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Country Update for Sweden

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ABSTRACT

This paper presents the status of geothermal energy use and market in Sweden. Geothermal energy in Sweden is dominated by low temperature, shallow geothermal energy systems and direct use. The vast majority of installed geothermal energy systems are ground source heat pumps (GSHP) for space heating and domestic hot water heating for single family buildings. About 20% of the Swedish buildings use GSHP, making Sweden a leading country within this technology. The market for larger shallow geothermal energy systems for residential as well as non-residential buildings has been expanding during the last years. Shallow geothermal energy systems provide some 15 TWh of heating and cooling in Sweden (excluding free cooling), with a total installed capacity of 5.6 GW. Most part of Sweden lacks the geological conditions for deep geothermal exploitation. However, there is one plant in Lund from the mid-1980's that is still in operation, providing some 200 GWh of geothermal heat, or about 20% of the heat demand, annually to the Lund district heating system.

1. INTRODUCTION

The extensive use of ground source heat pumps (GSHP) nationwide has made Sweden the European leader in geothermal energy utilization, in terms of installed units and capacity, as well as extracted thermal energy (Antics et al. 2013). Approximately one fifth of all single-family houses in Sweden are heated by a GSHP.

Geothermal energy utilization started in Sweden in the 1970's and 1980's, triggered by the oil crises, and the following nationwide efforts towards an oil-independent energy system. Heat pump technology was promoted, favored by the national power production strategy based on nuclear and hydropower. Ground source heat pump technology developed rapidly during the 1990's, and continuous improvement of heat pump COP today allows for rates around 4-5 for low temperature heated buildings.

As for deep geothermal energy, exploitation in Sweden remains minimal. Only one plant, taken into operation in the 1980's, is currently in operation in the very south of Sweden.

1.1 Geology of Sweden

The massive Baltic shield and its diverse crystalline eruptive and metamorphic rocks characterize the Swedish geology. Especially in the southern parts there are sedimentary rock formations of significant thickness, spot-wise containing porous sandstones at considerable depth and with very good hydraulic properties. The geothermal gradient is around 28-30°C/km in the south and seldom more than 15-16°C within the Baltic shield regions. The bedrock is commonly covered by glacial deposits.

Ground temperatures vary between +8°C in the south of Sweden down to +2°C in the north. The ground temperatures feature 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 ENERGY IN SWEDEN

Most part of Sweden lacks geological conditions suitable for deep geothermal exploitation. There is today only one deep geothermal plant in operation in Sweden; the Lund geothermal heat pump plant that was taken into operation in the mid 1980's. The plant provides today a little less than 200 GWh of geothermal heat, or roughly 20% of the local heat demand, annually, to the district heating system in Lund. Deep geothermal energy utilization for electricity production and direct use is non-existent in Sweden.

2.1 The Lund geothermal heat pump plant

The Lund deep geothermal plant is the largest geothermal heat pump set-up in Sweden. The first unit was taken into operation in 1984, and the second in 1985. It was first reported in Bjelm and Schärnell (1983). The geothermal concept relies on a set of very porous sandstones belonging to Campanian of Upper Cretaceous sitting in the border zone between the Danish-Polish embayment and the Tornquist tectonic deformation zone crossing the province of Scania. The sandstone aquifer was explored and test pumped by means of two explorations wells, confirming a very permeable aquifer with a transmissivity of about 3 x 10^{-3} m^2/s. The four production wells initially produced 450 l/s (1,620 m^3/h). Production temperature was initially around 22°C and has decreased to about 16-17°C for some of the production wells. The decrease is mainly due to the thermal breakthrough in the production field. The two heat pumps deliver 21 and 27 MW of heat respectively. Production from the Lund geothermal heat pump plant to the district heating net is currently around 200 GWh. The gravel pack in the injection wells tends to settle and has therefore been subject to air-lift treatment several times each year. Recently a new hydro-jetting method was introduced for cleaning the wells, and the specific injection capacity has been significantly improved (Andersson and Bjelm, 2013). Up to 30% improvement has been verified for some of the wells. In one case the specific injection capacity increased from 37 m^3/(h bar) to 199 m^3/(h bar).

2.2 Deep geothermal exploration projects

Geothermal research is going on at Lund University, Engineering Geology, since 1977. It is the main scientific body in Sweden for the exploration and utilization of deep geothermal energy resources. All together Engineering Geology has been involved in more than 15 deep geothermal exploration and production well drillings in Sweden and about the same amount of high temperature projects in Nevada, USA.

The latest deep exploration wells in Sweden were drilled 2002-2005. One of the wells was drilled to a depth of 3,700 m, the lower half in crystalline basement, partly as a drilling technology project (Bjelm (2006), Bjelm and Rosberg (2006)). The wells were never put into production due to limited water production from the second well.

Complementary site investigations were carried out for drilling of new geothermal production wells for the Lund plant. The project was initiated due to cooling of the original production wells. A seismic campaign was carried out for an enhanced geological and geophysical understanding of the production field and for final well site selections. New wells were designed and planned but have so far not been realized.

Two geothermal exploration boreholes were drilled in Malmö by E.ON some 20 km west of Lund in 2002-2003. The wells were drilled to a depth of 2 km where Triassic sandstones occur. Only one of the wells provided sufficient production capacity, and they were therefore abandoned (Malmö Stad 2007).

The Royal Institute of Technology in Stockholm started exploration for geothermal energy related to impact craters about a decade ago. Two core-drilled wells of 1,000 m depth were drilled at Birka, nearby Stockholm, but were abandoned when found too dry (Henkel et al. 2005). Fracturing the formation was planned but could not be realized.

A number of shallow exploration wells were recently drilled in the Siljan impact crater area, exploring a shallow geothermal sandstone aquifer. The formation may also contain natural gas resources, dissolved in the geothermal water.

In 2009, the National Science Foundation released around 4 million US dollar to Lund University for purchasing and implementing a top-of-the-line core-drilling package capable of drilling to a depth of 2,500 m in NQ size (hole size 76 mm and core size 47.6 mm). Lund is responsible for serving all national research institutions, with deep drilling capability and expertise. It may also be used outside Sweden if need be (Andersson and Bjelm 2013; Rosberg and Lorenz 2012). The first deep core drilling with the national rig started in late April 2014 close to Åre in central Sweden and in the geological provinces of the Scandinavian mountain range. The intention is to drill to 2,500 m. There are several scientific subtasks in the so called COSC-1 project. One of them is heat flow properties of the bedrock.

3. SHALLOW GEOTHERMAL ENERGY IN SWEDEN

Sweden has a heating dominated climate; however for commercial buildings the cooling demand is commonly predominant on an annual basis due to internal heat loads. To meet the heating demand, GSHPs is by far the most widely used technology for shallow geothermal energy utilization in Sweden, in particular for single-family houses. There are around two million single-family houses in Sweden, and approximately 20-25% of these houses are today heated with a GSHP. Market development for these small systems has been very strong for several years, however during the last few years the number of new installed small systems has stabilized. Instead there is a steady growth of larger GSHP systems for residential as well as commercial buildings. Also the market for underground thermal energy storage (UTES) for large facilities is steadily growing. The two main UTES categories used are Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES), and are used for both heating and cooling purposes, preferably combined.

Geothermal energy is considered an environmentally friendly technology by the general public and tends to increase the commercial value of a building. Geothermal energy has played a major part in replacing fossil fuel heating in the Swedish building stock, especially for small residential buildings. As the market for larger geothermal energy systems increases, it helps to regulate the pricing of alternative energy sources such as biofuel and district heating. This has led to a strong reaction from the district heating sector, which has a dominant market share in space heating and domestic hot water heating in Swedish buildings, and now leads an aggressive campaign against the use of heat pumps in general.

The vast majority of the Swedish shallow geothermal energy systems in Sweden are vertical boreholes in hard rock. Some recent market trends are that boreholes for GSHPs and BTES systems tend to be drilled to an increasing depth, which can be seen in Figure 1, and that the system size increases. Systems tend to be designed with increasing capacity and system efficiency.

3.1 Utilization of extraction systems

Shallow geothermal energy extraction systems use low temperature energy from the soil or upper parts of the bedrock as a heat source or heat sink either for space heating or cooling purposes. The typical Swedish shallow geothermal energy extraction system is a groundwater filled vertical closed loop GSHP system, drilled in crystalline rock, used for heat extraction only. The heat pump is typically electrically driven and is used for both space heating and domestic hot water (DHW) heating. These systems, mainly used for small to medium size systems for heating of residential buildings, are sometimes recharged with heat from exhaust air or solar.

About 20-25% of all shallow geothermal energy systems in Sweden are horizontal ground loops in soft ground material. Horizontal loops require larger surface areas, where plastic tubing is buried at about 1 m depth below the ground surface. In Sweden these systems are only used for heat extraction, and will freeze the moisture in the ground around the ground loops, thus taking advantage of the phase change energy. Horizontal ground loops work best in finely grained soil with high porosity and moisture content. They are most common in the south of Sweden where ground temperature is higher and deep layers of sedimentary formations cover the hard rock.

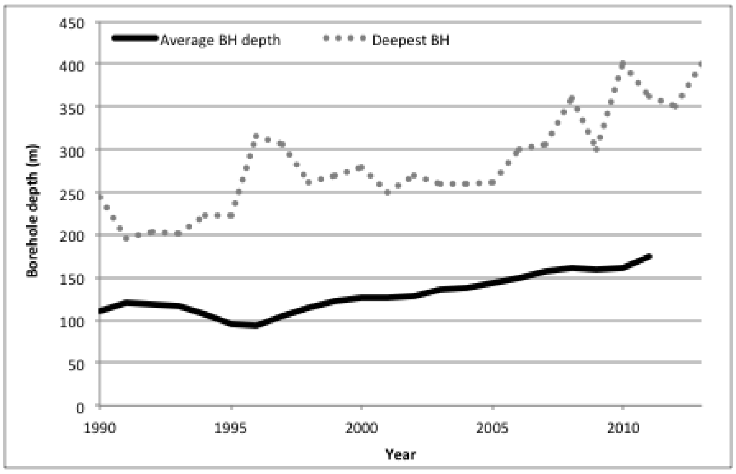

Figure 1: Average borehole depth and deepest borehole. SGU 2014.

Sales figures from the Swedish Heat Pump Association tell that currently some 500,000 ground source heat pumps are installed in Sweden, of which about 10,000 are open groundwater or surface water heat pump systems. Most of the open systems were installed in the 1980's and around 20 new such installations are reported each year. The last five years around 25,000 ground source heat pump units in sizes ranging from 5 to 10 kW have been installed per annum. The market for small units has stabilized these last few years but the market for larger systems is growing. Sweden is a world-leading nation in shallow geothermal energy usage, counted per capita.

Vertical boreholes in rock and ground water wells are also used for comfort cooling and free-cooling, for instance in the telecom and industrial sectors. Between 10-15% of the Swedish land area contain aquifers suitable for shallow geothermal energy utilization, and approximately 25% of the population lives in these areas (Andersson and Sellberg 1992), However, using groundwater is strictly regulated making the real potential considerably less.

Shallow geothermal energy extraction is also used as heat source for large heat pumps in district heating networks around Sweden. Figures from the Swedish District Heating Association show that in 2012 these plants provided some 0.65 TWh to the Swedish district heating network (Trad 2014). The use of ground- and surface water heat pumps in the Swedish district heating network has decreased in later years.

3.2 Utilization of underground thermal energy storage systems (UTES)

While shallow geothermal energy extraction systems are passively recharged by heat transport in the underground from the ground surface and with a minor contribution from the geothermal heat flux, underground thermal energy systems (UTES) actively store heat and cold in the underground, commonly as seasonal storage. This means that heat is stored from the summer season to be utilized during the winter season. Likewise, cold is stored during winter to be recovered during the summer for cooling purposes. Most of the Swedish larger shallow geothermal energy applications combine heating and cooling. The two commercial systems are Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). These are principally illustrated in Figure 2.

Figure 2: Aquifer Thermal Energy Storage (ATES) (left) and Borehole Thermal Energy Storage (BTES) (right). Illustration: Geotec.

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 rocks mass) that form the aquifer. Typical Swedish ATES operation temperatures are 12-16°C on the warm side and 4-8°C on the cold side of the aquifer (Andersson, 2007). ATES was introduced in Sweden during the mid 1980's and there are currently some 150 ATES system plants in operation. The growth rate has been quite steady the last decade at approximately 5% annually. The systems are large with high capacity, ranging between 500-5000 kW. ATES systems are sensitive to potential chemical problems such as corrosion and clogging by iron precipitation. They have high COP, in the order of 5-8. They are fast responding and highly efficient, and have generally low pay-back times, often less than 3 years (Andersson et al., 2013). The largest ATES system in Sweden is the Stockholm Arlanda Airport ATES plant, used for free-cooling and pre-heating of ventilation, and for de-icing of gates. It has been designed to a capacity of 10 MW and uses no heat pumps (Andersson 2009).

BTES systems consist of several closely spaced boreholes, normally 50 – 250 m deep, serving as heat exchangers to the underground. In Sweden the boreholes are typically groundwater filled and fitted with a closed loop single or double U-pipe. The heat transfer between the heat carrier and the underground is mainly conductive and the temperature change in the rock reaches only a few meters around each borehole. The temperature in the ground storage typically ranges between +2°C at end of winter and +8°C at the end of summer. The market for BTES systems in Sweden is growing and there are currently some 400 large systems with more than 20 boreholes in operation, for combined heating and cooling of mainly commercial and institutional buildings. The rate of growth is at present approximately 10% per annum. The systems have capacities ranging between 50-500 kW. COP is in the order of 5-6. The size of the systems tends to increase and include an increasing number of boreholes and deeper boreholes (Andersson et al., 2013). The largest BTES system in Sweden is currently being built for the Karlstad University Campus, with 204 boreholes to a depth of 240-250 m, giving a total of 48,240 drilled meters boreholes (Svensk Geoenergi, 2014).

There are two high temperature BTES systems in operation in Sweden today. One is used for seasonal solar heat storage for residential heating without heat pump and has a solar fraction of 40% after 12 years in operation (Heier 2013). The other is used for seasonal storage of industrial waste heat (Andersson & Rydell 2012).

4. CONCLUSIONS

Sweden is a world leading country in shallow geothermal energy utilization (Lund et al., 2010), and geothermal energy has a general goodwill among the public as an environmentally friendly and economically feasible technology. The market is dominated by shallow geothermal energy systems, and in particular GSHP systems with vertical boreholes in hard rock. The potential for deep geothermal energy exploitation in Sweden is limited and only one plant is in operation.

The market for small GSHP systems has stabilized during the last years, but there is a steady market growth for larger systems for residential buildings as well as for larger ATES and BTES systems in the commercial and institutional sector. Systems for BTES tend to be designed with increasing size, deeper boreholes and higher capacities. In 2014 the largest BTES system in Europe with regard to drilled borehole meters is taken into operation at the Karlstad University Campus.

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APPENDIX – STANDARD TABLES

TABLE 1. Present and planned production of electricity (* denotes contribution from wind power and ** denotes biomass)

	Geothermal		Fossil		Hydro		Nuclear		Other renewables *)Wind **) Biomass		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014	-	-	No info	9,600	16,200	64,200	9,336	64,900	5,000* 3,000**	11,300* 6,000**		156,000
Under construction in Dec 2014	-	-	-	-	-	-	-	-	No info	No info		
Funds committed, Not yet under construction in Dec 2014	-	-	-	-	-	-	-	-	-	-	-	-
Estimated total projected use by 2020	-	-	No info	9,700	16,200	69,000	9,336	72,600	No info	11,300* 13,700**		174,000

TABLE 2. Utilization of geothermal energy for electric power generation as of 31 December 2014

There is no existing or planned geothermal electricity production in Sweden.

TABLE 3. Summary of geothermal direct heat use as of 31 December 2014

There is no existing or planned geothermal direct use in Sweden.

TABLE 4. Geothermal (ground-source) heat pumps as of 31 December 2014

Locality	Ground or Water Temp (°C)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type	COP	Heating Equivalent Full Load Hr/year	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Lund	19	48,000	2	V	3.3	>7,000	720	-
Sweden (small V)*	-2/8	5-10	365,000	V	3-5	2,500	35,500	-
Sweden (small H)*	-5/+5	5-10	125,000	H	3-4	2,500	12,000	-
Sweden (small W)*	4-8	5-10	10,000	W	4-5	2,500	1,000	-
Sweden (ATES)*	4-16	500-5,000	150	W	5-8	3,000	1,260	360
Sweden (BTES)*	2-8	50-500	400	V	3-5	4,600	1,440	900
TOTAL			500,000	V W H	3-8		51,920	1,260

* Excluding free cooling

TABLE 5. Summary table of geothermal direct heat uses as of 31 December 2014

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr =10^{12} J/yr)	Capacity Factor
Individual Space Heating	-	-	-
District Heating	-	-	-
Air Conditioning (Cooling)	-	-	-
Greenhouse Heating	-	-	-
Fish Farming	-	-	-
Animal Farming	-	-	-
Agricultural Drying	-	-	-
Industrial Process Heat	-	-	-
Snow Melting	-	-	-
Bathing and Swimming	-	-	-
Other Uses (Specify)	-	-	-
SUBTOTAL	-	-	-
Geothermal Heat Pumps	5,600	51,920	0.3
TOTAL	5,600	51,920	0.3

TABLE 6. Wells drilled for electrical, direct and combined use of geothermal resources from January 1, 2010 to December 31, 2014 (excluding heat pump wells)

There are no wells drilled for electrical, direct and combined use of geothermal resources during this period, in Sweden.

TABLE 7. Allocation of professional personnel to geothermal activities (restricted to personnel with university degree)

Year	Professional Person-Years of Effort						
	Gov.	Publ. ut.	Universities	Paid For. Cons.	For. Aid prog.	Priv. ind.	Total
2010	-	2	5	-	-	2	9
2011	-	2	6	-	-	2	10
2012	-	2	7	-	-	3	12
2013	-	3	7	-	-	4	14
2014	-	3	7	-	-	4	14

TABLE 8. Total investment in geothermal energy (2014) in USD

Period	Research & Development Incl. Production	Field Development Incl. Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million USD	Million USD	Million USD	Million USD	%	%
1995-1999						
2000-2004	22.2					
2005-2009	0.07					
2010-2014	1				60	40