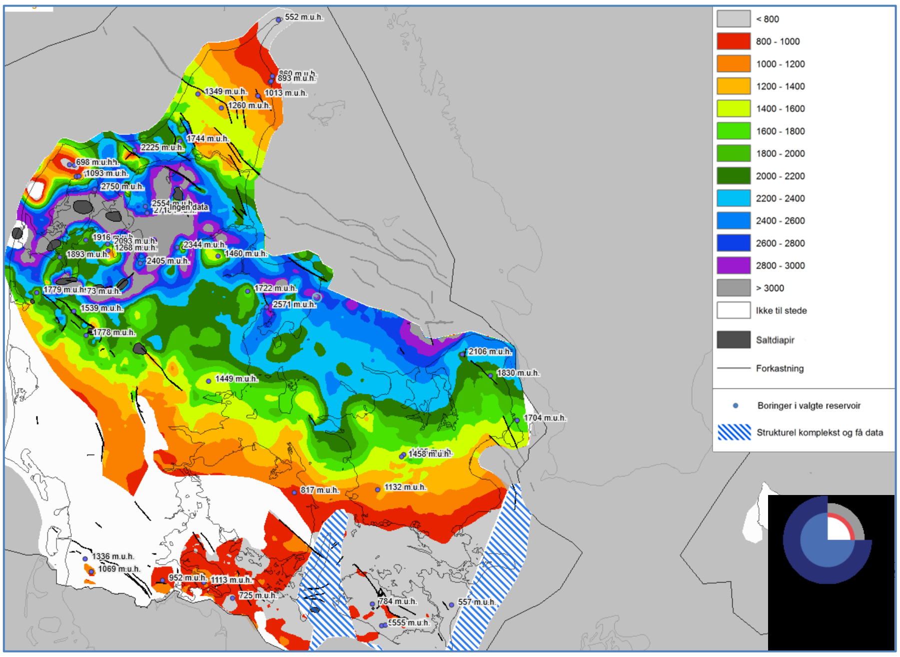
Data on Investment and Operation Expenses for Geothermal Energy Production for district Heating in Denmark

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**Client**
Danish Energy Agency

**Kontaktperson**
Jeppe Rydahl Mols
E jrm@ens.dk

**This report was prepared by:**
For PlanEnergi
Max Guddat
E: mgag@planenergi.dk

Karsten Juul
kj@planenergi.dk

For GEUS
Lars Kristensen
lk@geus.dk

Lars Henrik Nielsen
lhn@geus.dk

**QA**
Per Alex Sørensen
pas@planenergi.dk

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# 1 Introduction

The study is the result of a project for the Danish Energy Agency (DEA), conducted by PlanEnergi and Geological Survey of Denmark and Greenland (GEUS) throughout the summer of 2019. PlanEnergi and GEUS were appointed to collect data from European geothermal energy plants in order to upgrade the existing data regarding CAPEX and OPEX for future geothermal plants in Denmark. This data is to be used in a comparative study on heating supply costs in Danish district heating systems, supplied by district heating from large power plants. The reporting of the work is divided into the development of a datasheet and this report.

Geological data from the following plants located in Denmark, Sweden, Germany and Poland are particularly addressed in this project: Thisted, Lund, Neustadt-Glewe, Neubrandenburg, Pyrzyce, Stargard and Torun. The selection of plants is based primarily on geological criteria, but also operational data were considered.

The study focuses on the update of key design parameters and economic investment and operation data. The descriptive passages are mainly to be seen as an elaboration of the applicability of the gathered data and to what extent these are relevant, when describing economic and technical aspects of future geothermal projects in Denmark. For a description of the concept of geothermal energy for district heating purposes, please refer to the corresponding chapter in the Energy Technology Data Catalogue, published by the DEA[1] or a background report to geothermal energy (in Danish) prepared by GEUS[2]. The noted prices are given in 2019-€ if not stated differently.

The project group wants to thank the companies and persons involved for great cooperation and thus making a significant increase in data quality possible.

# 2 Identification of Relevant Comparative Geothermal Plants and Data Gathering

The work with the study at hand was initiated with a screening of known geothermal plants in Europe. For this, projects like GEOTHERM (funded by the Innovation Fund) and PERFORM (funded by the EU Geothermica program) were screened and plants in Sweden, Germany, Poland and the Netherlands were identified. Also, Lars Toft Hansen[3] was interviewed to include his professional network with Polish geothermal energy professionals. From Denmark only the long-lasting Thisted plant is included, whereas the two other plants, Margretheholm and Sønderborg were excluded due to their specific technical problems, which are regarded as atypical for geothermal plants in general.

Pronounced injectivity problems characterizes the Sønderborg plant. Interpretation of well test data indicates poor contact between the reservoir and the wellbore. This problem is attributed to technical inadequacies of the installations, including problems linked to well completions and screens. Furthermore, Sønderborg plant experiences operational difficulties due to clogging of the pores and perforations in the injection well, and these problems are attributed primarily to

[1] https://ens.dk/en/our-services/projections-and-models/technology-data

[2] http://dybgeotermi.geus.dk/geologiske-data/

[3] Chairman of Thisted District Heating and engaged in European geothermal and heat pump projects through previous engagement in SEG A/S.

calcite scaling and deposition of corrosion products. The injectivity problems are also related to precipitation of sulphides (ZnS and PbS), presumably caused by bacterial reduction of sulphates, as a high sulphate content characterizes the fluid system.

The iron casing in the Margretheholm plant is exposed to galvanic corrosion. The galvanic process implies chemical precipitation of metallic lead and carbonates, triggered by a high content of lead in the formation waters. Analyses of particle samples indicate a gradual transition from carbonates downhole to lead deposition close to the surface. The galvanic-induced scale and corrosion products clog the perforations and pores of the reservoir sandstones, causing severe injection problems.

The project group contacted contacts in the given plants for them to fill out datasheets, covering basic geological and economic data from the given plant. Due to reasons of corporate interests, the data gathering at this level is kept confidential and is only published in aggregated form in the study at hand.

The gathered data was processed into a set of datasheets that were developed for the purpose of this study. The aim of this development was to create a datasheet like the ones in the Energy Technology Data Catalogue. This is met by creating a datasheet for a generic plant design, with the possibility of scalability in order to meet given plant sizes. The plant design was determined based on design and operation experiences from both operating and decommissioned geothermal energy plants in Denmark and Europe.

As the format of released data on economy did vary significantly, the most comprehensive datasets were used as key-sources, using the remaining plants mainly for validation of components or the total plant costs. Likewise, the structuring of the CAPEX and OPEX were based on the best available data.

# 3 Geological and Reservoir Geological Evaluation

Data from the following plants are addressed in this chapter: the Thisted, Lund, Neustadt-Glewe, Neubrandenburg, Pyrzyce, Stargard and Torun plants. These plants produce geothermal water from good-quality sandstone reservoirs from within the depth interval 500–3000 m, and the reservoirs include sandstones of Late Triassic to Cretaceous age. In general, the producing sandstone layers are porous and permeable, and they include only small amounts of clay. The geological and reservoir geological aspects that characterize the different plants are reviewed in the text below, and Table 1 summarizes the reservoir parameters. The design of each geothermal plant varies, but as an example, a conceptual sketch showing the configuration of the Thisted plant is illustrated in Figure 1. The plants are categorized as either *doublets* (1 production well and 1 reinjection well) or *several wells* (more than one reinjection well per production well). Technical details on wells, installations, production and operational issues are listed in Table 2. For comparison, the two tables also include information about additional plants not directly described in the text.

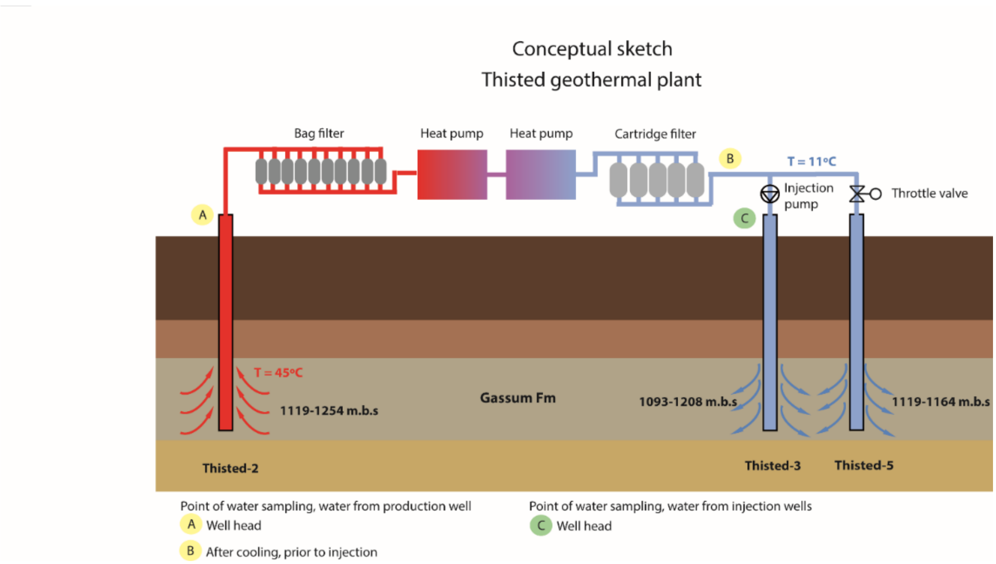


**Figure 1:** *Example of plant configuration. Conceptual model of the Thisted plant.*

With respect to geothermal exploration in Denmark, focus has until now been on the Gassum Formation and the Bunter Sandstone Formation, but also Haldager Sand Formation and Frederikshavn Formation are relevant exploration targets in certain areas in Denmark. However, the Upper Triassic–Lower Jurassic Gassum Formation generally exhibits the best reservoir properties relative to depth. The Gassum Formation is present in most of the Norwegian–Danish Basin, except where major salt structures occur and on the basement blocks of the Ringkøbing–Fyn High. A top Gassum depth structure map for the Danish area is shown in Figure 2 – note that the depth to top Gassum varies markedly throughout the Danish area. The formation was deposited in a humid climate and consists of marine and fluvial sandstones interbedded with marine and lagoonal mudstones. The Gassum Formation sandstones are widespread with relatively good lateral continuity, and data from deep wells located outside the Danish area shows that Gassum Formation equivalents are found in both the North German Basin and the Polish Trough.

The Gassum Formation has been flow tested with relatively high rates in wells from Thisted, Sønderborg and Stenlille due to the presence of good-quality sandstones with high permeabilities. Analyses of core data from additional Thisted and Stenlille wells also point to good reservoir properties. The Gassum Formation has been encountered in many deep wells in Denmark (Figure 2), but in general the formation was not flow tested as most of these wells drilled for hydrocarbon exploration and no oil was encountered.

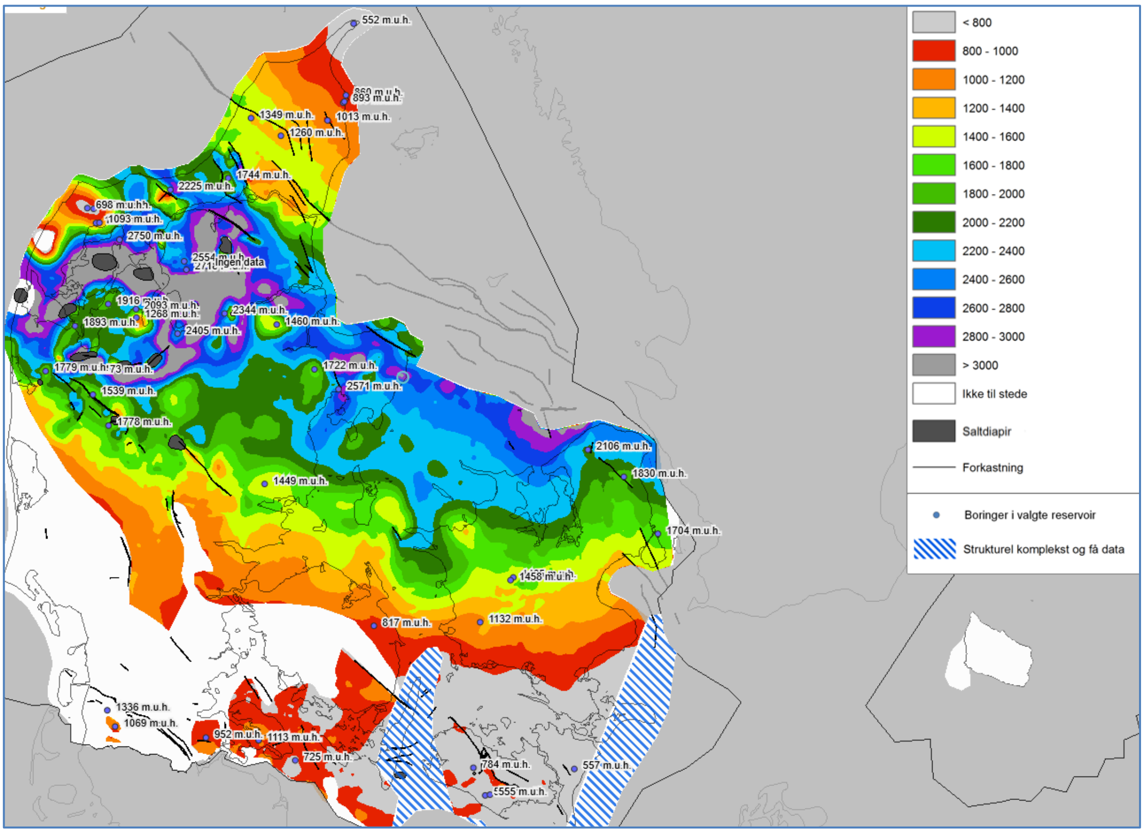


**Figure 2:** *Depth to the top of the Gassum Formation in the Danish area (metres). Locations of wells encountering the Gassum Formation are indicated. Figure from GEUS WebGIS portal [http://dybgeotermi.geus.dk/geotermikort/](http://dybgeotermi.geus.dk/geotermikort/) selected layers Gassum Fm and* Dybde til top.

The Thisted, Lund, Neustadt-Glewe, Neubrandenburg, Pyrzyce, Stargard and Torun plants all produce from good-quality sandstone reservoirs. Apart from the Lund sandstone, the geological age of these sandstones is Late Triassic to Early Jurassic and sedimentologically, these sediments basically belong to the Gassum Formation or a 'Gassum Formation Equivalent'. The Gassum Formation has been established for Danish area, and outside the Danish area an equivalent Gassum Formation is present in large parts of the study area. Figure 2 focusses on the Danish area, whereas Figure 3 roughly illustrates the distribution of these sandstones in Poland, Germany and Denmark, despite the figure only focuses on the Lowermost Jurassic. The sediment distribution illustrated in Figure 3 indicates that reservoir sandstones can be correlated across country borders. In geological terms, the sandstones of both the Mid Polish Trough and North German Basin most likely are comparable to Upper Triassic–Lower Jurassic reservoir rocks of the Danish area. This correspondence also suggests a similar geological development and comparable reservoir characteristics.

In the Danish area, the geothermal potential of the Gassum Formation has been proved in the Thisted and Sønderborg plants. The Thisted plant has successfully produced geothermal water at relatively high rates for more than 35 years from the Gassum reservoir. The Gassum reservoir at Sønderborg is excellent from a geological point of view, but recently the Sønderborg plant experienced injectivity problems. The observed problems are related to construction and well completion issues and not related to geological issues. Geological studies of cores and logs from deep wells in Denmark indicate that the Gassum Formation generally forms high-quality reservoirs at several locations in Denmark. The Gassum Formation consists of marine and fluvial sandstones interbedded with marine and lagoonal mudstone and generally, the sandstones are characterized by high porosities and permeabilities. Moreover, the sandstones are widespread with relatively good lateral continuity. It appears from Table 1 that the permeabilities of the Gassum Formation sandstones in the Danish area certainly are comparable to the reservoir permeabilities estimated for the German and Polish Upper Triassic–Lower Jurassic sandstones. Thus, there is a high probability that the geological development of these trans-national reservoir sandstones is similar. In addition, the reservoir properties are comparable.

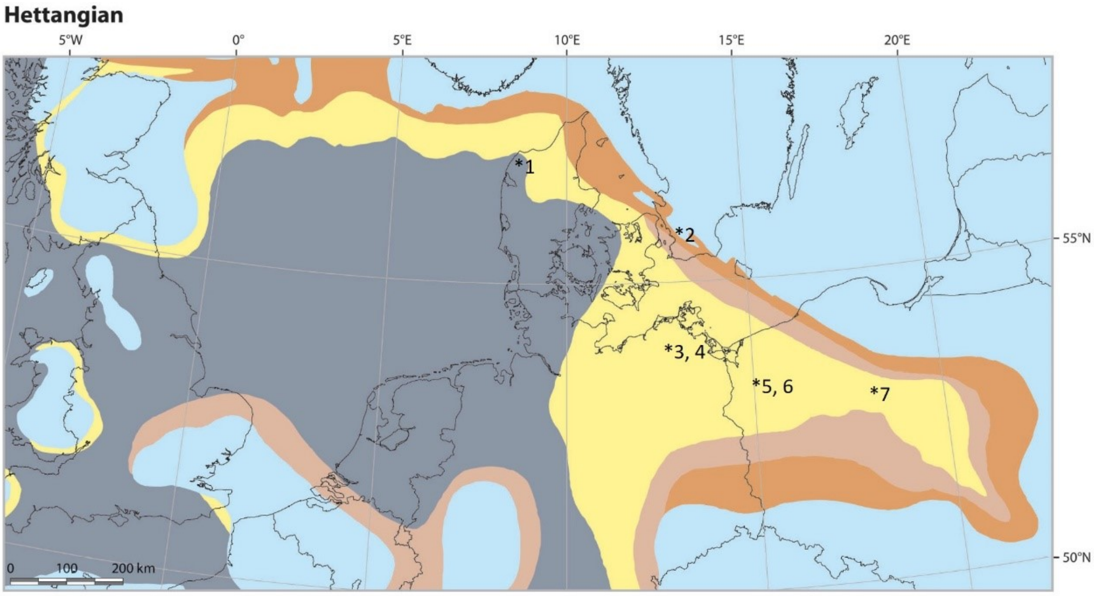


**Figure 3**: *Distribution of the Lowermost Jurassic sediments in the Danish Sub-basin, North German Basin and Mid Polish Trough (only sediments of Hettangian age are illustrated on the map). Dark grey: marine mud and carbonate; Yellow: shoreface sandstone; Light orange: fluvial to marginal marine sediment; Orange: non-marine continental. The sandstones (in yellow) form part of the Gassum Formation and the Gassum Formation Equivalent. Only the Lower Jurassic fraction of the formation is shown, the distribution of the Upper Triassic (Rhätian) part is not shown. Location of plants: 1: Thisted, 2: Lund, 3: Neustadt-Glewe, 4: Neubrandenburg, 5: Pyrzyce, 6: Stargard, 7: Torun. Figure adapted from 'Petroleum Geological Atlas of the Southern Permian Basin Area'.*

For a presentation of the characteristics of the evaluated geothermal plants, please refer to Annex A.

| Plant or Site | Location: Geological Basin | Reservoir depth (m) | Geological age (period) | Porosity of sandstone (%) | Perm. of sandstone (mD) | Gross sand (m) | Net sand (m) | Reservoir temp. deg.C | Geochem. TDS (g/L) |
|---|---|---|---|---|---|---|---|---|---|
| Margretheholm, DK | Danish subbasin | 2500 | Triassic | 20 | 400 | 137 | 30 | 73 | 218 |
| Thisted, DK | Danish subbasin | 1200 | Triassic-Jurassic | 25 | 1600 | 95 | 30 | 45 | 167 |
| Sønderborg, DK | N. German Basin | 1150 | Triassic-Jurassic | 28 | 4000 | 40 | 30 | 47 | 164 |
| Lund, S | Danish subbasin | 650 | Cretaceous | 30 | 4500 | 150 | 25 | 21 | 60 |
| Gross Schönebeck, D | N. German Basin | 4200 | Permian | 15 | N/A | N/A | N/A | N/A | N/A |
| Neustadt-Glewe, D | N. German Basin | 2300 | Triassic | 21 | 700 | 80 | 67 | 98 | 227 |
| Neubrandenburg, D | N. German Basin | 1250 | Triassic-Jurassic | 30 | 800 | 40 | 29 | 54 | 130 |
| Pijnacker-Nootdorp, NL | W. Netherlands Basin | 2050 | Jurassic-Cretaceous | 16 | N/A | N/A | N/A | N/A | N/A |
| Pyrzyce, PL | Mid Polish Trough | 1550 | Early Jurassic | 20 | 1100 | 150 | 100 | 64 | 120 |
| Stargard, PL | Mid Polish Trough | 2600 | Early Jurassic | unknown | unknown | 246 | 150 | 83 | 146 |
| Torun*, PL | Mid Polish Trough | 2200 | Early Jurassic | 20 | 1400 | 300 | 171 | 65 | 120 |

**Table 1** *Approximate reservoir parameters for selected water-bearing sandstones at various plant locations.*
*(*) Under construction*

**Legend:**

**Porosity**: The amount of pore space in the reservoir rock (measured in percent). Or in other words, the volume of connected pores in a unit volume of rock. The porosity is usually greater than 15% for a good geothermal reservoir.

**Perm. or permeability**: The ability to transmit fluids, typically measured in darcies or millidarcies. Formations that transmit fluids readily, such as sandstones, are described as permeable and tend to have many large, well-connected pores. Impermeable formations, such as shales and siltstones, tend to be finer grained or of a mixed grain size, with smaller, fewer, or less interconnected pores. The permeability is usually greater than 100 mD for a good geothermal reservoir.

**Gross sand:** The overall thickness of the sandstone layers within a formation.

**Net sand:** The thickness of reservoir sand. Reservoir sand equals herein sandstone layers having high porosity (>15%) and low clay content (<30%).

**TDS:** The amount of Total Dissolved Solids (TDS) indicates the salinity of the formation water (measured in gram/litre). High salinity corresponds roughly to TDS greater than *c.* 100g/L.

| Plant Or Site | Number of production wells | Number of injection wells | Vertical or deviated wells | Gravel pack installed | Screens installed | Flow in (m3/h) | Energy prod. (GWh/year) | Heat capacity (MW) | Design of plant (system) |
|---|---|---|---|---|---|---|---|---|---|
| Margretheholm, DK | 1 | 1 | Deviated | no | no | 200 | 58 | 14 | Doublet |
| Thisted, DK | 1 | 2 | Vertical | yes | yes | 170 | 22 | 7 | Several wells |
| Sønderborg, DK | 1 | 1 | Deviated | yes | yes | 75 | unknown | 12 | Doublet |
| Lund, S | 4 | 6 | Both | yes | yes | 1650 | 175 | 31 | Several wells |
| Gross Schönebeck, D | 1 | 1 | Both | no | no | unknown | unknown | unknown | Doublet |
| Neustadt-Glewe, D | 1 | 1 | Vertical | yes | yes | 80 | 18 | 4 | Doublet |
| Neubrandenburg, D | 1 | 1 | Vertical | yes | yes | 80 | 9 | 4 | Several wells |
| Pijnacker-Nootdorp, NL | 1 | 1 | Deviated | unknown | N/A | N/A | 41 | 7 | Doublet |
| Pyrzyce, PL | 2 | 2 | Both | yes | yes | 120 | 33 | 6 | Several wells |
| Stargard, PL | 1 | 2 | Both | unknown | No | 160 | 64 | 12 | Doublet |
| Torun*, PL | 1 | 1 | Vertical | yes | yes | 320 | 89 | 19 | Doublet |

**Table 2:** *Technical details on wells, installations, production and operational issues. Geothermal part only.*
*(*) Under construction*

**Legend**:
**Vertical or deviated wells:** Commonly 'Both' refer to a vertical production well and a deviated injection well.
**Gravel pack**: Gravel packing involves the complete placement of selected gravel across the production interval to prevent the production of formation fines or sand. Any gap or interruption in the pack coverage will enable undesirable sand or fines to enter the producing system.
**Screens**: A metal **filter assembly** used to support and retain the sand placed during gravel pack operations. A range of sizes and screen configurations is available to suit the characteristics of the wellbore, production fluid and the formation sand.
**Flow**: The production rate for the geothermal water. The flow rate is usually greater than 100 m3/h, when dealing with a good geothermal reservoir.
**Energy prod.:** The amount of energy produced per year (measured in GWh/year).
**Heat capacity**: The geothermal power of a plant (measured in Mega Watt).
**Design**: A doublet refer to one production well and one injection well.

# 4 Plant Design Parameters in Generic Geothermal Energy Plant for Datasheet

In order to create a generically useful datasheet, certain parameters were set for two generic geothermal energy plants, varying primarily in the depth of the reservoir and thus resulting in varying temperatures. The parameters regarding the corresponding expectable reservoir characteristics are assessed to be rather conservative, in order to estimate realistic energy yields.

The datasheet is created for six different setups, varying in the geothermal reservoir depth and thus temperature (A/B), the used heat pump technology and the temperature sets in the connected district heating grid. The choice of scenarios is estimated to cover relevant spans of the given alternatives in the context of reservoir depths in Denmark and the corresponding district heating grids.

Please note that all six scenarios are designed conservatively and that local preconditions may differ and thus result in e.g. higher energy yields for the same investment and other variations.

## 4.1 Depth and Temperature of Geothermal Reservoirs

For the Danish context it is assessed to be most relevant to assess geothermal potentials as potentials utilizing the Gassum Formation (please refer to Chapter 3 for elaboration on this). For the datasheets, depths of 1,200 m and 2,000 m are assumed, resulting in a reduction of the risk of failure, due to good knowledge about the Gassum Formation (compared to e.g. Bunter-Formation, cf. Chapter 3), i.e. contingeny costs are kept comparably low.

As there is found a correlation of high temperature differences in the cooling of geothermal potentials and operation issues like scaling and clogging, a max. temperature difference of 27/35 K is applied for the 1,200/2,000 m-reservoirs. The exact possible cooling of a given geothermal reservoir is to be determined through initial chemical and hydrological modelling. In a specific case, the flow and/or cooling of the reservoir may be higher, thus resulting in higher energy yields off the same well/geothermal plant. However, a more conservative approach is applied in this study, based on the more conservatively geothermal plants operating most continuously and stable.

## 4.2 Heat Generation (Geothermal/Direct Heat Exchange/Heat Pump)

For the assessment of the thermal effect of a geothermal plant, the following assumptions have been applied for the central estimate, based on the design and operation experiences from the European reference plants:

- Production wells:
  - 2 production wells
  - Specific flow: 160 $m^3$/hour/well
  - Total flow: 320 $m^3$/hour/plant
- Reinjection wells:
  - 4 reinjection wells
  - Specific flow: 80 $m^3$/hour/well
  - Total flow: 320 $m^3$/hour/plant

For the a-scenarios (1,200 m reservoir depth) this results in 9.4 $MW_{th\_geothermal}$ and for the b-scenarios (2,000 m reservoir depth) 12.2 $MW_{th\_geothermal}$.

The balance of reinjection and production wells is thought to secure a redundancy in reinjection wells, limiting the nominal flow necessary and giving the possibility to close a reinjection well for maintenance, while keeping considerable flow and effect in the system. Depending on the reservoir-characteristics, it may be necessary to provide further or fewer reinjection wells to achieve the same flow and thus thermal effect, but the above designed example is assessed to constitute a reasonable median plant design, based on the well-performing European reference cases.

The average flow in the reinjection wells is assumed to be half of the production well. This is due to many operational experiences in many of the reference plants, where a reduced reinjection flow solved issues with scaling and clogging, which proved to be avoidable, by limiting reinjection pressure and flow by dividing reinjection on to several reinjection wells.

The considered flow of 160 $m^3$/hour/production well and 80 $m^3$/hour/reinjection well is also based on the existing references.

## 4.3 Temperature of District Heating and heat production

Scenarios 1 and 2 describe possible plant designs for district heating plants with a supply temperature of 80°C and a return temperature of 40°C.

In scenario 3.a and 3.b, a system with a supply temperature of 70°C and 35°C return is presumed. Scenarios 3.a and 3.b are primarily to be used to evaluate the effect of temperature decreases on the secondary side, when comparing 1.a with 3.a and 1.b with 3.b respectively.

The reference projects vary from approx. 3,250 to 5,500 full load hours. It must be stated that geothermal plants often deliver heat in combination with other heating sources. In times with low heat demand and cheaper alternatives for heat production (e.g. solar thermal, waste-to-energy or industrial excess heat) the heat production may thus be limited for economic reasons. Based on the European reference projects and the operation considerations as stated above, it is presumed that a geothermal plant would produce at least 4,000 full-load-hours per year, resulting in the stated expectable heat production and energy consumption of submersible pumps and drive energy for heat pumps.
As it is not assessed feasible to utilize geothermal reservoirs with a temperature at supply temperatures of district heating grid (70-80°C presumed), heat pumps (or boilers, supplying heat at temperatures >supply temperature) are necessary to boost the geothermal energy to supply temperature. Coefficients of performance (COP) for the given working points have been calculated, using a publicly available tool, developed by PlanEnergi[4]. An example of this energy balance and COP-calculation is described in Annex B. The effects of lowering the supply temperature in the district heating grid and thus increasing the COP of a heat pump is illustrated in scenarios 3.a and 3.b. The use of the simple heat pump calculation tool is free of charge. A COP for a given, user defined point of operation is calculated based on a Lorentz-efficiency approach (default 50 %).

The thermal effect in the datasheet is stated as heat source from the geothermal reservoir at the given amount of wells with a given flow and a given temperature (th_geo) and the energy

[4] http://planenergi.dk/arbejdsomraader/fjernvarme/varmepumper/drejebog-til-store-varmepumpeprojekter-i-fjernvarmesystemet/

added as drive energy for a heat pump (th_HP; electricity for electrical compressor heat pumps or net heat from a boiler for absorption heat pumps).

If the reservoir temperature exceeds the return temperature of the connected district heating grid by more than 4 K (assumed loss of a heat exchanger), direct heat exchange is assumed to cover as much as possible of the heat production. The remaining geothermal heat is presumed to function as heat source for a heat pump. Possible designs for the given geothermal reservoirs have been calculated, taking into consideration energy balance on the primary and secondary side.

| | Heat pump type | | Reservoir temp. [°C] | | Reservoir depth | DH temp. [°C] | |
|---|---|---|---|---|---|---|---|
| Scen. | Electric | Absorption | $T_{res}$ | $T_{reinj}$ | m | $T_{supply}$ | $T_{return}$ |
| 1.a | X | | 44 | 17 | 1,200 | 80/40 | |
| 1.b | | | 68 | 33 | 2,000 | | |
| 2.a | | X | 44 | 17 | 1,200 | | |
| 2.b | | | 68 | 33 | 2,000 | | |
| 3.a | X | | 44 | 17 | 1,200 | 70/35 | |
| 3.b | | | 68 | 33 | 2,000 | | |

**Table 3:** *Scenario-overview for described combinations of geothermal and heat pumps.*

The energy consumption for submersible and circulation pumps is observed in the European reference projects to lie in the range of 0.02-0.09 $kWh_{el}/kWh_{geoth}$. The needed pump work and hence electricity consumption for pumps depends heavily on the reservoir characteristics, but considering the presumed conditions in Denmark, a factor of 0.05 is presumed valid as median value in the central estimate.

## 4.4 Technical and Economic Lifetime of Geothermal Energy Plants

No decommissioned plant was included in the frame of the project at hand, hence there is no empirically observed technical or economic lifetime of existing geothermal energy plants. However, it can generally be noted that several plants observe technical difficulties with primarily reinjection wells after approx. 25-30 years, typically leading to reinvestments in new wells or extensive restoration of existing ones.

Hence, the technical lifetime within the current framework is estimated to be 25 years, which is also reflected in the fixed O&M-expenses.

## 4.5 Economic data

**Risk Assessment and Division of Project Costs by Price Components and Project Stages**

The economic risk of geothermal energy plants differs extensively from other technologies. Whereas there is an upper limit for a financial risk, when investing in e.g. boilers in terms of a risk of upgrading certain components, the success of a geothermal energy plant may not be directly connected to the amount and quality of pre-studies and technical equipment. If e.g. a given reservoir does not contain permeable layers, increased investments in further wells and the alike will not lead to a successful project. Hence, the risk assessment approach, used for other technologies in the Energy Technology Data Catalogue, working with upper and lower limits to cover a certain risk is not directly applicable for geothermal energy. Please refer the paragraph *Applying Upper and Lower Limits* below for a description of adjusted parameters.

For the purpose of this study, the possible investments are split into components in the project phase. The project phase is generally split into three phases with corresponding milestones:

1. Pre-drill-studies
    1.1. Assessment of existing geological data
    1.2. Acquisition of supplementary data, often seismic data
    1.3. Establishment of geological model
2. Test-wells
    2.1. Test and demonstration wells
    2.2. Test pumping, water chemistry and hydraulic modelling
3. Decision for investment and project execution

After each milestone, the investor can decide whether to proceed the project or stop, based on the results of the analyses. Generally, the decision fundament and data quality increases significantly by every milestone reached. However, milestone 2 is key, as it only after carrying out test pumping and modelling of water chemistry and hydraulics is possible to assess the actual potentials of a given geothermal reservoir. Analogous to this, the risk of a possible total investment decreases significantly, once milestone 2 is reached and the reservoir proves to be feasible for geothermal exploration.

The cost elements for several cost elements are stated in M€/site. The extent of this site varies by the local circumstances but would regularly cover a surface area of 10x10 km, covering a reasonable level of details for decision making whether to proceed to test wells or not.

**Milestone 1: Pre-drill studies (incl. seismic analyses and geological modelling)**
The extent of necessary pre-drill studies depends heavily on pre-existing geological data. The stated cost elements are stated if data like the ones described in Chapter 3 do exist. For the Polish reference cases, rather detailed pre-studies do exist, due to hydrocarbon exploration programs in the 1980's. Hence, these cost elements could not be validated in the context of this study and estimates from the Energy Technology Data Catalogue are presumed to still be valid.

**Milestone 2: Test and demonstration well (M€/site)**
Initial costs for an (open) geothermal test and demonstration well. The costs for this well are approx. 1,800 €/m. From this, reservoir characteristics can be analyzed, e.g. permeability, water chemistry. Achieved through test pumping of the well, typically for a few days. If the test and demonstration well proves a feasible geothermal reservoir, the geological model can be improved to secure best possible data for decision whether to proceed with the project or not. The total duration of this milestone from establishment of an initial test well to an updated and upgraded hydrological model is typically 4-6 months.

**Milestone 3: Upgrade to full-standard geothermal plant**
After a possible decision to proceed with the project, the test and demonstration well needs to be upgraded to production quality (lining of wells, mounting of screens etc.). The total cost of these upgrades exceeds the costs of a production/reinjection well that is established in one single work process by approx. 300.000 €. Furthermore, over-surface installations like housing, hydraulic systems etc. account for approx. 900,000 €, a cost factor, which does also apply for all supplementary wells.

Over-surface installations like hydraulic pipework, power and control systems, buildings etc. account for approx. 2,1 M€/site.

Additional production and reinjection wells are established at a specific cost of approx. 1,900 €/m + 900,000 €/well for over-surface installations. This specific dwelling cost is based on the use of composite material for liners to ensure the desired technical lifetime of 25 years without reinvestments.

Miscellaneous costs, costs for administration etc. account for approx. 8 % of the total expenses regarding the geothermal energy plant.

**Total specific investment costs for the geothermal energy plant**

The total investment (M€/site and M€/$MW_{th\_total}$) is calculated on a plant design of 2 production wells and 4 reinjection wells. If a different plant size is desired, the plant design can be changed by increasing the amount of production wells. Please note that the stated effects for direct exchange and heat source for a heat pump in the note-column is not updated automatically! The given investments stated at M€/site are valid for a plant design of 1-3 production wells and correspondingly 2-6 reinjection wells. If a larger plant is desired, a number of smaller plants should be aggregated to get a valid estimate of expenses for pre-study.

The assessment of values for the variety of price components is based on the data collection. The most precise prices are given for the dwelling costs, which for all plants lies in the range 1,800-1,900 €/m. The data sources for other costs like the costs of developing a test well to full-standard production well are only specified for few plants. The costs for accompanying heat pumps are based on the Energy Technology Data Catalogue (absorption heat pumps) or PlanEnergi's estimation for 2019 (electric heat pumps). Scenarios 2.a and 2.b do include CAPEX for a boiler to supply drive energy for an absorption heat pump, which must be added if no boiler does exist. The price estimate is based on the central nominal investment estimate for wood chip HOP (ch. 9) in Ref. 4[5].

**Applying Upper and Lower Limits**

As mentioned above, the economic risk of technology costs for geothermal energy projects is best described in a milestone-model, as the technical circumstances (no available geothermal reservoir) may eliminate the technical possibility of a geothermal energy plant. However, lower and upper limits for the performance and expenses of geothermal wells are applied in the datasheet. These estimates are based on different plant design and contingency costs, in order to illustrate certain lower and upper limits of performance. For this, the following parameters are adjusted:

- For lower estimate:
  - Larger project of 3 production wells
  - High permeability, allowing flow of 180 $m^3$/hour/production well
  - Increased permeability leading to the same permeability at production and reinjection wells (no redundant wells necessary)
  - Electricity consumption for submersible pumps reduced to 0.02 $kWh_{el}/kWh_{geoth}$
  - Full load hours increased to 5,000 / year
  - Miscellaneous, unforeseen costs reduced to 5 %
- For upper estimate:
  - Smaller project of 1 production wells
  - Lower permeability, allowing flow of 120 $m^3$/hour/production well
  - Similar permeability leading to same flow at reinjection well as ratio in central estimate
  - Electricity consumption for submersible pumps increased to 0.09 $kWh_{el}/kWh_{geoth}$
  - Full load hours reduced to 3,000 / year
  - Miscellaneous, unforeseen costs increased to 10 %

[5] Danish Energy Agency and Energinet, *Technology Data - Energy Plants for Electricity and District heating generation*, 2019, v. 0005.

# 5 Conclusion and Perspectives

Seven geothermal plants are considered for their geothermal conditions in this study: Thisted, Margretheholm, Sønderborg, Lund, Neustadt-Glewe, Neubrandenburg, Pijnacker-Nootdorp, Gross Schönebeck, Pyrzyce, Stargard and Torun. The Margretheholm and Sønderborg plants are excluded from further analysis due to construction issues and pronounced technical problems. The Pijnacker-Nootdorp and Gross Schönebeck plants were de-selected due to geological issues. There is, however, a high probability that the geological development of the Thisted, Neustadt-Glewe, Neubrandenburg, Pyrzyce, Stargard and Torun reservoir sandstones is similar. In addition, the reservoir properties and reservoir characteristics of these sandstones are comparable. The study thus focuses on the latter six plants.

The energetical and economic key figures on investment and operation expenses for geothermal energy production for district heating in Denmark is outlined in detail in the related technology data sheets. A summary of the energetical key figures is presented in Table 4. As can be seen, the different plant designs vary significantly in capacity and energy consumption for drive energy. This is due to the higher efficiency (SCOP) of electrical heat pumps, compared to absorption heat pumps. Furthermore, the differences in the consumption of drive energy between scen. 1.a/3.a and 1.b/3.b indicate the effects of lowering the temperature of the connected district heating grid and thus increasing the efficiency of the heat pump. The electricity consumption for submersible pumps varies only little between the different reference plants.

| | Heat pump type | | DH temp. [°C] | Thermal effect | Heat production | El. cons., pumps | Drive energy |
|---|---|---|---|---|---|---|---|
| Scen. | El. | Abs. | $T_{supply}/T_{return}$ | [$MW_{total}$ ($MW_{geo}/MW_{HP}$)] | [$GWh_{total}/a$ ($GWh_{geo}$)] | [GWh/a] | [GWh/a (el./th.)] |
| 1.a | X | | 80/40 | 11,4 (9,4 / 2) | 45,7 (37,6) | 1,9 | 8 (el.) |
| 1.b | | | | 13,2 (12,2 / 1) | 52,6 (48,8) | 2,4 | 3,8 (el.) |
| 2.a | | X | | 22,9 (9,4 / 13,4) | 91,4 (37,6) | 1,9 | 53,8 (th.) |
| 2.b | | | | 17,7 (12,2 / 5,5) | 70,7 (48,8) | 2,4 | 21,9 (th.) |
| 3.a | X | | 70/35 | 10,9 (9,4 / 1,5) | 43,7 (37,6) | 1,9 | 6,1 (el.) |
| 3.b | | | | 12,7 (12,2 / 0,5) | 50,6 (48,8) | 2,4 | 1,8 (el.) |

**Table 4:** Key energy data cf. the technology data sheets. Please refer to **Table 3** for a full overview on the characteristics of the scenarios.

A summary of the economic key figures is presented in

| | Heat pump type | | $CAPEX_{total}$ | CAPEX | CAPEX |
|---|---|---|---|---|---|
| Scen. | El. | Abs. | [M€ (M€geoth / M€add.)] | [M€/$MW_{th\_geo}$] | [M€/$MW_{th\_total}$] |
| 1.a | X | | 34,6 (25,4 / 9,2) | 2,7 | 3 |
| 1.b | | | 38,9 (35,1 / 3,8) | 2,9 | 3 |
| 2.a | | X | 50,7 (25,4 / 14,4) | 2,7 | 2,2 |
| 2.b | | | 41,7 (35,1 / 2,2) | 2,9 | 2,4 |
| 3.a | X | | 32,9 (25,4 / 7,4) | 2,7 | 3 |
| 3.b | | | 37,2 (35,1 / 2,1) | 2,9 | 2,9 |

Table 5. As can be seen, the different plant designs vary significantly in total investments, but only little in specific investments (M€/$MW_{th\_geo}$ and M€/$MW_{th\_total}$)**Fejl! Bogmærke er ikke defineret.**. In a comparative study, the below presented investment costs must be paired with corresponding operational cost, as there are major differences in energy consumption for drive energy, cf. Table 4.


| | Heat pump type | | $CAPEX_{total}$ | CAPEX | CAPEX |
|---|---|---|---|---|---|
| Scen. | El. | Abs. | [M€ (M€geoth / M€add.)] | [M€/$MW_{th\_geo}$] | [M€/$MW_{th\_total}$] |
| 1.a | X | | 34,6 (25,4 / 9,2) | 2,7 | 3 |
| 1.b | | | 38,9 (35,1 / 3,8) | 2,9 | 3 |
| 2.a | | X | 50,7 (25,4 / 14,4) | 2,7 | 2,2 |
| 2.b | | | 41,7 (35,1 / 2,2) | 2,9 | 2,4 |
| 3.a | X | | 32,9 (25,4 / 7,4) | 2,7 | 3 |
| 3.b | | | 37,2 (35,1 / 2,1) | 2,9 | 2,9 |


**Table 5:** Key economic data cf. the technology data sheets. Please refer to **Table 3** for a full overview on the characteristics of the scenarios.

# 6 Literature

Ura-Binczyk et al., 2019: On-site monitoring and laboratory characterization of corrosion processes in the geothermal water of Polish Lowland. Geothermics, v. 77, pp. 267–277.

Hans Doornenball and Alan Stevenson (eds.), 2010: Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications.

Nicole Pastrik and Andrea Förster, 2017: GEOTHERM Project. Experiences gained from German geothermal plants. A synopsis. GFZ, Potsdam.

Michael Erlström, 2017: GEOTHERM Project. The Lund Geothermal System. Background, design and review of operational experiences. Lund University, Department of Geology.

Gorecki, Hajto, Strzetelski, and Szczepanski, 2010: Lower Cretaceous and Lower Jurassic aquifers in the Polish Lowlands. Prz. Geol., 58, pp. 589–593.

Weber, Barn and Moeck, 2019: Germany Country update. Proceedings European Geothermal Conference 2019.

Kepinska, 2019: Poland Country update. Proceedings European Geothermal Conference 2019.

Provoost, Albeda, Godschalk, van der Werf and Schoof, 2019: Netherlands Country update. Proceedings European Geothermal Conference 2019.

Poulsen, Bjørn, Mathiesen, Nielsen, Vosgerau, Vangkilde-Pedersen, Ditlefsen and Røgen, 2019: Denmark Country update. Proceedings European Geothermal Conference 2019.

Data supplied by the operating companies (Swedish, German and Polish plants).

GEUS WebGIS portal http://dybgeotermi.geus.dk/geotermikort/

# Annex A: Presentation of evaluated geothermal sites

**Thisted, Denmark**

The plant was established in 1984, and it includes one production well and two injection wells. The reservoir depth is 1150–1250 m, and the average porosity of the sandstones is c. 25%. The permeability varies considerably throughout the reservoir section and an average permeability of 1600 mD is estimated. Additional reservoir parameters are listed in Table 1, details on production and operational issues are given in Table 2. Gravel-packs and screens are installed in the wells. A reduced injectivity has been observed during recent years, and therefore a supplementary injection well (Thisted-5) was drilled in 2018.

The reservoir section consists several sandstone layers separated by clayey intervals. The Thisted plant produces from sandstones belonging to the Upper Triassic–Lower Jurassic Gassum Formation. The geology and reservoir aspects of the Gassum Formation is outlined above.

**Lund, Sweden**

The age of the Lund plant is about 35 years, and the plant system includes several production and injection wells. The reservoir depth is only c. 650 m (500–800 m), and the average porosity is very high, c. 30% (25–32%). Similar, the permeability of the reservoir sandstones is extremely high, on average c. 4500 mD. Refer to Table 1 for additional information about reservoir parameters, details on production and operational issues are given in Table 2. Gravel-packs and screens are installed in the wells. Only insignificant injectivity problems have been detected until now. So far, only minor corrosion of the casing has been observed. However, hydro-jetting of screens was carried out in 2012, and annual air lifting with compressors takes place.

The reservoir section consists of loose sand/sandstones, occasionally interbedded with clay and limestone beds. Geologically, the sandstones belong to the Höllviken Formation (Lund Member) of Cretaceous (Campanian) age. The mineralogical composition of the reservoir rock is primarily quartz and feldspar with minor calcite cement. The depositional environment is predominantly marine and deltaic.

**Neustadt-Glewe, Germany**

The plant is located in Mecklenburg-Vorpommeren (NE Germany), and the age of the plant is about 26 years. The plant is constructed as a geothermal doublet with one production well and one injection well. The reservoir depth is about 2300 m (2240–2320 m), and the average porosity is in the order of 21% (15–25%). The average permeability is about 700 mD, and it is noteworthy that the salinity of the formation brine is very high (TDS: 227 g/L). Refer to Table 1 for additional information about reservoir parameters, details on production and operational issues are given in Table 2. A gravel-pack is installed in the injection well, whereas an open-hole completion is used in the production well. The plant only experiences minor injectivity problems, but there are problems related to scaling (iron-hydroxides deposits) and electro-chemical corrosion. A regular acid stimulation was performed to remove precipitated minerals such as calcite, hydroxide and sulfide precipitation. Furthermore, the geothermal loop has been pressurized with nitrogen to avoid degassing and precipitation. It is planned to drill a new injection well within the next 5 – 10 years if injectivity continues to decrease.

The reservoir consists of sandstones, occasionally interbedded with clay beds. The sandstones belong to the Late Triassic Exter Formation (Rhätian age), and the reservoir rock is named 'Contorta Sandstone'. The mineralogical composition of the reservoir rock is primarily quartz and feldspar with small amounts of carbonates.

**Neubrandenburg, Germany**

The plant is located in Mecklenburg-Vorpommeren (NE Germany), and the age of the plant is about 30 years. The plant includes two production and two injection wells, but only one production and one injection well are in operation. The plant is a combined geothermal and heat storage plant (the storage is based on the Aquifer Thermal Energy Storage system). The average reservoir depth is 1250 m, and the porosity is high, approximately 30% (25–33%). The average permeability is in the order of 800 mD. Refer to Table 1 for additional information about reservoir parameters, details on production and operational issues are given in Table 2. Gravel-packs and screens are installed in the wells. Previously, the plant experienced corrosion problems, but now composite casing replaces iron casing to avoid corrosion. Furthermore, stainless steel production pumps are installed, also with the objective to avoid corrosion. The geothermal loop has been pressurized with nitrogen to avoid degassing and precipitation.

The reservoir consists of sandstones, occasionally interbedded with clay beds. The geothermal water production takes place from two reservoir sandstones of Late Triassic (Rhätian) age: the 'Postera Sandstone', and the 'Contorta Sandstone' belonging to the Exter Formation. The re-injection of the geothermal water and the heat storage involve, on the contrary, Lower Jurassic sandstones. The mineralogical composition of the reservoir rock is primarily quartz and feldspar with small amounts of clays and carbonates. The depositional environment is predominantly fluvio-deltaic, but also channel fill and alluvial (fan) settings are represented.

**Pyrzyce, Poland**

The plant is located in NW Poland, and the geothermal production started in the beginning of 1990. The configuration is based on vertical wells, i.e. two production wells and two injection wells. The reservoir depth is about 1550 m, and the average porosity of the reservoir sandstones is c. 20%. The average permeability is about 1100 mD. Refer to Table 1 for additional information about reservoir parameters, details on production and operational issues are given in Table 2. The geothermal brine is quite aggressive and characterized by a high content of sulphate ($SO_4$) along with dissolved gasses such as $CO_2$ and $H_2S$, leading to corrosion of the carbon steel installations (Ura-Binczyk et al., 2019). The volume of corrosion products and the magnitude of the corrosion rate are managed through a monitoring program combined with various electrochemical techniques.

The reservoir consists of sandstones with minor amounts of claystones. The producing sandstones are of Early Jurassic age and these sandstones, located in the Mid Polish Trough, correlate to sandstones that are present in the North German Basin and the Danish Sub-basin (Figure 3). The depositional environment is predominantly shallow-marine to fluvio-deltaic as described in 'Atlas of the Southern Permian Basin Area'.

**Stargard, Poland**

The plant is located in NW Poland close to the Pyrzyce plant, and the geothermal production started in the beginning of 2000. The plant system includes one production well and two injection wells, and the reservoir depth is about 2600 m. Refer to Table 1 for additional information about reservoir parameters, details on production and operational issues are given in Table 2. The plant produces from a Lower Jurassic sandstone aquifer like the Pyrcyze aquifer. The geological age and depositional environment also correspond to that of the Pyrzyce sandstone reservoir (see text above).

**Torun, Poland**

The plant is located in the northern part of Poland about 200 km east of the Pyrzyce and Stargard plants. The plant is under construction and the operator expects to start production of geothermal water in 2020. So far, the plant system includes one production well and one injection well, and the reservoir depth is about 2200 m. Not all reservoir parameters are known for the time being. Nevertheless, reference is made to Table 1 and Table 2 as these tables provide some information about reservoir parameters, production and operational issues.

Both Lower Jurassic and Lower Cretaceous sandstones with very good reservoir properties are present in the Torun area (Gorecki et al., 2010). The operating company signifies that the Torun plant produces from the Lower Jurassic aquifer. The operator also provided information about reservoir parameters including permeability, and these reasonably high values indicate that the producing sandstone aquifer is similar to that of Pyrcyze.

| Plant or Site | Location: Geological Basin | Reservoir depth (m) | Geological age (period) | Porosity of sandstone (%) | Perm. of sandstone (mD) | Gross sand (m) | Net sand (m) | Reservoir temp. deg.C | Geochem. TDS (g/L) |
|---|---|---|---|---|---|---|---|---|---|
| Margretheholm, DK | Danish subbasin | 2500 | Triassic | 20 | 400 | 137 | 30 | 73 | 218 |
| Thisted, DK | Danish subbasin | 1200 | Triassic-Jurassic | 25 | 1600 | 95 | 30 | 45 | 167 |
| Sønderborg, DK | N. German Basin | 1150 | Triassic-Jurassic | 28 | 4000 | 40 | 30 | 47 | 164 |
| Lund, S | Danish subbasin | 650 | Cretaceous | 30 | 4500 | 150 | 25 | 21 | 60 |
| Gross Schönebeck, D | N. German Basin | 4200 | Permian | 15 | N/A | N/A | N/A | N/A | N/A |
| Neustadt-Glewe, D | N. German Basin | 2300 | Triassic | 21 | 700 | 80 | 67 | 98 | 227 |
| Neubrandenburg, D | N. German Basin | 1250 | Triassic-Jurassic | 30 | 800 | 40 | 29 | 54 | 130 |
| Pijnacker-Nootdorp, NL | W. Netherlands Basin | 2050 | Jurassic-Cretaceous | 16 | N/A | N/A | N/A | N/A | N/A |
| Pyrzyce, PL | Mid Polish Trough | 1550 | Early Jurassic | 20 | 1100 | 150 | 100 | 64 | 120 |
| Stargard, PL | Mid Polish Trough | 2600 | Early Jurassic | unknown | unknown | 246 | 150 | 83 | 146 |
| Torun*, PL | Mid Polish Trough | 2200 | Early Jurassic | 20 | 1400 | 300 | 171 | 65 | 120 |

**Table 1:** *Approximate reservoir parameters for selected water-bearing sandstones at various plant locations.*
*(*) Under construction*

| Plant Or Site | Number of production wells | Number of injection wells | Vertical or deviated wells | Gravel pack installed | Screens installed | Flow in (m3/h) | Energy prod. (GWh/year) | Heat capacity (MW) | Design of plant (system) |
|---|---|---|---|---|---|---|---|---|---|
| Margretheholm, DK | 1 | 1 | Deviated | no | no | 200 | 58 | 14 | Doublet |
| Thisted, DK | 1 | 2 | Vertical | yes | yes | 170 | 22 | 7 | Several wells |
| Sønderborg, DK | 1 | 1 | Deviated | yes | yes | 75 | unknown | 12 | Doublet |
| Lund, S | 4 | 6 | Both | yes | yes | 1650 | 175 | 31 | Several wells |
| Gross Schönebeck, D | 1 | 1 | Both | no | no | unknown | unknown | unknown | Doublet |
| Neustadt-Glewe, D | 1 | 1 | Vertical | yes | yes | 80 | 18 | 4 | Doublet |
| Neubrandenburg, D | 1 | 1 | Vertical | yes | yes | 80 | 9 | 4 | Several wells |
| Pijnacker-Nootdorp, NL | 1 | 1 | Deviated | unknown | N/A | N/A | 41 | 7 | Doublet |
| Pyrzyce, PL | 2 | 2 | Both | yes | yes | 120 | 33 | 6 | Several wells |
| Stargard, PL | 1 | 2 | Both | unknown | No | 160 | 64 | 12 | Doublet |
| Torun*, PL | 1 | 1 | Vertical | yes | yes | 320 | 89 | 19 | Doublet |

**Table 2**: *Technical details on wells, installations, production and operational issues. Geothermal part only.*
*(*) Under construction*

# Annex B: Calculation of direct heat exchange and COP

In the cases, when the temperature of the geothermal reservoir exceeds the return temperature of the district heating system by more than the temperature difference of a heat exchanger, direct heat exchange is assumed. As much heat as possible is suggested to be exchanged directly. The remainder is suggested to be used as a heat source for a heat pump (absorption or electrically driven compressor heat pump).

An energy balance calculation is performed to calculate the effects for direct heat exchange and heat source for a heat pump of a given reservoir, respectively, at the given scenarios, cf. the datasheets.

The calculation is based on the following **assumptions for scenario 1.b** (some factors derived, based on given temperatures, resulting in slight deviations across scenarios):

- Flow, reservoir temperature, cooling of reservoir: Varying, cf. datasheets
- $\rho_{\text{DH-water}}$: 980 kg/m$^3$
- $c_{p\text{ DH water}}$: 4,19 kJ/(kg*K)
- $\rho_{\text{geoth.-water}}$: 1.120 kg/m$^3$
- $c_{p\text{ geothermal water}}$: 3,50 kJ/(kg*K)
- $\Delta T_{\text{heat exchanger}}$: 4K

- $V_{\text{geothermal}}$: 320 m$^3$/h
- $V_{\text{DH}}$[6]: 288 m$^3$/h
- $T_{\text{reservoir}}$: 68°C
- $\Delta T_{\text{reservoir}}$: 35K
- $T_{\text{DH\_supply}}$: 80°C
- $T_{\text{DH\_return}}$: 40°C

Total thermal effect of the geothermal reservoir:

$$V_{geothermal} * \rho_{\text{geothermal water}} * c_{\text{p geothermal water}} * \Delta T_{reservoir}$$

The total thermal effect of the entire system[7], consisting of the direct heat exchange, geothermal energy as heat source for the heat pump and drive energy of the heat pump is described as:

$$Q_{Out_{total}} = Q_{direct} + Q_{HP_{evap.}} + P_{HP}$$

The reservoir can only be cooled directly to $T_{\text{DH\_return}} + \Delta T_{\text{heat exchanger}}$, i.e.:

$$Q_{direct} = V_{geothermal} * \rho_{\text{geothermal water}} * c_{\text{p geothermal water}} * (T_{\text{reservoir}} - (T_{\text{DH\_return}} + \Delta T_{\text{heat exchanger}}))$$

The temperature of the district heating return flow after the direct heat exchange, which then is led into the heat pump as cold medium on the hot side, is described as:

$$T_{DH_{input}} = T_{DH\_return} + \frac{Q_{direct}}{V_{DH} * \rho_{water} * c_{p\ water}}$$

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[6] Calculated for the specific constellation with the given temperatures and flow on primary side to achieve energy balance.

[7] In the data sheet stated as $MW_{\text{th\_total}}$.

In scenario 1.b, the above means that $Q_{direct}$ = 8.36 MW and $T_{DH_{input}}$ = 65.5°C, leaving 3.83 MW for the evaporator of a heat pump at 44°C.

The following is thus entered into the simple calculation tool for heat pumps, developed by PlanEnergi[8] as input parameters:

- $T_{DH_{input}}$: 65.5°C
- $T_{DH_{supply}}$: 80.0°C
- $T_{Geothermal_{input}}$: 44.0°C
- $T_{Geothermal_{return}}$: 33.0°C
- Lorentz-efficiency: 50%

This returns a COP for the heat pump ($COP_{HP}$) at the given point of operation, in this case 5.05.

The necessary drive energy for the heat pump is calculated as:

$$P_{HP} = \frac{Q_{HP_{evap.}}}{COP_{HP} - 1}$$

A system COP is then calculated as:

$$COP_{system} = \frac{Q_{Out_{total}}}{P_{HP}}$$

Due to large amounts of produced heat that is supplied without using drive energy in a heat pump, a comparably high $COP_{system}$ of 13.89 is achieved.

Regarding the $COP_{system}$ it must be noted that the system does not include the electricity for submerged pumps as the system boundaries are set around the heat exchanger and heat pump(s). The electricity consumption for submerged pumps is stated specifically for the given scenario in the data sheets.

[8] http://planenergi.dk/arbejdsomraader/fjernvarme/varmepumper/drejebog-til-store-varmepumpepro-jekter-i-fjernvarmesystemet/
The use of the simple heat pump calculation tool is free of charge. A COP for a given, user defined point of operation is calculated based on a Lorentz-efficiency approach (default 50 %).