Could ground heat and geothermal energy be the answer to climate change prevention and energy demand?

Ilkka Vähäaho
Head of Soil and Bedrock Unit GEO, Chair of Ground Heat Committee, City of Helsinki
ilkka.vahaaho@hel.fi

Abstract. Global warming has caused and will continue to cause an increasing amount of extreme weather phenomena. Science has shown that the risks for irreversible and catastrophic changes will rise considerably if the climate warms up by more than 1.5 or even 2 degrees Celsius. The City of Helsinki bears its responsibility in mitigating climate change. The aim is to make Helsinki carbon neutral by 2035. The operating environment of energy produced by ground heat wells is changing in Finland – recently the interest in boring large energy well fields and deeper energy wells has increased considerably. There are two types of geothermal energy wells: wells based on a closed loop system and EGS wells, operating with the help of a network of clefts in the bedrock. EGS power stations are always associated with an earthquake risk, as they alter the stress state in the bedrock. The traditional ground heat wells are currently more cost-effective in Finland than the geothermal energy wells when their construction costs are compared with the value of the energy generated by them. The construction costs of geothermal energy solutions will most likely decrease along with future mass production. Geothermal energy wells will also bring many benefits compared with ground heat wells. In terms of underground construction, it is better to have fewer boreholes. Unlike traditional ground heat wells, geothermal energy will never run short over the years. The energy production of ground heat wells is typically calculated for a period of 20 to 50 years. Cooling also known as recharging will increase the lifespan of a ground heat system for some decades. The energy production of a two-kilometre deep geothermal energy well in the bedrock of Helsinki has been modelled for the next 1,000 years. The energy production of a two-kilometre deep geothermal energy well will initially reach 800 MWh annually and still be as high as 640 MWh annually after 1,000 years. Helsinki also aims to utilise renewable energy on a regional basis, and not only for individual building lots. Our intention is to integrate the utilisation of ground heat and geothermal energy as part of land-use planning. The pilot sites will include both new production and complementary development. This work is part of the background research for the Helsinki Underground Master Plan 2021.

1. Introduction
Global warming has caused and will continue to cause an increasing amount of extreme weather phenomena, such as floods, drought, melting of glaciers, sea level rise, changes in the distribution of animals and plants or even their extinction, occurrence of plant diseases and pests, shortage of food supplies and drinking water and migration of people fleeing these threats. Science has shown that the risks for irreversible and catastrophic changes will rise considerably if the climate warms up by more than 1.5 or even 2 degrees Celsius compared with the preindustrial era.
The City of Helsinki bears its responsibility in mitigating climate change. The aim is to make Helsinki carbon neutral by 2035. Carbon neutrality means that activities in the Helsinki area will no longer heat up the climate: there will be no greenhouse emissions from transport, buildings will be heated without emissions, and the electricity consumed by the residents of Helsinki will be produced without emissions. In a carbon neutral Helsinki, greenhouse emissions can be a maximum of 702 kiloton \(\text{CO}_2\) e a year and these emissions shall be compensated for. The emissions currently amount to 2,559 kiloton \(\text{CO}_2\) e a year, whereas in 1990 the emissions were 3,514 kiloton \(\text{CO}_2\) e. The Helsinki Climate Watch programme comprises 147 climate measures, which will help take the city in the right direction towards carbon neutrality. One central goal is to utilise ground heat and geothermal energy for the heating and cooling of buildings. At the end of 2019, ground heat accounted for 1\% of the heating energy of the building stock in Helsinki. By 2035, the aim is to increase the share of ground heat and geothermal energy to 15\% of all heating and cooling energy. What this means in Helsinki is that starting from 2035; ground heat and geothermal resources must produce approximately 1,000,000 MWh of energy annually.

2. **Different size categories of ground heat and geothermal energy**

In this paper, to keep matters simple, the term ground heat well or geoenergy well is used for wells with a maximum depth of 1,000 metres, and wells with a depth of more than 1,000 metres are called geothermal energy wells. There are two types of geothermal energy wells: wells based on a closed loop system where energy is collected inside the collector pipe of the energy well and wells based on an enhanced geothermal system (EGS) operating with the help of a network of clefts in the bedrock (figure 1). In an EGS, water is injected into the bedrock with high water pressure, so called hydraulic stimulation (up to c. 900 bars) under carefully controlled conditions that causes pre-existing fractures to re-open, creating permeability. Increased permeability allows water to circulate throughout the now-fractured rock and to transport heat to the surface. It is notable that EGS power stations are always associated with an earthquake risk, as they alter the stress state in the bedrock. Implementing an EGS power station in Helsinki would require geothermal energy wells to reach a depth of around 6,000 to 7,000 metres. Section 7 discusses the risk management of seismic hazards relating to EGS power stations.

![Elementary diagram of a geothermal EGS power station.](image-url)
3. The operating environment of energy produced by ground heat and geothermal energy in Finland

The operating environment of energy produced by ground heat wells and geothermal energy wells is changing in Finland – recently, the interest in boring large vertical energy wells and deeper energy wells has increased considerably. The 1.3-km-deep geothermal energy well and heat pump station in Koskelo, Espoo, and the EGS power station in Otaniemi, Espoo, which according to current plans will start its operation in the first half of 2021 with two geothermal energy wells reaching a depth of 6.1 kilometres, serve as examples of such activity. Numerous other power stations utilising geothermal energy have been planned for the regions of Helsinki, Tampere and Turku, but most of them have not yet been confirmed and are waiting for experiences of use from power stations that are already in use.

On 20 May 2018, a local newspaper in Espoo reported the news that “The boring of a geothermal energy well in Otaniemi has progressed to a depth in the bedrock that would generate a sufficient amount of heat. The first hole will reach a depth of over 6 kilometres, where the temperature is 121.5 degrees.” The temperature is considerably higher than what was originally estimated by calculations. Geothermal solutions can in that way enable sufficient energy supply also in a densely built-up urban environment.

The traditional ground heat wells are currently more cost-effective in Finland than the geothermal energy wells when their construction costs are compared with the value of the energy generated by them. The construction costs of geothermal energy solutions will most likely decrease along with future mass production. Geothermal energy wells will also bring many benefits compared with ground heat wells. In terms of underground construction, it is better to have fewer boreholes and to have them in fewer locations. Unlike traditional ground heat wells, geothermal energy will never run short over the years. The energy production of ground heat wells is typically calculated for a period of 20 to 50 years. Cooling also known as recharging will increase the lifespan of a ground heat system by approximately 17 to 24 years. Running short of the gained heat/cooling energy depends on the power used for pumping. The energy production of a two-kilometre deep geothermal energy well in the bedrock of Helsinki has been modelled for the next 1,000 years. The energy production of a two-kilometre deep geothermal energy well will initially reach 800 MWh annually and still be as high as 640 MWh annually after 1,000 years (figure 2).

![Figure 2. The cumulative energy production of two-kilometre deep geothermal energy wells, where d is the distance between the wells [1].](image-url)
4. Ground heat and geothermal energy on a regional basis

The City of Helsinki commissioned the Geological Survey of Finland (GTK) to calculate the geoenergy potential in the whole area of the city [2]. The geoenergy potential in the bedrock of Helsinki was calculated based on the assumption that Helsinki is one large energy well field with wells located at a distance of 20 metres from one another. This corresponds to a situation where Helsinki is divided into plots of 400 m² with an energy well in the middle of each of them. Each well was assumed to give as much energy as possible for fifty years, but this was without lowering the temperature of the wall of the well below zero degrees Celsius. Thus, the technical potential describes how much heating energy can be obtained from the bedrock by energy wells without lowering the bedrock temperature below freezing point. In this way, the calculation also takes into account the interaction between the energy wells.

Geothermal energy is energy stored in and generated by the bedrock. The geoenergy of the surface layers of the bedrock (0–1 km) is low-temperature energy. Even though the temperature levels of the surface layers of the ground are low compared to the temperature levels deeper down in the Earth’s crust, the geoenergy reserve for the exploitation of heating energy is so large that, in theory, it could cover the heating need of the whole of Helsinki (approximately 7,000,000 MWh/a) for decades, for example. This would, however, require the whole land area of Helsinki to be bored full of energy wells reaching a depth of over 300 metres at 20-metre intervals.

Besides containing the building-specific solar energy potential, the Helsinki Energy and Climate Atlas [3] also includes the geoenergy potential based on various types of rock as well as the parameters needed for dimensioning geoenergy wells (figure 3).

![Figure 3. The Helsinki Energy and Climate Atlas includes, among other things, the parameters needed for dimensioning geoenergy wells [3].](image-url)
Helsinki also aims to utilise ground heat and geothermal energy on a regional basis and not only for individual building lots [3]. The aim is to investigate regional solutions based on ground heat and geothermal energy in different size categories, to propose pilot areas, to examine feasibility risks and assess the impact on energy production and the economy. Our intention is to integrate the utilisation of ground heat and geothermal energy as part of land-use planning. The chosen existing test sites will be used for piloting the realisation of new energy solutions. The pilot sites will include both new production and complementary development. This work is part of the background research for the Helsinki Underground Master Plan 2021 [5].

As an example of a new way of exploiting renewable energy locally, we could mention, for example, Hermanninranta and Kyläsaari areas, which are new comprehensive developments totalling a floor area of 420,000 square metres near the centre of Helsinki (figure 4). The heating energy requirement could, in its entirety, be managed using geothermal energy wells of 2,000 metres in depth, which would be located underneath the 1,100-metre-long main road that passes through these areas. More than 600 wells would be needed if 350-metre-deep energy wells were used. In practice, it would be impossible to locate such a large number of energy wells in the public areas and the implementation costs would be very high because the soil layers are nearly 50 metres in depth in places.

Figure 4. According to the draft Hermanninranta and Kyläsaari areas plan new comprehensive developments represent totalling a floor area of 420,000 square metres near the centre of Helsinki. The heating energy requirement could, in its entirety, be managed using geothermal energy wells of 2,000 metres in depth.

5. New guidelines for the use of ground heat / geoenergy

5.1. General information
In August 2020, new guidelines [6] were introduced in Helsinki in which the term energy well is used instead of ground heat well, because energy wells are more and more often being used for both heating and cooling. In order to bore an energy well, it is necessary to apply for a permit. These guidelines concern energy wells with a depth of 3 kilometres at a maximum. The new guidelines are based on a proposal (“Ground heat wells in Helsinki”) [7] made by a ground heat well working group as a result of committee work that took three years to complete.
Energy wells are classified by their depth as follows:

- Shallow energy well of 1,000 metres in depth at a maximum;
- Medium-depth energy well of 1,001 to 3,000 metres in depth at a maximum;
- Deep energy well of over 3,000 metres in depth.

The prerequisites for boring will be ensured in conjunction with processing the application for an energy well permit. The permit describes the measures that are needed to ensure risk-free work, prevention of damage and updating of location data of the energy wells to the map data maintained by the City of Helsinki. The permit is also needed to ensure that no underground district heating, water, sewage and other pipes or cables are damaged when boring an energy well. The ground is also full of numerous underground spaces, such as cable ducts, emergency shelters and parking facilities. Energy wells must not be bored in these or in the surrounding protective areas.

5.2. Individual shallow energy wells
The minimum distance between two energy wells must be 15 metres at a minimum. In this way, adjacent energy wells will not reduce the amount of energy obtained from one hole. The energy well must be bored no closer than at a distance of 7.5 metres from the boundary of a plot. Boring closer to the boundary of a plot is possible only with the consent of the landowner of the adjacent plot and the first 100 metres must be bored down with controlled boring method to ensure that the borehole is vertical. An easement agreement is required when the boundary of a plot is crossed. If, after boring, it is noticed that an energy well is located closer than 7.5 metres to a boundary the neighbour’s consent is required or the hole must be filled.

5.3. Medium-depth energy wells and energy well fields
In the planning and implementation of medium-depth energy wells and energy well fields, energy calculations and modelling shall be used to show proof that the neighbouring buildings have corresponding opportunities for the use of energy wells. The minimum distance of a well from a neighbour’s boundary shall be defined on the basis of energy sufficiency calculations. The consent of a neighbour must be obtained when necessary. Calculations and modelling shall be used to prove the sufficiency of ground heat energy to neighbours from energy wells of more than 1,000 metres in depth. Calculations and modelling shall be used to prove the sufficiency of ground heat energy to neighbours from energy well fields, as well. An energy well field is a site with ten or more energy wells.

6. Risk management of seismic hazards for EGS power stations
To minimise seismic risks [8], the University of Helsinki Institute of Seismology has developed a tool for monitoring the first EGS power station in Finland located in Otaniemi, Espoo. Figure 5 illustrates the Traffic Light System (TLS). The operation can be continued normally if the peak ground velocity (PGV) remains under 1 mm/s and the magnitude under M1.0 (or the magnitude alone under M1.2). If the aforementioned limits are exceeded but the peak ground velocity (PGV) remains under 7.5 mm/s and the magnitude under M2.1, the operation can continue if the matter has been notified of as agreed. If the aforementioned limits are exceeded the operation must be ceased until permission to continue the operation has been received.
Figure 5. An example of a Traffic Light System [8].

7. Conclusions

The main conclusions of this paper are:

- The City of Helsinki bears its responsibility in mitigating climate change. The aim is to make Helsinki carbon neutral by 2035. One of the key measures is increasing the share of ground heat and geothermal energy from the current 1% to 15% in the production of heating and cooling energy, which means that starting from 2035 ground heat and geothermal resources must produce approximately 1,000,000 MWh of energy annually.
- The use of 150 to 500-metre-deep ground heat wells is currently more cost-effective in Finland than the use of over 1,000-metre-deep geothermal energy wells when their construction costs are compared with the value of the energy generated by them. On the other hand, the construction costs of geothermal energy solutions will most likely decrease along with future mass production.
- The energy production of traditional ground heat wells is typically calculated for a period of 20 to 50 years, by which time the temperature of the wall of the well has decreased to zero degrees Celsius. Cooling, also known as recharging, increases the lifespan of a ground heat system for some decades. Geothermal energy, on the other hand, will never run short over the years like traditional ground heat.
- Geothermal energy wells will also bring many benefits compared with ground heat wells. In terms of underground construction, it is better to have fewer boreholes and to have them in fewer locations.
- Geothermal solutions enable sufficient energy supply also in a densely built-up urban environment.
References

[1] Korhonen K., 2019, Cumulative energy production of two-kilometre deep geothermal energy wells, Geological Survey of Finland GTK, Email 15.4.2019, (In Finnish only)

[2] City of Helsinki, Urban Environment Division, 2019, Helsingin geoenergiapotentiaali, kaupunkiyrityksen julkaisuja 2019:25, www.bit.ly/helsingin-geoenergiapotentiaali, (In Finnish only)

[3] City of Helsinki, 2020, Energy and Climate Atlas, https://kartta.hel.fi/3d/atlas
[4] City of Helsinki, Urban Environment Division, 2020, Alueellisten maalämpöratkaisujen periaatteet maankäytön suunnittelussa ja toteutuksessa, Helsingin kaupungin kaupunkiyrityksen aineistoja 2020:22, https://www.hel.fi/kaupunkiyritysto/julkaisut-ja-aineistot/aineistoja-sarja, (In Finnish only)

[5] City of Helsinki, Underground Master Plan, 2020, https://www.hel.fi/helsinki/en/housing/planning/current/underground-master-plan

[6] City of Helsinki, Urban Environment Division, Building Control Services, 2020, Ohje, Maalämpökaivo, https://www.hel.fi/static/rakvv/ohjeet/Maalampo.pdf, (In Finnish only)

[7] City of Helsinki, Urban Environment Division, 2020, Maalämpökaivot Helsingissä –Maalämpötyöryhmän ehdotus, kaupunkiyrityksen julkaisuja 2020:8, www.bit.ly/maalampokaivot-helsingissa, (In Finnish only)

[8] Institute of Seismology, University of Helsinki, 2019, Selvitys geotermisen energian syväreikäporaamisesta, siihen liittyvistä ympäristönäkökohdista sekä riskienhallinnasta, http://hdl.handle.net/10138/301878, (In Finnish only)

Acknowledgment
The author wishes to thank the Helsinki ground heat well working group that has been working together for three years. During this period many matters in the industry took leaps forward and the same is true as regards understanding the exploitation of ground heat and geothermal energy. The Geological Survey of Finland did valuable work in modelling the geoenergy potential in the Helsinki area for which the City of Helsinki Executive Office ICT Development developed an application that serves the dimensioning of ground heat in Helsinki Energy Atlas. Cooperation with the University of Helsinki’s Institute of Seismology has built the base for safe construction, use and monitoring of EGS power stations. The regional ground heat solution principles in land use planning and implementation project, which serves the Helsinki Underground Master Plan 2021, has created the basis for the regional use of ground heat and geothermal energy instead of the current plot-specific use. The cooperation between numerous other operators in the industry and the City of Helsinki has been very close and fruitful. The future prospects look more than promising. All of this places us in a good position in our efforts to achieve emission free energy as part of a carbon neutral Helsinki.