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Geothermal Energy Use in Germany

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ABSTRACT

At present, 180 geothermal installations for direct use of geothermal energy are operating in Germany. The installed capacity of these plants amounts to roughly 260 (geothermal) / 650 (total, including peak load capacity etc.) MWt. The installations comprise centralised heating units (district heating), space heating in some cases combined with greenhouses, and thermal spas. Most of the plants are located in the North German Basin, the Molasse Basin in Southern Germany, or along the Upper Rhine Graben. In addition to these large-scale plants there are numerous small- and medium-size decentralised geothermal heat pump units (ground coupled heat pumps and groundwater heat pumps). Their installed capacity nearly reaches 2,600 (geothermal) / 3,500 (total, including electrical energy consumed) MWt. After a period of growth in the past decade, the number of newly installed geothermal heat pumps decreased over the last years, due to economic and regulatory shortcomings. By the end of 2013 direct thermal use of geothermal energy in Germany amounted to a total installed thermal capacity of about 2,850 (geothermal) / 4,150 (total) MWt.

Organic Rankine and Kalina cycle techniques allow efficient electricity production at temperatures down to 100°C and makes geothermal power production feasible even for countries like Germany lacking high enthalpy resources at shallow depth. In 2013 three new power plants Dürrnhaar (5.5 MWe), Kirchstockach (5.5 MWe) and Sauerlach (5 MWe) have been commissioned resulting in a total installed capacity of 27.1 MWe in Germany.

Apart from funding R&D projects, the Federal Government is also creating incentives for new projects by offering 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 has come into effect on 1st January 2012. The subsidy for geothermal electricity has been 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. The Renewable Heat Act (EEWärmeG) of 2009, which has come into force in an amended version in 2011, mainly aims at the installation of renewable heat sources in buildings.

The Leibniz Institute for Applied Geophysics (LIAG) is running an internet based information system on geothermal resources (Agemar et al. 2014a, b, GeotIS 2014). The system provides data of all centralised geothermal installations in Germany and information and data compilations of deep aquifers. The project aims at an improvement of quality in the planning of geothermal plants and at a minimization of exploration risks.

1. INTRODUCTION

As Germany lacks natural steam reservoirs, which can be used for a direct drive of turbines, geothermal electricity generation is based on the use of binary systems, which use a working fluid in a secondary cycle (Kalina cycle or ORC). Aquifers with temperatures and hydraulic conductivities suitable for power generation can be expected particularly in the Upper Rhine Graben and in the south-eastern part of the Molasse Basin (Schellschmidt et al. 2010). A successful development of hydraulic stimulation techniques in sediments and crystalline rocks (EGS) would change the situation in Germany fundamentally and make geothermal energy an option in regions without hydrogeothermal potential.

At present, 24 plants for district heating and/or power generation are in operation in Germany and a couple of new plants are under construction. The occurrence of deep hot aquifers has led to a vivid project development especially in southern Germany. Current project development concentrates in the Bavarian part of the South German Molasse Basin, where karstified Upper Jurassic limestones provide a suitable aquifer of several hundred meters thickness. Due to the southward inclination of the water-bearing horizon, fluid temperatures increase towards the Alps, reaching temperatures usable for power generation in the area of Munich. Several projects are also under development in the Upper Rhine Graben, which is another region of hydrogeothermal potential. Over-average geothermal gradients make this region interesting for the development of electricity projects.

This paper describes existing geothermal resources and potentials followed by the status of geothermal energy use in Germany. Different use categories such as district and space heating, thermal spas, as well as heat pumps and their contribution to the geothermal heat supply are listed. Furthermore, we give an overview of governmental support for geothermal projects and developments and discuss the future perspectives of geothermal energy use in Germany.

2. GEOTHERMAL RESOURCES AND POTENTIAL

The potential for geothermal power production in Germany was investigated in a study published by the "Office of Technology Assessment at the German Parliament" (Paschen et al. 2003), whereas the resources for direct use of geothermal energy in Germany were estimated in two European atlases: the "Atlas of Geothermal Resources in the European Community, Austria and Switzerland" (Haenel and Staroste 1988), and the "Atlas of Geothermal Resources in Europe" (Hurter and Haenel 2002).

2.1 Potential for Geothermal Power Production

Organic Rankine and Kalina cycle techniques allow efficient electricity production at temperatures down to 100°C and make geothermal power production feasible even for countries like Germany lacking high enthalpy resources at shallow depth. The geothermal resources for geothermal power production were estimated in a study performed in 2002 (Jung et al. 2002). Three types of reservoirs were considered: hot water aquifers (Fig. 1), faults (Fig. 2), and crystalline rocks (Fig. 3) with temperatures above 100°C and at depths down to 7,000 m.

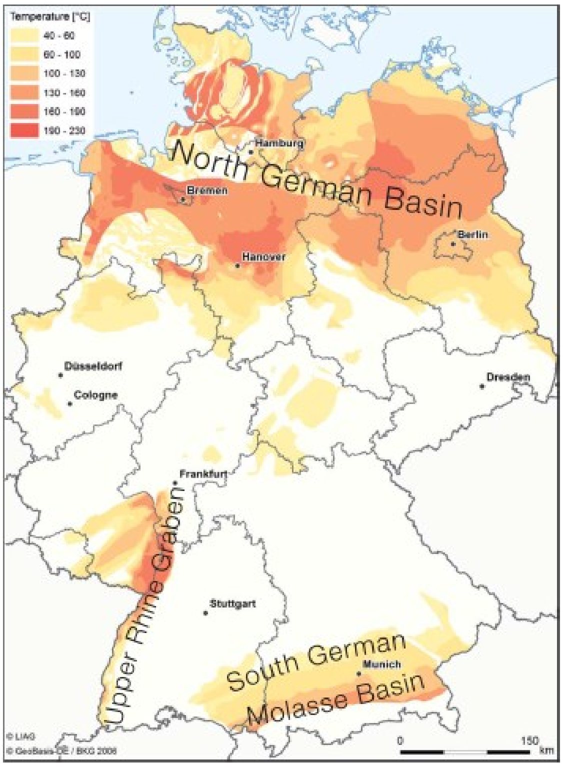

Figure 1: German regions with hydrothermal resources (proven and assumed) and associated temperature ranges (map adapted from Suchi et al. 2014). From North to South: Upper Rotliegend (Upper Permian) sandstone aquifer in the North German Basin; Upper Muschelkalk and Buntsandstein (Middle and Early Triassic) aquifers of the Upper Rhine Graben; Malmkarst (Upper Jurassic) aquifer in the South German Molasse Basin.

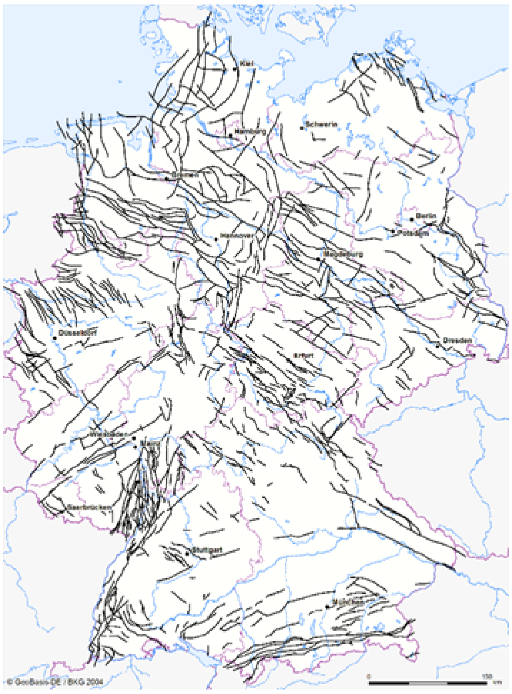

Figure 2: Major deep-seated fault systems in Germany (Schulz et al. 2013 modified after e.g. Zitzmann 1981, Haenel and Staroste 1988, Söllig and Röllig 1990, Brückner-Röhling et al. 2002 and Reinhold et al. 2008).

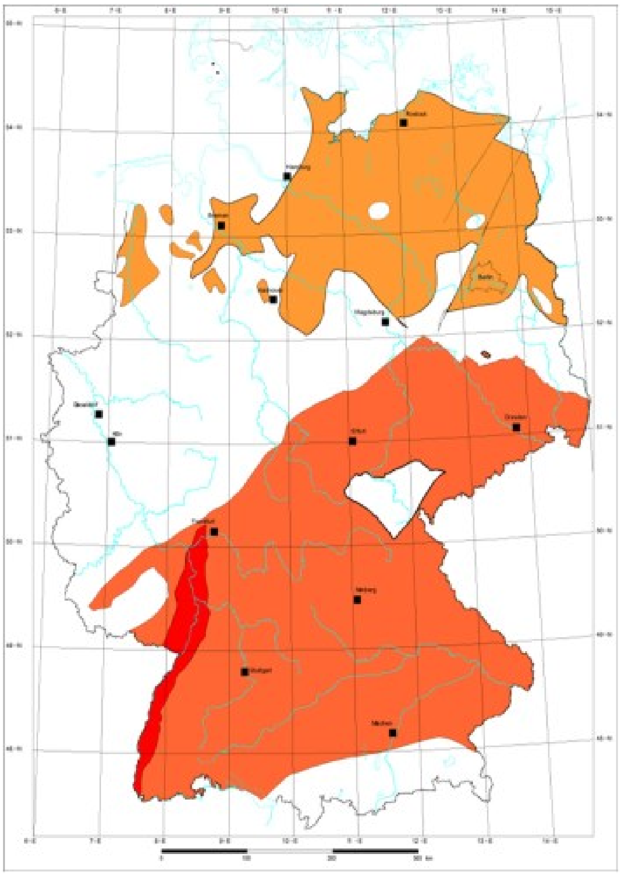

Figure 3: Crystalline rocks for geothermal power production in Germany. Red area: crystalline rock at 3 km depth and with a mean temperature of 100 °C; dark red area: crystalline rock in the Upper Rhine Graben at 3 km depth and with a temperature of 130 °C; orange area: Rotliegend (Permian) volcanic rock with temperatures exceeding 100 °C.

Assuming realistic values for the recovery factor and the efficiency factor, the accessible electrical energy was calculated. The electrical energy was estimated to 10 EJ (1 EJ = 10^{18} J) for the hot water aquifers, to 45 EJ for deep reaching faults, and to 1,100 EJ for crystalline rock. In comparison to these potentials the annual power consumption for Germany in 2012 was approximately 1.9 EJ (BMWi 2014a). To recover at least part of these huge resources further research and developments are necessary, especially in accessing heat from faults and crystalline rocks.

2.2 Resources for Direct Use of Geothermal Energy

The geothermal resources for most European countries have been estimated and compiled in the Atlas of Geothermal Resources in Europe (Hurter and Haenel 2002), a companion volume to the Atlas of Geothermal Resources in the European Community, Austria and Switzerland (Haenel and Staroste, 1988). The German contributions to these two atlases display the resources for direct use of geothermal energy in Germany. The most important regions for hydrogeothermal exploitation in Germany are the North German Basin, the Upper Rhine Graben, and the South German Molasse Basin (Fig. 1).

The North German Basin is the central part of the Central European Basin. The present-day sediment thickness ranges from 2-10 km. Halokinetic movements of the Zechstein layers are responsible for the intense and complex deformation of Mesozoic and Cenozoic formations (Franke et al. 1996, Kockel 2002). These movements were active up to recent times. This tectonic disturbance strongly influences the local conditions of the geothermal reservoirs.

The Mesozoic deposits of the North German Basin are made up of sandstones, clay and carbonates, with evaporite intercalations. Six Cretaceous, Jurassic and Triassic sandstone aquifers are of interest for direct use of geothermal energy: Valendis sandstone, Bentheimer sandstone, Aalen, Lias and Rhaetian, Schilfsandstein, and Buntsandstein. Because of the salt tectonics, great variations of depth and thickness, exceeding locally 1,000 m, occur along short distances. Therefore, temperature and energy content of the geothermal resources vary strongly on a regional scale. Table A shows the resources of these aquifers.

The Molasse Basin in southern Germany is an asymmetrical foreland basin associated with the uplift of the Alps. It extends over more than 300 km from Switzerland in the southwest to Austria in the east.

The basin is made up mainly by Tertiary, Upper Jurassic (Malm) and Triassic sediments. Eight aquifers of these sedimentary layers are of interest for direct use of geothermal energy: Burdigal, Aquitan and Chatt sandstones, Baustein and Ampfinger beds, Gault and Cenoman sandstones, Malm and Upper Muschelkalk. The Malm (karstic limestone aquifer of the Upper Jurassic) is one of the most important hydrogeothermal energy reservoirs in Central Europe because the aquifer is highly productive and present throughout almost the whole Molasse Basin. The Malm aquifer dips from north to south to increasing depths and temperatures. The estimate of resources of the Molasse aquifers is listed in Table A.

Table A: Resources of Germany (Schellschmidt et al. 2002)

Reg.	Aquifer	A km²	T_t °C	Resources 10^{18} J	Resources GJ/m²
A	Valendis Sst.	143	50	0.11	0.79
	Bentheimer Sst.	361	54	0.28	0.78
B	Aalen	66250	43	80.83	1.22
	Lias and Rhät	68125	38	102.87	1.51
	Schilfsandstein	63125	48	37.88	0.60
	Buntsandstein	67500	49	70.88	1.05
C	Garfenberg-Schicht	597	28	0.29	0.48
D	Hydrobien-Schicht.	2117	30	5.72	2.70
	Ob. Muschelkalk	2060	137	3.17	1.53
	Buntsandstein	2746	137	45.72	16.65
	Rotliegendes	2117	110	89.79	42.41
E	Hauptrogenstein	332	79	0.49	1.47
	Ob. Muschelkalk	1616	75	1.11	0.69
	Buntsandstein	1688	85	9.78	5.80
F	Aquitan-Sande	3776	48	6.79	1.80
	Chatt-Sande	2564	72	9.05	3.53
	Baustein-Schichten	880	45	0.36	0.41
	Malm	7740	69	11.79	1.52
	Ob. Muschelkalk	3728	67	1.29	0.34
G	Burdigal-Sande	268	45	0.22	0.82
	Aquitan-Sande	763	45	1.33	1.82
	Chatt-Sande	3348	53	10.48	3.13
	Baustein-Schichten	304	42	0.14	0.47
	Ampf., Priabon	436	79	0.39	0.89
	Gault/Cenoman	6112	77	4.61	0.75
	Malm	8790	78	17.05	1.94

T_t = mean Temperature at top of aquifer Reg.:
A = areal extent of potential area
A' = areal extent of probable reserves
P = thermal power (= reserves/30 years)

A = Western North German Basin
B = Eastern North German Basin
C = Lower Rhine Graben
D = Northern Upper Rhine Graben
E = Southern Upper Rhine Graben
F = Western Molasse Basin
G = Eastern Molasse Basin

The Upper Rhine Graben belongs to a large rift system which crosses the north-western European plate (e.g. Villemin et al. 1986). Between 30 and 40 km wide, the graben runs from Basel, Switzerland, to Frankfurt, Germany. The structure was formed in the Tertiary at about 45-60 Ma by up-doming of the crust-mantle boundary due to magmatic intrusions in 80-100 km depth. The induced thermo-mechanical stress results in extensional tectonics with a maximum vertical offset of 4.8 km.

Six aquifers (Tertiary, Jurassic, Triassic and Permian) are of interest for direct use of geothermal energy: Hydrobien-Schichten, Grafenberg-Schicht, Hauptrogenstein, Upper Muschelkalk, Buntsandstein and Rotliegend. The resources of these aquifers are listed in Table A.

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, as Germany lacks high enthalpy reservoirs, progress in the development of geothermal energy lags behind the development of other renewables. On the other hand, some regions provide good conditions for heating plants and regionally also for power production (Fig. 1). Thus, especially in the South of Germany a number of new projects have been realized and further developments are being planned.

Geothermal power only plays a marginal role in the German electricity market (BMU 2013). Though the development of geothermal electricity in Germany is rather slow, the new plants in Dürrnhaar, Insheim, Kirchstockach and Sauerlach and several power plants presently under construction will lead to a further increase of geothermal power generation in the next years.

Geothermal heat is produced in about 180 larger installations using thermal waters and numerous geothermal heat pumps for heating and cooling of office buildings and private houses. The most widespread utilizations of deep geothermal heat are thermal spas. However, the number of larger district heating plants is growing continuously. They presently account for more than the half of the deep geothermal heat production, with an upward tendency.

Geothermal heat pumps contribute the major portion to geothermal heat use in Germany. Though the strong positive trend of former years did not continue recently, the total number of geothermal heat pumps still increases and reached about 286,000 at the end of 2013.

3.1 Geothermal Power Production

With the recent commissioning of the two 5.5 MWe plants in Dürrnhaar and Kirchstockach as well as the two 5 MWe plants in Sauerlach and Insheim in 2012/2013 (the first three in the South German Molasse Basin adjacent to Munich; Insheim: Upper Rhine Graben), geothermal power in Germany had reached an installed capacity of 27.1 MW_e (Table 1). The electricity produced amounted to 35.5 GWh in 2013, which means an increase of about 10 GWh compared to 2012 (Agemar et al. 2014b, GeotIS 2014). A considerable increase in power generation can be expected in 2014 with a year-round production in Dürrnhaar, Kirchstockach and Sauerlach.

At the beginning of 2014, seven plants with facilities for geothermal power production were in operation (Fig. 4, Table 1 & 2):

- The new 5 MWe ORC plant in Sauerlach started producing geothermal electricity in March 2013. What is special about this project is that operation is realized by a triplet with two injection and one production well.
- The 5.5 MWe ORC plant in Kirchstockach started operation in March 2013 as well. Combined heat and power production is planned in the future.
- First electricity feed-in at the 5.5 MWe ORC plant in Dürrnhaar started in December 2012.
- The 5 MWe ORC plant of Insheim in the Upper Rhine Graben went online in November 2012. Heat extraction is planned in the further development of the project.
- The combined heat and power plant in Landau is in operation since November 2007. The ORC plant provides an installed capacity of 3 MWe. However, due to the uplift of the ground and formation of cracks in the area of the plant, production stopped in March 2014 for safety reasons and geological investigations.
- The heat-lead plant in Unterhaching, Bavaria, operates a 3.3 MWe Kalina unit. With 6.9 GWh electric power produced in 2013, this plant also contributes significantly to geothermal power generation in Germany.
- After extensive reconstruction works since 2012 and a pump test in March 2013 the 0.55 MWe Kalina unit in Bruchsal, Upper Rhine Graben was not in year-round operation. Nevertheless, production amounted to 1.2 GWh in 2013.
- Due to economic reasons the power production in the Neustadt-Glewe and Simbach-Braunau combined heat and power plants ended with the dismantling of the 0.2 MWe power stations in 2012. Heat is still provided for district-heating networks.

3.2 Centralised Installations for Direct Use

Common deep geothermal utilizations using thermal waters with temperatures over 20°C from wells over 400 m depth are district heating plants or combined heat and power plants (CHP), thermal spas, and space heating. Presently, about 180 geothermal installations of these types are in operation in Germany (Fig. 4, Table 3).

Common systems for district heating are geothermal doublets with production and injection well, while spas usually use single wells. Furthermore, three deep borehole heat exchangers are in operation in Germany: Arnsberg (Nordrhein-Westphalen) with a total depth of 2,835 m heating a spa, Prenzlau (Brandenburg, 2,786 m, used for district heating) and Heubach (Hessen) providing heat for industry (773 m).

In 2014, the total installed capacity, which includes auxiliary heat sources such as peak load boilers in addition to the geothermal source, reached about 650 MWt. The geothermal share of the installed capacity amounted to 260 MWt. The 19 district heating and combined plants (not including deep borehole heat exchangers) accounted for the largest portion of the total geothermal capacity with about 208 MWt. Altogether, the installed capacity of deep geothermal heat uses in Germany shows a considerable increase from about 160 MWt in 2010 to 260 MWt in 2014. Heat production by deep geothermal utilization rose from 716 GWh in 2010 to 925 GWh in 2013 (Agemar et al. 2014b; GeotIS 2014).

3.3 Geothermal Heat Pumps

Heat pump systems for heating and cooling of residential houses and office buildings are widespread in Germany. Geothermal heat pumps use the heat within the subsurface as the renewable heat source or they extract heat directly from the groundwater. Common systems are horizontal heat collectors or borehole heat exchangers (brine/water systems) and groundwater systems with extraction and injection well(s) (water/water systems). Direct expansion heat pumps with horizontal collectors and heat pipes used as borehole heat exchangers have their small market niche. The use of foundation piles or other concrete building parts in contact with the ground as heat exchangers ("energy piles") is increasing in areas with poor subsoil stability.

Typical installed capacities of heat pumps used in residential houses are about 10 kW for brine/water and about 14 kW for water/water systems (GZB 2010). Heat pump systems in office buildings reach capacities of several 100 kW. The largest heat pump installation known in Germany is running in an office building in Duisburg and has a heating capacity of over 1 MWt (BWP 2012); for large systems, see Table B.

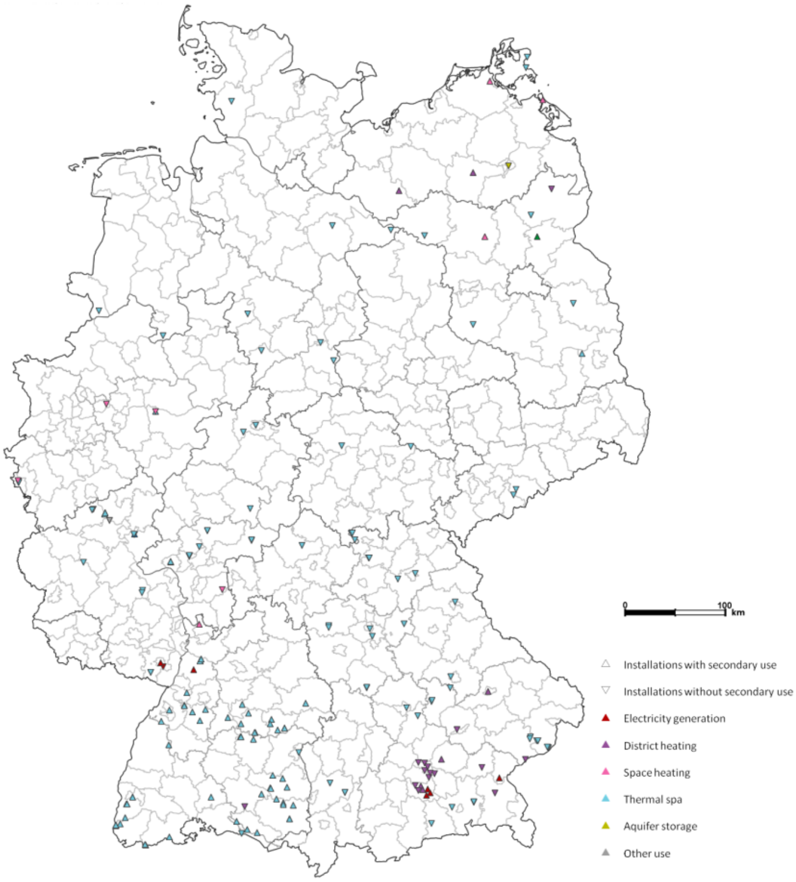

Figure 4: Installations for geothermal energy use in operation in Germany (from GeotIS 2014).

Table B: Large GSHP systems in Germany, status summer 2014 (from EGEC 2013, updated)

City, Name	Year	Inst. capacity [kW_{th}]	Type
Duisburg, ZBBW	2011	1,480 (H) / 1,030 (C)	180 BHE each 130 m deep, 3 HP
Bonn, Bonner Bogen	2009	920 (H) / 620 (C)	3 + 3 groundwater wells 28 m deep, HP
Munich, Dywidag	2001	840 (H) / 500 (C)	Several groundwater wells for 500 m^3/h, HP
Wetzlar, Leica	2014	800 (H) / 560 (C)	80 BHE each 120 m deep, HP and abs. chiller
Schwabach, MF Niehoff	2009	600 (H) / 900 (C)	103 BHE each 85 m deep, 2 HP
Frankfurt/M, Ordnungsamt	2009	600 (H/C)	112 BHE each 85 m deep, HP
Friedrichshafen, ZF Research	2009	600 (H/C)	325 energy piles each about 19 m deep
Bonn, „Bonnvisio“	2004	600 (H) / 550 (C)	2 + 2 groundwater wells 11 m deep, HP
Golm near Potsdam, MPI	1999	560 (H) / 360 (C)	160 BHE each 100 m deep, HP
Nuremberg, Panalpina	2008	560 (H) / 270 (C)	81 BHE each 75 m deep, 2 HP
Frankfurt/M, WestendDuo	2005	ca. 400 (H/C)	2 + 3 groundwater wells 140 m deep, HP
Münster, LVM 7	2008	550 (H/C)	91 BHE each 100 m deep, HP
Freiburg i.Br., Qu. Unterlinden	2011	ca. 500 (H/C)	108 BHE each 125 m deep, HP
Frankfurt/M, Maintower	1999	ca. 500 (C)	ca. 210 energy piles each about 30m tief, cold storage
Gelnhausen, MK-Forum	2005	400 (H) / 440 (C)	96 BHE each 99 m deep, HP

Frankfurt/M, Cargo City Süd 577	2010	380 (H) / 480 (C)	38 BHE each 130 m tief, HP
Leinfelden-Echertdingen, HC	2010	340 (H) / 355 (C)	80 BHE each 140 m tief, HP
Langen, DFS	2001	330 (H) / 340 (C)	154 BHE each 70 m deep, HP
Frankfurt/M, Baseler Platz	2003	300 (H) / 180 (C)	2 groundwater wells 80 m deep, HP
Hannover, NL Bank	1999	150 (H) / 350 (C)	122 energy piles each 20 m deep
Emden, VW factory	2013	? (mainly C)	3300 energy piles each 24 m deep

H: Heating, C: Cooling, BHE: Borehole Heat Exchanger

The total number of all heat pumps (brine/water, water/water and air/water systems) reached about 555,000 in 2013 (BMWi according to AGEE-stat 2014b), producing estimated 7.5 TWh of renewable heat. The number of geothermal systems reached about 286,000 at the end of 2013, a considerable increase compared to 265,000 geothermal heat pumps in 2012 (Fig. 5). Brine/water systems are the most common installations with a share of about 85 % of the geothermal heat pumps (GZB 2010). Geothermal heat pumps still constitute the major portion of the total number of heat pump systems used for space heating and cooling, however, sales figures of ground source heat pumps have decreased in the last five years (Fig. 6).

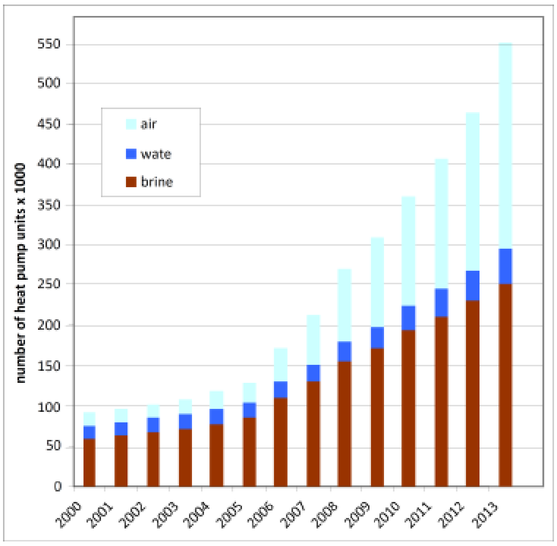

Figure 1: Development of the heat pump market in Germany since 2000 (BMWi according to AGEE-stat 2014b).

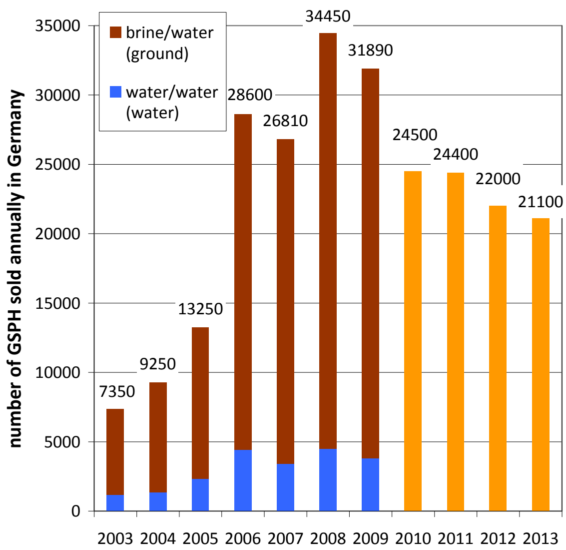

Figure 6: Annual number of new ground source heat pumps (after data from BWP 2014; from 2010 on, the distinction between water and brine heat pumps is no longer made by BWP).

Market figures of the German Heat Pump Association (BWP 2014) show that the share of air coupled systems in total heat pump sales increases continuously, while that of geothermal systems goes down. From a peak of about 85% of geothermal heat pumps in 1998 the decrease is accelerating steadily, reaching a low of only 35.2% in 2013 (Fig. 7). According to BWP, the reasons for the decreasing interest in ground source heat pumps are various:

- high cost for drilling, partly arising from imposed official requirements for geothermal boreholes,
- lower cost for installation of air source units and low prices of imported air-source heat pumps,
- lack of appropriate support measures and incentives (cf. chapter 4.2), and
- complicated approval practices.

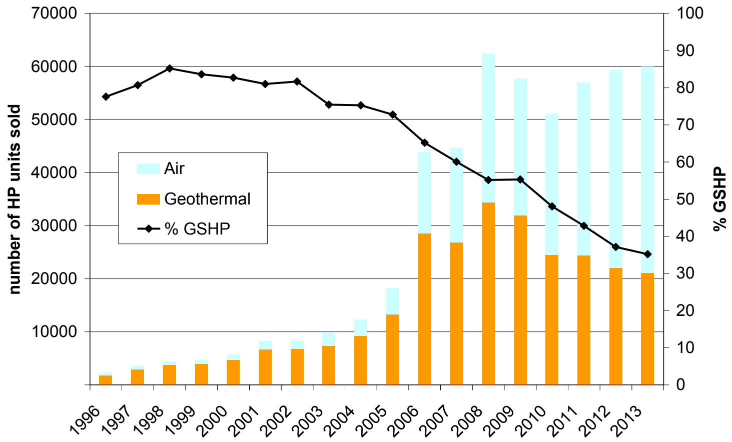

Figure 2: Development of sales for ground source (geothermal) and air source heat pumps in Germany (after annual data from BWP, latest BWP 2014).

According to the Working Group on Renewable Energy-Statistics (AGEE-stat), the heating capacity of the stock number of 244,000 geothermal heat pumps amounted to about 3,000 MWt in 2011, 3,200 MWt in 2012 by 265,000 units (AGEE-stat c/o ZSW, pers. comm.) and reached about 3,450 MWt in 2013 by 286,000 units. Assuming an average COP of 4 to 4.5 (GZB 2010, Miara et al. 2011), the geothermal contribution of the heating capacity can be estimated with about 2,250 MWt in 2011, 2,400 MWt in 2012 and 2,590 MWt in 2013.

Using an average runtime of 1950 full load hours (GZB 2010), the total heat produced by geothermal heat pumps can be estimated with 5 TWh in 2011 and 5.5 TWh in 2012. The renewable share of the produced heat amounted to 3,870 GWh in 2011, 4,170 GWh in 2012 (AGEE-stat c/o ZSW, pers. comm.), and 4,500 GWh in 2013.

For EU statistical purposes, the renewable (geothermal) contribution to the heating capacity from now on should be calculated according to the EU Directive 2009/28/EC “Renewable Energy”, Annex VII, by the equation:

$$E_{RES} = \mathrm{Q}_{\mathrm{usable}} * (1 - 1/\mathrm{SPF})$$

where E_{RES}, Q_{usable}, SPF are renewable energy (in GWh), estimated total usable heat (in GWh) and seasonal performance factor, respectively.

In March 2013, the EC has issued the necessary rules for applying this formula, prepared by Eurostat (Decision 2013/114/EU). As default (i.e. if no better data from actual measurements are available), Q_{usable} shall be calculated as:

$$\mathrm{Q}_{\mathrm{usable}} = \mathrm{H}_{\mathrm{HP}} * \mathrm{P}_{\mathrm{rated}}$$

where Q_{usable}, H_{HP}, P_{rated} are estimated total usable heat (in GWh), full-load hours of operation and capacity of heat pumps installed, respectively.

Also default values for H_{HP} and SPF are given in 2013/114/EU. For Germany, located in the “average climate” zone, H_{HP} is considered as 2,070 h/year (a rather high value), and SPF for Ground-Water and Water-Water heat pumps as 3.5 (this value is more on the low side for Germany). Then the full calculation is:

$$\mathrm{Q}_{\mathrm{usable}} = 2{,}070\ \mathrm{h/a} * 3{,}200\ \mathrm{MW} = 6{,}624\ \mathrm{GWh/a}$$

(so following this rule, Q_{usable} will be estimated considerably higher than the value of 5,500 GWh/a calculated by AGEE-stat).

The pure geothermal contribution from ground source heat pump systems in Germany thus can be estimated to be 4.73 TWh in 2012, according to the new EU calculation rule:

$$E_{RES} = 6{,}624\,\text{GWh/a} * (1 - 1/3.5) = 4{,}731\,\text{GWh/a}$$

(this is equivalent to 580 Ktoe).

It is also possible to calculate the amount of CO_2-emmissions saved by using ground source heat pumps instead of natural gas burners, still the most popular heat source in Germany (Fig. 8). Using the emission factors of 0.25 g/kWh for natural gas and 0.6 g/kWh for the electricity in Germany, and assuming the (low) average SPF of 3.5 as given by Eurostat, the total emission reductions would amount to about 631 Kt in 2013, or about 38% compared to the same heat provided by natural gas.

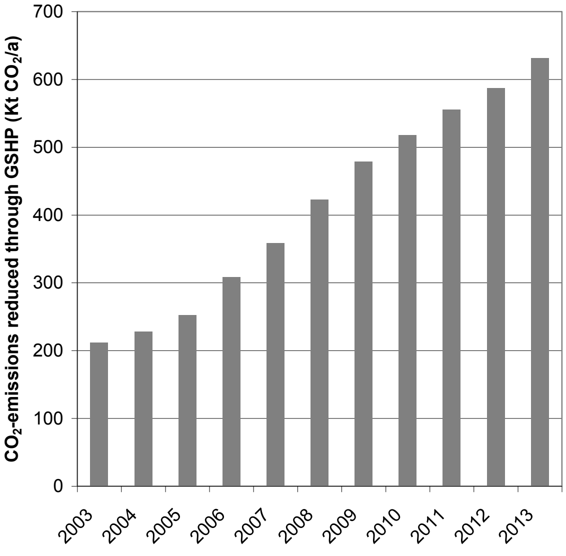

Figure 3: Annual reduction of CO_2-emissions due to GSHP in Germany (calculated after data from BWP 2014, see text).

4. GOVERNMENTAL SUPPORT AND FUTURE PERSPECTIVE

4.1 Energy Market and the Role of Geothermal

A new, conservative estimate of the total thermal capacity currently installed for direct use of geothermal energy in Germany amounts to roughly 3,850 MWt with a geothermal contribution of about 2,650 MWt and about 5,500 GWh renewable heat produced. About 85% of the renewable heat by geothermal applications is attributed to small decentralized units.

According to BMWi (2014a), the final energy consumption in Germany in 2012 was 8,998 PJ (1 PJ = 10^{15} J). A breakdown in figure 9 shows that about 55% of the final energy consumption was required for district and space-heating, hot water, and process heat.

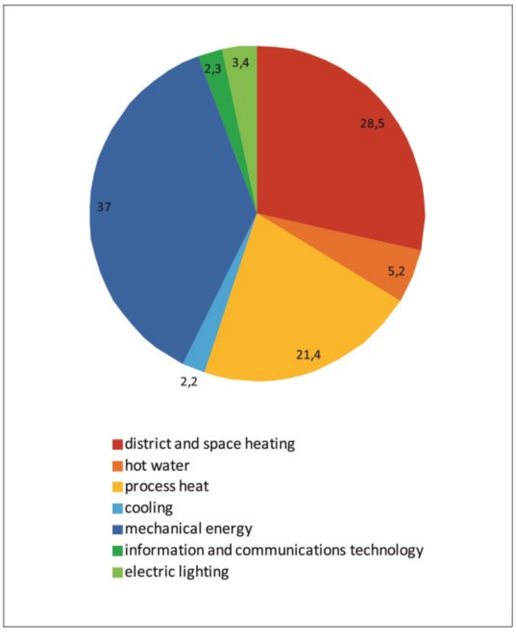

Figure 4: Share of different applications in the final energy consumption for Germany which amounted to 8,998 PJ in 2012 (data BMWi 2014a).

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.

4.2 Governmental Support

Germany has set itself ambitious climate protection targets and resolved to 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 final energy consumption by 2050 (BMU 2012).

To support the development of renewable energy, the German Government has set aside funds in the order of 3.5 billion Euros for the research and development (R&D) of future energy technologies from 2011 to 2014 under the 6th Energy Research Programme. 200 million Euros will be used for institutional funding, 1.3 and 1.1 billion Euros are allocated for research and project funding, respectively (BMU 2012).

In the field of geothermal R&D, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has granted funding for 29 new projects with a total volume of 20.6 million Euros (2012: 37 projects and 21.4 million €, Fig. 10). Furthermore, the financing of running projects was 17.1 million € in 2013 compared to 20.8 million € in 2012 (BMWi 2014c). According to a table of BMU, in summer 2014 more than 80 individual R&D-projects on deep geothermal were ongoing, a number of which were part of several cluster projects. The total annual value of the related grants amounts to about 20.5 million Euro, of which 74.5% went into projects that could benefit also geothermal district heating, while 2.4% are targeted at electricity exclusively, and 23.1% are concerning EGS.

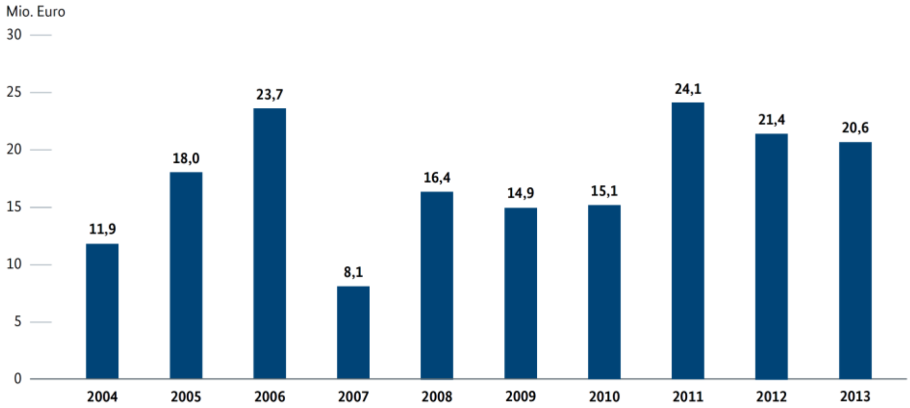

Figure 5: Funding for new geothermal R&D projects by BMU from 2006 to 2013 (BMWi 2014c).

Apart from funding R&D projects, the Federal Government is also creating incentives for new projects by offering 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 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 the summer of 2014 abolished the petrothermal bonus, and deteriorated the economic boundaries for selling the electricity.

The Renewable Heat Act (EEWärmeG) of 2009, which has come 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 lower SPF values for air-source heat pumps and the fact that only50 % of the annual heat load must be covered (i.e. bivalent/monoenergetic heat pumps are possible) are a clear benefit for air source heat pumps. As a result, the EEWärmeG politically sets the signal to continued decrease of the share of ground source heat pumps as discussed in chapter 3.3, in spite of the fact that they could render a higher contribution to CO_2 emission reductions.

The market incentive programme (MAP) of the German Government promotes renewable energy systems that provide space heating, hot water, cooling and process heat. It has a section for smaller buildings and one for larger investments. The MAP supports the installation of heat efficient heat pump systems. The section for smaller buildings is in the competency of the Federal Office of Economics and Export Control (BAFA). Investments in larger heat pump systems in commercial buildings as well as in deep geothermal projects are supported within the KfW Banking Group renewable energies program, which offers low-interest loans and repayment bonuses for larger investments.

For deep geothermal heat and power plants, a repayment bonus up to a maximum of 2 million €/plant and for drilling costs of wells over 400 m depth is offered. By order of the BMU, a loan program of KfW in cooperation with Munich Re (insurance provider) helps furthermore to hedge exploration risks. The program includes financing of up to 80% of the drilling costs and full risk coverage in case of unsuccessful exploration.

For geothermal heat pumps, the financial support from the MAP is only granted for existing buildings since March 2012. Before this it was limited in new buildings to very efficient systems only, since late 2010. The rules in the refurbishment sector now are disadvantageous to geothermal heat pumps; the same high values for SPF (up to 4.0) are stipulated for financial support of systems in existing buildings than those required in EEWärmeG for new buildings. To achieve this high values, refurbishment at high extra cost in existing buildings is required, which cannot be offset by the support granted. As a result, the number of plants supported within MAP dropped drastically from 2011 on, and is almost negligible today, in 2012 the share of supported plants was < 9% of all heat pumps installed in that year.

4.3 Internet Based Information System

The quantification of exploration risks for geothermal wells, respectively the estimation of probability of success is one of the most important factors for investors and decision makers (Schulz et al. 2010). In order to minimize the exploration risk of geothermal wells and to improve the quality in the planning of geothermal plants, the Leibniz Institute for Applied Geophysics (LIAG) at Hannover has developed a geothermal information system (GeotIS 2014, Agemar et al. 2014a, b). The project was funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. LIAG realized this project in close collaboration with partners.

GeotIS provides information and data compilations on deep aquifers in Germany relevant for geothermal exploitation. GeotIS includes data of the South German Molasse Basin, the Upper Rhine Graben, and the North German Basin. GeotIS is a public internet based information system and satisfies the demand for a comprehensive, largely scale-independent form of a geothermal atlas which can be continuously updated. GeotIS helps users to identify geothermal potentials by visualizing 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. An additional component contains a catalogue of all geothermal installations in Germany (Agemar et al. 2014b).

GeotIS is designed as a digital information system which is available free of charge to the public through the World Wide Web (www.geotis.de). For more details see Agemar et al. (2014a, b).

4.4 Outlook

Based on information on projects currently under construction, the development of geothermal power generation can be expected to exceed 50 MWe in 2015. Evaluating data from projects for deep geothermal heat use, the installed capacity is estimated to increase from almost 200 MWt in 2011 to over 300 MWt in 2015 with an annual heat production of about 1,075 GWh. Given a continuing trend, the number of geothermal heat pumps can reach 325,000 units in 2015 with a total installed capacity of over 4,300 MWt producing 5,500 GWh renewable heat. The total geothermal heating capacity can thus be estimated to reach about 3,500 MWt in 2015 with a renewable heat production of over 6,000 GWh (21 PJ).

The pilot study in 2010 for long-term scenarios and strategies for the development of renewables in Germany (BMU 2010) projects for the development of geothermal power installed capacities of nearly 300 MWe by 2020 and 1 GWe in 2030 in one scenario. Geothermal heat use is estimated to reach 8,000 GWh (29PJ) in 2020 and nearly 25,000 GWh (89 PJ) by 2030.

5. CONCLUSIONS

Due to moderate temperature gradients in most parts of Germany and a general lack of high enthalpy reservoirs, geothermal energy use in Germany is still on a comparably low level. Current project development concentrates in the southern part of Germany, where regional geologic settings provide good conditions for heat use and in part also for power generation.

The installed capacity of geothermal heat uses in Germany amounted to 4,150 MWt in 2014, with a pure geothermal contribution of about 2,850 MWt. About 90% of the installed capacity is attributed to geothermal heat pumps. The remaining 10% is contributed by centralized installations using thermal waters from depths over 400 m, such as heating plants and thermal spas. The geothermal heat production in Germany amounted to 5.5 TWh in 2013 with 15% attributed to deep geothermal utilizations. In 2015, geothermal heat production is estimated with about 6 TWh.

In 2014, seven geothermal plants for power generation are in operating state in Germany, three of them combined with heat production. Five of these plants went on line in the last three years. However, the generation of electricity has been discontinued at two heat controlled CHPs (Neustadt-Glewe and Simbach-Braunau) in 2012, due to economic reasons. With the commissioning of the new plants the installed capacity increased to 27.1 MWe what is nearly the fourfold of the 2010 value (7.3 MWe).

With the resolution of the amended Renewable Energy Sources Act (EEG) on 30 June 2011, the German Government further improved the conditions for the development of geothermal energy in Germany. The positive effect of the EEG on geothermal power development is backed up by financial support of pilot and demonstration projects by the German Government. However, a revision of the EEG in summer 2014 abolished the petrothermal bonus, and deteriorated the economic boundaries for selling the electricity. In addition, a market incentive programme grants support for the installation of efficient heat pump systems in private houses and office buildings. Furthermore, repayment bonuses for geothermal heat and power plants and drilling costs are granted and part of the exploration risk can be covered within a program.

Altogether, the use of geothermal energy in Germany shows a slow but continuous positive trend in the last few years. In regions with favourable conditions, a vivid project development takes place, which will further increase the geothermal heat and power capacity in the next years.

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STANDARD TABLES

Table 1: PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables[1)]		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014	27.1	36	84,600*	359,200**	10,400*	26,300**	12,700*	97,300**	71,504*	131,200**	179,231	614,036
Under construction in December 2014	16											
Funds committed, but not yet under construction in December 2014												
Estimated total projected use by 2020												

[1)] Wind, Photovoltaics, Biomass and Waste; * data for 2012 (BMWi 2014a); ** data for 2013 (BMWi 2014a)

Table 2: UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2014

Locality/Power Plant name**	Year Commissioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe*	Total Running Capacity MWe*	Annual Energy Produced 2013 GWh/yr	Total under Constr. or Planned MWe
Bruchsal	2009	1		O	0.55	0.44	1.2	
Dürrnhaar	2012	1		B	5.5	5.5		
Insheim	2012	1		B	4.3	4.3	14.22	
Kirchstockach	2013	1		B	5.5	5.5		
Landau	2007	1		B	3.0	3.0	13.24	
Neustadt-Glewe	2003	0	R	B				
Sauerlach	2013	1		B	5.0	5.0		
Simbach-Braunau	2010	0	R					
Unterhaching	2009	1		O	3.36	3.36	6.87	
Brühl								5-6
Kirchweidach								6.7
Taufkirchen		1		O				4.3
Total					**27.2**	**27.1**	**35.5**	16-17

* Installed capacity is maximum gross output of the plant; running capacity is the actual gross being produced, ** Plants are named after the localities, [1)] R = Retired, [2)] B = Binary (Rankine Cycle), O = Other (Kalina)

Table 3: UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2014 (other than heat pumps)

Locality	Type[1]	Maximum Utilization					Capacity	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy (kJ/kg)			Ave. Flow	Energy	Capacity
		(l/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(l/s)	(TJ/yr)	Factor
152 thermal spas	B	-	-				47.1	-	1,401.1	-
Arnsberg Erlenbach 2	H	20	55				0.35	3	-	-
Bochum Zeche Robert Müser	H	-	20				0.4	22	-	-
Heubach	H	-	-				0.09	5	-	-
Neuruppin	H	13.9	58				1.5	6.9	0.468	0.01
Weinheim (Miramar)	H	10	63.5				1.1	9	20.34	0.59
Aschheim	D	75	85.4				9.8	39-75	175.3	0.57
Erding	D	48	62				10.2	6-36	135.5	0.42
Garching	D	100	74				7.95	100	36.6	0.15
Ismanning	D	85	78				7.2	-	-	-
Landau in der Pfalz	D	70	159				5	40	10.8	0.07
München Riem	D	90	94.5				12	35-85	172.8	0.46
Neustadt-Glewe	D	35	97				4	11-35	63.3	0.50
Oberhaching	D	150	127.5				38	137	175.7	0.15
Poing	D	100	76.2				9	100	133.2	0.47
Prenzlau	D	3.3	55				0.15	3.3	0.9	0.18
Pullach	D	79	104				11.5	75	164.5	0.45
Sauerlach	D	-	-				4	110	-	-
Simbach-Braunau	D	80	80.5				7	61	172.9	0.78
Straubing	D	31.4	36.5				2.1	17.5	10.4	0.16
Traunreut	D	130-150	108				7	-	-	-
Unterföhring	D	75	86				9.5	-	104.4	0.35
Unterhaching	D	150	123.3				38	120	387.3	0.32
Unterschleißheim	D	93.3	78				7.98	65-93.3	144.5	0.57
Waldkraiburg	D	80	109				16.4	20	10.0	0.02
Waren/Müritz	D	17	63				1.3	17	11.2	0.27
TOTAL							**258.6**		**3,331.3**	

[1] B = Bathing and swimming (including balneology), H = Individual space heating (other than heat pumps), D = District heating (other than heat pumps)

Table 4: GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2013

Locality	Ground or Water Temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year	Thermal Energy Used[4] (TJ/yr)	Cooling Energy (TJ/yr)
Germany	8 - 12	10-12	286,000	V, H, W, O	4 - 4.5	1,950	16,200	
TOTAL			**286,000**				**16,200**	

[1] Average ground temperature for ground-coupled units or average well water or lake water temperature for water source heat pumps, [2] V = vertical ground coupled, H = horizontal ground coupled, W = water source (well or lake water), O = others (e.g. energy piles), [3] COP = output thermal energy/input energy of compressor, [4] Geothermal share only

Table 5: SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2013/14

Use	Installed Capacity (MWt)	Annual Energy Use[1)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[2)]
Individual Space Heating[3)]	3.4	20.8	0.2
District Heating [3)]	208.1	1909.4	0.3
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[4)]			
Industrial Process Heat[5)]			
Snow Melting			
Bathing and Swimming[6)]	47.1	1401.1	0.94
Other Uses (specify)			
Subtotal	**258.6**	**3331.3**	**0.42**
Geothermal Heat Pumps	2,590.0	16,200.0	
TOTAL	**2,848.6**	**19,531.3**	

[1)] Geothermal share only; [2)] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171; [3)] Other than heat pumps; [4)] Includes drying or dehydration of grains, fruits and vegetables; [5)] Excludes agricultural drying and dehydration; [6)] Includes balneology

Table 6: WELLS DRILLED FOR ELECTRICAL; DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2010 TO DECEMBER 31, 2014 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (m)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration	(all)					
Production	>150° C	1		1		9,355
	150-100° C		2	3		19,067
	<100° C		3			6,561
Injection	(all)		5	3		30,052
Total		**1**	**10**	**7**		**65,035**

Table 7: ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (NOT restricted to personnel with University degrees)

Year	Number of employees (NOT restricted to personnel with University degrees)
2010	13,300
2011	14,200
2012	16,400
2013	17,300
2014	n.a.

2010 and 2011 data (O'Sullivan et al. 2012); 2012 and 2013 data (O'Sullivan et al. 2014)

Table 8: TOTAL INVESTMENT IN GEOTHERMAL IN (2014) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004	see Figure 10					
2005-2009	see Figure 10					
2010-2014	see Figure 10					