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Geothermal Energy Use in Germany

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ABSTRACT

At present, 140 geothermal installations for direct use of geothermal energy are operating in Germany. The installed capacity of these plants amounts to roughly 177 MW_t. The installations comprise centralised heating units (district heating), space heating in some cases combined with greenhouses, and thermal spas. Most of the centralised plants are located in the Northern 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 exceeds 775 MW_t. By the end of 2006 direct thermal use of geothermal energy in Germany amounted to a total installed thermal capacity of 952 MW_t.

The first geothermal plant for electrical power generation in Germany is on-line since November 2003 with an installed capacity of about 230 kW_e. The economic situation in the electric power market is determined by the Renewable Energy Act (EEG), which sets a fixed rate for geothermal power sold to the utilities. Ratification of this law in 2000 has created a sound economic basis for the development of geothermal projects, and several have indeed been launched since then, mainly in the Upper Rhine Graben, the Munich area and Northern Germany. In 2004 the rate for geothermal power has increased from 0.089 €/kWh to 0.15 €/kWh.

A successful development of the Enhanced Geothermal Systems (such as Hot Dry Rock technology) will make an additional contribution.

A study of the “Office of Technology Assessment at the German Parliament (TAB)” investigated the potential for geothermal power production in Germany. This study shows that the resources for geothermal power production in Germany amount to about 10^{21} J.

1. INTRODUCTION

Due to a lack of natural steam reservoirs geothermal energy cannot be converted in Dry Steam or Flash Steam power plants into electric power in Germany. At present only Kalina or Organic Rankin Cycle (ORC) power plants can be used for electrical power generation. At Neustadt-Glewe the first German geothermal plant for electrical power generation is working since November 2003 with an installed capacity of about 230 kW_e.

A successful development of the Hot Dry Rock (HDR) technology and the hydraulic stimulation technique in sediments would change the situation in Germany fundamentally. An HDR geothermal power plant is in realisation at Groß Schönebeck. New innovative technologies are currently being developed for converting the heat of deep seated hot aquifers to power. Two of these innovative projects are in realisation in Unterhaching (Molasse Basin) and in Landau (Upper Rhine Graben). The plants for combined power generation and district heating are nearly completed.

These projects are supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

This paper describes the existing geothermal resources and potentials followed by the status of geothermal utilisation in Germany by the end of 2006, and the contribution from each type of installation: geothermal power production, large-scale centralised and small scale decentralised units. Future perspective of the use of geothermal energy in Germany will be discussed.

2. GEOTHERMAL RESOURCES AND POTENTIAL

The potential for geothermal power production in Germany was investigated in a study published in 2003 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 makes geothermal power production feasible even for countries like Germany lacking high enthalpy resources at shallow depth. The geothermal resources for geothermal power production in Germany 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 7000 m.

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 1100 EJ for crystalline rock. In comparison to these potentials the annual power consumption in 2005 for Germany was 1.875 EJ (BMWA 2007). To recover at least part of this huge resources further research and developments are necessary especially in accessing heat from faults and crystalline rocks.

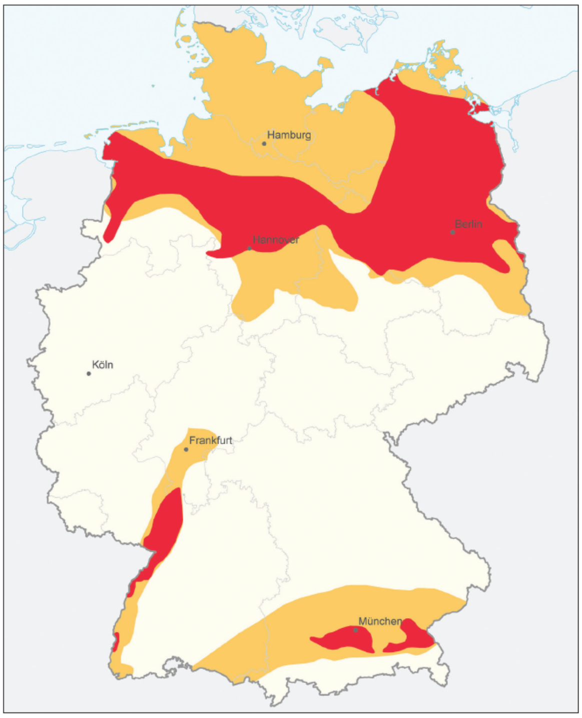

Figure 1: Red areas: Hot water aquifers for geothermal power production, temperature above 100 °C. Yellow areas: Hot water aquifers direct use of geothermal energy, temperature above 60 °C. (Schulz et al. 2007). From North to South: Upper Rotliegend (Upper Permian) sand stone aquifer in the North German 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.

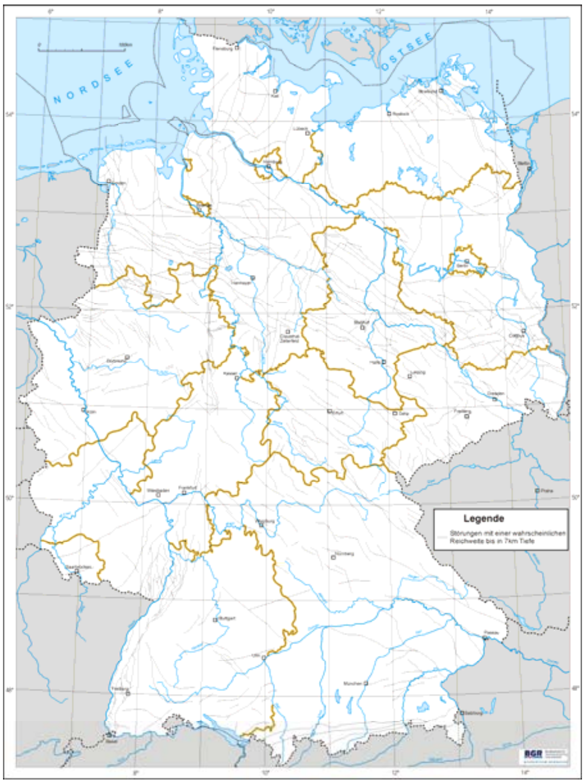

Figure 2: Deep-seated fault systems with a possible extension up to 7 km depth.

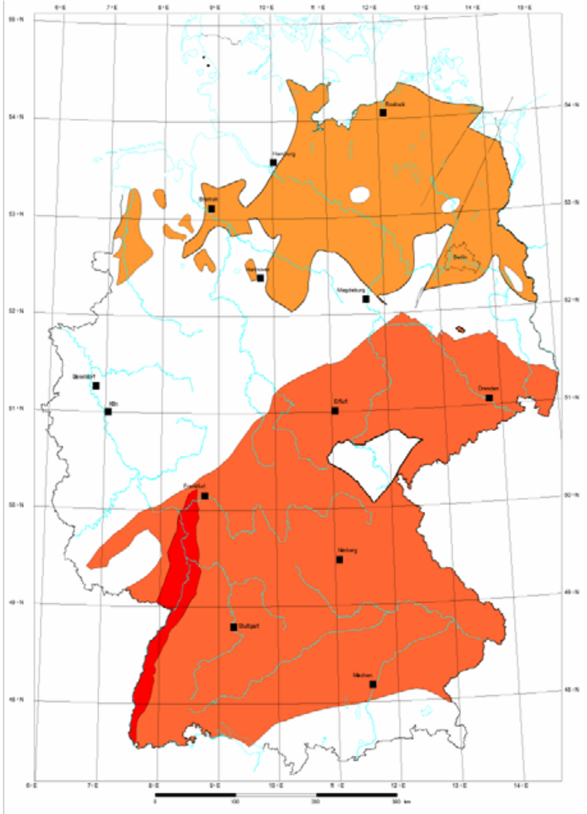

Figure 3: Crystalline rocks for geothermal power production in Germany. Red area: crystalline rock at 3 km depth and with a mean temperature of 100 °C; dark red area: crystalline rock in the Upper Rhine Graben at 3 km depth and with a temperature of 130 °C; orange area: Rotliegend (Permian) volcanic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

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. All aquifers of interest are located in the North German sedimentary basin, the Molasse Basin in southern Germany, and along the Upper Rhine Graben.

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). 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-Sandstein, Bentheimer Sandstein, Aalen, Lias and Rhät, Schilfsandstein, and Buntsandstein. Because of the salt tectonics, great variations of depth and thickness, exceeding locally 1000 m, occur along short distances. Therefore, the temperature and energy content of the geothermal resources vary strongly on a regional scale. Table 1 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-Sande, Aquitan-Sande, Chatt-Sande, Baustein-Schichten, Ampfinger Schichten, Gault/ Cenoman-Sandsteine, Malm and Upper Muschelkalk. The Malm (karstic limestone aquifer of the Upper Jurassic) is one of the most important hydro-geothermal 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 1.

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 1.

3. STATUS OF GEOTHERMAL ENERGY USE

Geothermal energy (Bertani 2005, Lund et al. 2005) is worldwide the most extensively used renewable energy besides hydro-power and biomass (direct use). Due to the lack of natural steam reservoirs geothermal energy got little attention in Germany in the past. The use of geothermal energy in Germany is actually restricted to a relatively small number of centralised installations and numerous small decentralised units (heat pump units). Geothermal power production has just started.

3.1 Geothermal Power Production

The first geothermal plant for electric power generation in Germany is working since November 2003. The power plant is situated in the eastern part of the North German Basin at Neustadt-Glewe (Fig. 4). The installed capacity is about 230 kW$_e$ to generate power. In addition 10.7 MW$_t$ are used for district and space heating. The power production of 1400-1600 MWh/a will provide 500 households with electric power (Broßmann et al. 2003). An Organic Rankin Cycle (ORC) is used for the electrical power generation. The thermal water (maximal flow rate 100 m³/h) enters the ORC-system with a temperature of 98 °C and is cooled down to 72 °C. For the thermodynamic realisation at these low temperatures perfluoropentan gas (C5F12) is used, which starts boiling at 31 °C at normal pressure (Kranz 2003).

3.2 Centralised Installations for Direct Use

At present, 140 geothermal installations for direct use of geothermal energy are operating in Germany (Fig. 4 and Table 2). The installations comprise centralised heating units (district heating), space heating in some cases combined with greenhouses, and thermal spas. The total thermal capacity installed is 177 MW$_t$ and the annual utilization amounts to roughly 523 GWh/a (Table 2) or 1883 TJ/a. Fluid temperature in all of them is below 110 °C.

Under the prevailing economic and political conditions, multiple uses or cascades can help to improve the economic efficiency of direct use of geothermal heat. For this reason many installations combine district or space heating with greenhouses and thermal spas.

The eight biggest geothermal units with an installed capacity of about 124 MW$_t$ (Table 3) are located in the North German and in the Molasse Basin. Many installations for power production combined with district heating are under construction in the Rhine Graben and the Molasse Basin (Fig. 5). These regions have the most favourable conditions in terms of geothermal potentials, temperature and achievable flow rates in Germany (Haenel and Staroste 1988, Hurter and Haenel 2002).

Reg.	Aquifer	A km²	T_t °C	Resources 10^{18} J	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

Table 1: Resources of Germany (Schellschmidt et al. 2002).

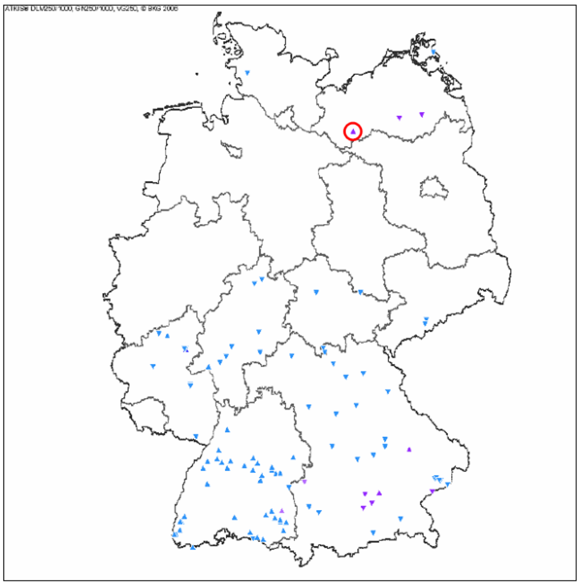

Figure 4: Operating installations for geothermal energy use in Germany (www.geotis.de). Red circle: power plant at Neustadt-Glewe.

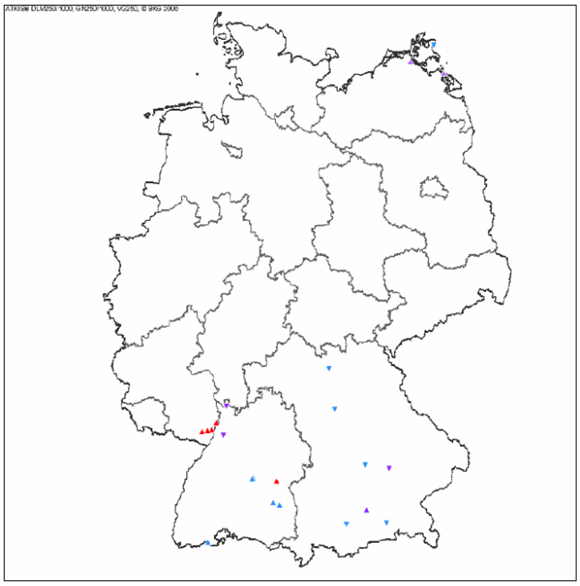

Figure 5: Installations under construction for geothermal energy use in Germany. Red (major use): power plants (www.geotis.de).

major use	number of installations	capacity total MWt	capacity geothermal MWt	annual use GWh/a
district heating	9	137.1	52.1	202.0
space heating	2	1.2	1.2	0.8
thermal spa	129	39.0	39.0	320.6
greenhouse	-	-	-	-
total	140	177.3	92.3	523.4

Table 2: Installed total and geothermal capacity and annual utilization.

location	basin	capacity total MWt	capacity geothermal MWt	annual use GWh/a
Unterschleißheim	M		12.9	28.3
München Riem	M	20.0	8.0	43.8
Erding	M	18.0	8.0	28.0
Simbach-Braunau	M	40.0	7.0	67.0
Neustadt-Glewe	NG	17.0	7.0	11.8
Straubing	M	5.4	4.1	11.8
Neubrandenburg	NG	13.8	3.8	8.3
Waren (Müritz)	NG	10.0	1.3	2.9
total		124.2	52.1	201.9

Table 3: The eight biggest geothermal units are located in the North German (NG) and in the Molasse Basin (M).

3.3 Small Decentralised Units for Direct Use

Geothermal energy use for space heating in small decentralised units is widespread in Germany, and experience in that technology dates back to the 1970s. The market introduction of ground source heat pumps in larger scale began in the mid 1990s, and was backed by support programs from utilities and from the federal government. Depending on local conditions these units consist of ground coupled heat pumps (horizontal heat collectors, vertical heat exchangers), or groundwater heat pumps.

The exact number of units presently installed in Germany is unknown since no national statistics are available. However, based on the number of heat pump sales in Germany, an estimation can be undertaken. According to sales statistics (BWP 2007) about 28,600 small decentralised unites have been newly installed in 2006, a doubling of sales compared to the previous year (Fig. 6). The mean installed geothermal power of each of these units typically varies from 8-15 kW_t, with an average of about 10-12 kW_t.

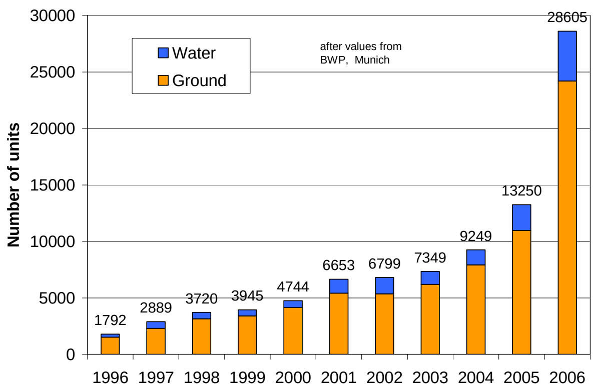

Figure 6: Annual number of new ground source heat pump units since 1996 (data from BWP 2007).

For the end of the year 2004, ca. 30’000 units with a total of 400 MW_t installed capacity had been reported by Schellschmidt et al. (2005). With the substantial increase in 2005 and 2006, almost 42’000 new units have been installed. Considering a replacement of older heat pumps, and abandonment of old plants, with a total of ca. 10 % of the new units, a conservative estimate of the increase can be given with 37’500 units, producing 350-420 MW_t.

Thus by the end of the year 2006, in Germany ca. 65’000 ground source heat pumps have been operational, supplying 740-810 MW_t of heating. With an average seasonal performance factor (ß) of 3 to 4, the pure geothermal contribution in small size decentralised units is equal to 500-600 MW_t. Thus, in decentralised units about three times more pure geothermal output is installed than in the centralised installations. The annual heat delivery of ground source heat pumps can be estimated, with a typical average of 1500 annual full load hours, to 1160 GWh/a (4180 TJ/a); this means, with the same seasonal performance factor as above, a geothermal heat contribution of 780-870 GWh/a (2800-3130 TJ/a).

4. PERSPECTIVE OF THE USE OF GEOTHERMAL ENERGY

A new, conservative estimate of the total thermal power currently installed for direct use of geothermal energy in Germany amounts to roughly 952 MW_t. The pure geothermal part of this sum amounts to 642 MW_t or 67 %. About one fifth is provided by large centralised installations and four fifth comes from the small decentralised units.

The final energy consumption in Germany in 2006 was 9288 PJ (1 PJ = 10^{15} J) (BMWA 2007). A breakdown in Fig. 7 shows that 58% of the final energy consumption was required for space-heating, hot water, or process heat (BMWA 2007). Most of this demand is at present supplied by fossil fuel. 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.

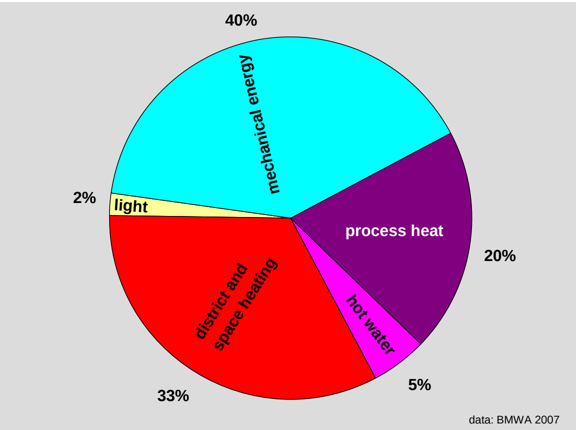

Figure 7: Final energy consumption in Germany according to usage (data from BMWA 2007). Distribution shown is for Germany in 2005. Final energy consumption in Germany was 9288 PJ in 2005.

According to Kayser (1999) the potential demand for geothermal heat from centralized geothermal units in Germany amounts to 1165 PJ a^{-1}. This would correspond to an installed thermal capacity of 36,917 MW_t. Kaltschmitt et al. (1995) assessed the potential demand for geothermal energy from ground coupled and groundwater heat pumps to 960 PJ a^{-1}, corresponding to an installed capacity of about 30,420 MW_t. The total potential demand for the direct use of geothermal energy in Germany is therefore 2125 PJ a^{-1} corresponding to 67,337 MW_t. This corresponds to 23 % of the 2006 German final energy consumption of 9456 PJ.

Thus, a good fifth of the final energy consumption in Germany could be supplied by the direct use of geothermal energy. However, at present only about 0.7 ‰ of the potential demand is covered by geothermal heat.

A revised edition of the Renewable Energy Act (Erneuerbare Energien Gesetz, EEG) came into force in August 2004. There is now a real chance for planning and installing geothermal power plants on a sound economic basis. The increase of remuneration for the feed-in allowance from 0.089 to 0.15 €/kWh (Table 4) for electricity produced from geothermal energy since August 2004 will presumably stimulate the build-up of a geothermal power industry in Germany and will open up new opportunities for geosciences and for the drilling and service industry.

renewable energy plant capacity (Mwe)	remuneration in Euro-Cent / kWh			
	≤ 5	5 - 10	10 - 20	> 20
geothermal	15.00	14.00	8.95	7.16
hydro	6.65 - 9.67	6.65	6.10	3.70 - 4.56
biomass	8.90 - 11.50	8.40	8.40	8.40
wind (onshore)	independent of plant capacity 5.50 - 8.70			
wind (offshore)	independent of plant capacity 6.19			
solar	54.00 - 57.40	---	---	---

Table 4: The new remunerations for power production by renewable energy sources are valid since August 2004.

The positive effect of the new Renewable Energy Act has been further enhanced by financial support of pilot and demonstration projects by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU).

The Leibniz Institute for Applied Geosciences (GGA-Institut) is setting up an internet based information system on geothermal resources (Schulz et al. 2007) in close collaboration with partners. For a start, the geothermal information system will contain data about hydrogeothermal resources only. The project aims at an improvement of quality in the planning of geothermal plants and at a minimization of exploration risks. The key parameters for this purpose are production rate (Q) and temperature (T). The basis for the estimation of subsurface hydraulic properties comes from the information system on hydrocarbons. This information system provides permeability and porosity values derived from the analyses of drilling cores (Fig. 8, Schulz et al. 2007). The IT targets will be realised by a relational database providing all data relevant to the project. A 3D model of the ground provides the basis for visualisation and calculation of geothermal resources. As a prototype, a data-recall facility of geothermal sites in Germany is available online.

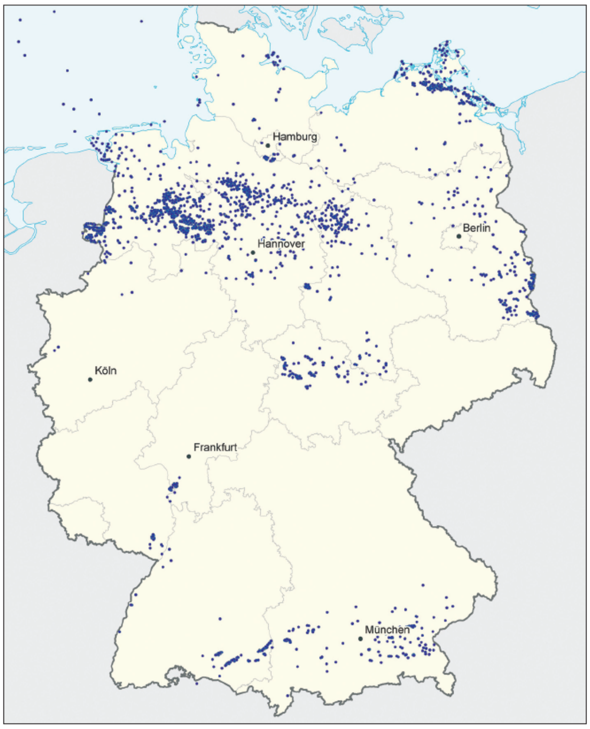

Figure 8: Locations of boreholes with core analysis from oil and gas companies (Fachinformationssystem Kohlenwasserstoffe, LBEG).

The project is funded by the BMU with funding number 0327542. It started in January 2006. The information is scheduled to be online by the end of 2008. Information on the status of the work is available from the GGA Institute website (www.gga-hannover.de). The project pages in particular (http://www.geotis.de) provide up-to-date information such as progress reports, meeting presentations and the first application.

6. CONCLUSIONS

Due to the moderate temperature gradients persisting in most parts of Germany geothermal energy use is still on a comparatively low level. The installed capacity for geothermal heat is about 950 MW_t. 80 % of which is attributed to about 65’000 decentralized units using heat from shallow depth. The remaining 20 % is attributed to 140 centralized installations exploiting mainly deep-seated aquifers. The first German geothermal power plant has just started operation with an installed capacity of 230 kW_e.

It is expected that the only moderate increase of the installed capacity will be accelerated during the next years by the implementation of the Renewable Energy Act and by other programs giving direct financial support.

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Appendix: Examples of largest ground source heat pump plants in Germany (status end of 2006):

City / project name	inst. capacity, kW_{th}	ground system	total BHE
Golm near Potsdam, MPI	ca. 800	160 BHE each 100 m deep, HP	16’000 m
Langen, DFS	330 (H) / 340 (C)	154 BHE each 70 m deep, HP	10’780 m
Gelnhausen, MK-Forum	ca. 400	ca. 80 BHE each 100 m deep, HP	8’000 m
Kornwestheim, Panalpina	600	60 BHE each 100 m deep, HP	6’000 m
Donaueschingen, bank	110 (H) / 250 (C)	56 BHE each 90-100 m deep, HP	5’320 m
Fulda, bank „Sparkasse“	<300	49 BHE each 98 m deep, HP	4’802 m
Minden, WAGO	100 (H) / 120 (C)	44 BHE each 100 m deep, HP	4’400 m
Wetzlar, Philips APM	290 (H) / 145 (C)	32 BHE each 110 m deep, HP	3’520 m
Usingen-Eschbach, school	190	32 BHE each 100 m deep, HP	3’200 m
Güstrow, Umweltzentrum	270	60 BHE each 50 m deep, HP	3’000 m
Emden, Kunsthalle	155 (H) / 200 (C)	11 BHE each 250 m deep, HP	2’750 m
Düsseldorf-Lichtenbroich	120 (H) / ca. 40 (C)	73 BHE (steel) each 35 m deep, HP	2’555 m
Todtmoos, Hotel	180	10 BHE each 250 m deep, HP	2’500 m
Crailsheim, office	140 (H) / 116 (C)	30 BHE each 74-90 m deep, HP	2’460 m
Rendsburg, ZET	110 (H) / 87 (C)	24 BHE each 100 m deep, HP	2’400 m
Kaiseresch, TGZ	ca. 100 (?)	32 BHE each 75 m deep, HP	2’400 m
Rostock, library (Univ.)	60 (H) / 120 (C)	28 BHE each 80 m deep, HP	2’240 m
Kochel	210	21 BHE each 98 m deep, HP	2’058 m
Gladbeck-Wiesenbusch	280 (H) / 180 (C)	32 BHE each 60 m deep, addit. horiz. loop, HP	1’920 m
Frankfurt-Höchst	240	32 BHE each 50 m deep, HP	1’600 m
Kolbermoor, office	ca. 100	13 BHE each average 122 m deep, HP	1’586 m
Bonn, fed. office for nature	125 (H) / 110 (C)	16 BHE each 85 m deep, HP	1’360 m
Bietigheim, industry shed	100 (H) / 70 (C)	10 BHE each 100 m deep, HP	1’000 m
Geothermal residential districts:			
Werne	ca. 700	134 houses x 1 BHE 100-150 m deep, HP	16’750 m
Dortmund-Mengede	ca. 500	98 houses x 1 BHE 100-150 m deep, HP	12’250 m
Stutensee	ca. 550	79 houses x 1 BHE 77-123 m deep, HP	7’900 m
Gütersloh	ca. 150	24 houses x 1 BHE 90 m deep, HP	2’160 m

H: Heating   C: Cooling   BHE: Borehole Heat Exchanger   HP: Heat Pump