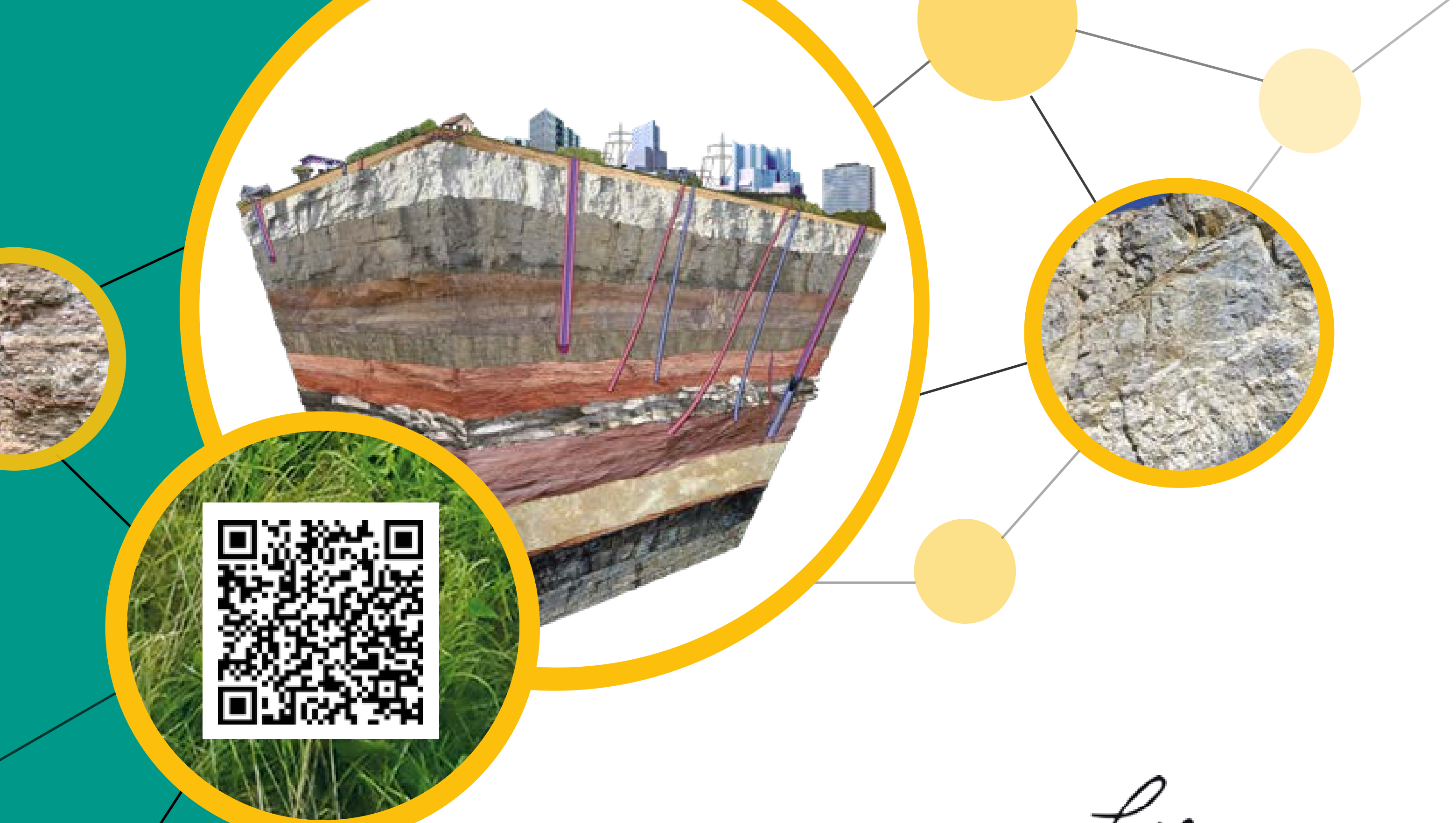
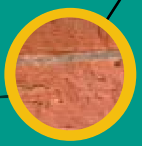
Leibniz Institute for Applied Geophysics

HEAT TRANSITION WITH GEOTHERMAL ENERGY

Chances and opportunities in Germany

Leibniz Association





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Cover photo

Example of sustainable heat supply in urban areas: geothermal heating plant Riem in Munich, operated by Stadtwerke München.

Production and injection well in the foreground, power station with integrated PV system in the background. In operation since 2004, the plant supplies environmentally friendly district heating for the Messestadt Riem (trade fair city) and the Neue Messe München.
Photo: I. Moeck

Leibniz Energiewende

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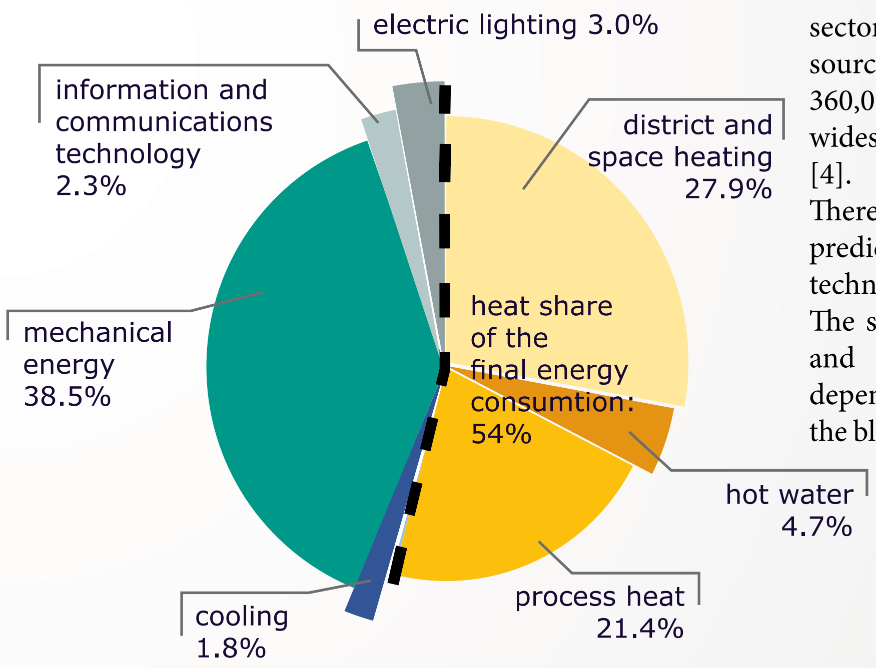
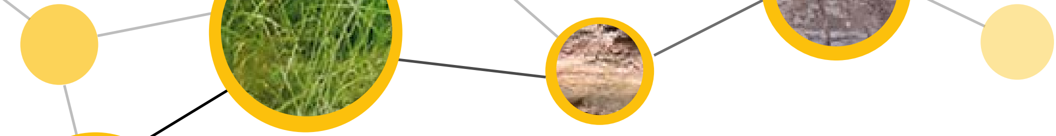
1. Energy consumption in Germany

The final energy consumption in Germany adds up to 9,151 petajoules (corresponding to 2,542 billion kilowatt hours) in 2016 [1]. More than the half accounts for the heat share with 54% (see figure below).
The German Renewable Energy Sources Act (EEG) stipulates that the share of renewable energies (RE share) in gross electricity consumption shall increase at least by 35% until 2020. This goal has already been achieved. In 2017, renewable energies accounted for 36.2% of gross electricity consumption, more than doubling their share since 2010 (17.0%) [2].
The situation is different for the share of renewable energies in heat consumption, although heat accounts for the greater part of final energy consumption in Germany. The RE share in the heat sector was 12.9% in 2017, and the target of 14% by 2020 cannot be achieved with the current activities focusing on renewable electricity. The increase of renewable heat was only 1.5 percentage points since 2010, and the RE share even fell by 0.3 percentage points compared to 2016 [2].
The RE share in both power and heat has therefore accounted for only 14.8% of gross final energy consumption in Germany [2].
At the moment biomass constitutes the largest contribution to renewable heat with almost 87%. However, due to its large demand for land and other influences on the environment, it has only limited potential for expansion.



In the case of geothermal energy, there is an enormous potential for expansion along with low land requirements. The geothermal gradient can be used in all scales resulting in a whole variety of geothermal applications. In many areas of heat generation fossil fuels such as coal, oil and natural gas can be substituted by geothermal energy. One example is the city of Munich, which aims to provide 100% of district heating from renewable energies by 2040 as the first German metropole.
Deep geothermal energy plays a key role in this visionary plan due to the favourable geological subsurface conditions. The expansion of geothermal heat grids enables a faster implementation of the heat transition than the energetic renovation of existing buildings [3].
Also for shallow and medium-deep geothermal resources, there is still a large growth potential through the utilisation of ground source heat pumps, especially for new buildings. Additionally, a lot of outdated heaters must be replaced in the private sector in the coming years. One solution are ground source heat pumps (GSHP). With already more than 360,000 installed systems in Germany, GSHP are a widespread, successful and affordable technology [4].
Therefore, heat pumps can be used for a reliable and predictable heat transition due to the market-ready technology not only for shallow but also larger depth. The strength of geothermal energy is its scalability and the wide range of applicable technologies depending on depth and user demand, illustrated in the block diagram on the centre page of this brochure.



2. Heat transition only feasible with geothermal energy

Essentially three major renewable energy sources are suitable to replace fossil fuels for heating purposes and to support the heat transition: geothermal, solar thermal energy and biomass.
Solar thermal energy, biomass as well as geothermal energy can be used for the heat supply in single-family homes, quarters or building complexes. Due to the weather-related dependency, however, a full-year provision of the base heat load is not feasible with solar thermal energy. Furthermore, the large land demand of biomass has a limiting effect on its growth potential, especially in metropolitan areas [5].
In contrast, geothermal energy is independent of weather conditions and has low requirement for land. Therefore, the provision of renewable base load heat requires the utilisation of geothermal resources from shallow to deep.

The growth potential of geothermal energy is still large because it is usable almost everywhere at any time and season.
Various geothermal technologies are available and offer versatile application possibilities depending on the surface heat demand and the subsurface geological conditions.
The scalability of geothermal use ranges from shallow geothermal applications (GSHP) for single-family homes, deeper wells for thermal spas, to deep geothermal boreholes for the supply of district heating networks of entire towns (see block diagram on the centre page).
The combination of heat and cold storage in the ground, geothermal resources offer even more applications.

Flexibility of geothermal utilisation

Geothermal utilisation systems are distinguished between open well systems and closed or cased well systems with indirect use. In open systems, the borehole has an open hole section in the reservoir and thermal water is directly used as heat carrier (well system or doublet). In closed systems, the borehole is completely cased and a working fluid collects heat indirectly from the subsurface from the borehole wall acting as borehole heat exchanger.
The precondition for the successful use of deep open systems are suitable geological reservoir formations that provide high thermal flow rates, like for example in the Munich region. The planning of deep geothermal projects must therefore include the exploration of the geological subsurface. Comparatively high initial investment costs for the exploration phase of deep geothermal projects are generally counterbalanced by low operating costs.
As an example to share costs, the municipalities of Aschheim, Feldkirchen and Kirchheim (AFK) near Munich saved investment costs by sharing a geothermal exploration and drilling. This intercommunal project supplies renewable heat for five districts and illustrates the reasons why municipalities jointly decide to use geothermal energy as base heat load:

- joint and efficient production of climate-friendly heat
- renewable heat supply regardless of day time, season, and weather
- no noise emissions
- minimizing the consumption of fossil fuels, low primary energy factor
- comfortable operation and high price stability
- service security, high operational safety and reliable functionality
- accelerated realization of the energy transition compared to building renovation

3. Potential applications of geothermal energy

deep borehole heat exchanger

system: closed, heat pump
depth: 400–3000 m
temperature: 20–60 °C
capacity: 100–350 kW heat
application: office building, industry (heating/cooling)

shallow borehole heat exchanger

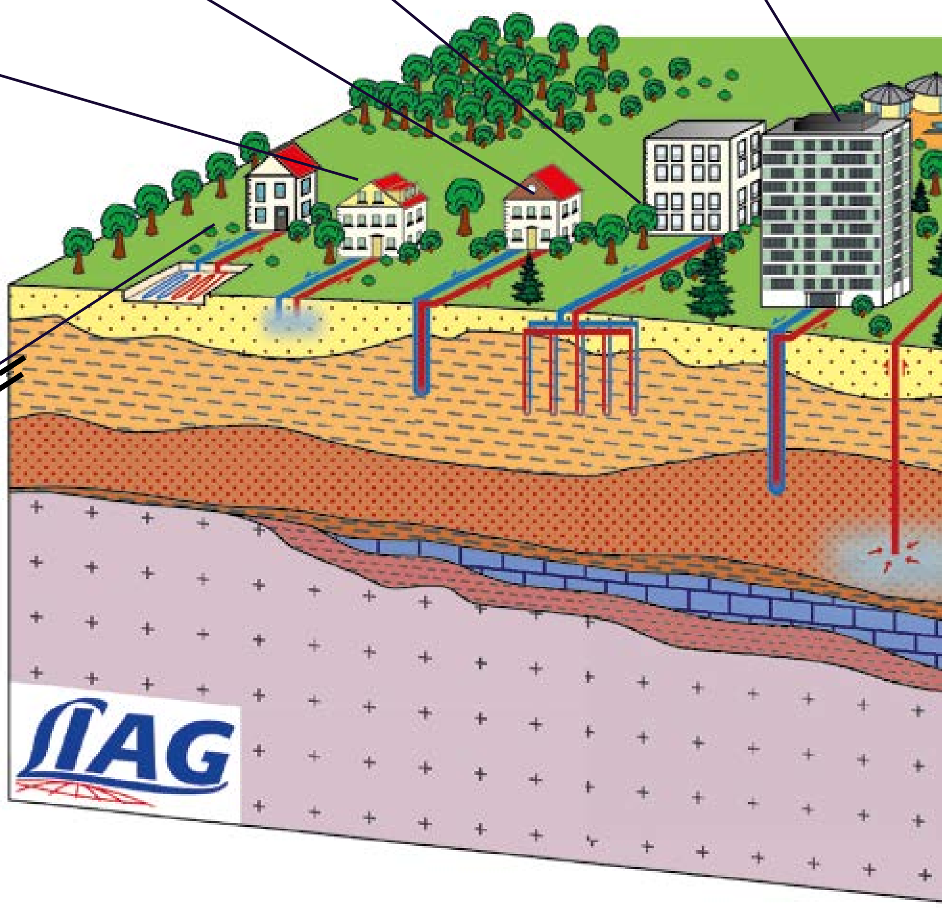
system: closed, heat pump
depth: Ø 100 m
temperature: 10–15 °C
capacity: Ø 8 kW heat
application: residential building (heating/cooling)

borehole heat exchanger field

system: closed, heat pump
depth: Ø 100 m
temperature: 10–15 °C
capacity: 100 kW bis > 1 MW heat
application: office building, industry (heating/cooling)

double well system

system: open, heat pump
depth: < 15 m
temperature: 8–15 °C
capacity: Ø 14 kW heat
application: residential building (heating/cooling)



ground heat collectors

system: closed, heat pump
depth: < 5 m
temperature: 8–15 °C
capacity: ~ 5 kW heat
application: residential building (heating/cooling)

hydrothermal doublet

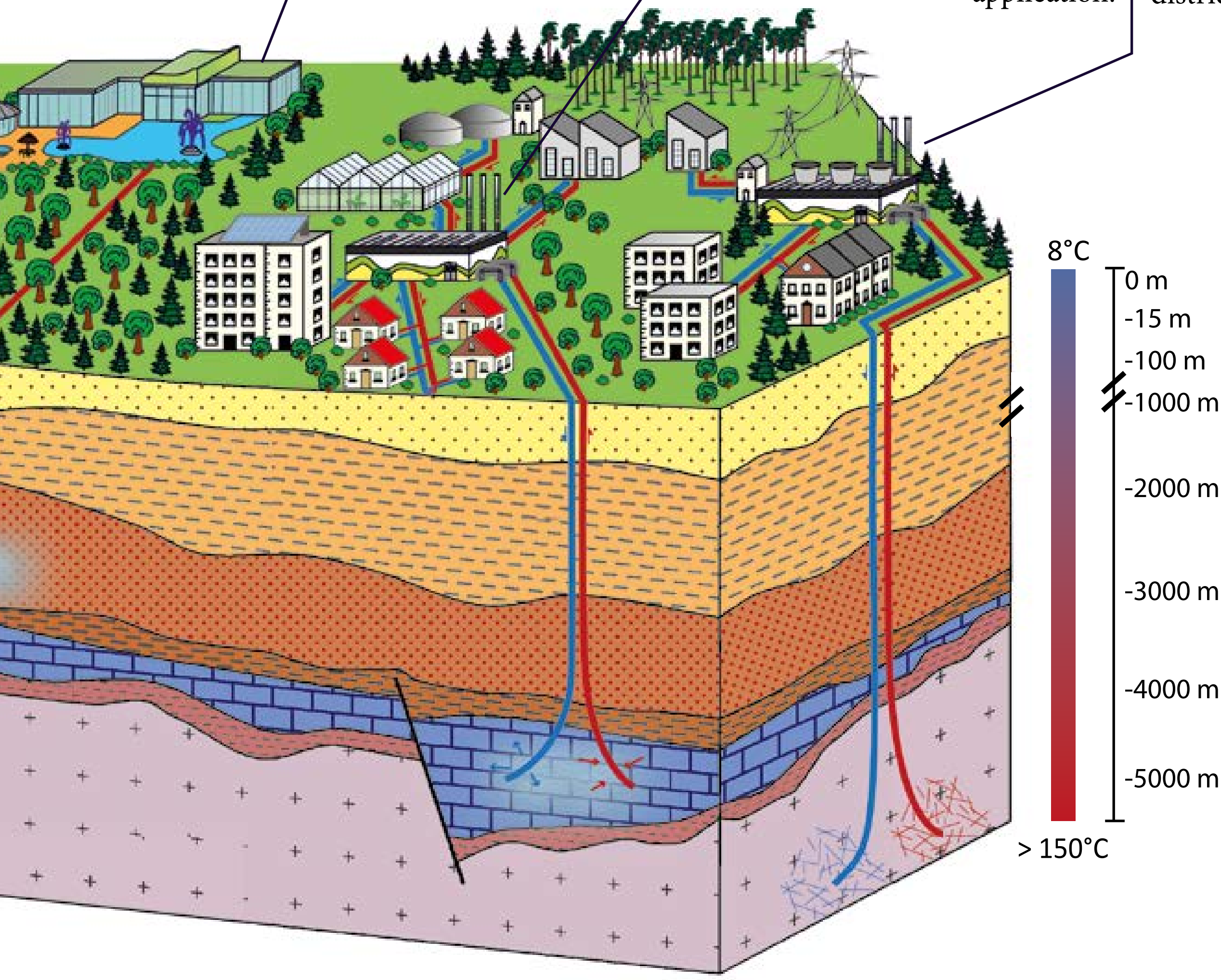
system: open, submersible pump
depth: 1000–4500 m
temperature: 40–150 °C
capacity: ~ 25 MW heat
≙ 2.5 MW power
application: district heating, power

thermal water borehole

system: open, submersible pump
depth: 100–3000 m
temperature: 20–100 °C
capacity: 0.02–4 MW heat
application: thermal spa

petrothermal doublet

system: open, submersible pump
depth: 4000–6000 m
temperature: > 150 °C
capacity: ~ 25 MW heat
≙ 2.5 MW power
application: district heating, power



4. Examples of geothermal use in Germany

Thermal spas

Thermal spas are the most widespread type of geothermal utilisation. In Bad Bevensen in northern Germany, for example, therapeutic water has been produced from a well since the 1970s. In 1987, brine with a temperature of more than 20 °C was tapped via a second well and, according to its definition, is classified as thermal water [6].
Through the establishment of a spa business and the settlement of various clinics, Bad Bevensen developed into a health resort with **regional added value.**

District heating

The use as district heating supplier is an optimal application for geothermal energy. One example is the heating plant Riem in Munich operated by the Stadtwerke München since 2004. Based on the success of this operation and the requirement to meet climate protection goals, the Stadtwerke München envision to supply the district heating network of the city completely with renewable energies by 2040. Geothermal energy shall act as major contributor to achieving this goal. Also in North Germany, the **sustainability** of geothermal energy is demonstrated in the pioneering facility Waren (Müritz), where the district heating network has been supplied with renewable geothermal energy since 1984. It is the first geothermal plant of Germany and was constructed in the German Democratic Republic (GDR) with the vision to develop domestic energy resources.

Aquifer storage

Geothermal reservoirs can also be used for heat or cold storage. In Neubrandenburg, the excess heat of a Combined Cycle Gas Turbine (CCGT) plant generated in summer is stored in the deeper subsurface and used by a geothermal heating plant, that delivers heat in winter into a district heating network. A large portion of otherwise required fossil fuels can be saved through this coupling, since a gas-fired boiler for peak loads is no longer needed in the heating plant.

Greenhouses

In the geothermally heated greenhouses in Kirchweidach (Bavaria), tomatoes and bell peppers are grown **regionally, sustainably and CO_2-free** on an area of about 20 hectares almost year-round. This results in a **saving of 16.5 million CO_2** per year compared to a conventional greenhouse heated with fossil fuel. Furthermore, regional cultivation avoids **1.5 million truck kilometres** per year compared to vegetable imports from Spain [7]. Remarkably, an increasing number of greenhouses are successfully heated with geothermal heat in the Netherlands.

Space heating

In Arnsberg (North Rhine Westphalia), geothermal energy is employed to supply the water park NASS with **CO_2-free** and **local** heat for heating the building and hot bathing and service water. At this site, the use of geothermal energy was implemented with the aid of a deep borehole heat exchanger (2,835 m), whereby a produced temperature of approximately 55 °C can be used at the surface. The challenge is to delineate the optimal circulation rate for an efficient operation of this closed system.

Power production

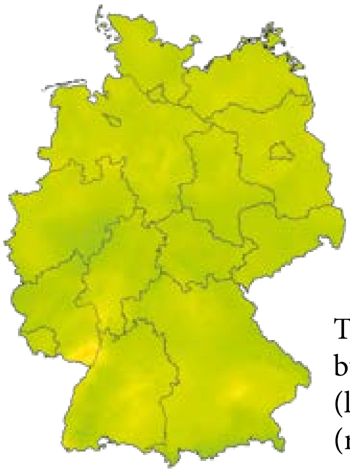
The hottest thermal water utilised so far in Germany is produced from a depth of 3,600 m at Insheim at the Rhine Graben. The 165 °C hot water from this fracture controlled reservoir is currently used for electricity production. Additionally to the power production, a district heating supply is planned to efficiently use the available reservoir through the coupling of power and heat.

Food processing

An example from Geinberg in Austria near the German border shows the **versatile and efficient** use of geothermal energy. At this location, the geothermal energy is used in multiple steps: first used in a dairy and afterwards fed into a district heating network. The residual heat is then used to supply a thermal bath and a greenhouse (so-called **cascade use**).

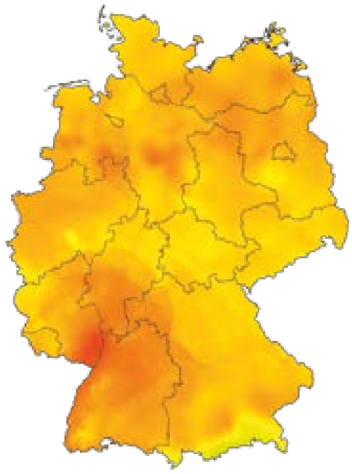
The maps show the temperature variation at certain depths depending on the subsurface conditions.

These temperature levels can be utilised in manifold ways. The map below shows the locations of different geothermal applications.



1,000 m depth

Temperature distribution in 1,000 m (left) and 3,000 m (right) depth below ground

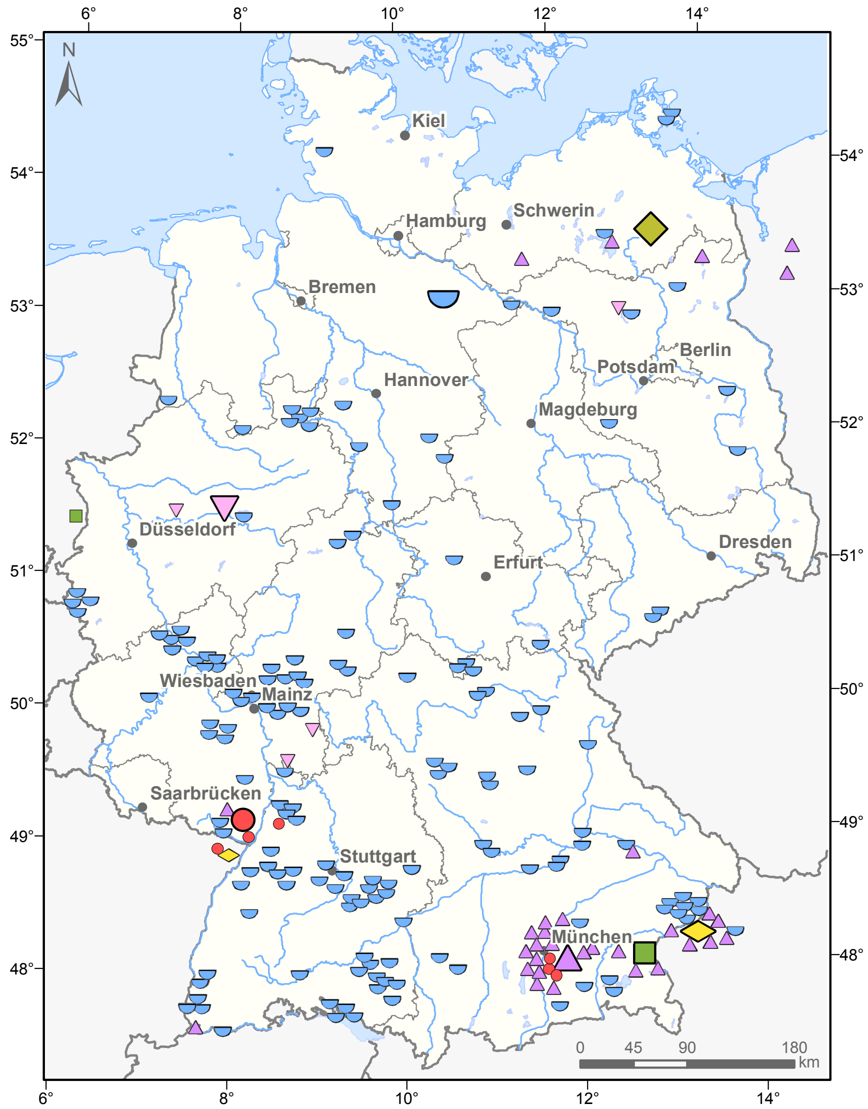


3,000 m depth

Temperature [°C]

Locations of medium-deep and deep geothermal applications in Germany

- Thermal spas
- District heating
- Power production
- Space heating
- Greenhouses
- Aquifer storage
- Food processing



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The larger symbols show the location of the examples explained on page 6.

5. Geothermal energy in combination with...

...biomass

In the future the **demand for biofuels** and raw materials will **increase** e.g. for the chemical industry, which can only be met by **biomass** on a larger scale (the share of renewables in the transport sector was only 5.2% in 2017 [2]).
Additionally, biomass can be **coupled efficiently** with **geothermal energy**. As an example, plant residues from a geothermally heated greenhouse can be utilised in a biogas plant for heat production. This heat can be delivered into a geothermal district heating network, e.g. to cover **peak loads.**

...solar thermal energy

Solar thermal energy can make valuable contribution to the heat provision in private households, but is **unsuitable** for a **large-scale heat supply.** Due to the daily and seasonal dependency on sunshine, heat is available especially in summer when the demand is rather low. However, a **combination with geothermal energy** can also be useful here. The heat generated in the summer can be **stored in the ground** via ground-based systems and later in the year used for heating purposes in the winter using a **geothermal heat pump.**

...photovoltaics and wind energy

Coupling geothermal energy with renewable electricity producers is also possible.
Photovoltaic systems can supply electricity for the **energy self-sufficiency** of a **geothermal plant** in order to operate pumps of the geothermal facility.
Renewable electricity can also be used for the operation of geothermal heat pumps to transfer power into the heat supply (power-to-heat).

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Outlook

Looking at the German energy transition shows:

- heat transition has so far been insufficiently addressed
- transition and/or expansion of municipal heating networks with geothermal energy is possible

Individual requirements in the heating sector can be met by:

- increased use of geothermal energy in industry, agriculture and food processing (e.g. greenhouses as in the Netherlands)
- use of underground heat storage, especially in connection with solar thermal or gas-fired power plants and for seasonal heat storage
- utilisation of low-temperature thermal water by raising the temperature with heat pumps powered by renewable electricity

Geothermal energy can be used more efficiently through:

- cascade operation with utilisation of residual heat
- increased direct use of thermal water, e.g. in municipal or industrial heating networks

From a scientific point of view, the growth of geothermal energy is hampered by:

- long planning phases
- drilling into the geological underground with partly unknown properties (= exploration risk) due to uncertainty increasing proportionally with depth
- so far high investment costs for deep geothermal projects with long pay-back periods, an obstacle especially for municipalities

From a scientific point of view, the growth of geothermal energy can be supported by:

- target-oriented political steering instruments to implement the heat transition combined with e.g. carbon tax to reduce climate-damaging emissions
- auxiliary research funding specifically for deep geothermal projects taking into account the increasing research demand with depth
- Systematisation of geothermal resources and assessment to gain reproducibility on an international level

More information at:
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