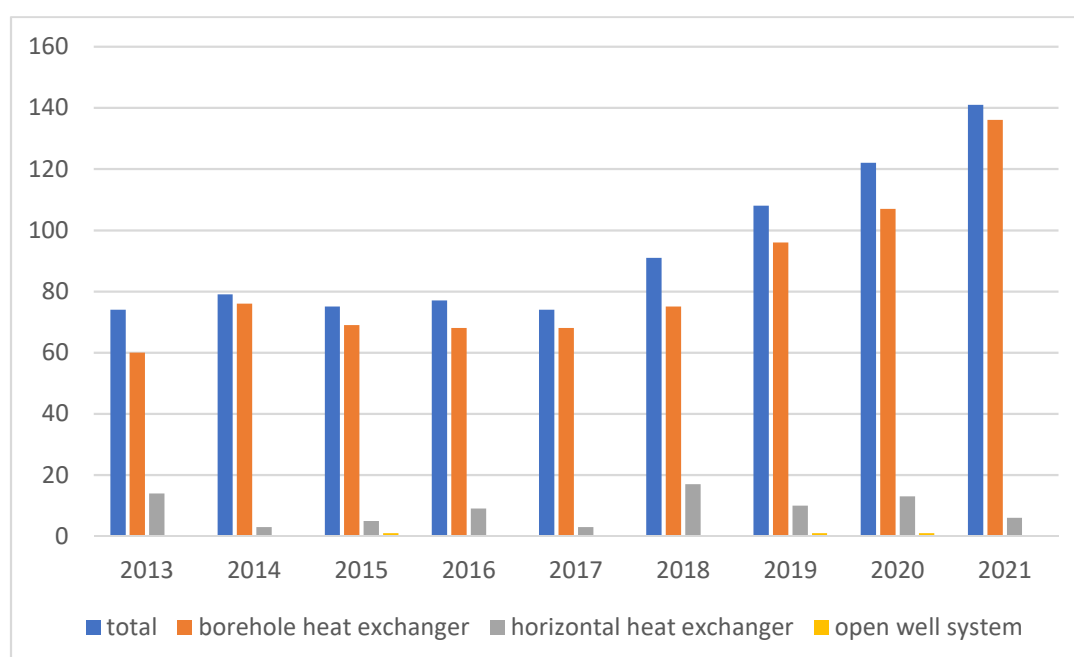


Figure 8: Number of new geothermal installations broken down to the type of heat pump system for a larger administrative district in Lower Saxony for the last nine years.

5. OUTLOOK

In Germany, about 75 % of the current heat supply for district/space heating and hot water are covered by the fossil fuels oil, natural gas and coal (BMWK, 2022).

In view of rising energy prices, geothermal energy, which has an enormous potential for expansion along with low land requirements, has to become a key pillar in German heat supply. The geothermal gradient can be used in all scales resulting in a whole variety of geothermal applications. In many areas of heat generation fossil fuels such as coal, oil and natural gas can be substituted by geothermal energy.

Besides deep geothermal energy utilisation there is also a large growth potential for shallow and medium-deep geothermal resources, through the utilisation of ground source heat pumps, especially for new buildings, or by using high temperature heat pumps, respectively.

In the case of shallow geothermal energy utilisation, it will be necessary above all to expand and strengthen human resources for all the steps required to set up a geothermal heat pump plant in order to be able to implement the enormous numbers of new plants that will be needed on the market in the coming years.

This includes the skilled trades of installers and drillers, who are already suffering from the increasing shortage of qualified workers in Germany, as well as the planning engineers and the licensing authorities. (BIBB, 2021; KOFA, 2021; prognos, 2018).

Furthermore, a change in the regulatory framework is urgently needed. In order to strengthen the use of geothermal heat pumps, a ban on the installation of new fossil heating systems in the short term and a ban on existing systems in the medium term would be an important step.

Geothermal heat pumps for heating and cooling purposes and for domestic hot water heating in individual buildings as well as in larger heating networks are an established technology for sustainable energy supply in Germany, whose extensive potential must be used much more extensively in the short term.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW _e)	Production (GWh _e /yr)	Capacity (MW _e)	Production (GWh _e /yr)	Capacity (%)	Production (%)
In operation end of 2021 *	47.6	190.63*	232'500	573'600*	0.0002	0.0003
Under construction end of 2021						
Total projected by 2023						
Total expected by 2028						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* 2020 numbers

Sources: BMWK (2022), GeotIS (2022)

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commissioned	No of units **	Status	Type	Total capacity installed (MW _e)	Total capacity running (MW _e)	2021 production * (GWh _e /y)
Bruchsal	Bruchsal	2010	1 (RI)	O	B-Kal	0.5	0.5	0*
Dürrnhaar	Dürrnhaar	2012	1 (RI)	O	B-ORC	5.5	5.5	34.4*
Garching a. d. Alz	Garching a. d. Alz	2021	1 (RI)	O	B-ORC	4.9	4.9	na
Grünwald/Laufzorn	Grünwald/Laufzorn	2014	1 (RI)	O	B-ORC	4.3	4.3	17.64*
Holzkirchen	Holzkirchen	2018	1 (RI)	O	B-ORC	3.6	3.6	24.04
Insheim	Insheim	2012	1 (RI)	O	B-ORC	4.8	4.8	21.0*
Kirchstockach	Kirchstockach	2013	1 (RI)	O	B-ORC	5.5	5.5	29.7*
Kirchweidach	Kirchweidach	2021		N		0.7	0	na
Landau	Landau	2007	1 (RI)	O	B-ORC	3.0	1.8	7,72*
Neustadt-Glewe	Neustadt-Glewe	2003	0	R	B-ORC	na	na	na
Sauerlach	Sauerlach	2013	1 (RI)	O	B-ORC	5.0	5.0	24.8*
Simbach-Braunau	Simbach-Braunau	2010	0	R	B-ORC	na	na	na

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commissioned	No of units **	Status	Type	Total capacity installed (MW _e)	Total capacity running (MW _e)	2021 production * (GWh _e /y)
Taufkirchen	Taufkirchen	2016	1 (RI)	O	B-Kal	4.3	4.3	na
Traunreut	Traunreut	2016	1 (RI)	O	B-ORC	5.5	5.5	31.33*
Unterhaching	Unterhaching	2009	0	R	B-Kal	na	na	na
total						47.6	45.7	190.63
Key for status:		Key for type:						
O	Operating	D	Dry Steam		B-ORC	Binary (ORC)		
N	Not operating (temporarily)	1F	Single Flash		B-Kal	Binary (Kalina)		
R	Retired / decommissioned	2F	Double Flash		O	Other		

* 2020 numbers

** (RI): re-injection

Source: GeotIS (2022)

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW _{th})	Production (GWh _{th} /yr)	Capacity (MW _{th})	Production (GWh _{th} /yr)	Capacity (MW _{th})	Production (GWh _{th} /yr)	Capacity (MW _{th})	Production (GWh _{th} /yr)
In operation end of 2021 *	345.8	1233.1*			4.28	10.0*	56.8 est.	474.6 est.
Under construction end 2021	90							
Total projected by 2023	440							
Total expected by 2028	500							

* 2020 numbers

Source: GeotIS (2022)

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commissioned	CHP **	Cooling ***	Geoth. capacity installed (MW _{th})	Total capacity installed (MW _{th})	2021 production * (GWh _{th} /y)	Geoth. share in total prod. (%)
Aschheim	Aschheim	2009	N	N (RI)	12.4	47.55	70.53 ^{a*} 91.17 ^{b*}	77.4
Bruchsal	Bruchsal	2009	Y	N (RI)	1.2	na	2.3 ^{a*}	na
Erding	Erding	1998	N	N (RI)	10.2	48.8	18.69 ^{a*} 91.12 ^{b*}	20.5
Freiham	Freiham	2016	N	N (RI)	13.0	78.0	91.4 ^{a*} 106.8 ^{b*}	85.6
Garching	Garching	2012	N	N (RI)	7.95	27.95	37.06 ^{a*} 49.65 ^{b*}	74.6
Grünwald/Laufzorn	Grünwald/Laufzorn	2011	Y	N (RI)	40.0	73.0	51.67 ^{a*} 268.29 ^{b*}	19.3
Holzkirchen	Holzkirchen	2017	N	N (RI)	24.0	24.0	177.9 ^{a*} 177.9 ^{b*}	100.0
Ismaning	Ismaning	2013	N	N (RI)	7.2	37.0	45.0 ^{a*} 59.0 ^{a*}	76.3
Kirchweidach	Kirchweidach	2013	N	N (RI)	30.6	30.6	60.0 ^{a*} 60.0 ^{b*}	100.0
Landau	Landau	2011	Y	N (RI)	5.0	33.0	0.92 ^{a*} na	na
München Riem	München Riem	2006	N	N (RI)	13.0	51.0	74.2 ^{a*} 84.1 ^{b*}	88.2
Neustadt-Glewe	Neustadt-Glewe	1994	N	N (RI)	4.0	14.0	15.36 ^{a*} 20.22 ^{b*}	76.0
Poing	Poing	2012	N	N (RI)	9.0	39.0	43.8 ^{a*} 55.8 ^{b*}	78.5
Prenzlau	Prenzlau	1994	N	N (BHE)	0.15	0.15	0.37 ^{a*}	na
Pullach	Pullach	2005	N	N (RI)	16.5	33.5	69.0 ^{a*} 75.0 ^{b*}	92.0
Sauerlach	Sauerlach	2013	Y	N (RI)	4.0	4.0	8.5 ^{a*} 8.5 ^{b*}	100.0
Simbach-Braunau	Simbach-Braunau	2001	N	N (RI)	9.0	48.26	50.67 ^{a*} 64.19 ^{b*}	78.9
Straubing	Straubing	1996	N	N (RI)	2.1	7.3	2.9 ^{a*}	na
Taufkirchen	Taufkirchen	2015	Y	N (RI)	40.0	40.0	92.0 ^{a*} 92.0 ^{b*}	100.0

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commissioned	CHP **	Cooling ***	Geoth. capacity installed (MW _{th})	Total capacity installed (MW _{th})	2021 production * (GWh _{th} /y)	Geoth. share in total prod. (%)
Traunreut	Traunreut	2015	Y	N (RI)	13.9	12.0	30.06 ^{a*} 43.65 ^{b*}	68.9
Unterföhring	Unterföhring	2009	N	Y (RI)	10.0	30.0	32.4 ^{a*} 32.4 ^{b*}	100.0
Unterföhring II	Unterföhring II	2015	N	N (RI)	11.3	31.3	27.8 ^{a*} 27.8 ^{b*}	100.0
Unterhaching	Unterhaching	2007	N	N (RI)	38.0	83.0	157.84 ^{a*} 176.47 ^{b*}	89.4
Unterschleißheim	Unterschleißheim	2003	N	N (RI)	8.0	35.0	36.21 ^{a*} 64.2 ^{b*}	56.4
Waldkraiburg	Waldkraiburg	2012	N	N (RI)	14.0	18.5	34.73 ^{a*} 35.93 ^{b*}	96.7
Waren	Waren	1984	N	N (RI)	1.3	10.74	1.79 ^{a*} 9.43 ^{b*}	19.0
total					345.8	857.65	1233.1 ^{a*} 1700.1 ^{b*}	72,5

* 2020 numbers

** CHP: Y (for yes); N (for no)

*** (RI): re-injection

^a geothermal^b total

Source: GeotIS (2022)

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commissioned	Cooling **	Geoth. capacity installed (MW _{th})	Total capacity installed (MW _{th})	2021 production * (GWh _{th} /y)	Geoth. share in total prod. (%)	Operator
Arnsberg	Erlenbach 2	2012	N (BHE)	0.35	na	2.1*	na	
Bochum	Zeche Robert Müser	2012	N	0.4	2.89	1.2*	na	
Essen	Essen	2010	N	0.8				
Heubach	Heubach	2013	Y (BHE)	0.09	na	na	na	
Landau	Landau	2014	N (BHE)	0.08	na	na	na	
Marl	Marl	2010	N (BHE)	0.06	na	na	na	
Neuruppin	Neuruppin		N (RI)	1.4	2.1	1.04	na	
Weinheim	Miramar	2007	N (RI)	1.1	4	5.65*	na	
various	168 thermal spas			56.8 est.	na	474.6 est.		
total				61.08		484.6	na	

* 2020 numbers

** (RI): re-injection

Source: GeotIS (2022)

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW _{th})	Production (GWh _{th} /yr)	Number	Capacity (MW _{th})	Share in new constr. (%)
In operation end of 2021	435'000	4930	7140 ^a 9830 ^b	27'000	280	18
Of which networks						
Projected total by 2023						

^a geothermal^b total

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Yes	Yes	Yes
Financial Incentives – Investment			Yes
Financial Incentives – Operation/Production	FIT		No
Information activities – promotion for the public			Yes
Information activities – geological information			Yes
Education/Training – Academic			(Yes)
Education/Training – Vocational			(Yes)
Key for financial incentives:			
DIS	Direct investment support	FIT	Feed-in tariff
LIL	Low-interest loans	FIP	Feed-in premium
RC	Risk coverage	REQ	Renewable Energy Quota
		-A	Add to FIT or FIP on case the amount is determined by auctioning
		O	Other (please explain)