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Geothermal Energy Use, Country Update for Sweden

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ABSTRACT

This paper presents the status of geothermal energy use and market in Sweden by the end of 2021. Geothermal energy use in Sweden is dominated by shallow geothermal energy systems, mostly vertical ground source heat pump systems (GSHP) but also horizontal loops. The vast majority of installed systems are for space heating and domestic hot water heating for single-family buildings. By the end of 2021, there were approximately 630'000 shallow geothermal energy systems installed in Sweden, with an increase of roughly 15'000 new systems per year. GSHP systems provided some 25.5 TWh of heating in Sweden of which approximately 18.5 TWh is renewable heat from the ground. The total installed GSHP heating capacity was 7.3 GW. These figures include the contribution of 68 GWh of geothermal heat produced by the Lund geothermal system plant connected to the district heating. In addition to the heat from the ground, at least 1 TWh is provided as ground source direct-cooling.

1. INTRODUCTION

The more than a half century history of geothermal energy utilization in Sweden was largely triggered by the oil crises in the 1970's and 1980's. At that time there were nationwide efforts to achieve an oil-independent energy system. This led to the promotion of heat pumps technology, and was further favoured by the national power production strategy based on nuclear power and hydropower. During the 1990's the heat pump technology in general and ground source heat pump (GSHP) technology in particular, developed rapidly in Sweden, resulting in a world-leading role in the GSHP research and industry.

The geothermal market and development in Sweden is mostly focused on shallow geothermal systems. Activities related to deep geothermal resources have so far resulted in one geothermal district heating plant in the south of Sweden, established in the 1985 and still in operation (Aldenius, 2017). It has moderate depth and has an extraction temperature <25 °C, hence does not meet the criteria for the EGC definition of deep geothermal district heating system.

In the 2010, 2015 and 2020 world geothermal surveys (Lund et al. 2010, Lund and Boyd 2015, Lund and Toth 2020), Sweden is rated as top three world leading country in geothermal energy utilisation, in terms of installed capacity and extracted thermal energy.

1.1 Geology, hydrogeology and climate in Sweden

The Swedish geology is characterized by the massive Baltic shield and its diverse crystalline eruptive and metamorphic rocks. In the southern parts of the country, sedimentary rock formations of significant thickness are found, spot-wise containing porous sandstones at considerable depth and with very good hydraulic properties (Figure 1).

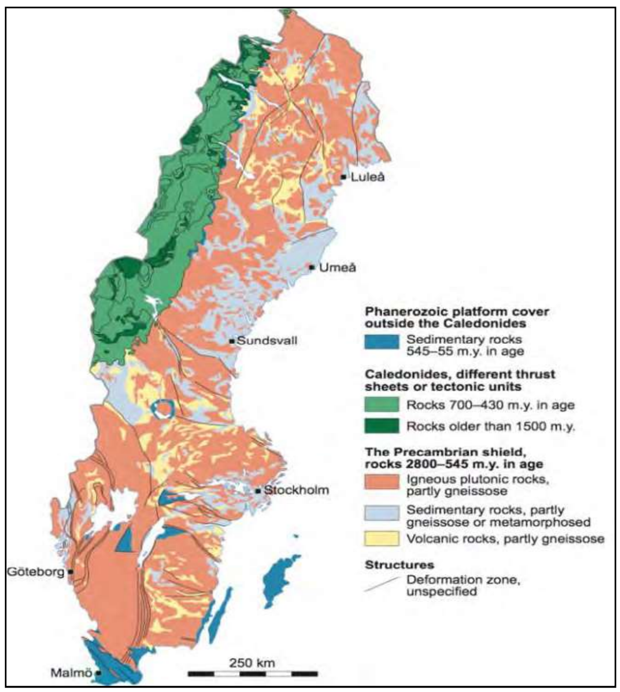

Figure 1: The bedrock geology of Sweden (© Swedish Geological Survey)

The geothermal gradient varies in the range of 15-25 °C/km. The higher value represents a geothermal well in the sedimentary basin in SW Sweden (Gustafson et al., 1979), while the lower values (15-19 °C/km) were found in deep boreholes in the Baltic shield region (Odén, 2013), see Figure 2.

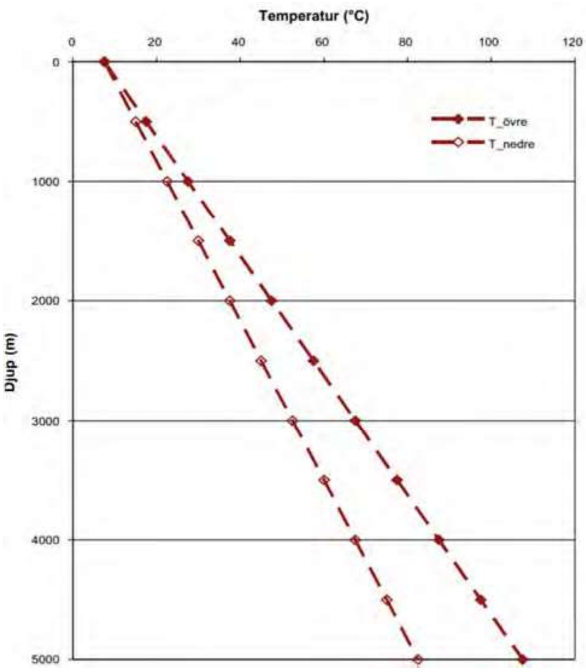

Figure 2: Upper and lower geothermal gradients in the Fennoscandian basement (Odén, 2013)

Rosberg and Erlström (2019 and 2021) presented gradients between 22-24 °C/km for two wells drilled through the sedimentary basin and further into the basement (3700 and 3330 m deep) in southernmost Sweden. Lorenz et al. (2015) presented a gradient of 20 °C/km for a deep well in the Swedish Caledonides.

The basement consists mainly of solid granites, and gneisses. It is favourable to drill with DTH hammer drilling, and has a generally low groundwater yield. Shallow geothermal boreholes are drilled to a depth up to 450-500 m without any major problems, though common depths are more in the range of 250-300 m.

Groundwater in the form of aquifers is mainly found in eskers. These are glaciofluvial deposits from the melting of the inland ice that covered Scandinavia some 10-20’000 years ago. The eskers with highly permeable gravel and sand deposits are located along the river valleys where also the population is dense. Apart from their use for drinking water supply, these eskers are also highly interesting for groundwater-based shallow geothermal systems for heat or cold extraction, as well as for thermal energy storage.

A limited number of large aquifers are also found in the sedimentary rock, mainly located in the southernmost part of Sweden. In particular it is the Mesozoic sandstones and limestones that are used for shallow geothermal systems.

Sweden has a climate that varies from north to south. The southern half is temperate continental while the northern half is continental. The variation in average high summer temperatures is small, with 21 °C in the south and 20 °C in the north. However, the variation during the winter season is more pronounced, with average temperatures varying from -3 °C in the south to -14 °C in the north (climatedata.eu 2019). The seasonal swing between summer and winter is favourable for underground seasonal storage systems. Ground temperatures at a depth of 100 m vary between +9 °C in the south and +2 °C in the north. The ground temperature features the annual mean temperature in the air at the location but is slightly higher in the north due to the insulating effect from snow cover in the winter.

2. DEEP GEOTHERMAL

In Sweden, the interest for using deep geothermal energy started during the 1970s (Bjelm et al., 1977; Eriksson et al., 1978, Bjelm et al., 1979, Bjelm et al., 1981). In southern Sweden the focus was to extract warm water from the sandstone aquifers and to apply the HDR-concept (Hot Dry Rocks) in other parts of Sweden dominated by Precambrian crystalline rock.

The first geothermal well (Höllviksnäs-1) was drilled and tested in 1977-78. It indicated a large potential in the Bunter sandstone at 1800-2000 m (Gustafson et al., 1979). In the next step a full-scale geothermal district heating plant was designed for a nearby village (Andersson, 1980) but was never realized in the end.

The initial exploration projects resulted in the Lund Geothermal Heat Production plant, which has been in operation since 1985 (see further section 2.1). Low-temperature, initially 22 °C, saline water is extracted from and later injected into a sandstone aquifer located between approximately 500 m and 800 m depth (e.g. Bjelm and Alm, 2010). At the same time an HDR-project was initiated in Fjällbacka, west Sweden, and a reservoir was created at around 450 m depth (e.g., Wallroth et al., 1999).

In 2002, Lund Energi AB (today Kraftringen AB) and the Department of Engineering Geology at the Lund University started a geothermal exploration project, with the aim of finding hot water in fractured crystalline bedrock associated to the Romeleåsen Fault Zone (e.g. Rosberg and Erlström, 2019). Two wells were drilled, the first one, DGE-1, was drilled to 3702 m depth, and penetrated the sedimentary succession before entering the crystalline basement at 1946 m depth. The drilling of the second well, DGE-2 was stopped at 1927 m depth after penetrating the sedimentary succession. Around that time Sydkraft (today E.ON) drilled two wells, FFC-1, 2110 m deep, and FFC-2, 2801 m MD or 2120 m TVD, for exploring the deep seated sandstone aquifers within the Mesozoic succession in Malmö (Tengborg and Erlström, 2007). An impact structure was investigated for geothermal purposes at Björkö in lake Mälaren, west of Stockholm at the same time

(Henkel et al., 2005). None of the projects were commercialised.

In 2016, around 10 years after the projects in Lund and Malmö were terminated, the interest for EGS (Enhanced Geothermal System) applications in the crystalline basement increased. The increased interest was driven by the EGS exploration project in Espoo, Finland with the focus on the Fennoscandian bedrock (e.g. Kukkonen and Pentti, 2021; Malin et al., 2021). E.ON (a large European electric utility company) initiated a geothermal exploration project to investigate the potential for applying EGS-plants in the city of Malmö, south Sweden. In 2020, after several years of feasibility studies, a decision was made to re-enter FFC-1, the well drilled in 2002 (see above). The aim with re-entering the well was to get increased knowledge about the crystalline basement below 2100 m depth as a part of planning for a full-scale EGS-plant. The only available information about the crystalline basement in southern Sweden was from the previous mentioned deep drilling, DGE-1, in Lund, around 20 km north-east of Malmö. The objectives with deepening the FFC-1 well were to obtain information such as drilling performance using air-percussion drilling, evaluate seismic monitoring during the drilling operation, obtain information about rock types, fracture intensity and characteristic, as well as information about hydraulic, mechanical, and thermal properties.

The initial plan was to deepen the well from about 2100 m depth to 4000 m depth using air-percussion drilling. The drilling method was only used for around 90 m of drilling and was found infeasible, due to too high inflow of formation fluid. The subsequent drilling was conducted with conventional rotary drilling using a solid-free salt polymer mud and it was used to the new target depth of 3133 m. The new target depth was set after changing drilling method. The drilling operation took about two months and valuable information from the upper one kilometre of the crystalline basement was obtained from the drilling. A logging operation was conducted by Weatherford three months after the drilling was terminated. The logging operation included surveys with the Gamma Ray, Spectral Gamma Ray, Photo-Density, Compact Cross Dipole (CXD), Slim Compact Micro-imager (SCMI) including multi-arm Caliper and borehole deviation tools (Badulescu and Ciuperca, 2021). Data from the crystalline basement section acquired during and after the drilling is compiled in Rosberg and Erlström (2021), as is an overview of the drilling operation. The bottom hole temperature in FFC-1 is of 84.1 °C and the calculated mean temperature gradient is 23.5 °C/km in the upper part of the crystalline basement, down to 2610 m depth and below 2880 m the calculated mean temperature gradient is 17.4 °C/km. The zone in between seems to be thermally disturbed. The lower gradient is more like gradients measured in other deep wells located in the Fennoscandian basement, see comparison in Rosberg and Erlström (2021). The EGS exploratory project in Malmö is for now put on hold.

During the last years a feasibility study to use EGS-plants for district heating production is ongoing in Gothenburg. The project is a cooperation between the energy company Göteborg Energi and Gothenburg University. In 2021, a borehole was drilled with continuous core drilling in crystalline bedrock to 1000 m depth and in 2022 a new core drilling operation was started. The target depth for the second borehole is 1300 m and the drilling is planned to target the intersection between two fracture valleys. Temperature and acoustic televiewer loggings have been conducted in the first borehole and are planned for the second borehole as well. The bottom hole temperature in the first borehole is 23.4 °C and the calculated mean temperature gradient is 15.1 °C/km.

Unfortunately, the 3702 m deep geothermal exploration well in Lund, the previously mentioned DGE-1, is now plugged and abandoned. The other mentioned deep wells in Lund, Malmö and Gothenburg are still open and available for additional in-situ measurements and, hydraulic and mechanical testing.

2.1 The Lund geothermal plant

There is no geothermal power production in Sweden, and the only geothermal plant in Sweden that meets some of the criteria for deep geothermal is the Lund geothermal heat pump plant. It has been operating since the mid 1980's. The geothermal resource at the well site Värpinge consists of a set of very porous sandstones at 400-800 m depth. The formation belongs to the Campanian of Upper Cretaceous located at the border zone of the Danish basin known as the Sorgenfrei Tornquist zone. The sandstone aquifer is highly permeable with a transmissivity of about 3 x 10^{-3} m^2/s.

Four production wells are pumped with a flowrate of 450 l/s (1620 m^3/h) at an average temperature of 21 °C. After heat extraction the water is reinjected into five injection wells normally at a temperature of 3 °C. The medium distance between the two well groups is in order of 2.1 km. The development of production temperature is shown in Figure 3, showing how the thermal break-through from the closest injection wells (VÄ-2 and VÄ-3) affect the temperature.

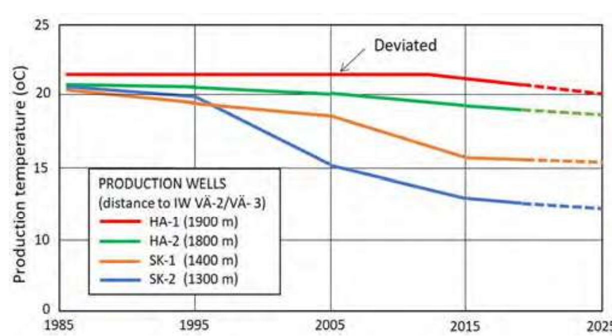

Figure 3: Production well temperatures from 1985-2019 with prognoses to 2025 (Bjelm and Andersson, 2018)

While the capacity of the production wells has been stable ever since the start, the gravel packs in the injection wells tend to clog by fine material. They have therefore been a subject to air-lift treatment at several occasions. In addition, hydro-jetting was introduced for treating the wells in 2011 and resulted in significantly improved injection capacity (Andersson and Bjelm, 2013).

The geothermal fluid is used as the heat source for two heat pumps. These heat pumps have a combined capacity of 47 MW. After 30 years run-time, the geothermal plant was evaluated by Aldenius (2017). At its peak in 1993, the plant produced 350 GWh of heat, providing 40 % of the energy in the Lund district heating network. Between 2015 and 2020 the heat production was between 100 and 140 GWh/year and in 2021 the production was 68 GWh. The decrease in production is mainly due to an increased amount of waste heat and co-generation heat production in other parts of the district heating system and is therefore not much related to the geothermal well capacity. In December 2021 the geothermal heat pumps were shut down due to the unusually high electricity price. So far (2021) the plant has produced approximately 8 TWh of heat, replacing some 800 000 m^3 of oil.

3. SHALLOW GEOTHERMAL

The typical shallow geothermal energy systems in Sweden is a vertical groundwater-filled borehole drilled in crystalline rock, connected to a ground source heat pump (GSHP) used for extraction of heat for space heating and domestic hot water (DHW) production in a single-family house. The heat pump is typically electrically driven.

Horizontal ground loops are used for heat extraction for heating and DHW in small buildings in Sweden. As they require larger surface areas these systems are mostly found on the countryside where enough space for the loops can be found more easily than in urban areas. In Sweden these systems are used only for heat extraction.

Shallow geothermal energy systems from larger buildings in Sweden occur both as GSHP systems and underground thermal energy storage (UTES). GSHP systems for larger residential buildings often require some kind of active recharge, such as waste heat from exhaust air or solar heat. Commercial buildings typically apply boreholes or aquifers for extraction and storage of both heating and cooling (see further section 4).

Vertical boreholes in rock and groundwater wells are also used for direct-cooling only. Such systems are mostly applied in the telecom and industrial sectors, but there are rare examples of low-temperature geothermal direct-heating and -cooling applications also for residential and commercial buildings. Skanska has developed an application with boreholes for direct-cooling and pre-heating of ventilation air where no heat pumps are used. They call their system Skanska Deep Green Cooling and an example of the application is described by Skanska (2014) and by Liu and Zhang (2020). The main heating source in those applications is district heating. The housing company HSB has also developed a pre-heating concept called Geo-FTX where boreholes are used for pre-heating of ventilation air in residential buildings (Kempe and Jonsson, 2015; Kempe et al., 2021).

Figures 4 and 5 show trends in sales for GSHP units in Sweden between 2010 and 2021. Sales volumes for smaller fluid-to-fluid heat pump units (<10 kW) have decreased with three fifths between 2010 and 2021. Improved energy efficiency in buildings, competition from air-source heat pumps and an ambition to minimize the need for supplementary heating while maximizing the heat pump use, are likely explanations to this development. Sales volumes for larger GSHP units with capacity >10 kW for single-family buildings, multi-family buildings and commercial buildings have been steadily growing and have almost tripled since 2013 (Figure 5). The biggest increase is seen for heat pump sales of units with a capacity between 11-25 kW for the single-family house market, which compensates largely for the decreased sales volume of smaller heat pump units. Larger heat pump units (>100 kW) are not always reported to the Heat Pump Association. Hence, many of the larger systems are missing in the statistics.

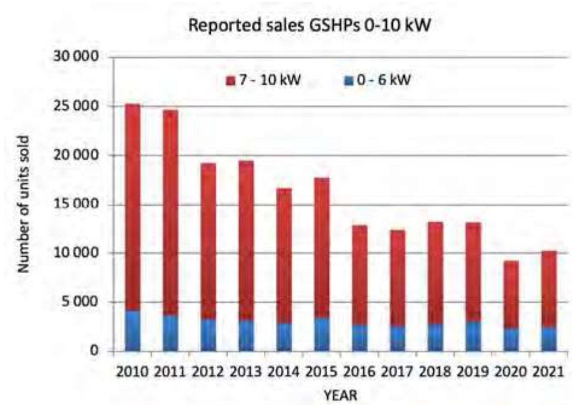

Figure 4: Reported sales of GSHPs up to 10 kW capacities in Sweden (SKVP 2022).

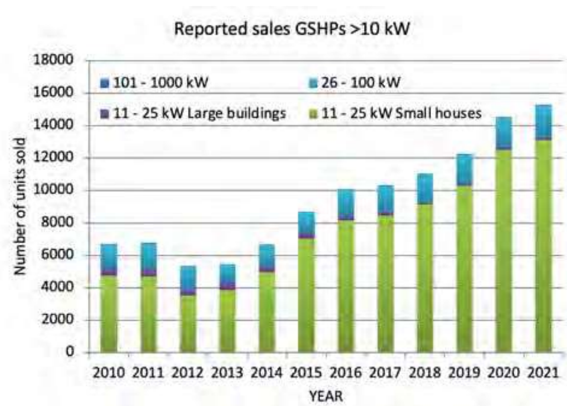

Figure 5: Reported sales of GSHPs >10 kW for large buildings in Sweden (SKVP 2022).

Figure 6 shows the amount of borehole meters drilled between 2010 and 2021. The figures for 2021 are under-estimated due to a delay in registration to the well database. The number of drilled meters per year has been relatively stable around 3.3 million meters per year.

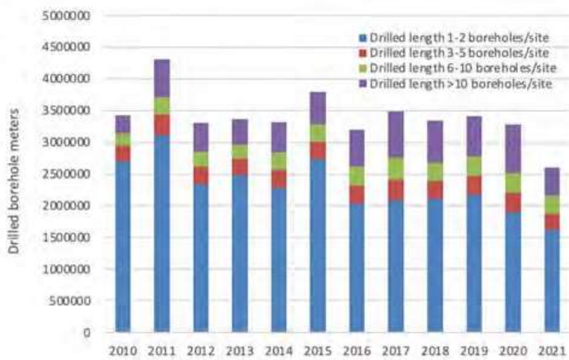

Figure 6: Reported annual number of drilled borehole meters for different system sizes. (SGU Well database 2022).

The trend with increasing borehole depth for GSHPs and BTES systems that started in the late 1990's when drill rig compressor capacity increased, as mentioned by Gehlin and Andersson (2013) and Gehlin and Andersson (2019), has continued (Figure 7). The preliminary overall average borehole depth in Sweden in 2021 was 200 m, as compared to 162 m in 2010 and 193 m in 2018, an increase with ~1-2 % per year.

The preliminary average borehole depth for the system size of one or two boreholes, i.e. single-family buildings, was 182 m in 2021, which is an increase with 24 m (15 %) since 2010, and with 4 m since 2018. For system size >10 boreholes, the average borehole depth has increased from 187 m in 2010 to 269 m in 2021, an increase with 82 m (44 %). The increase between 2018 and 2021 was 25 m (10 %).

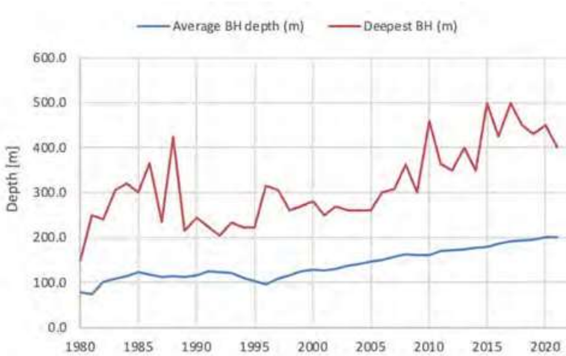

Figure 7: Average borehole depth and deepest borehole. (SGU Well database 2022).

Based on sales volumes for GSHP units reported to the Swedish Heat Pump Association around 630'000 ground source heat pumps were installed in Sweden by the end of 2021. Roughly 475'000 of these are vertical closed loop borehole systems while some 145'000 systems are estimated to be horizontal loops in soil and lake sediments. An estimate of 10'000 systems are open loop systems using groundwater or surface water as the heat source. This figure has been near constant over time with only a handful new registered systems per year. Since 2016 around 22'000 new ground source heat pump units in sizes ranging from 3 kW to 25 kW have been installed per annum. An increasing number of these heat pump units are replacement heat pumps for older heat pump units. In 2020 GSHP sales were slightly affected by the general financial decline due to the pandemic, but bounced back in 2021, even despite component shortage due to a temporary world-wide shortage of semi-conductors. The number of new installed larger GSHP units of >25 kW nominal capacity has increased from 1750 in 2018 to 2030 in 2021.

By the end of 2021 the calculated heating energy provided by GSHP systems in Sweden reached 25.5 TWh, with a total installed nominal capacity of 7.3 GW. The calculations are based on the assumption of an average heat pump running time of 3500 hours/year. In addition to this, ATES and BTES systems provide approximately 1-2 TWh direct cooling from the ground. The latter estimation is derived from an assumption that approximately 1000-2000 systems run with 1000-2000 full load hours of cooling on average. Commercial and institutional buildings often need cooling throughout the year and may reach 2 000 full-load hours. Within the residential sector the need for comfort cooling is approximately 500 full-load hours annually. A small number of ATES and BTES systems are used for cooling only and may reach 4000 full-load hours per year.

4. UNDERGROUND THERMAL ENERGY STORAGE

Underground thermal energy storage (UTES) systems that combine heating and cooling are common applications for larger buildings in Sweden, with the two commercial systems being Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). A limited number of Cavern Thermal Energy Storage (CTES) systems, where heat or cold is stored in rock caverns, also exist in Sweden, and in recent years the interest for such applications has increased.

4.1 Aquifer thermal energy storage (ATES)

ATES systems use groundwater for carrying the thermal energy into and out of an aquifer. The wells are normally designed with a double function – both as production and injection wells. Energy is stored in the groundwater and in the grains (or rock mass) that form the aquifer. Between 10-15 % of the Swedish land area contains aquifers suitable for ATES, and approximately 25 % of the population lives in these areas (Andersson and Sellberg, 1992). The use of groundwater is strictly regulated, making the real potential for ATES systems considerably smaller.

An estimate of some 210 ATES plants with a capacity of 100 kW or more are installed in Sweden, as of 2021. This estimate is based on the number of boreholes that are classified as “energy wells” in the SGU well data base, and are not deep enough to belong to the closed system category. The larger systems (>1 MW) are fairly well known from engineering reports, articles etc.

Systems larger than 100 kW nominal capacity are estimated to represent a total of some 195 MW. These are mainly located in aquifers in eskers, sandstones and limestones (Table 1). In addition to these ATES plants, there is an estimate of approximately 320 installed groundwater-source heat pumps with an average capacity of 50 kW. Some of these may still be ATES applications, but the majority is probably used only for heat extraction within the residential sector.

Table 1: Estimated number and size distribution of ATES plants with a capacity > 100 kW

Capacity size (MW)	Number of units	Total capacity (MW)
0,1-0,49	125	40
0,5-0,99	50	40
1,0-5,0	30	75
>5,0	5	40
Sum	**210**	**195**

Typical ATES system storage temperature levels are 12-16 °C on the warm side and 4-8 °C on the cold side (Andersson, 2007).

One of the largest ATES systems in Sweden is the Stockholm Arlanda Airport ATES plant. An esker is used for seasonal storage of heat and cold. The cold is used for air conditioning of the airport buildings, while the heat is used for pre-heating of ventilation air and for snow melting at some airport gates. Cold is stored at 2-3 °C and heat at 20-25 °C. The system has been designed for a capacity of 10 MW and uses no heat pumps (Andersson, 2009). The system delivers 22 GWh of heat and cold annually (Arvidsson, 2016).

The very largest ATES plant in Sweden was designed in 1998 for short-term storage for cooling. It is connected to the district cooling system for Stockholm City, and was designed for a cooling capacity of 25 MW for peak shaving during hot summer days. Due to well problems it is working at approximately 15 MW capacity. The working temperature is +3/+14 °C and when fully charged it holds around 1000 MWh of cold (Andersson, 2007).

4.2 Borehole thermal energy storage (BTES)

Swedish BTES systems typically consist of multiple closely spaced groundwater-filled boreholes of 150-300 m depth in crystalline rock. Single or double U-pipe borehole heat exchangers (BHE) are most commonly used and the storage temperature typically ranges between +2 °C in the winter and +8 °C in the summer, though some systems with direct-cooling may reach +16 °C in the summers. BTES systems have been in use in Sweden since the 1970’s and 1980’s (Gehlin, 2016).

By the end of 2021 there were about 5200 GSHP and BTES systems with more than 1000 borehole meters and more than 2000 systems with 10 boreholes or more registered in the Swedish Geological Survey Well database (SGU Well database 2022).

The number of new large GSHP and BTES systems per year has been relatively stable over the past decade (Table 2 and Figure 8). Data for 2021 is incomplete due to delay in reporting to the well database. On average some 50 new systems with >20 boreholes have been registered in the well database annually since 2016. As can be seen in Figure 8 is GSHP and BTES systems with between 20 and 50 boreholes that account for the major part of these systems.

Table 2: Number of new BTES systems of various sizes reported in SGU Database *(SGU Well database 2022)*

Year	Units 1-2 holes	Units 3-5 holes	Units 6-10 holes	Units 11-19 holes	Units ≥20 holes
2000	5673	134	27	8	4
2001	7886	151	26	6	2
2002	12989	227	41	10	7
2003	14875	294	52	25	4
2004	18260	381	78	21	7
2005	18987	569	142	39	9
2006	20833	609	154	43	23
2007	14279	555	171	50	34
2008	10862	489	146	62	33
2009	13387	392	114	37	16
2010	15377	404	136	39	26
2011	17303	517	187	75	46
2012	12824	434	163	69	36
2013	13559	416	141	50	35
2014	12344	426	180	57	32
2015	14564	424	178	73	38
2016	10511	406	191	71	50
2017	10741	457	213	87	59
2018	10740	367	182	79	51
2019	10896	393	187	75	41
2020	9439	412	186	96	52
2021*	8029	336	156	58	26

** Data for 2021 is incomplete due to delay in reporting.*

The largest BTES system in Sweden is still the BTES system at the Volvo Powertrain plant in Köping, constructed in 2015-2016. The system has a total of 215 boreholes with average borehole depth of 270 m, and a total borehole length of 58’000 m (Svensk Geoenergi, 2017).

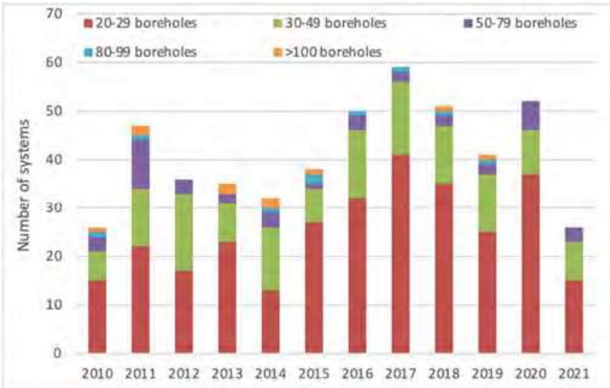

Figure 8: New large BTES systems 2010-2021 registered in the SGU Well Database. Data for 2021 is incomplete due to delay in reporting. (SGU Well database 2022).

Two high-temperature BTES systems are currently in operation in Sweden: The Anneberg residential plant and the Xylem Emmaboda HT-BTES plant. The Anneberg HT-BTES has been in use for seasonal storage of solar heat for residential heating of 50 houses since 2002. It uses no heat pumps and had a measured solar fraction of 40 % after 12 years in operation (Heier, 2013). Many of the system components (solar collectors and control system) are now reaching the end of their technical life span and in 2021 a process started in which the future of the HT-BTES will be decided. One of the considered options is to decrease the storage temperature, replace the solar collectors with PV panels and install heat pumps. A decision will be made in 2022.

The Emmaboda Xylem HT-BTES plant is used for seasonal storage of industrial waste heat, as well as for process cooling (Andersson and Rydell, 2012; Nordell et al., 2016; Andersson et al., 2021). Heat pumps were installed in 2018 and the storage temperature was decreased. The installation of heat pumps improved the system efficiency as was shown in the case study report from the IEA HPT Annex 52 project (Andersson et al., 2021). The first HT-BTES plant in Sweden, the Luleвärme project (Nordell, 1994), is no longer operating. It stored industrial waste heat from steel industry and was used for space heating of a university building in wintertime. It was an experimental plant that was operational during 1981-1989.

5. FUTURE AND TRENDS

The market for small residential building GSHPs has been relatively stable since the previous country update (Gehlin and Andersson, 2019) and the market for larger GSHPs and UTES applications is growing, despite uncertainties in material delivery, increased material cost and component shortage due to the pandemic in 2020-21 and the Ukraine war in 2022.

The on-going research program TERMO (Swedish Energy Agency, 2017) on heating and cooling technologies, run by the Swedish Energy Agency has funded and stimulated several R&D projects related to geothermal energy and thermal energy storage. The research program encourages development of geothermal and thermal storage applications combined with district heating and small to medium scale thermal networks. Several research and development projects related to geothermal energy have been initiated with funding from the TERMO program. These include studies of new high-temperature ground heat exchangers, and high-temperature underground thermal energy storage applications. One of the funded TERMO projects is the Swedish participation in the international collaboration project IEA HPT Annex 52 on long-term performance measurements of large GSHP systems. The project closed in 2021 and Sweden contributed with 14 case studies (IEA HPT Annex 52, 2022).

There has been a growing interest for EGS (Enhanced Geothermal Systems) placed in the crystalline basement over the last three years. This has been trigged by the deep drilling SP-project in Otaniemi (Espoo), Finland. In Sweden E.ON finalized a deep well in Malmö in 2020 and in 2021 exploration drilling started for an EGS project in Gothenburg (Rosberg and Erlström, 2021).

Sweden participates in two international collaboration projects related to geothermal energy. One of these projects is the IEA TCP ES Task 38 – Ground Source De-Icing and Snow Melting Systems for Infrastructure. The focus is set on geothermal systems for de-icing and snow-melting. The other project is the EU supported InterReg project CoolGeoHeat that is focused on the fifth generation (5G) district heating and cooling with integrated thermal energy storage.

6. CONCLUSIONS

Even if the pandemic has slowed down the growth to some extent, the market for GSHP and UTES systems has continued to grow. These systems are nowadays recognised as true commercial alternatives for any new, or retrofit, system for heating and cooling.

In the three latest geothermal energy utilization world overviews from World Geothermal Congress 2010-2020, Sweden has been rated number three world leading country in geothermal energy utilisation and is the leading geothermal energy market in Europe. The Swedish market is completely dominated by shallow geothermal energy, with no geothermal power production or deep geothermal energy within the definition of EGC.

Of great interest is that stakeholders are taking steps to go deeper into the Scandinavian crystalline bedrock in order to achieve higher temperatures. This effort seems to be partially linked to the development of the fifth generation of district heating and cooling.

The current energy prices in Sweden are remarkably high due to the war in Ukraine. The effect of this on the geothermal market is yet unclear. Shallow geothermal systems are dependent on moderate electricity prices for running the heat pumps. The cost of diesel also significantly affects the drilling cost, which in turn affects the willingness to invest in geothermal projects. If the current prices (April 2022) remain over a longer time this will be unfavorable for most shallow geothermal applications. Environmental benefits from geothermal still favor the future use of shallow geothermal.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers

There is no geothermal power production in Sweden.

Table B: Existing geothermal power plants, individual sites

There is no geothermal power production in Sweden.

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

There is no present or planned deep geothermal DH plant in Sweden that meets the criteria of >25 °C.

Table D1: Existing geothermal district heating (DH) plants, individual sites

There is no existing deep existing geothermal DH plant, nor individual ones, in Sweden that meets the criteria of >25 °C

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

There are no existing large geothermal systems for heating and cooling in Sweden that meets the criteria >500 MW.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021	630’000	7’280	25’500	15’440	285	n/a
Of which networks **	n/a	n/a	n/a	n/a	n/a	n/a
Projected total by 2023	660’000	8’900	27’500			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021	210	H: 195 C: 240	H: 780 C: 660	800	H: 240 C: 280	H: 840 C: 400
New (additional) in 2021	10	H: 15 C: 17	H: 55 C: 40	50	H: 15 C: 18	H: 52 C: 27
Projected total by 2023	240	H: 225 C: 270	H: 960 C: 840	950	H: 285 C: 330	H: 1000 C: 495

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	0	0	0	0
Shallow geothermal	> 3000	> 10'000	>3000	>10'000
total	> 3000	> 10'000	>3000	>10'000

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

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

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	none	none	The Swedish Energy Agency runs the research programme TERMO from which geothermal energy research may be partially funded.
Financial Incentives – Investment	none	none	New GSHP installations for private residential buildings are partly deductible from tax, as is the case for a number of other types of renovation work.
Financial Incentives – Operation/Production	none	none	none
Information activities – promotion for the public	none	none	The Swedish Geoenergy Center arranges courses, conferences/workshops, seminars, information activities, and issues the journal Svensk Geoenergi (Swedish Geoenergy).
Information activities – geological information	none	none	Open access well database administered by the Swedish geological Survey (SGU).
Education/Training – Academic	none	none	Short courses and lectures at universities
Education/Training – Vocational	none	none	Short courses in basic geothermal energy and EED training by the Swedish Geoenergy Center Two weeks education of new drillers once every year

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)