REVIEW OF GEOTHERMAL ENERGY POTENTIAL IN EUROPE

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ABSTRACT

Geothermal energy worldwide is the most extensively used renewable energy besides hydro-power. In 2000 about 52,000 GWh of geothermal energy were extracted worldwide for direct use for space heating, process heat, thermal spas or greenhouses. Geothermal energy can be exploited with various technologies, although it generally, albeit not exclusively, involves drilling and pumping water from a certain depth. It feeds a great diversity of applications, alone or in combination with other sources of energy.

Over 25% of the EU population live in areas directly suitable for Geothermal District Heating (GeoDH). There are 237 Geothermal District Heating plants (including cogeneration systems) in Europe representing the total installed capacity of 4.3 GWth and production of some 12883 GWh or 1107 ktoe in 2012. In order to increase awareness, GEODH, an IEE project co-financed by the EU - has assessed and presented for the first time the potential of geothermal energy in Europe on an interactive map. In the EU there are 27 countries which have 3550 DH systems providing heat for 2160 cities and towns for over 5000 inhabitants, thus satisfying 12% of total heat demand of the population. The majority of the systems are fed by gas and only 1% by renewables (mostly biomass). Despite the favorable geothermal conditions in Europe, geothermal energy contributes only 0.001% of the district heating systems. The major markets are in France, Iceland, Germany and Hungary, however most of the European countries foresee a significant growth by 2020, also in line with their NREAP (National Renewable Energy Action Plans) targets. By 2020, nearly all the countries in Europe will have GeoDH.

Key words: geothermal energy, geothermal district heating, renewable energy.

INTRODUCTION

A large portion of the global energy supply is used for electricity generation and space heating, with the majority derived from fossil fuels. Fossil fuels are finite resources and their combustion is harmful to the environment through the emission of greenhouse gases and contribute to climate change and other pollutants. The use of renewable energy sources leads to the reduction of the environmental pollution which is well described in a similar study (Shipkovs, 2012). The demand for energy is increasing and future fossil fuel shortages are predicted (Ediger, 2007). A variety of different renewable energy sources are presented on the energy market and some of them have a potential to substitute or partly replace fossil fuels, thus contributing energy independence for countries which are geographically deprived of fossil energy sources. The use of solar potential for sustainable development is well evaluated in a similar study (Shipkovs, 2009), however an additional study is needed on geothermal potential as another promising renewable energy source. Geothermal energy worldwide is the most extensively used renewable energy besides hydro-power. By the end of 2000, geothermal power plants amounted worldwide to an installed capacity of about 8,000 MWel. They produced electrical energy of roughly 50,000 GWh per year. Besides this, about 52,000 GWh of geothermal energy per year were extracted worldwide for direct use for space heating, process heat, thermal spas or greenhouses. Compared to other renewable energies, geothermal heat is advantageous since it is available all day and during all seasons. This and its great resource make geothermal energy an attractive option for a sustainable energy supply in the future.

Geothermal energy can be exploited with various technologies, although it generally, albeit not exclusively, involves drilling and pumping water from a certain depth. It feeds a great diversity of applications, alone or in combination with other sources of energy. Geothermal energy is stored in the subsurface in certain concentrations and modes, which influence the type of application and extraction method that can be adopted.

Over 25% of the EU population live in areas directly suitable for Geothermal District Heating (GeoDH) (Aalborg University, 2013). There is a large potential in Central and Eastern Europe, with GeoDH systems in operation in 22 European countries including Hungary, Poland, Slovakia, Slovenia, the Czech Republic, and Romania, where existing heat networks are well developed. Leading countries by GeoDH capacity installed are Iceland, Hungary, France, Germany, Italy. There are 237 Geothermal District Heating plants (including
cogeneration systems) in Europe representing the total installed capacity of 4.3 GWth and production of some 12883 GWh or 1107 ktoe in 2012 (GeoDH, 2014). Additionally it would be useful to mention the relevance and potential of geothermal energy within the development of smart cities (Zajacs, 2014), where steps are being taken to improve the energy efficiency of the residential sector by the renovation of multi-apartment buildings (Borodinecs, 2015) and decrease the consumption of thermal energy, in this case the use of geothermal energy for heating and hot water preparation sees promising and feasible measure.

**GEOTHERMAL BENEFITS AND POTENTIAL IN EUROPE**

Geothermal generation has its roots in Europe. In the EU, 180 geothermal district heating systems have a total capacity of 1.1 GWth installed, producing some 4256 GWh of thermal power, (i.e. 366 ktoe in 2012). The main benefits of geothermal heating and cooling are the provision of a local base load and flexible renewable energy, diversification of the energy mix and protection against volatile and rising fossil fuels prices. Using geothermal resources can provide economic development opportunities for countries in the form of taxes, royalties, technology export, and jobs. The geothermal potential is recognised by some EU Member States in their National Renewable Energy Action Plans. However, the actual potential is significantly larger. In order to increase awareness, GEODH, an IEE project co-financed by the EU - has assessed and presented for the first time the potential in Europe on an interactive map: [http://loczy.mfgi.hu/flexviewer/geo_DH/](http://loczy.mfgi.hu/flexviewer/geo_DH/).

From the map we can conclude that:
- GeoDH can be developed in all 28 EU countries;
- Geothermal can be installed with existing DH systems during extension or renovation, replacing fossil fuels;
- New GeoDH systems can be built in many regions of Europe at competitive costs;
- The Pannonian basin is of particular interest when looking at potential development in Central and Easter Europe.

According to Eurostat, about one third of the EU’s total crude oil (34.5%) and natural gas (31.5%) imports in 2010 originated from Russia. Of this, 75% of the gas is used for heating (2/3 in households and 1/3 in the industry). Geothermal DH technology has the potential to replace a significant part of that fuel (GeoDH, 2014). Geothermal resources are defined as that part of the geothermal energy which can be extracted economically and legally in the near future. (Muffler and Cataldi, 1978). In order to quantify these resources, it is necessary to define the amount of heat available in the rock (geothermal reservoir) and the characteristics of the reservoir with respect to the extraction of this heat. There are numerous methods and models that can be used to quantify geothermal resources. The assessment of geothermal resources is based on a volumetric heat content model for porous reservoirs assuming...
exploitation of geothermal energy by a doublet (Muffler and Cataldi, 1978).

The resource $H_1$ (in Joules), is given by

$$H_1 = H_0 \cdot R_0 \quad (1)$$

where $H_0$ represents the heat in place (in J) in the reservoir under a surface area $A$. The fraction of this heat that can be extracted is $R_0$, a recovery factor that depends on the extraction technology used. $H_0$ comprises the heat stored in the rock matrix (index $m$) and in the water filling the pores (index $w$):

$$H_0 = [(1 - P) \cdot \rho_m \cdot c_m + P \cdot \rho_w \cdot c_w] \cdot [T_t - T_0] \cdot S \cdot \Delta z \quad (2)$$

where $\rho_m$, $\rho_w$ are the density of the rock matrix and water, respectively in kg/m$^3$, $c_m$, $c_w$ are the specific heat capacity of the rock matrix and water, respectively, in J/(kg*K), $P$ is effective porosity, dimensionless, $T_t$ is the temperature at the top of the aquifer, in °C, $T_0$ is the temperature at the surface, in °C, $S$ is the surface area under consideration, in m$^2$, and $\Delta z$ net aquifer thickness, in m.

In a doublet system, where there is a production borehole and an injection borehole used to reinject the fluid after use, it can be shown that (Lavigne, 1978):

$$R_0 = 0.33 \cdot \frac{(T_1 - T_r)}{(T_t - T_0)} \quad (3)$$

where $T_r$ is the reinjection temperature. A group of experts from the European Commission (EC) recommended a value of 25 °C for $T_r$. Reinjection avoids a pressure decline in the aquifer during exploitation and prevents environmental pollution of superficial water and soil as a result of disposing of highly saline geothermal water (Hurter, 2003).

The geothermal gradient of temperatures through the crust is 25–30 °C (77–86 °F) per kilometer of depth in most of the world. The conductive heat flux averages 0.1 MW/km2. These values are much higher near tectonic plate boundaries where the crust is thinner.

With knowledge of surface temperature ($T_0$) in °C, heat production ($A$) in $\mu$W/m$^3$, thermal conductivity ($K$) in W/m/°K, and heat flow ($Q$) in mW/m$^2$, the temperature at any depth ($T_z$) can be approximated by:

$$T_z = T_0 + \frac{Q}{K} \cdot (z - z_0) - \frac{A}{2K} \cdot (z - z_0)^2 \quad (4)$$

Temperature distribution at depths of 1000 m (Figure 2) and 2000 m provide a large scale view of the thermal field, while maps depicting the cities of presently operating geothermal installations (red dots) and the areas for which more detailed resources assessment can be found in specific national contributions.

**Figure 2.** Temperature distribution at depths of 1000m $T>50°C$ (blue) and 2000m $T>90°C$ (red) (MFGI, 2014)
The map is not a tool to determine drilling sites for geothermal installations. Rather, it should be employed in activities preceding the targeting of drilling for geothermal purposes. It serves as a guide to set priorities for future investments in local studies and auxiliaries in delineating target areas for these investments.

**Geological Structure of Latvia’s territory**

The utilization of geothermal energy in the territory of Latvia can be classified in the following groups:

- **Geothermal resources of low temperature** 
  <20°C; applicable for heating small objects and individual buildings and for preparing hot water with heat pumps;

- **Geothermal resources of medium temperature** 
  20°C - 30°C; applicable for heating buildings and for preparing hot water with heat pumps;

- **Geothermal resources of high temperature** 
  >30°C; applicable for heating small residential areas and for preparing hot water with heat pumps, for direct heating as well as in combined electric power stations;

- **Petrothermal energy resources >100°C;**
  applicable for electricity production, heating and preparing hot water.

An average geothermal gradient varies within the interval of 0.8°C/100m – 1.9°C/100m in the north and east part of Latvia, but on average the geothermal gradient reaches 3.5°C /100m in the central and southwest part of Latvia. The change of geothermal gradient in the cross section happens in the point where a blocking layer meets the water horizon. The graphs of rocks’ temperature measurements carried out in the boreholes reflect it as the change of an angle between a vertical axis and a temperature graph. Three lithological stratigraphical structures with different geothermal gradients are apparent in the geological cross section of Latvia:

1. Devonian terrigenous Carboniferous rocks,
2. Silurian and Ordovician Carboniferous clay deposits,
3. Cambrian and Venda terrigenous rocks.

In the Cambrian and Venda cross section, gradients vary from 0.6°C/100m to 3.1°C/100m. The maximum value is reached in the southwest of Latvia. The analysis of the changes in an average temperature of Cambrian structure in the territory of Latvia is based on the observation data from measurements of temperature conditions in 72 boreholes that are scattered unevenly.

There are 2 geothermal zones in the Cambrian structure with an increased temperature:

1. the zone in the direction to the south, southeast of Liepaja, where the temperature in Cambrian deposits reaches 38°C – 62°C in the depth of 1,281 – 1,714m.
2. From the borders of Jurmala to the Lithuanian border (Eleja geothermal anomalous zone), where the water temperature of the Cambrian reservoir is 33°C – 55°C in the depth of 1,100 – 1,436m (Pshenichnaya, 2011).

![Image](image.png)

**Figure 3.** An average temperature map in the Cambrian underground water horizon (LNGA, 2014)
GEOTHERMAL TECHNOLOGY FOR RESIDENTIALS

GHPs (Geothermal Heating Plants) exploit the relatively constant temperature in the ground, which is warmer than the ambient air during winter and cooler in summer. The ground temperature remains nearer to the desired temperature inside a building. When there is a large variation between inside and outside temperatures, as is the case for air source heat pumps, more work is required to provide the same degree of heating, which reduces the COP. If an excessive temperature difference exists, heat pump systems do not operate as intended.

In the case of using of geothermal energy, temperature of the underground aquifer remains constant and relatively high, depending on the area and depth of the geothermal borehole. The system principles are the same for residential building heating or for district heating plant changing only the scale and depth of facilities (Self, 2013).

Closed loop systems

In closed loop systems, which are commonly utilized, the heat transfer fluid is enclosed in a circulating loop and has no direct contact with the ground; heat transfer with the ground occurs through the piping material. There are four classes of closed loop heat exchange systems: vertical, horizontal, spiral, and pond. For residential buildings and private houses it is possible to apply all of these system types, but for industrial plants vertical loop systems are applied (Fig. 4).

Vertical closed loop

A vertical closed loop system includes a loop field consisting of vertically oriented heat exchange pipes. A hole is bored into the ground, typically ranging from 45 to 75 m deep for residential and over 150 m for larger industrial applications. Pairs of pipes, connected at the bottom by a U-shaped connector, are fed into the hole (Fig. 5).

To enhance heat transfer, the gaps between the pipes and the borehole wall are filled with a pumpable grout material. The borehole diameter is approximately 102 mm for a typical residential home. For a typical residential application the spacing between boreholes is around 5–6 m in order to prevent adjacent boreholes from affecting one another and changing ground conditions. To ensure equal flows for multiple borehole systems a manifold system is used, which can be located in the building or buried in the loop field. An advantage of the vertical loop configuration is a reduced installation area, making them advantageous where land is limited. Another incentive for these systems is low landscape disturbance, since drilling has a reduced impact compared to trenching. Also, locating the piping deep in the ground, where the temperature is constant year round, allows consistent heat pump performance and reduces overall loop length. The main disadvantage of using a vertical system is the installation costs, since drilling is normally more costly than horizontal trenching. Consequently the vertical loop systems are normally more economic for larger applications. The main advantage of geothermal heat pumps is their ability to utilize soil and ground water temperatures between 5 °C and...
30 °C, which is common at reasonable depths around the world (Self, 2013).

GEOTHERMAL DISTRICT HEATING

District heating (DH) is a system which distributes heat from a centralized generation plant to users, connected via a heating grid and substations. DH achieves higher energy, economic and environmental performance compared to the traditional central heating systems, as heat supply is best adjusted to users demand. Last but not least, it reduces greenhouse gas emissions and excess heat losses, thus significantly contributes to the climate and energy policy targets. In the EU there are 27 countries which have 3550 DH systems providing heat for 2160 cities and towns for over 5000 inhabitants, thus satisfying 12% of the total heat demand of the population. The majority of the systems are fed by gas and only 1% by renewables (mostly biomass). Despite the favorable geothermal conditions in Europe, geothermal energy contributes only 0.001% of the district heating systems. Nevertheless geothermal district-heating (Geo-DH) dates back to the Roman ages, when city homes and baths were heated via natural hot water catchments and piping. In 2011 there were 212 Geo-DH systems operating in Europe with a total installed capacity of ~ 4700 MWt capacity. The major markets are in France, Iceland, Germany and Hungary, however most of the European countries foresee a significant growth by 2020, also in line with their NREAP (National Renewable Energy Action Plans) targets (GeoDH, 2014).

Geothermal District Heating (GeoDH) is the use of geothermal energy (i.e. the energy stored in the form of heat below the earth’s surface) to heat individual and commercial buildings, as well as for industry, through a distribution network. The first regions to install GeoDH, were those with the best hydrothermal potential, however with new technologies and systems, there is an ever increasing batch of regions that are developing geothermal technology for heating & cooling. Systems can be small (from 0.5 to 2 MWth), and larger with a capacity of 50 MWth. There are some new District heating schemes that utilise shallow geothermal resources, assisted by large heat pumps (GeoDH, 2014).

The ‘hot’ GeoDH markets in Europe are in France (Paris, and renewed activity in the Aquitaine basin), Germany (Munich) and Hungary, but it is important to always note that geothermal DH systems can be installed in all European countries. In recent times, there have been new entrants to the market: The Netherlands, Spain (Madrid), UK (Newcastle) etc. By 2020, nearly all the countries in Europe will have GeoDH.

Figure 6. Geothermal doublet system for district heating (GeoDH, 2014)
Many GeoDH systems (such as in the Paris Basin) are based on a dependable sedimentary resource environment, and on the doublet concept of heat extraction. Modern doublet designs include two wells drilled in deviation from a single drilling pad. Bottom hole spacings are designed to secure a minimum twenty year span, before cooling of the production well occurs. Well depths (deviated) of 2,000m to 3,500m are not uncommon; and these are often located in sensitive, densely populated urban environments, therefore requiring heavy duty silent rigs (up to 350 ton hook loads, diesel electric drive) Figure 6.

The installation for systems with a lower temperature assisted by heat pumps is also possible. In several instances (Denmark, Germany, Iceland) absorption heat pumps, often associated with geothermal Combined Heat & Power plants (CHP), have been successfully installed and operated.

Additionally, the installation of GeoDH systems becomes more economical close to areas with a higher urban density, as both resources and demands need to be geographically matched. One considerable challenge in the current economic crisis concerns the financing and the development of new heat grid infrastructures. Retrofitting is an alternative for developing the GeoDH market.

Oradea, in Western Romania, is an example of the insertion of a geothermal heating system into the existing city: a coal fired/back pressure system, combined heat and power (CHP) network, typical of previous Central/Eastern Europe district heating practice is being used.

Geothermal district cooling is actually poorly developed in Europe, with merely 30 MWh of installed cold power. This development issue should be challenged by geothermal operators (and users), as it could provide additional summer loads to GeoDH systems. In the Paris Basin, for instance, absorption chillers can be placed in grid substations and the primary hot fluid supplied by the geothermal heat plant. The chilled water can be piped to consumers via the same flow circuit used for heating (GeoDH, 2014).

CONCLUSIONS

Geothermal heat pumps are highly efficient heating technologies that allow for reductions in CO₂ emissions, the potential avoidance of fossil fuel usage and economic advantages. Heat pumps utilize significantly less energy that is harmful to the environment to heat a building than alternative heating systems. Many variations of geothermal systems for heating exist, with different configurations suitable in different situations and most locations around the world. In deciding among heating options it is important to determine the benefits for different ground heat pump options, typically in terms of efficiency, emissions and economics. Exploitation of geothermal resources is critically determined by the transmissivity of the aquifer, which constrains production rates. Transmissivity data and pumping test results are only available for specific areas. It would not be possible to obtain assessments for most of Europe based on such data. Furthermore, permeability may vary over several orders of magnitude within short distances, with almost unpredictable consequences for the exploitation.

With the increased interest in geothermal heat pumps, geothermal energy can now be developed anywhere, for both heating and cooling. Low-to-moderate temperature geothermal resources are also being used in cogeneration heating plants (CHP). CHP projects certainly maximize the use of the resources and improve the economics, as has been shown in Iceland, Austria and Germany.

Using low-to-moderate temperature geothermal resources in the direct heat applications, given the right conditions, is an economically feasible business and can make a significant contribution to a country’s or region’s energy mix. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy.

With geothermal energy becoming increasingly more competitive with fossil fuels and the environmental benefits associated with renewable energy resources better understood, development of this natural “heat from the earth” should accelerate in the future. An important task for all of us in the geothermal community is to spread the word on geothermal energy, its various applications, and the many environmental benefits that can accrue from its use (John, 2011).

REFERENCES


