HEATSTORE
National screening process for Underground Thermal Energy Storage (UTES) sites in Denmark

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HEATSTORE (170153-4401) is one of nine projects under the GEOTHERMICA – ERA NET Cofund aimed at accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximise geothermal heat production and optimise the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe.

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About HEATSTORE

High Temperature Underground Thermal Energy Storage

The heating and cooling sector is vitally important for the transition to a low-carbon and sustainable energy system. Heating and cooling is responsible for half of all consumed final energy in Europe. The vast majority – 85% - of the demand is fulfilled by fossil fuels, most notably natural gas. Low carbon heat sources (e.g. geothermal, biomass, solar and waste-heat) need to be deployed and heat storage plays a pivotal role in this development. Storage provides the flexibility to manage the variations in supply and demand of heat at different scales, but especially the seasonal dips and peaks in heat demand. Underground Thermal Energy Storage (UTES) technologies need to be further developed and need to become an integral component in the future energy system infrastructure to meet variations in both the availability and demand of energy.

The main objectives of the HEATSTORE project are to lower the cost, reduce risks, improve the performance of high temperature (~25°C to ~90°C) underground thermal energy storage (HT-UTES) technologies and to optimize heat network demand side management (DSM). This is primarily achieved by 6 new demonstration pilots and 8 case studies of existing systems with distinct configurations of heat sources, heat storage and heat utilization. This will advance the commercial viability of HT-UTES technologies and, through an optimized balance between supply, transport, storage and demand, enable that geothermal energy production can reach its maximum deployment potential in the European energy transition.

Furthermore, HEATSTORE also learns from existing UTES facilities and geothermal pilot sites from which the design, operating and monitoring information will be made available to the project by consortium partners.

HEATSTORE is one of nine projects under the GEOTHERMICA – ERA NET Cofund and has the objective of accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximize geothermal heat production and optimize the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe. The three-year project will stimulate a fast-track market uptake in Europe, promoting development from demonstration phase to commercial deployment within 2 to 5 years, and provide an outlook for utilization potential towards 2030 and 2050.

The 23 contributing partners from 9 countries in HEATSTORE have complementary expertise and roles. The consortium is composed of a mix of scientific research institutes and private companies. The industrial participation is considered a very strong and relevant advantage which is instrumental for success. The combination of leading European research institutes together with small, medium and large industrial enterprises, will ensure that the tested technologies can be brought to market and valorised by the relevant stakeholders.

Document Change Record

This section shows the historical versions, with a short description of the updates.

Version	Short description of change
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1 Introduction

To further the development of storing excess heat from e.g. district heating companies, power plants, waste incineration and industry an initial screening process has been conducted in Denmark. The screening aims to identify potential areas for Underground Thermal Energy Storage (UTES) as well as technical or legislative barriers against establishment of storage sites.

To aid in the decision-making process a web tool has been developed with access to a variety of information specific to heat storage. This report summarizes the screening process applied in the project "Evaluation of the potential for geological heat storage in Denmark, EUDP 1887-0017"[1], for further use in the HEATSTORE project.

2 Screening process

For the screening process, relevant open source data have been collected, analyzed and made available through a heat storage online web service[2]. The screening process has involved identifying areas feasible for subsurface heat storage focusing on geology, groundwater, distribution of district heating companies and legislation. Finally, the number of district heating companies within identified areas have been assessed to give a first indication of the potential for UTES in Denmark.

The screening process focusses mainly on near surface reservoirs and evaluates sedimentary deposits to a depth of 300 m. Here, temperature restrictions apply according to the current legislation, not allowing injection temperatures higher than 25 degrees Celsius. A local/regional study of heat storage in chalk deposits down to a depth of 1000 m has been conducted in a previous project[3] (HTES, EUDP 64016-0014), but only shallow limestone/chalk deposits has been evaluated as part of this screening process. On the island of Bornholm, potential sites in areas with bedrock have also been assessed.

The deep geothermal heat storage potential has also not been evaluated nationwide as part of this screening process, but an initial evaluation and reservoir modelling of a sandstone interval at an approximate depth range of 700-1500 m near the city of Aalborg has been conducted as a case study. Furthermore, a comprehensive online web service[4] established in previous projects with information on the potential for deep geothermal energy is also highly relevant for heat storage. This online service offers information on depth, thickness and properties of sandstone reservoirs at a depth range between 800-3000 m.

3 Storage types

Four types of geological heat storage have been assessed in the screening process. Each type requires different geological conditions to optimize the efficiency of the heat storage system. A thorough review on UTES storage types has been conducted by Kallesøe and Vangkilde-Pedersen[5].

3.1 ATES

An ATES system uses groundwater from suitable aquifers to create a cold storage and a warm storage in the subsurface. It is done by using well doublets and injecting cold or warm groundwater into the aquifer. The groundwater can later be extracted and used seasonally for heating or cooling before reinjection into the aquifer again.

[1] GEUS, 2019: Evaluation of the potential for geological heat storage in Denmark. EUDP 1887-0017, Final report.
[2] https://eng.geus.dk/products-services-facilities/data-and-maps/heat-storage-map-and-data/
[3] Kristensen, L, Mathiesen, A., Nielsen, C. M., Bjergager, M., Ditlefsen, C., Møller, I. Rasmussen, P., Nielsen, L. H. & Sonnenborg, T. 2017: Examining the possibilities of establishing thermal storage in the chalk/limestone aquifer in the greater Copenhagen area. GEUS RAPPORT 2017/22.
[4] https://dybgeotermi.geus.dk/en/main/
[5] Kallesøe, A.J. and T. Vangkilde-Pedersen, (Eds.), 2019: Underground Thermal Energy Storage (UTES) – state-of-the-art, example cases and lessons learned. HEATSTORE project report, GEOTHERMICA – ERA NET Cofund Geothermal.

An ATES system requires an aquifer where it is possible to extract the necessary amount of groundwater to yield the desired energy output as well as injecting the groundwater after heat transfer. At the same time, it is important that the hydraulic conductivity/groundwater flow is not so high as to remove the storage plumes from around the wells.

ATES systems can also be used only as storage for excess heat from sources that periodically creates a surplus. The stored heat can later be retrieved and used, thereby expanding the district heating companies supply and creating a buffer for situations with either peaks or lows in the production. Aquifers down to 300 m have been part of the screening process.

3.2 BTES

BTES systems circulate hot brine in closed loop tubes installed in boreholes thereby heating the surrounding geological formation. To retrieve the heat, cold brine is circulated in the boreholes thereby being heated by the formation. To prevent cooling of the formation and losing energy from the system, it is preferable to place the systems in areas with no or very little groundwater flow. The screening process has therefore focused on areas with large unsaturated zones, areas with highly plastic and impermeable clays and areas with bedrock where groundwater flow will be limited. Local clay tills have not been part of the screening process, but these may also offer prospects for BTES systems, though they require analysis of groundwater flow specific to the chosen area.

3.3 HT-ATES

HT-ATES systems have been investigated as a case study for deeper lying sandstone formations close to the city of Aalborg. Knowledge of porosity, permeability, thickness and content of pure sandstone are essential for this type of system. This screening has shown that higher quantity and quality of seismic data are necessary to properly investigate the potential for HT-ATES in the specific area.

3.4 Hybrid storage

A hybrid storage system, which combines BTES and PTES technologies, has been assessed in the screening. The combination ensures larger capacity from the BTES system utilizing the fast reacting PTES system both as a buffer storage and permanent storage. The geological conditions required for a hybrid system are similar to that of BTES.

4 Screening data

Available national open source data for the screening process have been collected and evaluated. Data include information from the national borehole database Jupiter[6] where geological and hydrological data from boreholes are collected. Geological data include information on soil type and layer boundaries, whereas hydrogeological data provide information on aquifer transmissivity, geochemistry and hydraulic head.

Environmental data and administrative data including data on heat producing companies, protected environmental areas, soil contamination and reports on the national groundwater mapping have been collected from The Danish Energy Agency, The Danish Environmental Portal and The Danish Environmental Protection Agency.

5 Location

Optimal location of UTES depends on several factors such as subsurface geology and groundwater flow, as well as more specific local interest in an area in regards to drinking water extraction and industry.

In Denmark, groundwater is used for drinking water purposes and has therefore been mapped according to importance for the water supply. Special regulation applies to areas classified as designated groundwater protection areas.

[6] https://eng.geus.dk/products-services-facilities/data-and-maps/national-well-database-jupiter/

UTES can potentially be placed in designated groundwater protection areas, but will most probably require relatively extensive documentation and initial flow modelling. To develop methods for feasibility screening for possible UTES sites within these areas will require further research, as the potential will vary depending on distance to boreholes used for water supply, availability and quality of the groundwater resource as well as plans for using the resource. Potential sites for ATES systems within designated groundwater protection areas therefore awaits presentation in the web application[2] at present.

Placing BTES systems within these areas are considered less of a risk because preferred sites will be areas with little or no groundwater flow, thereby minimizing risk to local groundwater supply. An individual assessment at such sites is required though.

6 Assessment of suitable areas for UTES

Thorough examination of all available data has led to classification of potential areas for UTES systems.

6.1 ATES

For ATES three different geological settings have been recognized and mapped using existing geological maps and models:

- Shallow sandy aquifers
- Shallow limestone/chalk aquifers
- Deeper sandy aquifers with poor groundwater quality

For sand aquifers, the areas shown are greater than 1 km^2, and to enhance the likelihood of the aquifer being saturated, only areas below level +25 m are considered. These areas are most commonly found in relation to meltwater plains, but areas dominated by freshwater deposits are also found.

For chalk and limestone aquifers, there has been an evaluation of borehole data to avoid dislocated blocks caused by glacial tectonics and ensure that the layers are in situ. Only areas where the depth to the limestone/chalk is less than 25 m are taken into consideration. Whether the chalk and limestone layers have a permeability suited for ATES has not been evaluated in this screening, but permeability is estimated to be highest in the upper 10-15 m of the limestone/chalk succession according to other studies[7]. Placing UTES in fault zones is an option for ATES, since fault zones often provide a high permeability, which makes for easier extraction and injection of groundwater. The risk of losing the stored heat to fast moving groundwater flow must, however, be assessed for the specific fault zone[3].

Deeper lying sand aquifers with poor water quality have been mapped in areas outside designated groundwater protection areas. These aquifers might in the future be used for ATES systems with higher temperatures than otherwise accepted by legislation. Further research focusing on biological and chemical changes in the aquifer as a response to the greater temperature changes need to be conducted though. The aquifers have been identified using local geological models and data on groundwater geochemistry.

Existing traditional ATES systems with seasonal heating and cooling or only groundwater cooling operates within a set temperature range defined by Danish legislation with maximum temperatures of 25 degrees Celsius. A study from 2009[8] shows that injection of 30 degrees warm water did not lead to critical increase in microbial growth in the aquifer during normal operation of an ATES system.

6.2 BTES

For BTES three different geological settings have been recognized and mapped using existing geological maps, borehole information and geological models:

- Unsaturated sediments
- Impermeable “plastic” clays
- Impermeable bedrock

[7] Klitten, K., F. Larsen, and T.O. Sonnenborg, 2006: Saltvandsgrænsen i kalkmagasinerne i Nordøstsjælland. GEUS.
[8] Naturstyrelsen, 2016: Mikrobiologisk risikovurdering af øgede temperaturer i grundvandet ved ATES.

For BTES systems groundwater data containing information on water level soundings were analysed and areas with more than 20 m to the saturated zone were mapped. Data from a BTES test site shows that heat dispersion downwards is very small and it is therefore possible to place BTES systems within designated groundwater protection areas[1].

Highly plastic clays are considered impermeable with no groundwater flow and are regarded as potential sites for BTES. Geological information from borehole data have been analysed to ensure in situ formations of clays as opposed to dislocated slabs caused by glacial tectonics. Only areas with less than 25 m to the top of the clay formations are shown.

Lastly, areas with hard bedrock have been identified. These areas are considered relatively impermeable if outside fault zones and below weathered subsoil, but has a limited extent in Denmark on the island of Bornholm only.

6.3 HT-ATES

The potential for HT-ATES in the Aalborg area has been assessed as part of the screening process and the investigation has found that several deeper sandstone layers exist with the potential for heat storage. It is recommended that further research, such as collecting seismic data and borehole data, is carried out to determine the parameters of the reservoirs as well as identify fault zones in the area.

To identify areas with potential for HT-ATES nationwide, initial information can be found on the geothermal online web service[4] mentioned above, but will require further investigations.

7 Numerical modelling

When estimating the efficiency of a future UTES system it is important to evaluate groundwater flow and thermal flow in the formation and generalized modelling scenarios have been conducted in the national screening process[1].

For ATES systems, it is found that the most important parameters are hydraulic conductivity and aquifer thickness. The systems are most efficient when hydraulic conductivity is high, but they are very sensitive to a high natural groundwater flow, which results in high energy loss. Cold, near surface aquifers are optimal for traditional ATES systems with seasonal heating and cooling, whereas deeper and warmer aquifers favour systems for heat storage.

Efficiency of BTES systems depends on the ratio between storage volume and surface area, as well as the thermal conductivity of the soil and the construction of an insulating lid. High thermal conductivity favours the speed of charging/discharging the storage, but also results in greater heat loss. It is found that the surrounding soil volume are only slightly affected by heat storage because heat transport in the geological sediments occur very slowly, but the heat loss should nevertheless be taken into consideration.

8 District heating companies

As energy production in Denmark increasingly stems from renewable energy sources, some of which produce surplus of energy and heat for shorter or longer periods of time, so arises the opportunity for UTES systems. The capacity needed by the district heating companies varies greatly depending on the production size and the energy source used, and UTES systems need to be individually adapted.

For district heating companies placed in cities, UTES offers a way of storage in areas with limited space. The location of existing district heating companies is shown on the heat storage online web service[2]. This gives an easy overview of types of UTES that are suitable for a particular plant, though other types of UTES may still be optional with further study of the local subsurface conditions. An overview of the number of district heating companies within potential areas for UTES is shown in Table 1 below.

Table 1 Number of district heating companies within potential areas for UTES

Type of area	Number of district heating companies
Shallow sandy aquifers (ATES)	264
Shallow limestone/chalk aquifers (ATES)	103
Deeper sandy aquifers with poor groundwater quality (ATES)	25
Unsaturated sediments (BTES)	70
Impermeable "plastic" clays (BTES)	23
Impermeable bedrock (BTES)	7

9 Legislation

At present, heat storage is regulated by The Environmental Protection Act supplemented by The Environmental Impact Assessment Act and The Danish Subsoil Act for deeper applications.

ATES systems are further regulated by the Act on Heat Extraction plants and Groundwater Cooling Systems and supplemented by The Water Supply Act. The legislation sets up a number of requirements, such as temperature limitations, feasibility studies and initial calculations. At present, legislation for ATES emphasizes the importance of thermal equilibrium and avoidance of mixing different groundwater types as well as preventing unwanted chemical reactions and transport of pollutants. The establishment of a UTES system are not allowed to cause any effect on the drinking water supply and natural habitats.

A specific act exists for closed loop ground source heating covering both horizontal and borehole heat exchangers, but only takes heat production and not heat storage into consideration and in practice no legislation currently exists for BTES.

As part of the screening, a review of the legislation has been conducted for the application of UTES. The conclusions are that there is a need for more specific legislation in regards to UTES. Several of the storage types are not covered specifically by the regulation, and permits are granted according to the general rules for soil and groundwater as well as dispensation evaluations.

It is recommended to create specific legislative guidelines for UTES systems. The guidelines should include a comprehensive review of the present legislation and technical knowledge on the subject. From the UTES industry, a desire for certification of involved parties has been mentioned as well as regular inspection of UTES systems by certified personnel.

Based on the relatively limited 2009 study[8] it is recommended to allow for further test of storage at higher temperatures in aquifers and eventually adjust the legislation to allow ATES systems reinjection of higher temperature groundwater (30 degrees Celsius) where this is considered safe. This will, however, still not take high temperature heat storage at e.g. 90 degrees Celsius into consideration.