Geothermal Energy Use, Country Update for Germany 2016 - 2018

Josef Weber[1], Holger Born[2], Inga Moeck[1]

[1] Leibniz Institute for Applied Geophysics (LIAG), Stilleweg 2, 30655 Hannover, Germany

[2] International Geothermal Centre (GZB), Lennershofstr. 140, 44801 Bochum, Germany

josef.weber@leibniz-liag.de

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ABSTRACT

This country update will give an overview of the geothermal energy use in Germany for the years 2016 to 2018. It covers geothermal power production, direct use applications as well as geothermal heat pump units for heating and cooling.

At the end of 2018, about 180 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 capacity of these facilities amounted to 394.6 MW_{th} (renewable share) end of 2018 with a geothermal heat production of 1,377.5 GWh in 2017. District heating plants accounted for the largest portion of the geothermal capacity with 334.5 MW_{th} and a geothermal heat production of 893.3 GWh in 2017.

Geothermal electricity generation in Germany is based on the use of binary systems (ORC or Kalina cycle). These technologies allow power production even at temperatures down to 100 °C. At the end of 2018, nine geothermal plants with an installed capacity of about 38 MW_{el} fed electricity into the German grid. The geothermal power production in 2017 summed up to a total of 159.8 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.

Data of all centralised geothermal installations in Germany and statistics on their contribution to the renewable heat and power supply can be retrieved from the Web-based open access Geothermal Information System GeotIS, which is operated by the Leibniz Institute for Applied Geophysics (LIAG). Besides data on geothermal energy use, the system provides information and data compilations on indicated or measured deep hydrothermal resources as well as inferred petrothermal resources. The GeotIS project aims at an improvement of quality in the planning information for geothermal projects, hence at the minimisation of exploration risks.

In addition to installations using geothermal energy from a greater depth range between 400 and 5,000 m, 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. 84,000 heat pumps (all types including air source heat pumps) were sold in 2018, with a share of about 28% for geothermal systems (brine and water systems). At the end of 2018, more than 380,000 geothermal heat pumps were running successfully in Germany and supply renewable heat mostly for residential buildings. Collectively, installed geothermal heat pumps have a thermal output of about 4,400 MW_{th} in total and provided 6,600 GWh of renewable heat in 2018. The share of near-surface geothermal systems combined with a heat pump reached about 1.6% of the total heat demand (private households) in Germany.

Besides supporting R&D projects, the Federal Government of Germany incentivizes new projects by a feed-in tariff for geothermal electricity under the Renewable Energy Sources Act (EEG). The amendment of the EEG with improved conditions for geothermal energy came into effect on 1st January 2012. The subsidy for geothermal electricity was increased to 0.25 €/kWh with additional 0.05 €/kWh for the use of petrothermal (EGS) techniques. A revision of the EEG in summer 2014 abolished the petrothermal bonus, and deteriorated the economic boundaries for selling the electricity.

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). A successful development of geothermal technologies enhancing reservoir productivity from tight sedimentary and crystalline rocks (EGS) would change the situation in Germany fundamentally facilitating geothermal energy as an option in regions without hydrothermal resources.

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 2018, 29 geothermal plants for district heating and/or power generation were in operation in Germany and several new plants are under construction. 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 (Fig. 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. Furthermore, governmental support for geothermal projects is outlined and future perspectives of geothermal energy use in Germany are discussed.

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 & Staroste 1988, Hurter & Haenel 2002, Jung et al. 2002, Paschen et al. 2003). Paschen et al. (2003) suggested in their study on the potential for geothermal power generation the preparation of a digital atlas of geothermal resources in Germany. From 2005 on, the Geothermal Information System GeotIS (www.geotis.de) was developed and established as an open-access geothermal atlas (see 2.2) (Agemar et al. 2014a). 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 CO_2 storage. The resulting maps of that study are also available in GeotIS.

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 1,000 m in Germany are the North German Basin, the South German Molasse Basin, and the Upper Rhine Graben (Fig. 1).

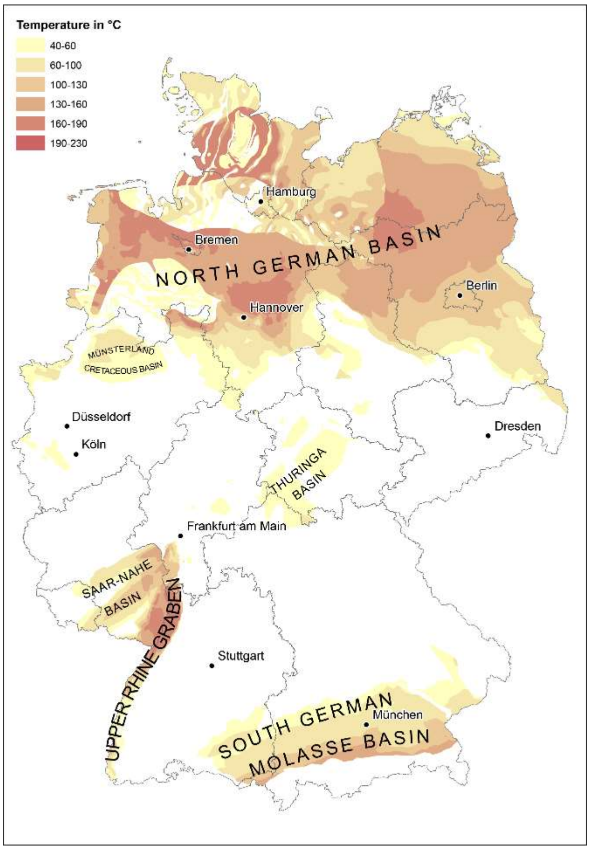

Figure 1: Regions with hydrothermal resources in Germany (inferred and indicated) and associated temperature ranges (map adapted from Suchi et al. 2014).

2.1 Regions with hydrothermal resources

The North German Basin

The North German Basin (NGB) is the central part of the Central European Basin. The thickness of its present-day sediment fill ranges from 2 to 10 km. Salt tectonic movements of the Upper Permian Zechstein evaporites are responsible for the intense and complex deformation of the overburden Mesozoic and Cenozoic formations (Franke et al. 1996, Kockel 2002). Affected by these salt tectonics, the geologic successions vary in depth and thickness which lead to strong variations of temperature and energy content of the individual geothermal resources on a regional scale (Agemar et al. 2014a).

The Mesozoic successions of the NGB consist of siliciclastic rocks and carbonates with evaporitic intercalations. Aquifers of high permeability are the main horizons of interest for geothermal use in this region. Porous sedimentary aquifers suitable for geothermal use are defined by a minimum aquifer thickness of 20 m, a porosity > 20%, and a permeability > 250 mD (Rockel et al. 1997). Several formations contain sandstone strata which are expected to meet these requirements (Fig. 2). Potential reservoir rocks with temperatures suitable for geothermal use were identified primarily in Mesozoic sandstone units (Hurter & Haenel 2002, Feldrappe et al. 2008). Hitherto, geothermal exploration in the NGB concentrated predominantly on the Rhaethian Sandstones in the eastern part of the North German Basin (Upper Triassic Contorta and Postera sandstone) which are used successfully by geothermal plants at Neustadt-Glewe, Neubrandenburg, and Waren. Hydrothermal potential is also attributed to the Palaeozoic Rotliegend sandstones, while the underlying volcanites of the Rotliegend formation have considerable EGS potential (Jung et al. 2002).

The South German Molasse Basin

The Molasse Basin in southern Germany is an asymmetrical foreland basin associated with the formation of the Alps. It extends over more than 300 km from Switzerland in the Southwest to Austria in the East. The basin fill is made up mainly by Tertiary Molasse sediments, Cretaceous, Upper (Malm) to Middle (Dogger) Jurassic and Triassic sediments (StMWIVT 2012).

The Malm (karstic-dolomitic fractured carbonate reservoir of the Upper Jurassic) is one of the most important hydrothermal energy reservoirs in Central Europe because the aquifer is highly productive and present throughout almost the whole Molasse Basin. The aquifer´s geothermal potential and its hydraulic properties were subject to intense R&D activities (e.g. Frisch et al. 1992, Birner et al. 2012). The reservoir fluid of freshwater quality is particularly suitable for economic geothermal utilisation since corrosion effects are minimal and scaling effects are manageable.

Due to the southward deepening and wedge-shaped geometry of the basin, reservoir temperatures and depth of the Malm reservoir increase towards the Alps from 40 °C in the North to more than 160 °C in the South of the basin near the Alpine Molasse. Thus, district heating plants can be found in the northern part of the basin while combined heat and power plants are located further in the South. Temperatures suitable for power generation are reached south of Munich where several power plants are in operation.

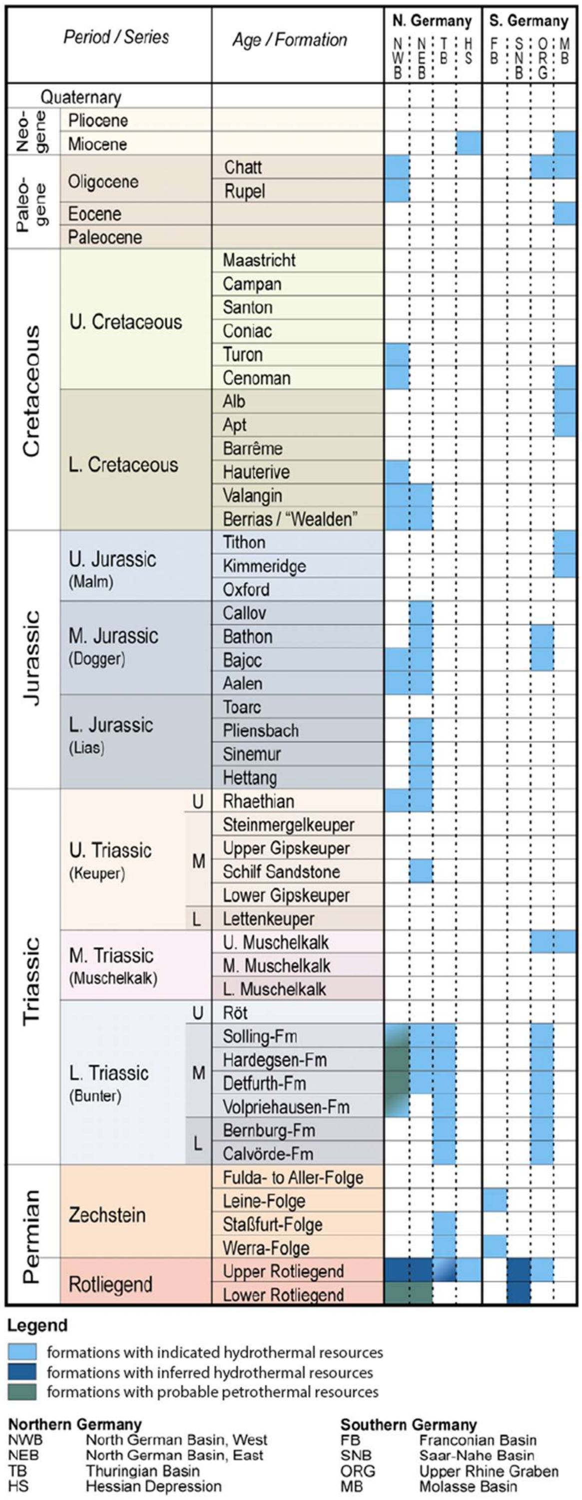

Figure 2: Stratigraphic units of interest for deep geothermal energy use (table adapted from Suchi et al. (2014), data for CO_2 storage omitted).

Besides the Malm aquifer, further sedimentary layers were identified as probable aquifers for direct use of geothermal energy (Tertiary Burdigal, Aquitan and Chatt sandstone, and Baustein and Ampfinger beds, Cretaceous Gault and Cenoman sandstones, and Upper Muschelkalk) (StMWIVT 2012). Some of the aquifers provide thermal fluids (brine) for spas in Bavaria and Baden-Württemberg.

The Upper Rhine Graben

The Upper Rhine Graben belongs to a large European rift system which crosses the Northwestern European plate (e.g. Villemin et al. 1986). Between 30 and 40 km wide, the graben elongates from the Jura Mountains near Basel, Switzerland, to Frankfurt, Germany. The graben was formed by repeatedly reactivation of complex fault patterns. Crustal extension in the Tertiary 45-60 Ma ago formed depocenters along a pre-existing WSW-ENE fault trend associated with up-doming of the crust-mantle boundary and magmatic intrusions in 80-100 km depth (Pribnow & Schellschmidt 2000). The induced thermo-mechanical stresses result in extensional tectonics with a maximum vertical offset of 4.8 km. The graben evolution changed from Oligocene on from extension to dextral strike-slip and related local uplift, subsidence and finally sinistral strike-slip from Pliocene on up to date (e.g. Schumacher 2002).

Major exploration targets for geothermal projects in the Upper Rhine Graben are the Upper Muschelkalk and Bunter formations in combination with fault zones. Further indicated or inferred geothermal resources are in the Hydrobien and Grafenberg strata (both Tertiary), Hauptrogenstein (Jurassic), and Rotliegend (Permian) (Hurter & Haenel 2002, Jodocy & Stober 2008).

2.2 Web-based open access Information System (GeotIS)

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) (Agemar et al. 2014a), funded by the German Government. LIAG realized the project in close collaboration with several research partners. 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).

GeotIS provides information and data compilations on deep aquifers in Germany relevant for geothermal exploitation. It includes data of the South German Molasse Basin, the Upper Rhine Graben, and the North German Basin. The internet based information system satisfies the demand for a comprehensive, largely scale-independent form of a geothermal atlas which is continuously updated. GeotIS helps users to identify possible geothermal resources by visualising temperature, hydraulic properties, and depth levels of relevant stratigraphic units (Agemar et al. 2014a). A sophisticated map interface simplifies the navigation to all areas of interest. Additionally, essential information of all geothermal installations in Germany is provided including annual statistics on installed capacities and energy produced.

3. 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 (Fig. 1). For example, especially in southern Germany, a number of new projects have been realised and further developments are being planned.

Geothermal power plays only a marginal role in the German electricity market (BMWi 2016). The development of geothermal electricity in Germany is rather slow. While new geothermal capacity was installed at two sites in 2016 (Traunreut) and 2018 (Taufkirchen) the power unit in Unterhaching was shut down end of 2017.

Geothermal heat is produced in about 180 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 65 % 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.

3.1 Geothermal Power Production

Since the last country update in 2016 two new geothermal power plants were commissioned in Germany: the 5.5 MW_{el} plant in Traunreut in November 2016 and the 4.3 MW_{el} plant in Taufkirchen in 2018 (both located in the South German Molasse Basin). However, the 3.36 MW_{el} geothermal plant in Unterhaching was shut down end of 2017. Therefore, the installed geothermal capacity in Germany showed only a small growth and reached about 38 MW_{el} end of 2018 (Table B). Electricity production amounted to 159.8 GWh in 2017.

At two sites (Holzkirchen and Kirchweidach, both in Bavaria) it is planned to expand the existing heating plant with a power unit. In Garching a. d. Alz drilling of two boreholes is completed and first tests point to a possible electrical capacity of 4.5 MW_{el}.

Figure 3: Installations for geothermal energy use in operation in Germany (from GeotIS 2019).

3.2 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 180 geothermal installations of these types are in operation in Germany (Fig. 3, Table D1 and D2).

Geothermal well doublets consisting of a production and an injection well are typically used for district heating, while spas only need a single well for standard operation. Furthermore, five deep borehole heat exchangers are in operation in Germany: Arnsberg with a total depth of 2,835 m heating a spa, Prenzlau (2,786 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.

In 2018, the geothermal installed capacity of direct heat use applications reached 394.6 MW_{th}. The 29 district heating and combined plants accounted for the largest portion of the geothermal capacity with about 334.5 MW_{th}. Altogether, the installed capacity of deep geothermal heat use in Germany shows a considerable increase from about 160 MW_{th} in 2010 to 336.6 MW_{th} in 2015 to 394.6 MW_{th} in 2018. Heat production by deep geothermal utilisation rose from 716 GWh in 2010 to 1,110 GWh in 2015 to 1,377 GWh in 2017 (GeotIS 2019).

The development of direct heat use from geothermal energy is still ongoing. One example is the vision of the Stadtwerke München to supply the district heating network of the city completely with renewable energies by 2040. Geothermal energy shall act as major contributor to achieving this goal. For this purpose a total of six wells is drilled from one site in the Munich inner city. As at January 2019, two of the six wells have been successfully completed and work on the third well has already started.

Development also continues in the North German Basin. The first well of the medium deep project in Schwerin has been finished and exceeded expectations (as at March 2019). When finished, heat will be fed into a district heating network.

3.3 Geothermal Heat Pumps

Geothermal heat pumps reached the German market, after a first peak in the 1980s, with the beginning of the 2000s. The systems are mainly used for heating residential buildings and are especially installed in new buildings. However, there are also large-scale geothermal heat pump installations used for heating and cooling commercial buildings (offices, industry) within the same system.

The most common systems are borehole heat exchangers or horizontal heat collectors (brine/water systems). The share of groundwater systems with two or more wells (water/water systems) is less than 15% of all geothermal heat pumps. Other options - like activated foundation piles or direct vaporiser probes - have only a small share in the market.

The following market data is mainly based on the study *Analyses of the German heat pump market* (Born et al. 2017), which was prepared on behalf of the Working Group on Renewable Energies Statistics (AGEE-Stat) by order of the Federal Ministry for Economic Affairs and Energy. The general aim of the study was to evaluate the amount of renewable heat that is provided by heat pumps in Germany.

For the calculation of the amount of renewable heat, the following input parameters of installed and running heat pumps in Germany are relevant:

- the sales figures of geothermal heat pumps and the lifetime of the heat pumps,
- the average coefficient of performance (COP) and the average seasonal performance factor (SPF),
- the average capacity,
- the average full load hours per year.

Each year, the German Heat Pump Association (BWP) and the Federation of German Heating Industry (BDH) gather the sales figures of all heat pumps in Germany; geothermal heat pumps as well as air heat pumps (Fig. 4).

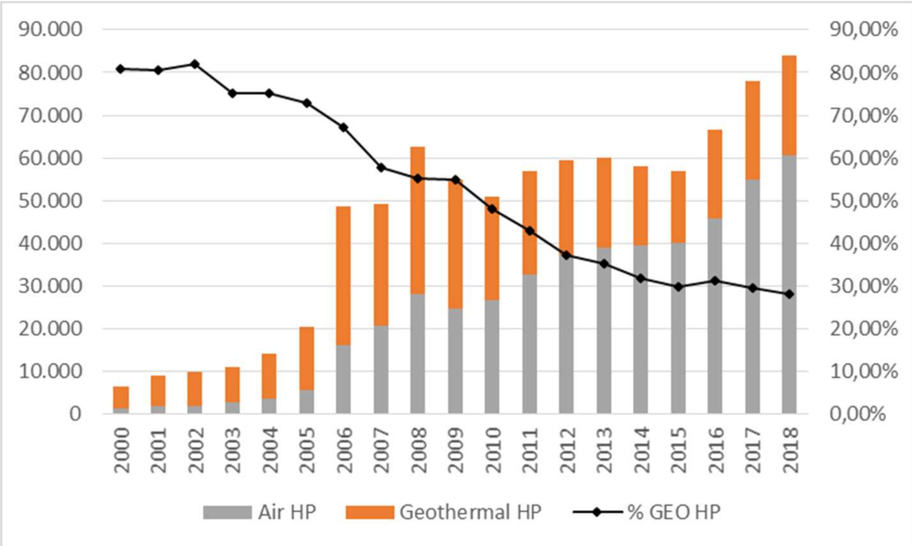

Figure 4: Development of sales figures for heat pumps in Germany (after annual data from BWP&BDH, latest BWP&BDH 2018).

In 2018, the sales figures reached the highest level with 84,000 sold units (all type of heat pumps). From 2008 until 2015 the whole market volume stays on the same level (50,000 to 60,000 units per year), before the sales rises up to ~80,000 units in 2017 and 2018. Within the same time, the market share of geothermal heat pumps decreased from more than 50% to less than 30% in 2018. About 23,500 geothermal heat pumps were sold in Germany in 2018.

For the calculation of the number of installed and running heat pumps in Germany it is necessary to imply a function for the typical lifetime of heat pumps. Such a function is provided by the BWP in its publications (BWP 2011). However, it presents two problems. First of all the function is given as a figure, so it is not possible to verify the calculations. Moreover, the BWP hypothesise that about 35% of the heat pumps are still operating at the end of their life time (logjam of modernisation). To solve these problems, the following abstract and simplified function is used to reproduce the life time of heat pumps.

End of 2018, about 382,000 geothermal heat pumps were installed and running in Germany, of which about 333,500 are brine/water systems and about 48,500 are water/water systems. (2016: 340,000 units; 2017: 362,000 units)

The Wärmepumpen-Testzentrum der Interstaatlichen Hochschule für Technik (WPZ BUCHS) measured the COP of heat pumps according to the EN 255 and EN 14511 during the last years. The COP measurements show an increasing COP over the time for geothermal heat pumps as well as for air source heat pumps. The data shows a correlation of the COP and the year of audit, which can be described by a linear function (Fig. 6).

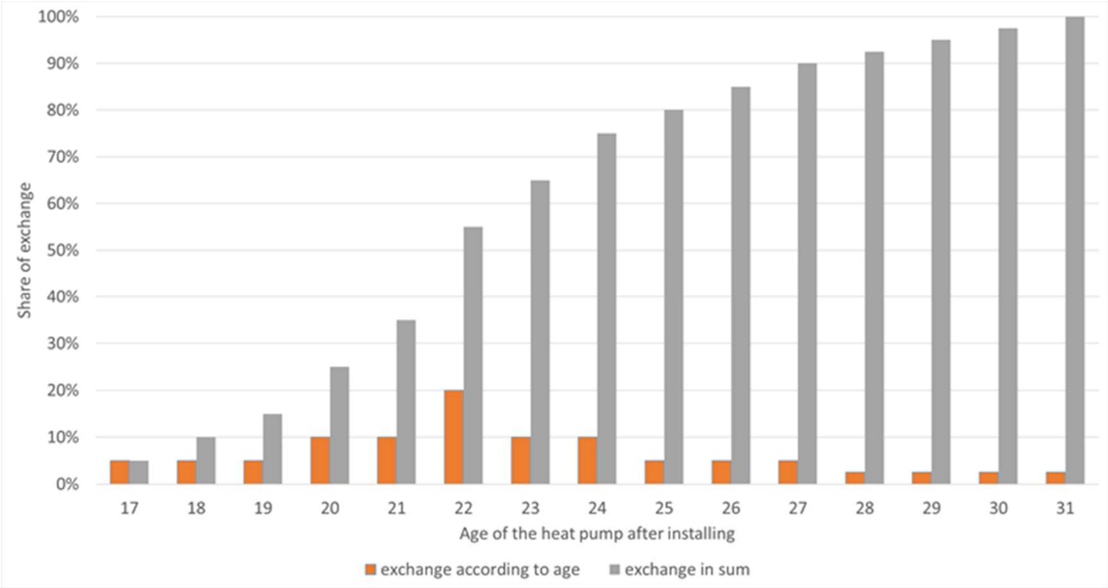

Figure 5: Lifetime of heat pumps – exchange rate of heat pumps according to the age after installation

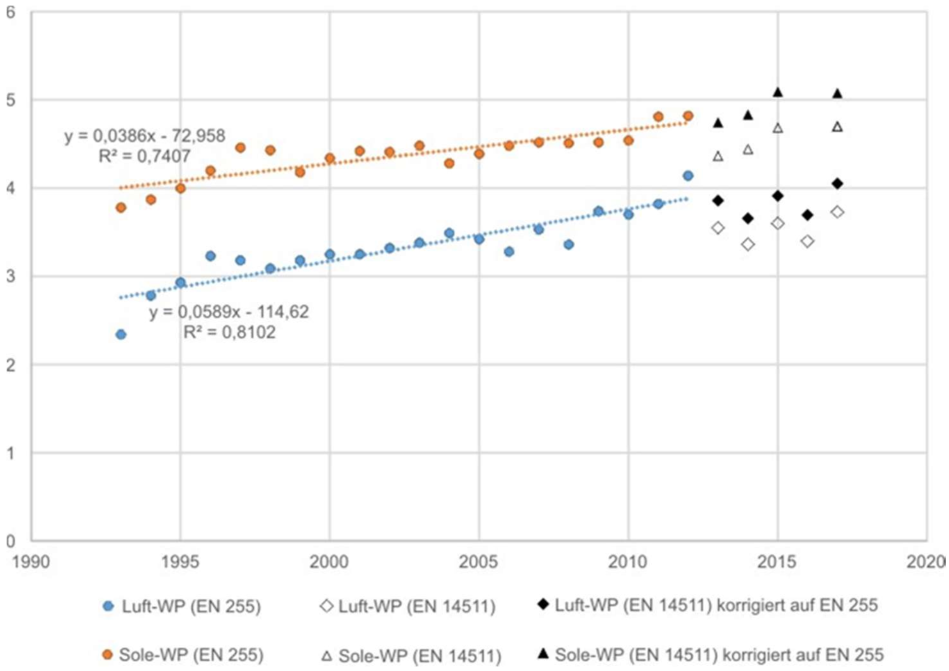

Figure 6: Progression of COP EN 255 [own diagram based on Eschmann, WPZ Buchs 2012 & 2013 and WPZ Buchs 2017]

The better performance and efficiency measured in the lab are reflected by the performance data of the running heat pump system in the market. The Fraunhofer ISE (ISE 2010, 2011 & 2014) published a couple of studies that evaluated the seasonal performance factor (SPF/JAZ) of different heat pump installations under real-life conditions (Fig. 7).

Comparing with the COP of a specific year, the identified SPF reaches about 77% (air) and 80% (ground) of the COP. Therefore, the SPF can also be described as a function depending on the year of installation (Fig. 7). Ground source heat pumps which were installed in 2018 have an average SPF of 3.99.

The average capacity of the installed and running heat pumps in Germany decreases since the beginning of the 2000s according to the energetic standards of new build houses. In 2018, the average capacity of newly installed geothermal heat pumps was about 10 kW (brine/water) and about 16 kW (water/water), respectively.

The average full load hours per year of a heating system is a factor during the planning process, which depends on building physics, the climate of the location, the kind of utilisation, the heat demand and the question if the heat pump is used for heating and/or hot water.

Normally, the average full load hours should not depend on the heat generator. There are a couple of references which specify the average full load hours per year (BWP 2011 & 2013; Europäische Kommission 2013; SIA 2010; VDI 1993, 2001 & 2015) ranging from 1,800 h/a up to 2,400 h/a. By consideration of all presumptions it seems to make sense to calculate with a value of 2,050 h/a, but it should be noted that this value is quiet vague.

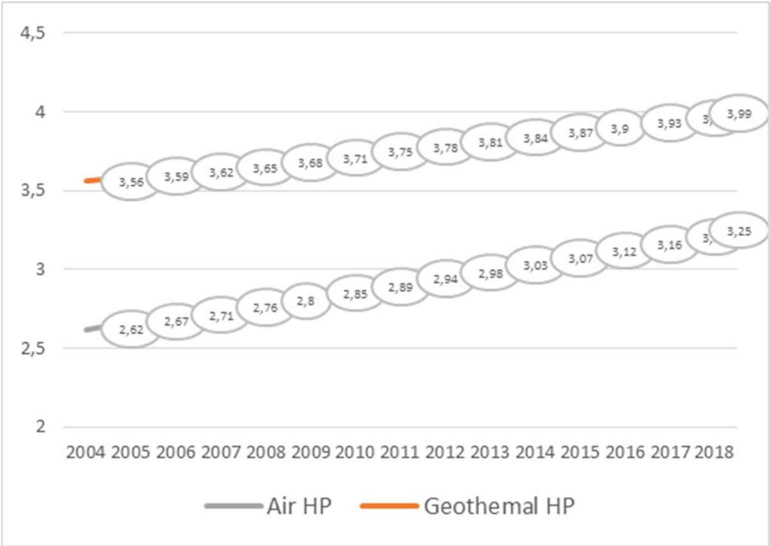

Figure 7: Calculated SPF of newly installed heat pumps (depending on year of installation)

The renewable heat that is provided by 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.

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

Table 1 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.

Table 1: Installed capacity, usable heat and renewable energy provided by geothermal heat pumps

	2016	2017	2018
P_{rated} [GW]	3,880	4,085	4,400
Q_{usable} [GWh]	7,950	8,375	9,025
E_{RES} [GWh]	5,800	6,150	6,600

4. GOVERNMENTAL SUPPORT

4.1 Energy Market and the Role of Geothermal

According to BMWi (2019), the final energy consumption in Germany adds up to 9,151 petajoules in 2016. About 54% of the final energy consumption was required for district and space heating, hot water, and process heat.

Most of this demand at present is supplied by fossil fuels. A significant proportion of this demand could, in principle, be supplied by geothermal heat. This would make a significant contribution to reducing the present CO_2 output of Germany.

According to the German Federal Environmental Agency (UBA) the total heat demand in Germany was 4.931 PJ in 2016 (Fig. 8). The three sectors industry, commerce and residential have a total heat demand of 2.973 PJ for heating and hot water of which the residential sector alone accounts for 2.009 PJ. Shallow to medium deep geothermal applications combined with heat pumps can provide heat on a relatively low temperature level suitable for (space) heating and/or hot water.

In 2018, the installed geothermal heat pumps supplied 1.62% of the residential heat demand (1.18% renewable energy) or 1.09% of the total heat demand for heating and hot water (0.8% renewable) in Germany. Based on this, there is still huge potential to replace fossil fuels by geothermal energy, especially in the residential sector.

The German government has an agenda for the transformation of the energy sector in Germany until 2050 to reach the ambitious national climate protection targets. After all Germany has set the target to reduce the greenhouse gas emissions by about 90%-100%

within the next 30 years. Heat pumps shall be one of the key technologies to reach the targets, especially for the heat supply. However, there is already a gap between the current additional installed heat pumps per year and the aim of 5 to 6 million installed heat pumps in 2030. The Fraunhofer Institute IWES/IBP quantifies this gap: 3 to 4 million heat pumps will be lacking in 2030 (Fraunhofer IWES/IBP 2017).

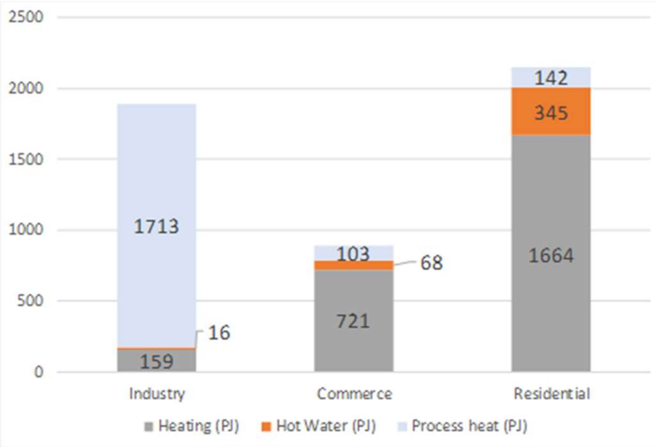

Figure 8: Heat demand by sectors 2016 (UBA 2018)

To fill the lack within in the next 15 years is not only a question of the rate of modernisation and the will of private owners to trust in heat pump technologies. Open issues are moreover the capacity and the knowledge of plumbers and drilling contractors to install the systems, the training and education structure, the development of energy costs, the progress of the modernisation of existing heating systems and not least the legal framework in Germany. A higher market penetration can be reached if the counterpart, fossil heating units, will be pushed more or less out of the market. The procedure could be a (partly) prohibition of fossil heating units or an additional fee for gas and oil to raise their market price.

4.2 Governmental Support

Germany has set ambitious national climate protection targets including the phase out of nuclear energy by 2022. The German Government aims for an energy supply based predominantly on renewables, meeting 80 % of the electricity demand and 60 % of the gross final energy consumption by 2050 (BMWi 2014).

Considering the large potential of geothermal energy and its valuable contribution to a renewable energy supply, the BMWi supports various related research projects. The funding comprises all aspects of geothermal technology, from planning and exploration to drilling and operation of plants, with the aim to reduce the costs of geothermal projects and to make them economically successful.

Apart from funding R&D projects, the Federal Government created incentives for new projects by offering a feed-in tariff for geothermal electricity and the Renewable Energy Sources Act (EEG). The amendment of the EEG with improved conditions for geothermal energy has come into effect on 1st January 2012. The subsidy for geothermal electricity has been increased to 25 €-cents/kWh with additional 5 €-cents/kWh for the use of petrothermal (EGS) techniques. A revision of the EEG in summer 2014 abolished the petrothermal bonus, and deteriorated the economic boundaries for selling electricity.

The Renewable Heat Act (EEWärmeG) of 2009, which came into force in an amended version in 2011, mainly aims at the installation of renewable heat sources in buildings. An obligation for use of renewable energy in new buildings is given in EEWärmeG; geothermal heat pumps are eligible if they meet the criteria, for example certain quality labels, a minimum coverage of 50 % of the annual heat load by the heat pump, and a minimum seasonal performance factor (SPF). The EEWärmeG, and a similar act on the state level in Baden-Württemberg, did not yet prove to be useful for geothermal heat pumps; in the absence of reliable statistics detailing the causes for investment, the main share of renewable energy installations triggered by these obligations seems to be in solar thermal systems for domestic hot water.

Since a couple of years, the German government provides a grant for new heating technologies by the market stimulation program (MAP). The rules of the MAP changed a couple of times in the past (amount of the grant, type of technologies, grant for new and/or existing buildings). Since 2015, very good conditions for the installation of geothermal heat pumps were established. The minimum grant for geothermal heat pumps was raised to 4,000 € and can be over 7,000 €. The better conditions led to an increase of the number of subsidised heat pump units: from about 8,500 in 2016 to already about 11,700 supported heat pump installation until 31th October 2017. (BAFA 2016 & 2017)

In addition, there are some corresponding programmes in the federal states. For example, North-Rhine-Westphalia includes geothermal heat exchangers and geothermal wells for heat pumps in the existing progres.nrw programme. Heat exchangers will be supported with 5 € per borehole meter for new buildings up to 10 €/m for existing buildings, and wells get subsidised by 1 € per liter flow rate per hour.

5. OUTLOOK

As already mentioned earlier, about 54% of the final energy consumption in Germany is required for district and space heating, hot water, and process heat (Arbeitsgemeinschaft Energiebilanzen 2018). However, only 12.9% of the heat consumption were covered by renewable energies in 2017, and the target of 14% by 2020 cannot be achieved with the current activities focusing on renewable electricity (BMWi 2018).

This could be a chance for geothermal energy, which has an enormous potential for expansion along with low land requirements. 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. One example is the city of Munich, which aims to provide 100% of district heating from renewable energies by 2040 as the first German metropole.

Deep geothermal energy plays a key role in this visionary plan due to the favourable geological subsurface conditions. The expansion of the geothermal heat grids enables a faster implementation of the heat transition than the energetic renovation of existing buildings (Moeck & Kuckelkorn 2015).

Also for shallow and medium-deep geothermal resources, there is still a large growth potential through the utilisation of ground source heat pumps, especially for new buildings. Additionally, many outdated heaters must be replaced in the private sector in the coming years. One solution are ground source heat pumps. With already more than 380,000 installed systems in Germany, GSHP are a widespread, successful and affordable technology (Born et al. 2017).

Therefore, heat pumps can be used for a reliable and predictable heat transition due to the market-ready technology not only for shallow but also larger depth. The strength of geothermal energy is its scalability and the wide range of applicable technologies depending on depth and user demand.

Although prices for oil and gas are low at the moment, it is necessary to invest in the energy of the future and increase the development of geothermal energy, since this technology, in contrast to other renewables, is predestined to secure the heat supply of Germany.

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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 2018	38	159.8*	219,300*	653,700*	0.00017	0.00024
Under construction end of 2018	8.6					
Total projected by 2020	45					
Total expected by 2025	50					
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2018 (indicate exploration/exploitation if applicable):					Under development	
					Under investigation	

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2018 pro-duction * (GWh_e/y)
Bruchsal	Bruchsal	2010	1 (RI)	O	B-Kal	0.55	0.44	0.3*
Dürrnhaar	Dürrnhaar	2012	1 (RI)	O	B-ORC	6	6	25.8*
Grünwald/Laufzorn	Grünwald/Laufzorn	2014	1 (RI)	O	B-ORC	4.3	4.3	17,6*
Insheim	Insheim	2012	1 (RI)	O	B-ORC	4.8	4.8	22.6*
Kirchstockach	Kirchstockach	2013	1 (RI)	O	B-ORC	6	6	35.0*
Landau	Landau	2007	1 (RI)	O	B-ORC	1.8	1.8	na
Sauerlach	Sauerlach	2013	1 (RI)	O	B-ORC	5	5	31.8*
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	25.6*
Unterhaching	Unterhaching	2009		R (2018)	B-Kal			1.1*
total						38.25	38.15	159.8*

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	2F	Double Flash	O	Other

* If 2017 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

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 2018	334.5	893.3			3.3	9.6	56.8	474.6
Under constru-ction end 2018	50							
Total projected by 2020	385							
Total expected by 2025	450							

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

Locality	Plant Name	Year commis-sioned	CHP	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2017 produc-tion * (GW_{th}/y) [a]geothermal [b]total	Geoth. share in total prod. (%)
Aschheim	Aschheim	2009	N	N (RI)	10.7	44.5	66.1[a*] 89.0[b*]	74.2
Erding	Erding	1998	N	N (RI)	7.7	48.8	35.6[a*] 103.0[b*]	34.6
Freiham	Freiham	2016	N	N (RI)	13.0	78.0	27.6[a*] 59.6[b*]	46.3
Garching	Garching	2012	N	N (RI)	7.95	27.95	31.7[a*] 42.1[b*]	75.3
Grünwald/Laufzorn	Grünwald/Laufzorn	2011	Y	N (RI)	40	71	68.5[a*] 285.7[b*]	24.0
Holzkirchen	Holzkirchen	2017	N	N (RI)	21	na	na	na
Ismaning	Ismaning	2013	N	N (RI)	7.2	22	33.9[a*] 46.7[b*]	72.6
Kirchweidach	Kirchweidach	2013	N	N (RI)	max. 30.6	max. 30.6	91.6[a&b*]	100.0
Landau	Landau	2011	Y	N (RI)	5	33	na	na
München Riem	München Riem	2006	N	N (RI)	13	51	66.5[a*] 81.8[b*]	81.3
Neustadt-Glewe	Neustadt-Glewe	1994	N	N (RI)	4	14	16.9[a*] 20.8[b*]	81.3
Poing	Poing	2012	N	N (RI)	8-10	38-40	34.0[a*] 52.0[b*]	65.4
Prenzlau	Prenzlau	1994	N	N (BHE)	0.15*	0.5*	0.4[a*] 2.9[b*]	13.8
Pullach	Pullach	2005	N	N (RI)	15.5	32.5	63.0[a*] 67.0[b*]	94.0
Sauerlach	Sauerlach	2013	Y	N (RI)	4	4	7.8[a&b*]	100.0
Simbach-Braunau	Simbach-Braunau	2001	N	N (RI)	9	46.2	50.5[a*]	na
Straubing	Straubing	1996	N	N (RI)	2.1	7.3	2.9[a*]	na
Taufkirchen	Taufkirchen	2015	Y	N (RI)	40.0	40.0	35.0[a&b*]	100.0
Traunreut	Traunreut	2015	Y	N (RI)	12.0	13.9	26.9[a*] 35.8[b*]	75.1
Unterföhring	Unterföhring	2009	N	Y (RI)	10	30	23.5[a&b*]	100.0
Unterföhring II	Unterföhring II	2015	N	N (RI)	11.3	31.3	33.7[a&b*]	100.0

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

Locality	Plant Name	Year commis-sioned	CHP	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2017 produc-tion * (GW_{th}/y) [a]geothermal [b]total	Geoth. share in total prod. (%)
Unterhaching	Unterhaching	2007	N	N (RI)	38	83	108.0[a]* 144.0[b]*	75.0
Unterschleißheim	Unterschleißheim	2003	N	N (RI)	7.98	23.78	42.0[a]* 64.7[b]*	64.9
Waldkraiburg	Waldkraiburg	2012	N	N (RI)	14	17.5	24.8[a]* 25.3[b]*	98.0
Waren	Waren	1984	N	N (RI)	1.3	10.742	2.4[a]* 10.1[b]*	23.8
total					334.5	800.6	893.3[a]* 1375.5[b]*	

* If 2017 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

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

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion * (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	
Heubach	Heubach	2013	Y (BHE)	0.09	na	na	na	
Neuruppin	Neuruppin		N (RI)	1.4	2.1	0.64*	na	
Weinheim	Miramar	2007	N (RI)	1.10	4	5.65*	na	
various	160 thermal spas			56.8 est.	na	474.6 est.		
total				60.1		484,2		

* If 2017 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018	382,000	4,400	9,025 * 6,600 **	23,500	250	
Projected total by 2020				* total heat ** geothermal/renewable share		

Table F: Investment and Employment in geothermal energy

	in 2018		Expected in 2020	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power				
Geothermal direct uses				
Shallow geothermal	~ 450 Mio. € (only installation)			
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	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)