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Geothermal Energy Use, Country Update report for Denmark

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ABSTRACT

The deep Danish onshore subsurface contains huge geothermal resources, but only a very limited fraction of these resources are utilized in three existing geothermal heating plants. At the three plants deep situated warm formation water is pumped to the surface from a production well and, after heat is extracted and distributed to the district heating system, the cooled water is returned to the reservoir through injection well(s). To stimulate the exploitation of the geothermal resource and thus the transformation to a more sustainable energy mix in Denmark a recently completed research project (GEOTHERM, under the Innovation Fund Denmark) has thoroughly evaluated seismic reflection surveys and well data acquired during former hydrocarbon and geothermal exploration activities. The results of the last years research and geological assessments presented in a public available WebGIS portal have reduced the exploration risks significantly and is expected to stimulate the interest from the industry in the coming years, in line with the large distribution of district heating in Denmark. The Danish basins are classic low enthalpy sedimentary basins characterized by long-term subsidence and infilling by sediments. The widely distributed fluviatile Lower Triassic Bunter Sandstone and the mainly marginal marine Upper Triassic-Lower Jurassic Gassum formations constitute the most important geothermal reservoirs and are utilized in the present geothermal plants. Furthermore, formations with more local distribution also have geothermal potentials. In many areas, where existing detailed geological subsurface data are limited, predrilling reservoir prognosis are associated with large uncertainties, especially regarding the reservoir permeability. The temperature gradient of typical 25–30°C/km in the Danish subsurface implies that at depths shallower than 800 m the temperature is generally too low, whereas at depths greater than 3000 m, diagenetic alterations related to high pressure-temperature conditions reduce the porosity and permeability of the reservoir sandstones. Pronounced temperature anomalies are absent and variations in the temperature gradients are mainly due to differences in the thermal conductivity of the geological strata. Shallow geothermal energy (down to ca. 250 m) has been utilized in Denmark since the late 1970's following the oil crisis and is commonly described as Ground Source Heating and Cooling. Energy extraction by heat pump technology from shallow geological formations is beginning to play a significant role in Denmark in the transition towards a sustainable heat supply, especially in areas without district heating. The shallow geothermal resources have become more attractive as there are now five collective 5th generation district heating and cooling grids based on borehole heat exchangers (BHE) and aquifer thermal energy storage (ATES) in Denmark, all being economically feasible when compared to alternative means of supply. Furthermore, Denmark has one dedicated borehole thermal energy storage (BTES) system with 48 BHE's to a depth of 45 m storing seasonal heat from solar thermal in a district heating system.

1. INTRODUCTION

Several publicly financed research projects during the last decade have identified the presence of huge deep geothermal resources in the deep Danish subsurface below ca. 800 m and have stimulated the interest for utilizing the resource as an important component of a green sustainable energy mix. The recently completed three-year research project (GEOTHERM-project, supported by the Innovation Fund Denmark) further addressed geological, technical and commercial obstacles for utilization of the geothermal resources including the entire geothermal life cycle as well as the whole geothermal brine circuit from reservoir to the plant on the surface and back to the reservoir. The main goal of the project was to provide data and guidelines to ensure stable operation and realization of commercially profitable geothermal projects by describing the governing key elements for utilizing geothermal energy and for optimal integration into the existing district heating infrastructure. The project also developed a business case model for large-scale utilization of geothermal energy.

Denmark has moderate temperature gradients, but widespread geothermal aquifers and district heating networks in most of the Danish towns supplying heat to 60 % of Danish houses. Aquifers have been identified around many of these towns with sufficient heat to cover 20–50 % of their heat demand for hundreds of years. A previous study has assessed the reserves in a license for Greater Copenhagen Area to 60,000 PJ or 1/3 of the heat demand for about 5000 years (Mahler et al. 2010).

In Denmark shallow geothermal energy is commonly described as Ground Source Heating and Cooling which covers horizontal collectors as well as borehole heat exchangers (vertical or inclined), foundation pile heat exchangers and groundwater based open loop systems. Energy extraction by heat pump technology from shallow geological formations is beginning to play a significant role in Denmark in the transition towards a sustainable heat supply, especially in areas without district heating.

The use of shallow geothermal resources (down to ca. 250 m) is still limited, but in recent years, the Termonet concept for collective GSHP-based sustainable heating and cooling outside the district heating network (1/3 of consumers) has emerged, and it has been shown to be economically feasible when compared to alternative solutions. Moreover, the Termonet facilitates passive cooling/seasonal heat storage and balancing of the power grid by storing electrically heated water when electricity prices are favorable, giving it significant added value compared to traditional alternatives.

Shallow geothermal energy has been utilized in Denmark since the late 1970's following the oil crisis. Energy is produced primarily by means of ground source heat pumps with horizontal collectors but also from a limited number of borehole heat exchangers (BHE). In one case, a pilot borehole thermal energy storage (BTES) with 48 BHEs is used for seasonal heat storage by the local district heating company in Brædstrup, Denmark. In addition to closed loop borehole heat exchangers, aquifer thermal energy storage (ATES) systems are used mostly for cooling of e.g. hospitals and larger office buildings but to some extent also for heating.

1.1 Licenses, legislation and administration

Exploration for and production of deep geothermal energy requires a license pursuant to the provisions of the Danish Subsoil Act. It is the Danish Energy Agency, which administrates and supervise the licenses. The newly updated map of geothermal licenses and applications in Denmark reveals applications for large license areas by private investors whereas the existing holders primarily are municipal holders (Fig. 1). This illustrates that the industry now is taking interest in geothermal exploration and sees it as a promising business case into which it is willing to invest and share the exploration risks. Two major private investors have shown interest in overlapping areas (Geotermisk Operatørselskab A/S (Geoop) and APMH Invest IV A/S, see Fig. 1).

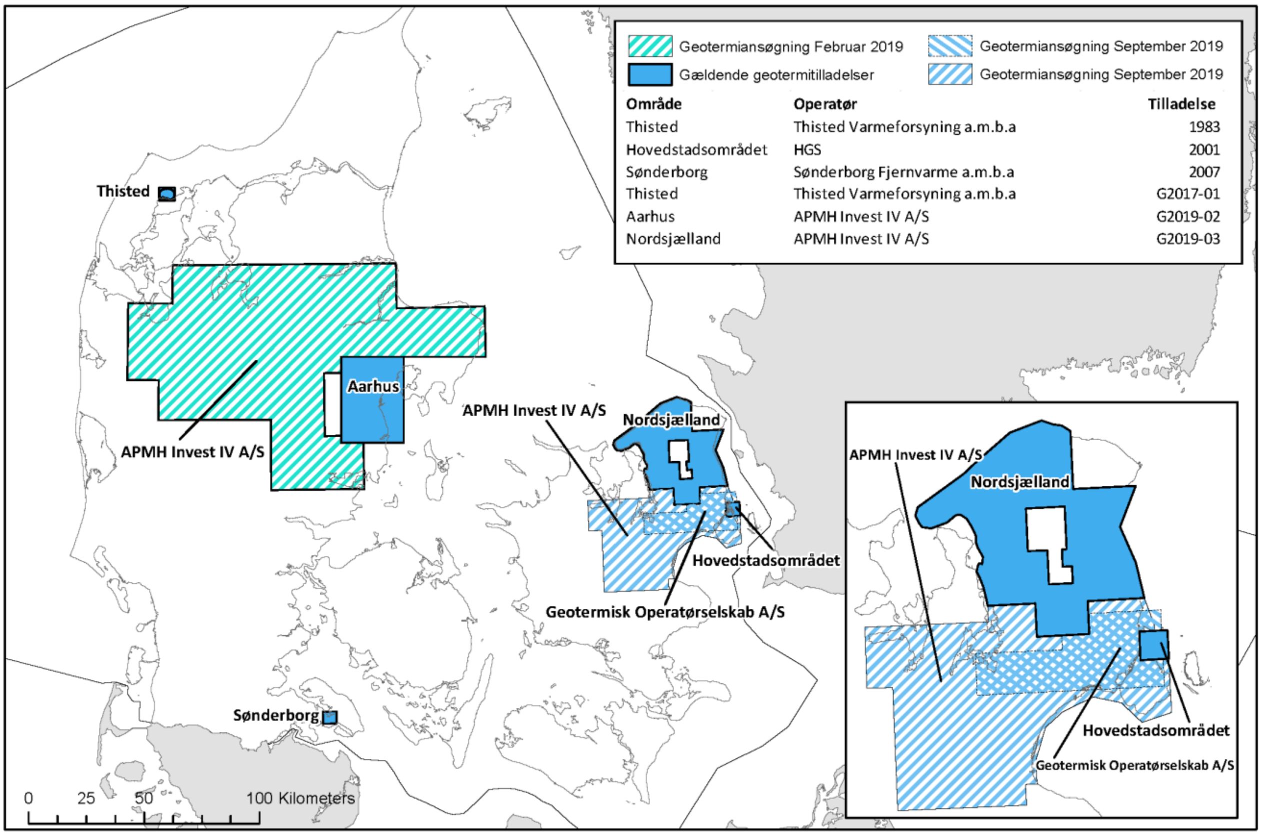

Figure 1: Geothermal licenses and applications in Denmark, October 2020 (from www.ens.dk, in Danish). Solid blue areas are license areas already granted while areas with light blue and green oblique lines are pending applications.

The shallow Ground Source Heating and Cooling is regulated pursuant to the Danish environmental protection act and The Groundsource Heating Act (BEK nr 240 af 27/02/2017). Permissions are issued by the municipalities, who must include groundwater interests in their considerations.

Protection of the groundwater is normally not a limitation for horizontal collectors, but for borehole heat exchangers, the regulation provides the municipalities with a possibility to increase the required safety distance to water wells and to stipulate special conditions in the permit regarding e.g. the construction of the installation, in order to protect a water catchment against contamination. Some municipalities reject applications for borehole heat exchangers if there is uncertainty regarding a possible content of anti-corrosives in the brine. Others are generally very reluctant to issue permits for borehole heat exchangers because of general considerations regarding the groundwater protection and drinking water quality.

The regulation of groundwater based open loop systems is regulated by the Act on “Heat extraction plants and groundwater cooling systems” (BEK no. 1716 of 15/12/2015) The regulation is rather strict and specifies investigations and documentation regarding the geology and hydrogeology of the aquifer as well as the hydraulic and hydrothermal properties and the chemical and microbiological conditions. Furthermore, numerical modelling is required in order to document that the temperature of the groundwater in existing catchments will not increase more than 0.5 degree Celsius. For "areas of specific drinking water interests" it is required, that the groundwater resource must be exploitable again 10 years after the closing of the installation, which should also be documented by numerical modeling. These requirements are rather costly and imply that only larger installations are economically feasible.

Over the last years there has been an increasing interest in geothermal energy among district heating companies and municipalities. Geothermal plants receive no funding, but high taxes on fossil fuels and the focusing on CO_2 makes it attractive to substitute the burning of fossil fuels on CHP plants with wind turbine power, biomass and geothermal heat.

2. GEOLOGICAL BACKGROUND

Information about the deep geological setting in Denmark originates largely from hydrocarbon exploration activities with seismic profiles and wells covering most of the country, however with an uneven distribution (Vosgerau et al., 2016). The interpretation of these data provides information on the regional structural setting and spatial distribution of sedimentary units.

The Danish onshore subsurface is divided into five major structural units (largely from north to south): the Skagerrak-Kattegat Platform (SKP), the Sorgenfrei-Tornquist Zone (STZ), the Danish Basin (DB), the Ringkøbing-Fyn High (RFH) and the North German Basin (NGB). The geothermal resources relate to two deep sedimentary basins: the Danish Basin (DB) and the North German Basin (NGB) (Fig. 2).

The sedimentary basins contain Palaeozoic, Mesozoic and Cenozoic sedimentary sequences of up to 5–10 km in total thickness. In contrast, sedimentary thicknesses of 1-2 km, and less, are found in areas with shallow basement highs (the RFH and SKP). The Ringkøbing-Fyn High consists of shallow basement blocks, where the thin Mesozoic sedimentary cover mainly comprises erosional remnants of Triassic sediments and Upper Cretaceous Chalk with a low geothermal potential. Both sedimentary basins host very large geothermal resources and several potential reservoirs and are classic low-enthalpy sedimentary basins formed by crustal thinning followed by long-term thermal subsidence and infilling by a variety of sediments (e.g. Michelsen et al. 2003; Michelsen & Nielsen 1991). These structural differences exert a decisive influence on the geothermal prospectively of the Danish subsurface, as they essentially determine the distribution, thicknesses, facies types and burial depths of the potential reservoirs (e.g. Erlström et al., 2018; Nielsen et al. 2004; Nielsen 2003).

Four main lithostratigraphic units with regional geothermal potential have been identified (Nielsen et al. 2004; Mathiesen et al. 2010). Within these four main units, five important geothermal reservoirs have been defined based on their stratigraphical and spatial extent and include the Lower to Upper Triassic Bunter Sandstone and Skagerrak reservoirs, the Upper Triassic - Lower Jurassic Gassum reservoir. Other reservoirs, e.g. the Middle Jurassic Haldager Sand reservoir and the Upper Jurassic - Lower Cretaceous Frederikshavn reservoir and the Lower/Upper Cretaceous Arnager Greensand may locally also contain potential aquifers. Each reservoir generally comprises several sandstone layers with reservoir properties. So far, the focus has been on the combined Bunter Sandstone-Skagerrak reservoir and the Gassum reservoir, with current geothermal production (Røgen et al. 2015).

The geographical coverage and quality of the data vary considerably. The mostly 2D seismic data combined with information from deep wells have been used in major mapping campaign for mapping of depth, thickness and lateral extent of lithostratigraphic units, and with special emphasis on units known to contain geothermal reservoir sandstones, as well as for identification and mapping of major faults and salt domes (Vosgerau et al., 2016). Regional maps were interpreted in two-way travel time (TWT) and were converted to depth ensuring that the difference between measured depths in wells and those extracted from the depth-converted maps are as small as possible. The deepest mapped seismic reflector is the Top Pre-Zechstein horizon. The maps are accessible from the WebGIS portal, as is a number of seismic cross-sections and an interactive 3D tool that exemplify the structural distribution of the onshore subsurface units. The lack of coverage and high-quality data hampers the interpretation and mapping of the deepest horizons and consequently, mapping uncertainties are generally larger for the deepest horizons than for the shallower horizons and the associated reservoir units.

The derived subsurface 3D structural (and geological) model with main lithological units includes information on potential geothermal reservoirs with burial depth and spatial distribution. Well data contain information about the reservoir quality (e.g. distribution of sandstone layers, facies type, heterogeneity, porosity, and permeability) as well as information on temperature and geochemistry of the formation water, where such data were measured (e.g., Weibel et al., 2017; Kristensen et al., 2016; Olivarius et al., 2015).

The shallow geology is dominated by soft sediments and characterized by a variable depth to the groundwater table. The sediments consist of glacial sand and clay deposits of variable thickness. In the western part of Denmark, they are found on top of Miocene fluvio-deltaic sands and marine silts and muds, whereas in the eastern and northeastern part, the glacial deposits overlay relatively soft limestone from the Danien and Cretaceous.

The energy extraction from shallow installations depends on the thermal properties of the sediments surrounding the heat collectors, (e.g. Vangkilde-Petersen et al., 2012). Relatively few investigations of thermal properties of Danish sediments have been carried out (Balling et al. 1981; Porsvig 1986; Møller et al., 2019), and thermal conductivity values for different rock and sediment types published by e.g. VDI (2010) show large variations for sediments relevant in a shallow geological context. However, a recent investigation has narrowed down this span for a number of relevant shallow sediments (Ditlefsen et al. 2014).

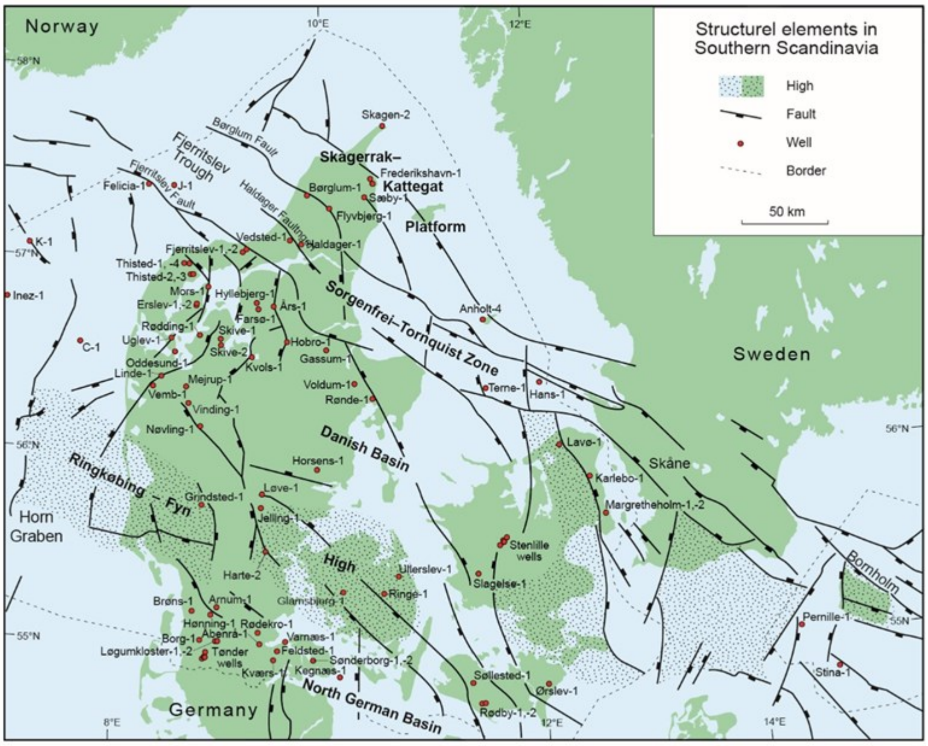

Figure 2: Well locations and principal structural elements in southern Scandinavia. Based on Nielsen (2003).

3. GEOTHERMAL RESOURCES AND POTENTIAL

The geothermal resources in the deep Danish underground are enormous (corresponding to around 3 times the heat from the Danish North Sea oil) and may potentially constitute the district heating to 1/3–1/2 of the Danish households for hundreds of years. At present, only a very limed fraction of the resources is utilized in the three existing geothermal power plants in Thisted, Sønderborg and on Margretheholm near Copenhagen (see locations in Fig. 3)), and of these, only the first-mentioned plant is in stable production.

Several initiatives have been undertaken in order to stimulate the exploitation of the geothermal resource and thus the transformation to a more sustainable energy mix in Denmark. A number of public financed research projects has thus been carried out over the last decades, focusing on the implementation of deep geothermal energy for district heating and thereby replacing fossil fuel, especially coal and oil. These projects have considerably increased our knowledge of the Danish subsurface and confirmed the presence of its huge geothermal resource and indicated where the geological conditions are most suitable for the extraction of deep geothermal energy.

In Denmark, successful geothermal exploitation in the deep subsurface requires the presence of thick and laterally coherent sandstone reservoirs with high porosity and permeability, which can ensure effective and long-term extraction and re-injection of formation water. A thick and coherent reservoir that is not hydraulically compartmentalized by faults, lateral lithological changes (e.g. grain size) or diagenetic features implies that a large volume of warm water may be accessible, and that production and injection wells can be placed at appropriate distances from each other while remaining hydraulically connected.

The temperature gradient of typical 25–30°C/km in the Danish subsurface implies that at depths shallower than 800 m the temperature is generally not sufficiently high to be economically profitable for a district heating plant, whereas at depths greater than 3000 m, diagenetic alterations related to high pressure–temperature conditions reduce the porosity and permeability of the reservoir sandstones. Thus, most interest is currently devoted to reservoirs with burial depth within the range of 800–3000 m and with a cumulative thickness of reservoir sand of good reservoir quality of more than c. 15 m (Vosgerau et al., 2016).

An outcome of the recent major mapping campaign resulted in a user-friendly WebGIS portal providing an overview of the amount and quality of existing geodata, the geological composition of the subsurface, and interpreted thematic products such as depth and thickness maps of potential geothermal reservoirs in the deep Danish subsurface (*http://DybGeotermi.GEUS.dk;* Vosgerau et al. 2016). An important thematic map outlines where in Denmark the geothermal potential appears most promising based on current knowledge and may thereby ensure that future explorations are directed towards these areas, thereby also reducing the risk of making unsuccessful wells in areas where the geothermal potential is low (Fig. 3).

The WebGIS portal, have reduced the exploration risks significantly, and have stimulated the interest from the industry, and provides a robust and consistent frame for more comprehensive estimates of the geothermal potential. Estimates in specific area more local geothermal license areas must however be based on more detailed analysis of the local dataset defining local geological models that may serve as the geoscientific background for technical and economic considerations.

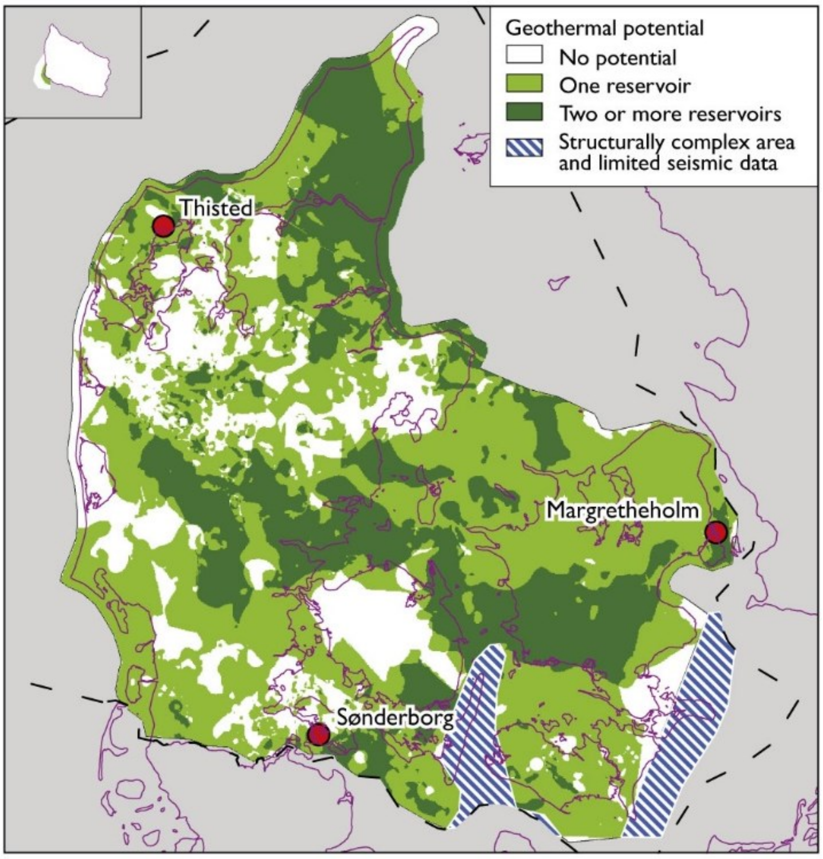

Figure 3: Distribution of lithostratigraphic units with reservoir properties suitable for geothermal exploration in the geothermal depth zone (800–3000 m). Notice the location of the three existing geothermal plants. After Vosgerau et al. 2016.

4. GEOTHERMAL UTILIZATION

In addition to the three current geothermal plants (positions in Fig. 3), several are at the planning stage. All the geothermal plants use absorption heat pumps and produces heat for district heating. Absorption heat pumps can be driven at low cost if other heat producers such as biomass boilers can supply 160°C driving heat at district heating cost levels.

Furthermore, all the geothermal plants use the doublet concept; warm formation water is pumped to the surface from a production well using no stimulation of the geothermal reservoir. After heat is extracted and distributed to the district heating system, the cooled water is returned to the reservoir through injection well(s). In Thisted, the production well produces c. 44°C warm water from the Gassum Formation at a depth of 1250 m where the water has a salinity of 15%. The plant produces up to 7 MW from 200 m^3/h geothermal water and transfer 10 MW heat to the district heating net by heat exchange and through absorption heat pumps driven by heat primarily from a biomass boiler. In Sønderborg, the production well produces 48°C warm water from the Gassum Formation at a depth of 1200 m where the water has a salinity of 15%. The plant is designed to produce up to 12 MW from 350 m^3/h geothermal water with the use of absorption pumps driven by biomass. The Margretheholm plant exploits a geothermal reservoir in the Lower Triassic Bunter Sandstone Formation at 2600 m depth where 19% saline geothermal water is available at c. 74°C. The plant is designed to extract 14 MW heat from 235 m^3/h geothermal water and transfer 27 MW heat to the district heating net by heat exchange and through 3 absorption heat pumps driven by 14 MW steam primarily from wood pellet based CHP plant. Comprehensive descriptions of the technical part of the three geothermal plants is given in previous Country updates, e.g. Mahler, at al. 2010; Mahler et al. 2013 and Røgen et al. 2015.

5. CURENT STATUS, FUTURE DEVELOPMENT AND INSTALLATIONS

Assessment of the geothermal resources in Denmark indicates a great potential in large parts of the country. The three existing geothermal plants may potentially produce geothermal heat for district heating from deep Danish geothermal aquifers with a total design rate of 33 MW heat extraction from the 15–20 % saline geothermal water. A number of district heating companies are considering the possibilities for establishing geothermal production.

The huge amounts of geothermal energy resources that are present in sedimentary basins may play an important role in future sustainable energy supply and has resulted in the need for e.g. accurate thermal information and thermal models. A recent published 3D numerical crustal temperature and heat-flow model for onshore Denmark including a comprehensive analysis of well-log data provides well-constrained input for a fully parameterized and calibrated numerical subsurface temperature model (Fuchs et al., 2020). The study shows that pronounced temperature anomalies are absent and variations in the temperature gradients are mainly due to local salt diapirs and differences in the thermal conductivity of the geological strata.

The Danish Government has just recently established an expert committee to evaluate applications from license holders who wish to insure themselves against the economic risk associated with geothermal drilling project, and recently, APMH Invest IV A/S has been awarded licenses around Aarhus (Fig. 1). In Aarhus the intent is to produce geothermal district heating for more than 100,000 consumers. Within the next years, it is planned to drill exploration wells to examine if the subsurface conditions are suitable for geothermal utilization (in the period 2021–2024), and to take the full responsibility for exploration, establishment and operational risks the following 30 years.

The plants on Margretheholm and in Sønderborg has experienced problems with reinjection causing the plants to be temporary out of operation. Research into the causes for this is ongoing, among others in the GEOTHERM project. In contrast, the Thisted plant has been running smooth since it came into operation in 1984 and without experiencing any breakthrough to the production well of the cooled, re-injected water from the injection well situated c. 1500 m from the production well. However, an extra injection well was added to the plant in 2018 as the existing injection well over the years gradually demanded more and more electricity for the pumps to inject the cooled water into the reservoir. The new injection well reduces the electricity consumption and extends the lifetime of the plant and will furthermore increase the proportion of geothermal heat of the total district heating supply in Thisted from 15 to 25 %.

Furthermore, during the later years there has been an increasing interest for using the subsurface for seasonal heat storage. Several projects, including the GEOTHERM project are investigating the possibilities of integrating heat storage with exploitation of the geothermal resource. One scenario may thus be to inject surplus heated water in the production well in the summertime, and then extract it when needed during the winter (Major et al. 2018).

Deep Danish aquifers have not been found suitable for power production, as sufficiently permeable sandstone layers are too cold due to the moderate temperature gradient of typical 25–30°C/km subsurface. They may, however, in the future be used for power production supplied by stored heat from the sun, excess incineration plant heat or heat pumps driven by excess wind turbine power. Thus, geothermal plants can be used for long term heat storage with low temperature losses. A study has been initiated to investigate the possibilities and problems.

Shallow geothermal energy, either as individual or collective supply, is expected to become more widespread in the future especially in areas with no district heating or natural gas supply. However, despite a large potential, the application of shallow geothermal energy in Denmark is relatively limited compared to e.g. Sweden or Germany. Today, the total number of ground source and air-to-water heat pumps in Denmark is around 57,000 and currently increasing with around 5,000 per year. Most of the existing ground source systems are using horizontal collectors, and it is not possible to assess the number of GSHP systems exclusively. Only hundreds are borehole heat exchangers and more than 40 are groundwater well open loop systems. During the last couple of years, the number of installed BHEs/year has declined somewhat relative to five-ten years ago (see Figure 4).

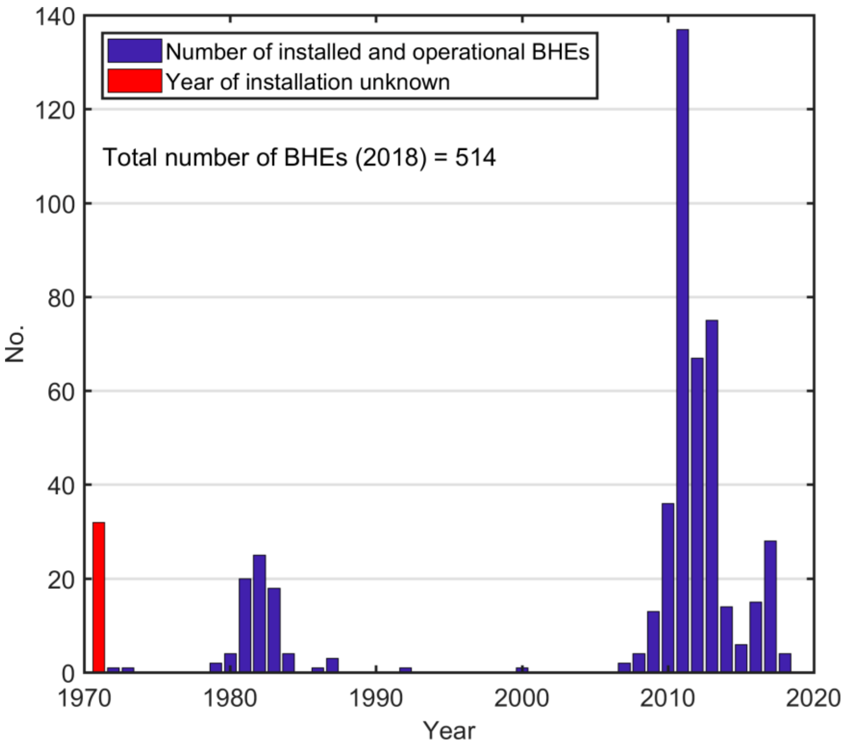

Figure 4: Number of installed and operational borehole heat exchangers (BHE). BHEs that have not been put into operation are excluded from the plot. Source: geus.dk.

Some open loop systems were installed in the eighties for house heating. Later installations were primarily for industrial cooling and now large systems are applied with alternating operation (heating in winter and cooling in the summertime). One local district heating company has established a borehole thermal energy storage (BTES) (48 boreholes, 45 m deep) in combination with a thermal solar installation, while 3-5 others have established pit thermal energy storage (PTES) also combined with solar energy and a few more PTES installations are planned or under construction.

A new concept for collective shallow geothermal district heating and cooling of residential areas, without the possibility of traditional district heating, has emerged in Denmark in the past two years. The concept is coined Termonet (Thermo-net) and comprises BHEs connected to a horizontal distribution network of uninsulated geothermal piping from which individual consumers extract energy with heat pumps (Fig. 5).

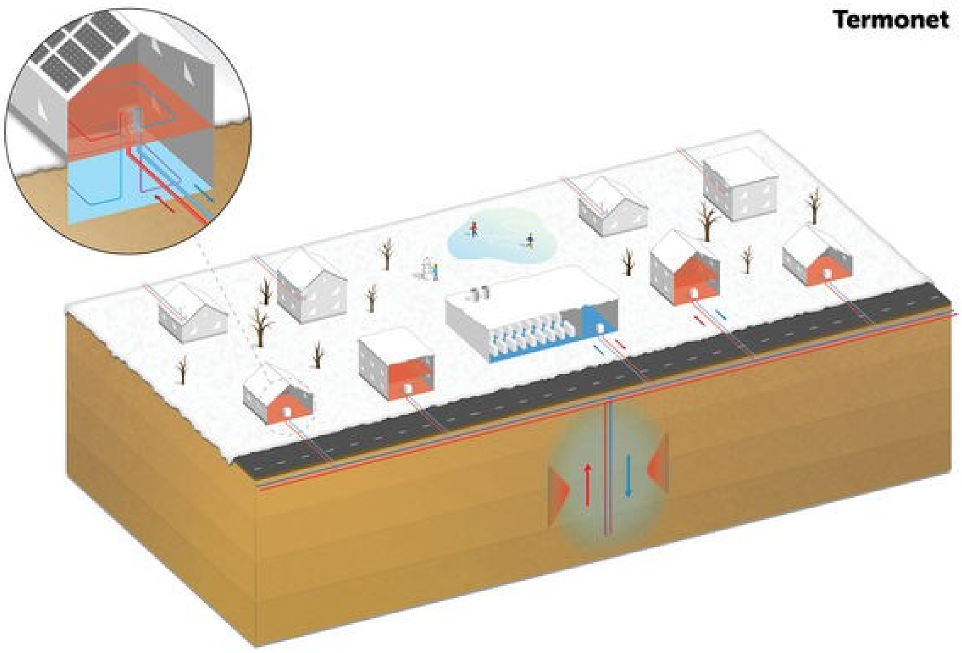

Figure 5: The Termonet with borehole heat exchangers (BHE) and the horizontal distribution network that supplies houses with heating by means of individual heat pumps and passive cooling/seasonal heat storage. Source: Termonet.dk

During the hot season, excess heat is stored for the winter by passive cooling of the connected buildings. In addition to improving the COP of the heat pump, seasonal heat storage/passive cooling significantly improves the thermal comfort during the hot season.

Three Termonet have been established in Denmark in 2017 and 2018 for which three different business models have been developed. The Silkeborg Termonet is owned and operated by the non-profit and consumer-owned, local district heating company (Silkeborg Forsyning), and supplies 15 residential units, utilizing 6 BHEs connected to the horizontal uninsulated distribution network. In the village of Skjoldbjerg, three houses are supplied by three BHEs in a collective district heating and cooling network, whereby savings are made possible relative to establishing individual BHEs. Here, the private company HeatPlan A/S owns and operates the Termonet. In a yet-to-be developed residential area in the city of Brenderup, Middelfart Municipality has established a Termonet that is jointly owned by the future landowner association. The Termonet will supply 13 residential units from 8 BHEs.

All Termonet projects are based on a worst-case scenario, where all energy is supplied by the BHEs. BHEs can be established anywhere, but they are a relatively costly energy source. In spite of this, all three projects conclude that the Termonet is competitive with the alternatives.

The project "Evaluation of the potential for geological heat storage in Denmark" (EUDP, jour.nr. 1887-0017) has recently been finalized and one of the main results of the project is a web-based GIS application for assessment of the possibilities for heat storage in the shallow subsurface. The application shall support planning and construction of underground thermal energy storage (UTES) facilities and is based on existing geological and hydrogeological information, location of existing district heating networks and environmental designation areas. Other activities have been evaluation of the potential for heat storage in deeper geological formations in the city of Aalborg, Denmark and modelling of the efficiency of different geological heat storage scenarios.

UTES project activities are continued in the project "High Temperature Underground Thermal Energy Storage - HEATSTORE" (EUDP, jour.nr. 64018-0301, EU GEOTHERMICA-ERA NET 170153-4401) and activities in Denmark comprise compilation of lessons learned from existing UTES systems internationally and development of general specification and design for UTES systems. Pilot UTES projects are developed in the Netherlands (high temperature aquifer thermal energy storage, HT-ATES) Switzerland (HT-ATES), France (BTES) and Germany (mine thermal energy storage, MTES), while in Denmark the geological conditions are characterized in selected areas with a potential for UTES and where a stakeholder-survey has indicated a specific interest. Finally, new software and workflows developed in the HEATSTORE project will be tested on Danish cases.

The recent project "Renewable, building-integrated heating and cooling supply for future resilient cities" (EUDP, jour.nr. 64017-05182) has explored the possibilities of implementing foundation pile heat exchangers (energy piles) for collective, GSHP-based heating and cooling (i.e. Termonet) in a new urban area in Rosborg, Vejle, Denmark. The project found that most buildings founded on energy piles can produce excess energy that forms the basis for supplying additional buildings with heating and cooling, when connected to a collective heating and cooling network.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)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 2019		0		9.800		24		0		22.800		32.600
Under construction in December 2019		0										
Funds committed, but not yet under construction in December 2019		0										
Estimated total projected use by 2020		0										

1) Coveres solar PV, wind and biomass
https://www.energidanmark.dk
http://www.eia.gov/electricity/data/browser; U.S. Energy Information Administration, Form EIA-923, 'Power Plant Operations Report.'

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

1F = Single Flash
2F = Double Flash
3F = Triple Flash
D = Dry Steam

B = Binary (Rankine Cycle)
H = Hybrid (explain)
O = Other (please specify)

Electrical installed capacity in 2019

Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status1)	Type of Unit2)	Total Installed Capacity MWe3)	Total Running Capacity MWe4)	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
- none -									0
Total									0

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting

H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy[2)] (kJ/kg)		(MWt)	Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
			Inlet	Outlet	Inlet	Outlet				
- none -										
TOTAL										

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the rejected to the ground in the cooling mode as this reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate - typically 3 to 4

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

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[4)]	Thermal Energy Used[5)] (TJ/yr)	Cooling Energy[6)] (TJ/yr)
Thisted	42	7000	1	V			84,4	
Copenhagen	72	14000	1	V			44	
Sønderborg	48	8500	1	V			23,8	
Shallow, for DH		7460	4	H, V			71	2
Distributed in DK		714 MW all together	65000	V, H			3800	
TOTAL		751000	65007				4023,2	2

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)

Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

4) Other than heat pumps

5) Includes drying or dehydration of grains, fruits and vegetables

6) Excludes agricultural drying and dehydration

7) Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)	1	2	0,06
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]			
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps	751	4023	0,17
TOTAL	752	4025	0,23

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

1) Include thermal gradient wells, **but not ones less than 100 m deep**

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)				60[2]	
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total					60	

2) Based of an estiamte of shallow heat boreholes/wells ('Jordvarme) drilled from 2015-2019 and drilled to more that 100 m and with expected temprature measurements.

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	3					
2016	3					
2017	3	2	2			
2018	3	2	2	2		5
2019	3	2	3	2		5
Total	15	6	7	4		10

Estimated values

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004						
2005-2009						
2010-2014						
2015-2019	3				50	50

Estimated values