Geothermal Energy Use, Country Update for 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 336.6 MW_t (geothermal share) and 720.1 MW_t (total, including peak load capacity, etc.) with a heat production of 1,099.0 GWh_t (geothermal) and 1,259.9 GWh_t (total), respectively. 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 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 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 deep hydrothermal aquifers as well as potential petrothermal resources. The GeotIS project aims at an improvement of quality in the planning of geothermal projects and at the minimisation of exploration risks.

In addition to installations using “deep” geothermal energy numerous small- and medium-sized decentralised geothermal heat pump units are in use for heating and cooling of individual houses and office buildings (ground coupled heat pumps and groundwater heat pumps). Their total installed capacity (including electrical energy consumed) reached 3,900 MW_t in 2015 with a geothermal (renewable share) heat production of about 5,700 GWh_t. 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.

Binary power plant technologies like organic Rankine and Kalina cycle allow electricity production at temperatures down to 100 °C. This circumstance, combined with feed-in tariffs, makes geothermal power production economically feasible even for countries like Germany, lacking high enthalpy resources at shallow depth. With the commissioning of the 4.3 MW_e power plant at Grünwald/Laufzorn at the end of 2014, the installed geothermal electrical capacity in Germany reached 34.5 MW_e and a geothermal power production of 151,05 GWh_e in 2015.

Besides supporting R&D projects, the Federal Government of Germany incentivizes new projects with the above mentioned 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. 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.

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 (Kalina cycle or ORC). 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 potential.

At present, 27 plants for district heating and/or power generation are 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 potential 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 AND POTENTIAL

The potential for geothermal power production and heat use in Germany was 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 2.3) (Agemar et al. 2014). The system provides information and data compilations on deep aquifers relevant for geothermal exploitation. Furthermore, maps and data compilations of regions with hydrothermal potential and with suitability for enhanced geothermal systems (EGS) were published by Suchi et al. (2014) in their study about competing use of the subsurface for geothermal energy and CO_2 storage. The resulting maps are also available in GeotIS.

Although a great theoretical potential for geothermal power generation is attributed to EGS (Paschen et al. 2003), project development to date is limited to hydrothermal resources. The most important geologic systems including such resources in Germany are the North German Basin, the South German Molasse Basin, and the Upper Rhine Graben (Fig. 1).

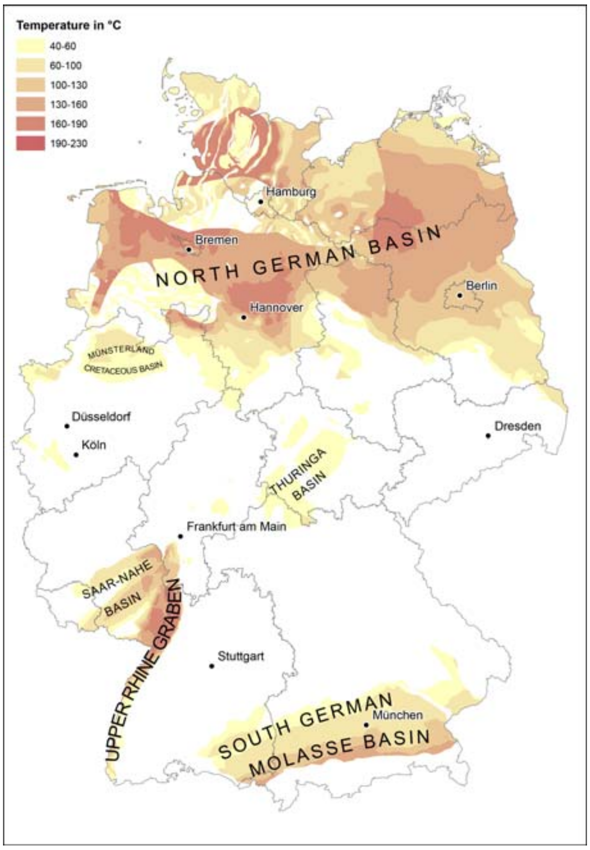

Figure 1: Regions with hydrothermal resources in Germany (proven and supposed) and associated temperature ranges (map adapted from Suchi et al. 2014).

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. Halokinetic 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 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 (Figure 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).

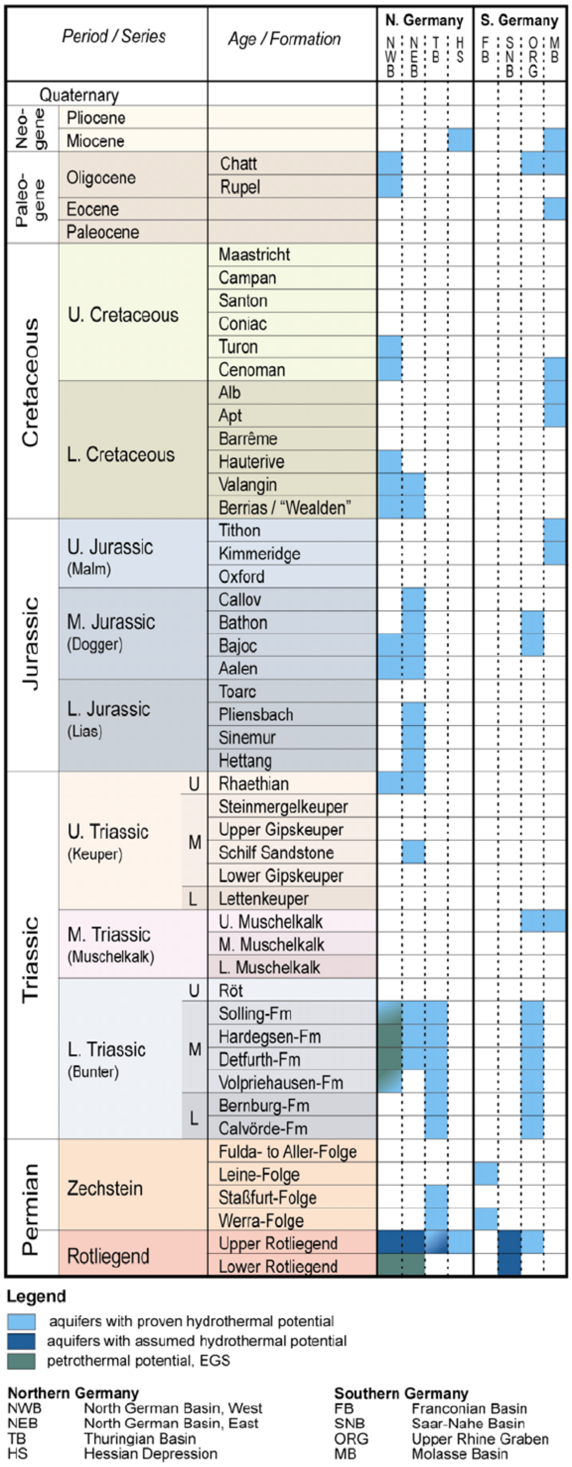

Figure 2: Stratigraphic units of interest for deep geothermal energy use (table adapted from Suchi et al. (2014), data for CO_2 storage omitted).

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.

Besides the Malm aquifer, further sedimentary layers were identified as possible 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 structural discontinuities. Crustal extension in the Tertiary 45-60 Ma ago formed depocenters along a pre-existing WSW-ENE 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 stress results in extensional tectonics with a maximum vertical offset of 4.8 km. The graben evolution from Oligocene on was complex ranging from dextral strike-slip to partial uplift, subsidence and finally sinistral strike-slip from Pliocene on up to date (Schumacher 2002).

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

2.2 Potential for power generation

Organic Rankine and Kalina cycle techniques allow electricity production at moderate temperatures and make geothermal power production feasible even in countries like Germany lacking high enthalpy resources at shallow depth. While a fluid temperature of less than 100 °C is frequently referred to as the minimum temperature for power production (Paschen et al. 2003), experiences from plants in operation in Germany showed that for a stable, economically feasible power generation the temperature should exceed 115 °C.

Favourable conditions for geothermal power generation from hydrothermal resources, often in combination with fault zones, are found in the Upper Rhine Graben and in the South of the Molasse Basin where the Malm reaches the necessary temperature. The Neustadt-Glewe plant which uses a Rhaethian sandstone aquifer in the North German Basin proved that geothermal power production is technically possible even at fluid temperatures around 100 °C (Seibt et al. 2005). However, the 0.2 MW_e ORC turbine was dismantled in 2012 due to economic reasons.

Besides the current use of hydrothermal reservoirs, a large potential for geothermal power generation in Germany is attached to EGS in tight rock and fault zones. The theoretical electrical energy was estimated by Jung et al. (2002) to 10 EJ for hot water aquifers, to 45 EJ for deep-reaching fault zones, and to 1,100 EJ for crystalline rock. In comparison to these potentials the final energy consumption for electricity in Germany in 2014 was approximately 1.8 EJ (BMWi 2016a). To produce at least parts of this huge potential, further research and development is required, especially in exploring and utilising heat from fault zones and tight e.g. crystalline rocks.

2.3 Internet Based Information System (GeotIS)

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 of planning geothermal plants, the Leibniz Institute for Applied Geophysics (LIAG) has developed a geothermal information system (GeotIS) (Agemar et al. 2014a), funded by the German Government. LIAG realized the project in close collaboration with several partners. 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 geothermal potentials 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.

Currently, geothermal power plays only a marginal role in the German electricity market (BMWi 2016b). Although the development of geothermal electricity in Germany is rather slow, the new plants in Dürrnhaar, Insheim, Kirchstockach, Sauerlach, and Grünwald/Laufzorn as well as several power plants presently under construction will lead to a further increase of geothermal power generation over the next years.

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 more than 60 % of the deep geothermal heat production, with an upward tendency.

Numerous geothermal heat pumps for heating and cooling office buildings and private houses 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 325,000 at the end of 2015.

3.1 Geothermal Power Production

With the commissioning of the 4.3 MW_e plant in Grünwald/Laufzorn close to Munich in the South German Molasse Basin in November 2014, geothermal power in Germany reached an installed capacity of 34.5 MW_e at the end of 2015 (Table B). Electricity production amounted to 151.05 GWh in 2015, almost doubling the power production in 2014 (79.96 GWh).

Two more geothermal plants near Munich are about to start power production in the first half of 2016. The 5.5 MW_e ORC plant in Traunreut already went into a 4-week-long test phase in March 2016 and the commissioning of the 4.3 MW_e Kalina plant in Taufkirchen is scheduled for the first quarter of 2016 (Table B).

Therefore, the installed capacity for geothermal power production already increased to 44.3 MW_e at the beginning of 2016.

Figure 3: Installations for geothermal energy use in operation in Germany (from GeotIS 2016).

3.2 Centralised Installations for Direct Use

Common deep geothermal utilisations using thermal water with temperatures above 20 °C from wells deeper than 400 m are district heating plants or combined heat and power plants (CHP), thermal spas, and space heating. At present, 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).

In 2015, the total installed capacity, which includes auxiliary heat sources such as peak load boilers in addition to the geothermal source, reached about 720.1 MW_t with a geothermal share of 336.6 MW_t. The 23 district heating and combined plants accounted for the largest portion of the geothermal capacity with about 285 MW_t. Altogether, the installed capacity of deep geothermal heat use in Germany shows a considerable increase from about 160 MW_t in 2010 to 336.6 MW_t in 2015. Heat production by deep geothermal utilisation rose from 716 GWh_t in 2010 to 1,099.0 GWh_t in 2015 (GeotIS 2016).

Development of direct heat use from geothermal energy also continues in 2016 as for example in Unterföhring. After drilling a second well doublet in 2014, the extended energy station was commissioned in February 2016. For the first time in Germany an existing geothermal plant has been expanded and a geothermal field has been further developed by two more wells, leading to an increase of geothermal capacity from 10 to 22 MW_t.

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 differential heat between subsurface and ambient temperature as 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 capacities of heat pumps used in residential houses are about 10 kW_t for brine/water and about 14 kW_t for water/water systems (GZB 2010). Heat pump systems in office buildings reach capacities of several 100 kWt, usually with additional cooling supply in warm seasons. While heating requirement is decreasing due to improved insulation, the need for cooling is often increasing. Buildings like supermarkets, cinemas and shopping malls can have a much higher annual cooling demand than heating demand even in a moderate climate like in Germany. As a result, the limiting design factor for the ground source installation here is the prevention of heating up the underground, instead of the past long-term problem of cooling down the underground in heating-only installations.

The largest German ground-source heat pump installation known today is operational since 2013 for an IKEA market in Lübeck-Dänischburg in the North of the country. The ground system consists of 215 borehole heat exchangers each 150 m deep, resulting in >32 km total borehole length. A list of large installations is given in table 1. The development of very large installations started around 2000, and after a hiatus of a few years, new large plants (and borehole metres) were added steadily since 2008 (Fig. 4).

The total number of heat pumps (brine/water, water/water and air/water systems) reached about 665,000 in 2015 (BMWi according to AGEE-stat 2016c). The number of geothermal systems reached about 325,000 at the end of 2015. However, sales figures have decreased in the last seven years (Fig. 5). Brine/water systems are the most common installation with a share of about 85 % of the geothermal heat pumps.

Market figures of the German Heat Pump Association (BWP 2016) 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 30 % in 2015 (Fig. 5).

According to the German Heat Pump Association, the reasons for the decreasing interest in ground source heat pumps are various:

- high cost for drilling, partly by means of imposed official requirements for geothermal boreholes,
- lower cost for installation of air source units and low prices of imported air-source heat pumps, and
- complicated approval practices.

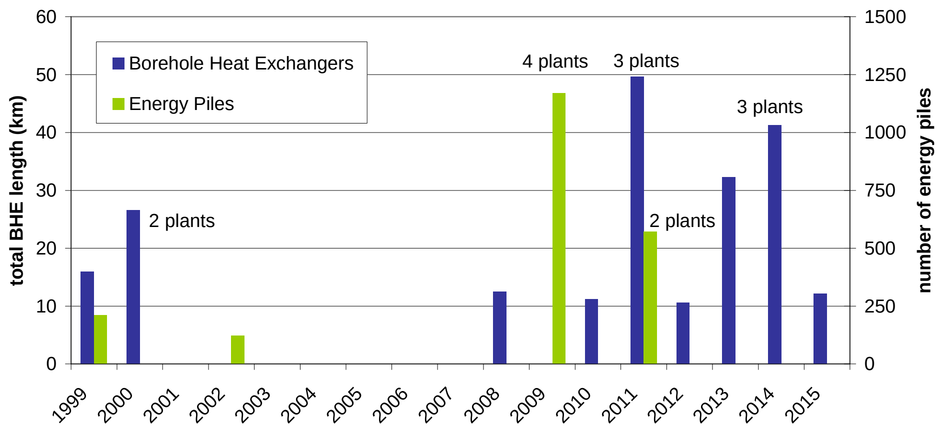

Figure 4: Construction of very large geothermal heat pump plants in Germany (more than 10 km BHE, and for energy piles more than 350 kW system capacity).

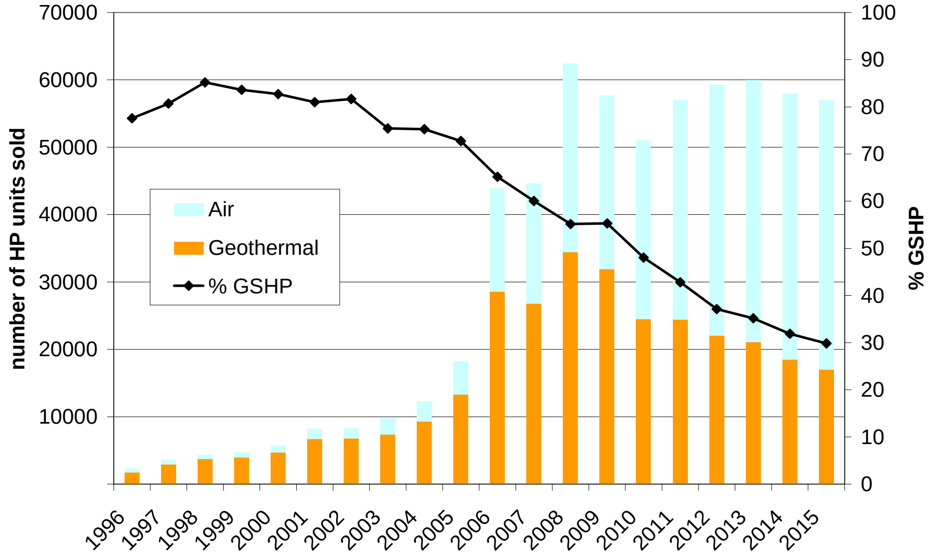

Figure 5: Development of sales for ground source (geothermal) and air source heat pumps in Germany (after annual data from BWP, latest BWP 2016).

Table 1: Very large shallow geothermal plants in Germany (list probably not exhaustive)

Plants using borehole heat exchangers (BHE), with more than 10 km total BHE length

City, Name	No. BHE	Depth BHE (m)	Total BHE (m)	Year
Lübeck, IKEA Dänischburg	215	150	32250	2013
Duisburg, ZBBW	180	130	23400	2011
Hagen, Rathausgalerie	94	200	18800	2014
Golm near Potsdam, MPG	160	100	16000	1999
Neckarsulm, Quartier Amorbach (BTES)	528	30	15840	2001
Freiburg i.Br., Quartier Unterlinden	108	125	13500	2011
Altensteig, Boysen Factory Turmfeld	98	130	12740	2011
Stuttgart, EnBW City offices	96	130	12480	2008
Nürnberg, DATEV IT-Center	156	78	12168	2015
Frankfurt, Henninger-Turm	121	100	12100	2014
Leinfelden-Echertdingen, Humboldt Carré	80	140	11200	2010
Langen, DFS	154	70	10780	2001
Dortmund, AOK Nord-West	107	99	10593	2012
Biebergemünd, Engelbert Strauss	110	94	10340	2014

Plants using energy piles, with more than 350 kW thermal capacity

City, Name	Number of energy piles	Capacity (kW)	Year
Frankfurt, Palais Quartier	390	900	2009
Friedrichshafen, ZF Research	315	600	2009
Offenbach, Kaufhaus Komm	146	600	2009
Munich, ADAC Headquarters	391	550	2011
Frankfurt, Maintower	210	500	1999
Berlin, Airport Berlin-Schönefeld	318	400	2009
Hannover, NL Bank	122	350	2002
Hamburg, Spiegel (Ericusspitze)	180 (+ 70 BHE, each 55 m)	?	2011

Plants using groundwater wells, with more than 400 kW thermal capacity

City, Name	No. Wells	Depth Wells (m)	Capacity (kW)	Year
Bonn, Bonner Bogen	3 + 3	28	920 (H) / 620 (C)	2009
Regensburg, Continental factory	2 + 2	45-70	840 (H) / 1500 (C)	2006
Munich, Dywidag	several		840 (H) / 500 (C)	2001
Bonn, BonnVisio	2 + 2	11	600 (H) / 550 (C)	2004
Frankfurt/M, WestendDuo	2 + 3	140	400 (H/C)	2005

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:

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

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

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:

$$Q_{usable} = H_{HP} \cdot P_{rated} \quad [2]$$

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

Also default values for H_{HP} and SPF are given in Decision 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 (a rather low value for Germany).

Since the EU encourages improvements of these values, the following calculation is based on 1,950 full-load hours per year (H_{HP}) and a SPF of 4.0, which are more realistic specifications for Germany. The capacity of all small heat pumps installed (P_{rated}) was estimated at 3,900 MW_t, assuming an average capacity of 12 kW_t for the 325,000 ground source heat pumps operating in 2015. According to equation [2], Q_{usable} is calculated as follows:

$$Q_{usable} = 1,950 \, {}^{h}\!/_{a} \cdot 3,900 \, MW_t = 7,605 \, GWh \quad [3]$$

The pure geothermal contribution from ground source heat pump systems in Germany can then be calculated according to formula [1]:

$$E_{RES} = 7,605 \, {}^{GWh}\!/_{a} \cdot \left(1 - \frac{1}{4}\right) = 5,704 \, {}^{GWh}\!/_{a} \quad [4]$$

4. GOVERNMENTAL SUPPORT

4.1 Energy Market and the Role of Geothermal

According to BMWi (2016a), the final energy consumption in Germany in 2014 was 8,648 PJ (1 PJ = 10^{15} J). A breakdown in figure 7 shows that 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.

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).

In the field of geothermal R&D, the Federal Ministry for Economic Affairs and Energy (BMWi) has granted funding for 21 new projects with a total volume of 17.3 million Euros in 2015 (2014: 15 new projects and 12.7 million Euros). Furthermore, the financing of running projects was 11.6 million € in 2015 compared to 15.6 million € in 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. This also includes the creation of concepts for public relations activities and the development of geothermal energy in unexploited or rather unsuitable regions.

The GRAME project of the Stadtwerke München (Munich municipal energy supplier) and associated LIAG's GeoParaMol project, for example, are being funded by the BMWi with a budget of about 4.6 million Euros. The project which started in 2015 includes a large-scale urban 3D seismic exploration within the city of Munich in order to verify suitable locations for 20 geothermal well doublets. This is an important step towards Munich's goal to supply the heat for the city from renewable energies until 2040.

Apart from funding R&D projects, the Federal Government created incentives for new projects by offering a feed-in tariff for geothermal electricity und 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.

A much better support tool for geothermal heat pumps today is the incentive program MAP. This program basically exists since the late 1990s, but has experienced some quite drastic changes of rules. Around the year 2000 it helped to get the geothermal heat pump market going (cf. Fig. 5). Political reservations against "electric heating" through heat pumps resulted in changes to the MAP which rendered it almost useless for heat pumps in the first decade of the new Millennium. The main blow came with the EEWärmeG coming into force in 2009, when heat pump in new buildings were no longer supported, as they were covered in the obligations under that act. Luckily, in April 2015 the rules changed for the better, and the amount of support was increased substantially. Private home owners can claim a grant for a geothermal heat pump of a minimum 4000 € (4500 € when using borehole heat exchangers and contracting a certified driller). The support increases by 100 € per kW heating capacity above the threshold of 40 kW, up to a maximum capacity of 100 kW. The positive effect of the new rules can clearly be seen in the number of applications (Fig. 6), which increased drastically from April 2015 on.

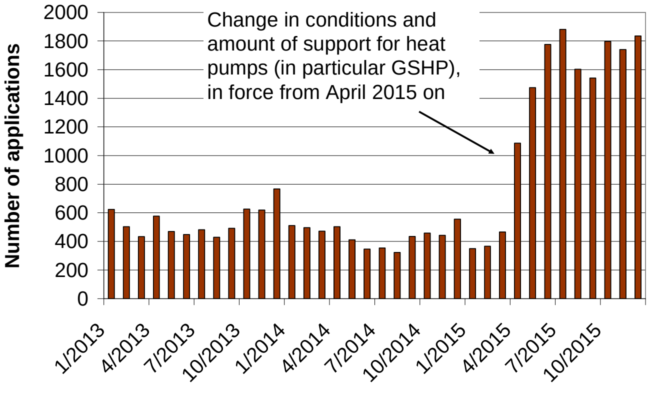

Figure 6: Monthly number of applications for MAP-support for heat pumps (all heat pumps considered), after data from BAFA.

5. OUTLOOK

The envisioned geothermal power generation of 50 MW_e in Germany was not achieved in 2015 since the activity of geothermal project development decreased significantly from 2013 on. Main reason was a dry well in the Molasse Basin (Geretsried) in 2013 and the associated exit of the insurance industry from geothermal projects. This situation indicates still further necessity in applied research to support geothermal development and technology in Germany. The above mentioned dry well in Geretsried turned into a R&D project under the scientific lead of the LIAG. More drilling activities in 2016 in Bavaria, Hesse, and Northern Germany signify a revival of deep hydrothermal development in Germany. Supposedly, the 50 MW_e milestone in geothermal power generation could be achieved in 2018.

A significant change in the geothermal energy market might have been induced by the new engagement of Enel Green Power in the German geothermal industry with the prospect Weilheim in the Bavarian Molasse basin. While small scale companies have lead the geothermal development in Germany, Enel is now the first large scale company interested in the German geothermal market and its development.

Key to the recognition and allocation of geothermal projects is the Geothermal Information System of Germany, GeotIS. Further development and continuous improvement of the data base is required and ongoing. One of the major improvements will be the integration of the estimated geothermal potential of the large scale fault systems in Germany.

It is noteworthy, that 56 % of Germany's final energy consumption is attributed to the supply of district and space heating, hot water, process heat, and cooling (Fig. 7). In 2014, only 12.0 % of this share was covered by renewable energies with an increase of only 0.9 % since 2010. Therefore it is necessary to put a stronger focus on the development of the heat market in order to reach Germany's goal to cover 14 % of the energy needed for heating and cooling by renewable energies until 2020.

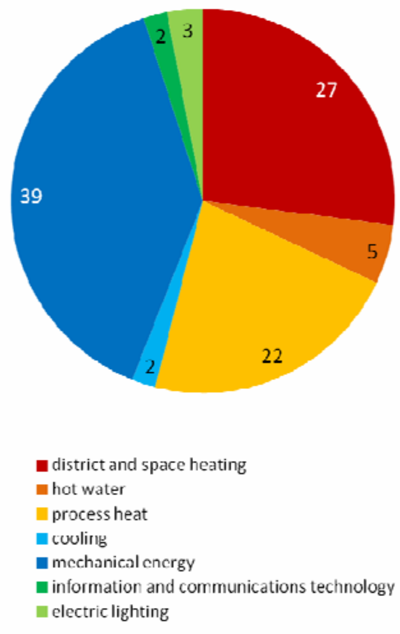

Figure 7: Share of different applications in the final energy consumption in Germany which amounted to 2,402 TWh (8,648 PJ) in 2014 (data BMWi 2016a)

Due to its huge potential as well as its constant availability and related base load capability, geothermal energy could easily close the gap between the actual status and the climate protection goals.

But in order to stimulate the development of geothermal heat utilisation, financing measures like for example the WärmeEEG and the MAP have to be revised in favour of geothermal energy.

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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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 2015	31.4	151.05	202,500*	647,000	0.00016	0.00023
Under construction end of 2015	9.8					
Total projected by 2018	50					
Total expected by 2020						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2015 (indicate exploration/exploitation, if applicable):						

* 2014 numbers (BMWi 2016a)

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)	2015 pro-duction (GWh_e/y)
Bruchsal	Bruchsal	2010	1 (RI)	N	B-Kal	0.55	0.44	0
Dürrnhaar	Dürrnhaar	2012	1 (RI)	O	B-ORC	7	7	30.5
Grünwald	Laufzorn	2014	1 (RI)	O	B-ORC	4.3	4.3	10.65
Insheim	Insheim	2012	1 (RI)	O	B-ORC	4.3	4.3	42.894
Kirchstockach	Kirchstockach	2013	1 (RI)	O	B-ORC	7	7	31.5
Landau	Landau	2007	1 (RI)	N	B-ORC	3	0	0
Neustadt-Glewe	Neustadt-Glewe	2003	-	R (2010)	-	-	-	-
Sauerlach	Sauerlach	2013	1 (RI)	O	B-ORC	5	5	28.171
Simbach-Braunau	Simbach-Braunau	2009	-	R (2012)	-	-	-	-
Taufkirchen	Taufkirchen	2016	1 (RI)		B-Kal	(4.3)#	(4.3)#	-
Traunreut	Traunreut	2016	1 (RI)	O	B-ORC	(5.5)#	(5.5)#	-
Unterhaching	Unterhaching	2009	1 (RI)	O	B-Kal	3.36	3.36	7.33
total						34.51 (44.31)#	31.4 (41.2)#	151.05

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

* RI: plant applies re-injection

\# Numbers in brackets indicate new development in 2016. These numbers are not included in the total sum of installed and running capacity for the reporting year 2015.

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

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for individual buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th}) total[a] geothermal[b]	Production (GWh_{th}/yr) total[a] geothermal[b]	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 2015	662.37[a] 284.98[b]	847.439[a] 689.557[b]			3.3	9.47	48.3 est.	400 est.
Under construction end 2015								
Total projected by 2018								
Total expected by 2020								

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})	2015 production (GWh_{th}/y) total[a] geothermal[b]	Geoth. share in total prod. (%)
Aschheim	Aschheim	2009	N	N (RI)	9.8	29	74.28[a] 50.20[b]	67.6
Bruchsal	Bruchsal	2010	Y	N (RI)	5.5	na	0	na
Erding	Erding	1998	N	N (RI)	10.2	48.8	97.567[a] 29.067[b]	29.8
Garching	Garching	2012	N	N (RI)	7.95	27.95	34.4[a] 26.0[b]	75.6
Grünwald	Laufzorn	2011	Y	N	40	69	60.4[a] 59.58[b]	98.6
Ismaning	Ismaning	2013	N	N (RI)	7.2	22	35.5[a] 27.3[b]	76.9
Kirchweidach	Kirchweidach	2013	N	N (RI)	12	na	48.5[b]	na
Landau	Landau	2011	Y	N (RI)	5	33	0	na
München Riem	München Riem	2006	N	N (RI)	13	45	71.165[a] 64.226[b]	90.3
Neustadt-Glewe	Neustadt-Glewe	1994	N	N (RI)	4	14	21.282[a] 18.332[b]	86.1

Table D1 continued

Poing	Poing	2012	N	N (RI)	8-10	38-40	44.042[a] 33.554[b]	76.2
Prenzlau	Prenzlau	1994	N	N (BHE)	0.15*	0.5*	2.9[a]* 0.37[b]*	na
Pullach	Pullach	2005	N	N (RI)	15.5	32.5	53.0[a] 51.1[b]	96.4
Sauerlach	Sauerlach	2013	Y	N	4	4	4.744[b]	na
Simbach-Braunau	Simbach-Braunau	2001	N	N (RI)	9	44.1	46.752[b]	na
Straubing	Straubing	1996	N	N (RI)	2.1*	7.3*	2.9[b]*	na
Taufkirchen	Taufkirchen	2015	Y	N (RI)	35	35	na	
Traunreut	Traunreut	2015	Y	N (RI)	12	12	31[a] 31[b]	100
Unterföhring	Unterföhring	2009	N	Y (RI)	10	30	49[a] 49[b]	100
Unterföhring II	Unterföhring II	2015	N	N (RI)	11.3	33.3	0	na
Unterhaching	Unterhaching	2007	Y	N (RI)	38	85	85.947[a] 85.947[b]	100
Unterschleißheim	Unterschleißheim	2003	N	N (RI)	7.98	23.78	55.15[a] 38.86[b]	70.5
Waldkraiburg	Waldkraiburg	2012	N	N (RI)	15	16.4	19.73[b]*	na
Waren	Waren	1984	N	N (RI)	1.3	10.742	9.18[a] 2.395[b]	26
total					284.98	662.37	847.439[a#] 689.557[b#]	81.4

* 2014 numbers

** Combined heat and power use: Y for yes, N for no

*** Y (for yes) if cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), otherwise N (for no). RI: the plant applies re-injection.

\# If only one number for either total or geothermal production was available, the respective value was used for the calculation of the total sum for both total and geothermal production.

Table D2: Existing geothermal direct use other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 production (GWh_{th}/y)	Geoth. share in total prod. (%)
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	0.52	na
Weinheim	Miramar	2007	N (RI)	1.10	4	5.65*	na
various	152 thermal spas			48.3 est.	na	400 est.	
total				51.74	57.73#	409.47	na

* 2014 numbers

** Y (for yes) if cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), otherwise N (for no). RI: the plant applies re-injection.

\# If total capacity was not available, geothermal capacity was used for calculation of entire capacity.

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

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015	325,000	3,900	7,605 (total heat) 5,704 (geothermal)	17,000	204	
Projected total by 2018						

Table F: Investment and Employment in geothermal energy

	in 2015		Expected in 2018	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power		1,100* (for deep geothermal power and direct uses)		
Geothermal direct uses				
Shallow geothermal		16,100*		
total		**17,200***		

* 2014 numbers

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	yes	yes	
Financial Incentives – Investment			
Financial Incentives – Operation/Production	FIT		
Information activities – promotion for the public	yes	yes	yes
Information activities – geological information	yes (GeotIS)	yes (GeotIS)	yes
Education/Training – Academic	yes	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)