Geothermal energy use in the Nordic countries

SIGNHILD GEHLIN
Ph.D., Technical Expert,
The Swedish Geoenergy Center,
Box 1127, 22104 Lund, Sweden
signhild.gehlin@geoenergicentrum.se
(Photo credit: Svenskt Geoenergicentrum)

Geothermal energy – or **geoenergy** – can be extracted either from deep geothermal resources, typically reaching kilometers below the ground surface, or from shallow geothermal resources in the uppermost few hundred meters below the ground surface. Deep geothermal resources originate from heat transferred from the center of the Earth as well as from nuclear processes in deep geological formations. Such geothermal resources may be used for geothermal power production, or directly for heat. Shallow geothermal energy may be used for heating as well as for cooling, and mainly originates from passively stored solar energy. In some systems, heat or cold is actively stored in the ground utilizing a variety of sources, such as solar radiation, indoor air, outdoor air, or thermal waste from industrial processes. A vast majority of shallow geothermal systems utilize heat pumps. Shallow geothermal energy systems have the ability to store thermal energy over seasons.

Figure 1. Examples of shallow geothermal energy use. Top left: Aquifer thermal energy storage (ATES), top right: bore hole thermal energy storage (BTES), bottom left: horizontal loop and bottom right: vertical borehole heat exchanger. [Original pictures by Geotec]

Geothermal energy contributes significantly to the energy supply in all five Nordic countries (Sweden, Norway, Finland, Denmark and Iceland) where it has a strong position as an efficient and environmentally beneficial renewable energy resource. The Nordic countries together have a total installed capacity of nearly 13 GW_{th} and in 2018 provided some 40 TWh_{th} of geothermal heating and cooling. This accounts for 34% of the total installed capacity and 43% of the total geothermal energy use in Europe. Of this, the main part, 11 GW_{th} and 34 TWh_{th}, comes from shallow geothermal energy. Iceland is the only Nordic country that has geothermal electric power production. The 2015 Icelandic installed geothermal power capacity of 661 MW_{el} and geothermal electrical energy production of 5003 GWh_{el} accounts for 22% and 27%, respectively, of the European geothermal installed capacity and electrical energy production. Sanner (2019) provides an overview of the geothermal energy use in 32 European countries including the Nordic countries.

Although the climate in the Nordic countries does not vary widely, there are major differences between the countries in the way geothermal energy is applied (**Figure 2**). Deep geothermal energy resources are readily available and utilized in Iceland and, to a lesser degree, in Denmark. However, so far, Sweden, Norway and Finland only utilize shallow geothermal energy. The reasons for this are not only due to geological factors, but also such factors as differences in available alternative energy sources and typical building energy distribution systems have an impact. **Table 1** shows some key figures for the five Nordic countries. Country-wise updates on the geothermal energy use and market for a number of

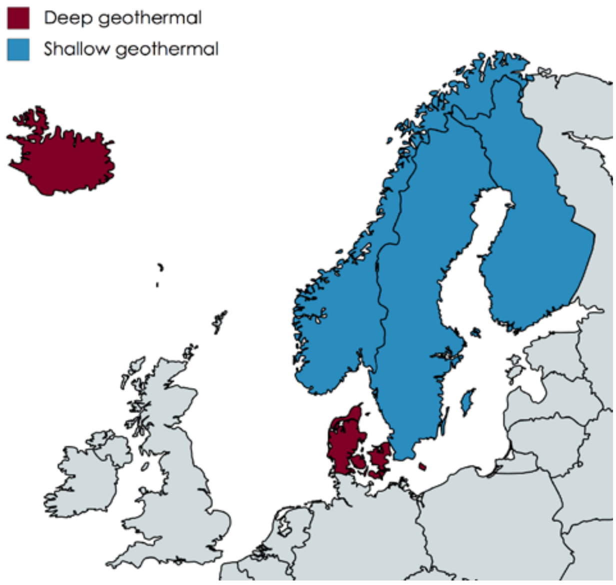

Figure 2. Geothermal energy in the Nordic Countries. Shallow geothermal energy use is predominant in Sweden, Norway and Finland, while deep geothermal is predominant in Iceland and Denmark. [ILLUSTRATION BY SIGNHILD GEHLIN]

Table 1. *Summary of key factors for the five Nordic countries.*

	SWEDEN	NORWAY	FINLAND	DENMARK	ICELAND
Population [Million people]	10.3	5.4	5.5	5.8	0.35
Area [km^2]	450 000	324 000	338 000	43 000	103 000
Energy consumption 2015*** [Million tonnes oil equivalents, MTOE]	32	21	24	13	2.9
Geology	Mainly crystalline rock, and sedimentary rock in the south	Crystalline rock, sparsely covered with marine clay and quarternary deposits	Crystalline rock and smaller areas with sandstones	Unmeta-morphosed sediments	Volcanic rock
Geothermal gradient [°C/100 m]	1.5–3	1.4–2.7	0.8–1.5	2.5–3	5–15*
Number of GSHP systems 2018	580 000	55 000	140 000	40 000	70 (in 2014)
Geothermal power	None	None	None	None	661 MW_{el}** 5 003 GWh_{el}**
Geothermal direct use (heat) 2018	None	None	None	33 MW_{th} 98.7 $GWht_{h}$	2 130 MW_{th}** 7 676 GWh_{th}**
GSHP heating/cooling 2018	6 520 MW_{th} 22 950 GWh_{th}	1 023 MW_{th} 4 103 GWh_{th}	3 000 MW_{th} 6 000 GWh_{th}	400 MW_{th} 598 GWh_{th}	1 MW_{th}** 5 GWh_{th}**

* (Flovenz & Saemundsson, 1993) ** Values for 2015 (Ragnarsson, 2015) *** (Nordic Energy Research, 2019)

European countries are published every three years at the European Geothermal Congress. In the following sections, short descriptions are given of the characteristics of the geothermal energy situation at the end of 2018 in the Nordic countries based on the country updates for Sweden (Gehlin and Andersson 2019), Norway (Kvalsvik et al 2019), Finland (Kallio 2019) and Denmark (Poulsen et al 2019). The description of Iceland is based on the country report for World Geothermal Congress 2015 (Ragnarsson 2015), as Iceland did not report at the European Geothermal Congress in 2019.

Sweden

Swedish geology is largely characterized by crystalline rock with thermal properties that are highly suitable for shallow geothermal systems, especially vertical ground source heat pumps (GSHP) and borehole thermal energy storage (BTES). Groundwater in the form of aquifers are mostly found in eskers along the river valleys and in limited numbers in sedimentary rock, mostly in the southern parts of the country. These aquifers are of interest for groundwater-based shallow geothermal applications, so-called aquifer thermal energy storage (ATES). The geological conditions in Sweden are not favourable for deep geothermal power and heat production, but there is a budding new interest in deep geothermal energy for district heating, following a current pilot project in Finland.

Sweden has been an active country in the development of shallow geothermal energy use since the 1970s and is rated number three worldwide in use of geothermal energy (Lund et al 2015). There are more than a half million shallow geothermal energy systems installed in Sweden, most of them using vertical boreholes in rock for space heating and domestic hot water heating for single-family buildings. While the market for small GSHP systems has decreased over the last decade due to market saturation, the market for larger shallow geothermal energy systems for residential as well as non-residential buildings is expanding. By the end of 2018, GSHP systems provided some 23 TWh of heating in Sweden of which approximately 17 TWh is renewable heat from the ground. The total installed GSHP heating capacity was 6.5 GW. These figures include the contribution of 250 GWh of geothermal heat produced by a geothermal energy plant, using large heat pumps and 20°C water from a thermal resource at 700 m depth, connected to the district heating network in Lund. In addition to the heat from the ground, approximately 1 TWh is provided as ground source direct-cooling. There are two high-temperature borehole thermal energy storage systems in operation in Sweden – one residential solar heat storage in Stockholm and an industrial application in Emmaboda. BTES applications in Sweden tend to be designed with increasing size, deeper boreholes and increasing capacities.

Norway

The Norwegian geology is characterized by crystalline rock, suitable for shallow geothermal systems and unfavourable for deep geothermal energy utilization. There is no geothermal power production or deep geothermal energy used in Norway, but shallow geothermal energy applications are increasingly common and accounted for some 4.1 TWh in 2018. This is an increase of 28% compared to 2015. The estimated number of installed geothermal energy systems in Norway is 55 000. The abundance of inexpensive and clean hydropower in Norway is both favourable and a challenge for geothermal energy use. Many small residential buildings have direct electric heating installed, and a conversion to a GSHP system with hydronic heat distribution may be regarded as too costly.

Most shallow geothermal energy systems in Norway are GSHP systems with vertical boreholes. As in Sweden, there is a general trend towards increasing borehole depth in Norwegian geothermal energy applications. A recent geothermal installation at the Oslo airport Gardermoen, used for de-icing without the use of heat pumps, has two boreholes of 1 500 m depth. A high-temperature borehole thermal energy system for residential use is currently being built in Drammen and another such high-temperature application is planned in Oslo.

Finland

The geology in Finland is similar to that of Sweden, with crystalline rock, localized sandstone formations and deposits of glaciofluvial origin. These conditions are highly suitable for shallow geothermal systems, but less so for deep geothermal utilization and power production. Since around 2005 the market for heat pumps in general has increased rapidly, mostly for replacement of oil burners and direct electric heating in small residential buildings. Although the majority of the 900 000 installed heat pumps in Finland are air-source heat pumps, some 140 000 GSHP systems are in use for heating of small residential buildings as well as for heating and cooling of large commercial and institutional buildings.

In Finland also, there is a definite trend with increasing numbers of GSHP installations and larger systems.

Several shopping malls, both new and existing, have recently had large-scale BTES systems installed. Residential GSHP systems show the fastest growth rate. Many new GSHP installations are seen to keep previous district-heating connections and solar systems as back-up systems. Another trend is the development of new business models and service models, where investments are done by the providing company, and the customer pays for the used energy.

In 2015 the private company St1 Nordic Oy initiated a first deep geothermal pilot project in Espoo. The idea is to drill two deep geothermal wells to 6 000–7 000 m depth for a district heating network, and the expected capacity is 40 MW of geothermal heat extraction. The first borehole has reached the final depth of 6 400 m, and the second borehole has been drilled to 3 300 m. Decision whether to continue the project will be made in 2019.

Denmark

Unlike Sweden, Norway and Finland, the Danish geology is mainly sedimentary, with moderate geothermal gradients and vast geothermal aquifers suitable for deep geothermal utilization. Aquifers identified close to urban areas have been calculated to have enough capacity to sufficiently cover 20–50% of the heating demand in these areas for centuries.

An extensive district heating network, reaching most of the urban areas supply district heating to 60% of the Danish residential buildings today. Three deep geothermal plants, extracting geothermal heat at 40–75°C from 1.2–2.6 km depth, are connected to this network, providing some 33 MW_{th} and 98.7 GWh_{th} in 2018. There is an increasing interest in deep geothermal energy among district heating companies and municipalities. Several district heating companies are presently considering deep geothermal plants and are conducting exploration. There is no geothermal power production in Denmark, due to low temperature levels in the aquifers.

Shallow geothermal energy use is utilized, although not to a large extent, in Denmark since the late 1970s following the oil crisis. These GSHP systems, used for small residential buildings, are primarily horizontal ground loops. There are also some GSHP systems using vertical borehole ground heat exchangers, and a few examples of ATES systems, mostly used for cooling of e.g. hospitals and larger office buildings. The Brædstrup district heating plant runs a borehole storage with

48 boreholes, used for seasonal heat storage. Shallow geothermal energy applications are expected to increase in Denmark in the future, in particular in areas without district heating or natural gas supply.

Iceland

In Iceland, with its young and volcanic geology and abundant supply of geothermal resources, geothermal energy has played a major role in the energy supply for heating as well as power generation for several decades. In 2015 geothermal energy accounted for more than two thirds of the total energy use. Geothermal electricity generation started in the 1970s and accounts for a third of the total electricity generation in the country. Geothermal water is used for space heating (covering 90% of all energy used for house heating), domestic hot water, swimming pools, snow melting, industry, greenhouses and fish farming. Due to the abundance of high temperature geothermal resources, GSHPs are not very common in Iceland. Less than 100 such systems were in operation in Iceland in 2015, most of them horizontal ground loops.

Conclusions and future

With over 40% of the geothermal energy share, and a market growth that exceeds most other European countries, the five Nordic countries have and will continue to have a dominating position as geothermal energy providers in Europe. The Nordic countries have contributed considerably to geothermal R&D since the 1970s and continue to do so. Several of the world leading ground source heat pump manufacturers have Nordic origins, and several early shallow geothermal energy design models, simulation tools and pilot projects were developed here. Iceland has been leading the way in deep geothermal energy utilization for decades.

Interesting future trends in the Nordic countries are R&D on deeper boreholes for GSHP systems with and without heat pumps, direct heating and direct cooling applications (not using heat pumps) with shallow geothermal energy and various solutions connected to thermal networks and so-called Smart Grids, where underground thermal energy storage will play a central role.

A long tradition of public awareness and concern for environmental issues and energy efficiency, as well as for indoor comfort and human health among the Nordic countries partly explains the success of geothermal development in this part of the world. Abundant hydroelectric resources have also facilitated use of heat pumps to take advantage of shallow geothermal energy. ■

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