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Utilization of decentralized geothermal energy potential in a densely populated urban area - Case Helen

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	D.Sc. (Tech) Mika Luoranen
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ABSTRACT

Lappeenranta-Lahti University of Technology LUT
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Utilization of decentralized geothermal energy potential in a densely populated urban area - Case Helen

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Keywords: geothermal energy potential, urban environment, district heating, ground heat

This master's thesis work was made with co-operation with Helen Oy that is currently searching for substitutive solutions to cover usage of coal by the year 2029. Possibilities of local solutions for utilizing geothermal energy potential have been noted by Helen Oy and more research about them must be done. Aim of this study was to geothermal energy potential of Helsinki for three ground depths and their relation to current and 2050 heat energy demand of the building stock. Another goal was to find out possible CO_2-emission reduction potential when part of the most emission intensive times of utilizing district heating is substituted by local geothermal energy potential according to the planned district heating production for years 2025 and 2035.

The answers for made research questions were provided by utilizing public data concerning for example building stock of Helsinki and datasets of Helen Oy including information about measured district heating consumption and planner energy production and emission occurring from it in the future. The theory part of the thesis was implemented mostly as a literary review. The results of the study showed that relation between local heat energy demand and geothermal energy potential varies between different ground depths and part of the city. Especially coverage rate was noted to be much smaller in the city center than in the outskirts. Emission calculation demonstrated that there could be achieved approximately 25 % emission reduction potential by utilizing geothermal energy potential locating at district heating account areas within depth of 300 meters in 2025 and 2035. Also, it was noted in this connection that there is still role for district heating in the future energy system.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
LUT School of Energy Systems
Ympäristötekniikan koulutusohjelma
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Hajautetun geotermisen energiapotentiaalin hyödyntäminen tiheästi asutetulla kaupunkialueella - Case Helen

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Asiasanat: geoenergiapotentiaali, kaupunkirakenne, kaukolämpö, maalämpö

Diplomityö toteutettiin yhteistyönä ja toimeksiantona Helen Oy:ltä, joka etsii parhaillaan ratkaisuja korvata kivihiilen käyttö energiantuotannossa 2029 mennessä. Paikallisten ratkaisujen mahdollisuudet maalämmön hyödyntämistä koskien on todettu Helen Oy:n puolesta ja niitä on tarve selvittää enemmän. Työn tavoitteina oli selvittää Helsingin alueen geoterminen energiapotentiaali kolmelle syvyysasteelle suhteessa nykyiseen ja vuoden 2050 rakennuskannan lämmitysenergian tarpeeseen. Tavoitteena tämän lisäksi oli selvittää, kuinka paljon hiilidioksidipäästöjä voidaan vähentää, kun osa kaukolämmön käytön päästöintensiivisimmistä ajanhetkistä korvataan olemassa olevalla geoenergiapotentiaalilla vuosien 2025 ja 2035 suunnitellun kaukolämmön tuotantorakenteen ja päästöjen perusteella.

Asetettuihin tutkimuskysymyksiin vastattiin hyödyntämällä julkista Helsingin kaupungin dataa koskien mm. rakennuskantaa, sekä Helen Oy:n omaa dataa mitatuista kaukolämmön kulutuslukemista sekä ennusteita koskien energiantuotantoa ja sen päästöjä tulevaisuudessa. Työn teoriaosa toteutettiin pää asiassa kirjallisuuskatsauksena. Tutkimuksessa ilmeni, että lämmitysenergian tarve suhteessa paikalliseen geotermisen energian potentiaaliin vaihtelee tutkittavasta hyödyntämissyvyydestä ja kaupunginosasta riippuen. Eritysiesti keskusta-alueella kattoaste todettiin pienemmäksi kuin esikaupunkialueilla. Päästölaskentaosiossa todettiin, että kaukolämmön kulutusalueilla 300 metrin syvyydessä sijaitsevan geoenergiapotentiaalin päästövähennyspotentiaali on noin 25 % vuosina 2025 ja 2035. Tässä yhteydessä todettiin myös, että kaukolämmöllä tulee olemaan merkittävä rooli lämmitystarpeen kattamisessa yhä tulevaisuudessa.

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Diplomityön kirjoittaminen töiden ohessa oli erittäin opettavainen prosessi vastuun ottamisesta sekä priorisoinnista. Työ myös muutti muotoaan matkalla pariin otteeseen, mikä ei ollut yllättävää; energia-ala todella on suuressa murroksessa ja joka päivä tuo tullessaan uutta tutkimustietoa sekä kokemuksia. Koen olevani onnekas, että saan olla Helenin matkassa mukana juuri tänä päivänä.

26. Tammikuuta Vantaalla

Henni Vornanen

TABLE OF CONTENTS

ABSTRACT

TIIVISTELMÄ

ACKNOWLEDGEMENTS

SYMBOLS AND ABBREVATIONS 3

1 INTRODUCTION 4

1.1 Background of the study 6

1.2 Objectives and limitations 7

1.3 Methods and materials 8

2 URBAN AREAS AND GEOTHERMAL ENERGY 9

2.1 Urbanization and trends resulting from it 9

2.2 Typical characteristics of urban areas 10

2.3 Land use planning 14

3 GEOTHERMAL ENERGY POTENTIAL 15

3.1 Renewability of geothermal energy 15

3.2 General thermogeological features of Finland 17

3.3 Geothermal energy potential in Helsinki 19

4 UTILIZATION OF THE GEOTHERMAL ENERGY 32

4.1 Laws and policies 32

4.2 Dimensioning and utilization technologies 34

5 CO_2-EMISSIONS OF GEOTHERMAL ENERGY AND DISTRICT HEATING 39

5.1 Geothermal energy 39

5.2 District heating 42

6 GEOTHERMAL ENERGY POTENTIAL AND HEAT ENERGY DEMAND 47

6.1 Used data and data sources 47

6.2 QGIS calculation 50

6.2.1 Existing geothermal energy potential and current heat energy demand at block areas.. 50

6.2.2 Existing geothermal energy potential and heat energy demand in 2050 at grid plan..... 52

6.3 Calculation results 53

6.3.1 Existing geothermal energy potential and current heat energy demand at block areas.. 53

6.3.2 Existing geothermal energy potential and heat energy demand in 2050 at grid plan..... 66

7 CO_2-EMISSION REDUCTION POTENTIAL 81

7.1 Calculation principles and background 81

7.1.1 Functions 82

7.1.2 Default values and assumptions 84

7.2 Calculation results 87

7.2.1 2025 88

7.2.2 2035 90

8 CONCLUSIONS AND DISCUSSION 93

9 SUMMARY 97

REFERENCES 99

APPENDICES:

APPENDIX 1: Coverage rate maps for local geothermal energy potential and heat energy demand in 2050 base by the scenario of population growth

SYMBOLS AND ABBREVATIONS

CHP = Combined heat and power

DH = District heating

EEA = European Environmental Agency

EU = European Union

GHG = Greenhouse gas

GTK = Geological Survey of Finland

IPCC = Intergovernmental Panel on Climate Change

CO_2 = Carbon dioxide

1 INTRODUCTION

Increased awareness of policy-makers and consumers, about climate change and challenges that are resulted from it, has led off to the ongoing energy structure change. This has exposed many questions about the adequacy of energy resources and intelligence of our current energy system. The climate policy of European Union (EU) follows guidelines of Kyoto Protocol, international agreement of United Nations, which first commitment period was during years 2008 to 2012. Emission reduction target of the first commitment period for EU countries was to reduce total 8 % of greenhouse gas (GHG) emissions compared to the emission level of the year 1990. For Finland, the target was to aim the GHG emission level of the year 1990. Second, and ongoing, commitment period is during years 2012-2020. The target of this commitment period is the emission reduction rate of 20 %, which is also compared to the emission level of the year 1990. (Ministry of the Environment 2013.)

In addition to Kyoto Protocol, European Commission has also its own climate targets that cover all member countries. These targets were regulated in 2020 climate and energy package, which includes three key points: 20 % cut in GHG emissions (from the level of year 1990), 20 % share of renewables of produced energy in EU and energy efficiency improvement of 20 %. 2020 climate and energy package also includes emission trading system as a main tool to control GHG emissions from aviation, power and industry sector, national emission reduction targets and targeted share of renewable energy production. National targets vary according to the national wealth level of the member country. (European Commission 2019.) The European Council has also set targets to year 2030 in 2014 as a part of The Paris Agreement: GHG emission reduction of 40 %. 2030 climate package includes land use and forestry regulation (LULUCF), updated EU Emission Trading System and effort sharing regulation, for example. According to the effort sharing regulation, the reduction rate of GHG emissions for the year 2030 for Finland is 38 % compared to the emission level in year 2005 and for the year 2020 the reduction rate is 16 %. (Ministry of the Environment 2018.)

Apart from the climate targets of EU, Finland has set more ambitious targets of its own. The long-term target set by the Finnish Government is to reduce GHG emissions at least 80 % by 2050 compared to the emission levels in 1990. The long-term target is enacted in the Climate Change Act (609/2015) entered into force in 2015. Climate Change Act defines, in addition to the long-term planning for national climate policies, a provision about climate policy planning system for the medium-term targets opted by the Finnish Government during the government term. The goal of the Climate Change Act is to coordinate and accelerate information and activities of different state authorities in terms of mitigation of climate change. (Ministry of Economic Affairs and Employment 2017.)

In October 2018 the Intergovernmental Panel on Climate Change (IPCC) published special report "Global Warming of 1.5 ℃" which was effectively noticed globally. The report is aimed to the leaders and decision-makers and it claims that global warming of 1.5 ℃ (compared to the pre-industrial period) will have significant impacts on life on Earth and the report also compares the concrete consequences of global warming of 2.0 ℃ compared to the warming of 1.5 ℃. IPCC claims in the report that the difference of 0.5 ℃ is major. The report also states that the current targets are not enough to stay in the global warming limit of 1.5 ℃. "Global Warming of 1.5 ℃" is currently the most comprehensive scientific research about the consequences of the global warming. Due to that, the report can be assumed to taken into account exceedingly by the policy-makers and the current climate targets can be assumed to be tightened even more.

In Finland 38 % of the end-use of the energy is consumed by the building sector and approximately about 30 % of the total GHG emissions of Finland are from heating energy consumption of buildings (Suomen Ympäristökeskus 2017). Because of the high share of the emissions from energy and building sector, tightening climate targets will most likely to have impact on that area. The fifty most largest municipalities in Finland cover about one third of the total emissions of the country and from that three quarters are from traffic and heating energy. According to Sitra, after 2015 the average ambition level of GHG emission reduction targets of municipalities in Finland has risen and energy sector and land use planning are the most common subjects in the climate action plans of municipalities. (Sitra 2018.) It can be seen that not only international or national climate targets will be tightened, but regional targets of municipalities will be stricter too. It is also obvious that considerable part of the GHG emission reductions will touch even more on the energy resources and the effective way to utilize them.

1.1 Background of the study

In April 2018 The Finnish Government decided that using coal in production of energy will be prohibited in year 2029 by law. This will affect the most on district heating companies. Nine heat plants or district heating grits use 90 % of total coal consumption in Finland. In 2016 the most significant use of coal in combined heat and power production were in eight cities and five of these cities are on top eight list of the most populated cities in Finland. These five cities are Helsinki, Turku, Espoo, Vantaa and Lahti. (Pöyry Management Consulting 2018.)

The prohibition of coal use is effecting the most on district heating production sector. District heating companies will have to come up with new ways of energy production or energy efficiency technologies. At the moment, the planning of the substitutive energy production technologies in these cities is concentrated mainly for biomass use and other multi-fuel boiler solutions, heat pump and heat recovery technologies and stored heat (Pöyry Management Consulting 2018).

As district heating grit and production systems being somehow straightforward, primitive and unyielding in addition to giving up the coal usage in such short term, the change will be challenging especially in more populated cities. It has been said by Helen Oy for example, that there is no one solution or substitutive energy source to replace coal in the district heating production in Helsinki (Helen Oy 2019a). Tight time schedule and many replacement energy sources needing perhaps more than expected investments require quick decision-making.

In addition to problems of tight time schedule, there are other practical challenges related to energy transition especially in the urban environments. In dense populated areas there are many smaller scale and local heat sources like household or industrial sewerage and server rooms but the invocation of these separated sources may be challenging. Also, lack of space for the utilization systems may occur in urban environment.

Growing demand of better living conveniences especially in terms of cooling has enhanced the markets of heat pumps in Finland. Also increase in prices of district heating (Energiateollisuus 2019a) has added more interests of consumers to heat pump systems. In 2015 ground-source heat pump was the most used heating system in detached houses in Finland (Tilastokeskus 2016). In larger real estates the interests towards ground-source heat pump solutions has been noticed too. According to Finnish heat pump organization SULPU ry many service buildings and shopping centers like IKEA or Skanssi in Turku or campus of Aalto University in Otaniemi utilize heating and cooling energy from the drilled wells (SULPU ry 2019).

1.2 Objectives and limitations

This master's thesis work is made with co-operation with Helen Oy, the energy company locating at Helsinki. Helen Oy has the widest district heating grit in Finland and is the biggest district heating producer. The aim of this thesis is to produce more information to Helen Oy that is currently planning and making decisions about investments concerning substitute heat energy production to cover coal usage. Also, currently market planning to the future is in the making and lot of research is done about different scenarios of ongoing energy revolution.

Helen Oy has seen local geothermal energy as an option rather than competitor to the current district heating system. New kind ways to come up expectations and demand of customers as a energy supplier has to be innovated and local geothermal energy as a supportive heat energy source beside district heating is decided to be investigated. As Helsinki is being such densely populated and built-up environment, there are definitely many possible aspects that should be considered when investing on geothermal energy solutions.

The main research questions that are answered in this study are:

- What is the relation between heating energy demand and local geothermal energy potential in Helsinki currently and in 2050?
- What is the CO_2-emission reduction potential of utilizing the existing geothermal energy at district heating account areas in 2025 and 2030?

This study is limited to consider only utilizing geothermal energy stock locally as a heating purposes and the study is focused on the area of Helsinki only. Cooling as a restocking element for the geothermal energy stock is not taken into consideration in this study. Only shallow geothermal energy from 150 meters to one kilometer is studied.

1.3 Methods and materials

The answer to the first research question is provided by utilising existing geospatial data concerning Helsinki. Used data is gathered some from Helen Oy and some from public data platform of the Helsinki. Part of the data provided by Helen is classified as secret information and because of this can not be presented as its full complexity. Different data sources are put together by using software called QGIS that enables processing of geospatial data.

Answers to the second research question concerning emission reduction potential is provided by using data about district heating production plans of Helen Oy. Also, the results from the geothermal energy potential calculation is used. Calculation is made mainly by using excel.

2 URBAN AREAS AND GEOTHERMAL ENERGY

2.1 Urbanization and trends resulting from it

Before industrial revolution a lot of ground surface area were needed when majority of population earned their livelihoods from it, which generated decentralized population and production. Urbanization has been one of the most remarkable societal changes in human history. (Laakso & Loikkanen 2016.) The population in urban areas has globally grown from 751 million to 4,2 billion between 1950 and 2018. According to the information of the United Nations 55 % of the population of the world lived in urban areas in 2018. That is assumed to increase to 68 % by the year 2050. (United Nations 2018.) Urbanization is noted to be strongest in the most affluent countries like in northern and western Europe and North America where the share of urban population is over 80 %. (Laakso & Loikkanen 2016.)

The phenomenon has been seen in Finland from the post-war period to present-day and the change is still strongly ongoing. It is approximated that 1,83 million (Maaseudun tulevaisuus 2019) people are living in the Helsinki region in 2040 which is 33 % (Tilastokeskus 2018) of the predicted population of Finland at that time. However, the Helsinki region covers only 0,2 % of the whole surface are of Finland. At the moment half of the Finnish population lives in the seven biggest cities. (Laakso & Loikkanen 2016.)

Unbalanced area development means the situation where population is concentrated in certain parts of the country followed by declined population in countryside and urbanization. Innovations and the growth of productivity and population have always been varying between territories and this has also decreased income differences as measured by gross national product. The growth in Finland has concentrated to cities where universities and other institutes which offer tertiary education are located. Urbanization is resulting from the siting of corporation units, households and units of the public sector. Especially siting to city centres has been very popular. (Laakso & Loikkanen 2016.)

Geographical differences in activity of business and production can be noted by comparing the gross national product of different areas. In the Helsinki region gross national product per capita is 40 % higher than in the whole country. Due the most profitable business locating in the urban areas also innovation investments and research funding is directed there. In Finland approximately 4/5 of these investments is directed to most populated cities. (Laakso & Loikkanen 2016.)

2.2 Typical characteristics of urban areas

Urbanization challenges the capabilities of urban areas to adapt population growth and employment. Geographical location, history and politics effect on the land use solutions which enables meeting these challenges. Adaptation capabilities between different countries and cities can vary substantially. (Laakso & Loikkanen 2016.)

The law of supply and demand has promoted the price increases in the urban areas. The price increases concerns strongly the real estate sector due to increased demands for good accessibility. And further, this increases the call for more efficient construction because effective land use correlates strongly with price of the land. Effective land use can be measured by built floor space per surface area of the land. (Laakso & Loikkanen 2016.) Built floor space per ground surface space in the area of Helsinki is presented in the picture below (Figure 1). In Helsinki area the biggest space efficiency is concentrated to the city core where built floor space is over 1 floor square meter per ground space.

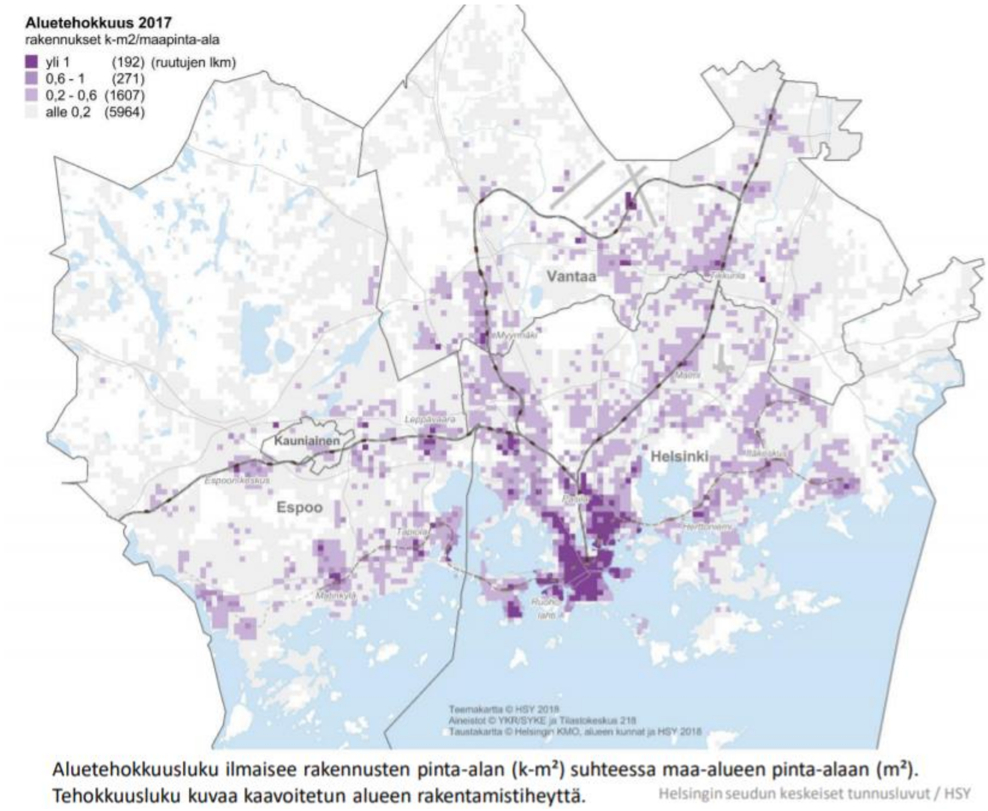

Figure 1. Building efficiency in the area of Helsinki (Helsingin Seutu 2019).

The surface area is used more effectively by using bigger part of it as construction land and building higher buildings. Market-based construction is yet depended on the limitations set by the society which means the number of permitted building volume of the area's building plan. (Laakso & Loikkanen 2016.)

Geographical characteristics determine the trends for development of the urban areas. For example, Helsinki locating in wedge-shaped headland by the sea limits the growing course. In Helsinki central city area, population and workplace density has remained on the same level from the 1960's even though the number of population and workplaces has doubled during the last 50 years in the area of Helsinki. (Laakso & Loikkanen 2016.) The population density of the area of Helsinki in 2019 is presented in the Figure 2 below. The Figure 2 presents well the situation where the city centre of Helsinki has spread and more sub-centres are formed causing more distributed urban conditions. The biggest growth in population has took place in Espoo, Kauniainen and Vantaa. Distributed city structure is also one of the reasons for the risen price level compared to other areas in Finland. (Laakso & Loikkanen 2016.)

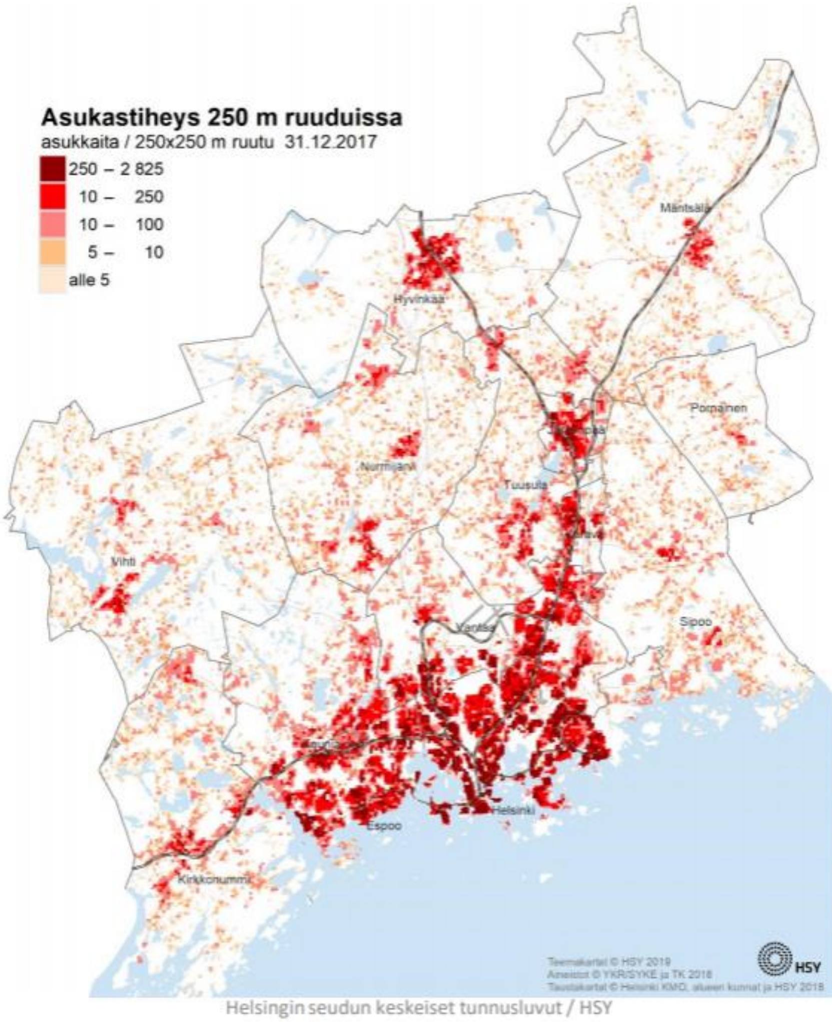

Figure 2. Population density in the area of Helsinki (Helsingin Seutu 2019).

European Environmental Agency (EEA) has expressed their concern about the distribution of land use in Helsinki generating possible threat against cultural basis and environmental, social and economic impacts to the urban area as well as to the countryside. According to EEA, the distribution is consequence of weak land use planning which results inefficient land use in the border areas of the city. The public sector in Finland guides land use heavily using four-level planning system which include national land use targets, regional plan, master plan and city plan. In addition, the landowner has also power to effect on the land use planning; for example, the city of Helsinki owns 63 % of the ground surface area in Helsinki. (Laakso & Loikkanen 2016.)

In the Figure 3 is presented the current areal efficiency of building in Helsinki in unit of floor square area per used land square area. Areal efficiency is over one in the city center. Over one areal efficiency of building is also occurring in the area of Lauttasaari and Munkkiniemi. Most areas in the outskirts of the city have building efficiency of approximately maximum of 0,4. (Helsingin kaupunki 2020.)

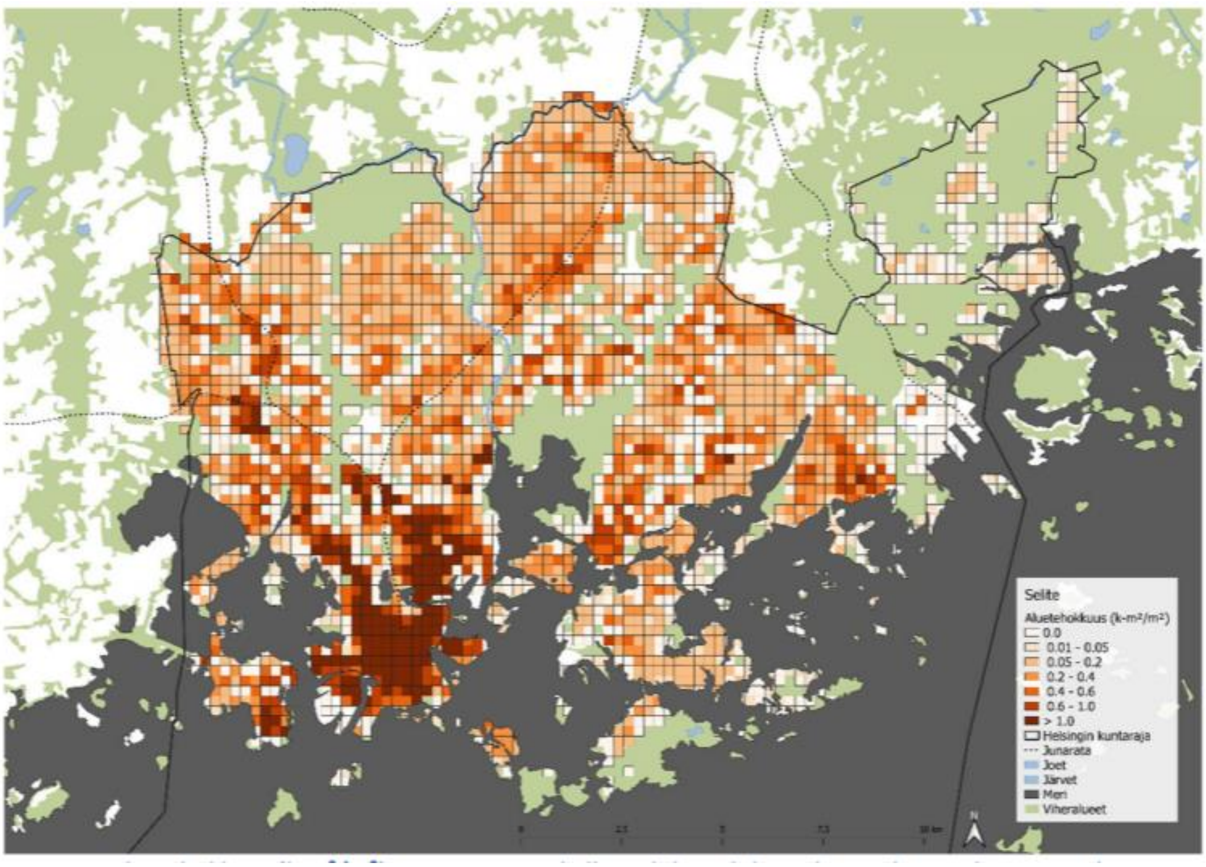

Figure 3. Building efficiency of Helsinki represented in grid areas of 250x250 meters (Helsingin kaupunki 2020).

2.3 Land use planning

Land use planning rules how the residential areas, neighborhoods, workplaces, green areas and traffic infrastructure are positioned to the city. City planning is levelized to different specificities. Master plan shows the way to more specific street plans. Master plan is renewed in Helsinki approximately every ten years and the current master plan of Helsinki, City of Helsinki master plan 2016, came into effect in 2018. Street plans regulates the amount of building at that area and for example height of the buildings and width of the streets are defined in the street plan. Land use planning is under control of the city. (Helsingin kaupunki 2019a.)

At the moment some big areas are currently being planned and formed like Jätkäsaari, Kalasatama, Kruunuvuorenranta and Keski-Pasila. In addition, lot of complementary building is occurring around Helsinki. More commercial building is needed and planned around areas that are appropriate in terms of the city structure. (Helsingin kaupunki 2019a.) The most important goals of the current master plans are ecoefficiency, accessability, environmental values and good urban living. The master plan does not directly take a stand on developing the energy system, but it does enables possibilities to many various solutions. For example, it is stated that in the city center it is allowed to locate bigger sized of energy production plants. (Helsingin kaupunki 2020.)

Currently also new underground master plan is in the making. Existing underground master plan is from the year 2011 and newer version is much needed due to new kind space requirements. Underground master plan states that energy wells are not allowed to be bored at planned areas or tunnels. Plan proposal will be published approximately at the end of 2020. Only the most remarkable planned projects are listed to the underground master plan. The aim of the new underground master plan is to increase the effectiveness of the underground usage and to diversify the use of these underground spaces. City of Helsinki master plan 2016 steers urban environment to be even more densely built which increases the pressure of relocating some functions underground. (Helsingin kaupunki 2019b.) In the upcoming underground master plan are considered the preconditions of energy well’s implementation (Helsingin kaupunki 2020).

3 GEOTHERMAL ENERGY POTENTIAL

Geothermal energy is energy charged into bedrock and soil or waterways, and it can be used as heating energy, as well as for cooling, by using heat pumps. European Renewable Energy Council has labeled geothermal energy as renewable energy source (Helsingin kaupunki 2017) and it is one of the possible solutions to reduce the usage of fossil fuels globally. In this chapter, renewability of geothermal energy is assessed due to it's being somehow complex issue.

Thermogeological features of Finland are also discussed and how they might effect on the possible geothermal energy potential. In 2016 Geological Survey of Finland (GTK) published national geothermal energy potential map on a scale of 1: 1 000 000. GTK has also created regional and more specific reports about local geothermal energy potential. For example, one of the largest geoenergy plants in Finland is located in Otaniemi and it was discovered according to the analysis of GTK. Geoenergy in Otaniemi is utilized by using 67 heat wells to cover 90 % of heating and 95 % of cooling of the campus building. (Peura 2017.) Geothermal energy potential report that GTK created for the city of Helsinki is used in this chapter as a main source to clarify technical and theoretical potential of geothermal energy in such urban area.

3.1 Renewability of geothermal energy

Two thirds of the geothermal heat energy is resulting from breakdown of radioactive isotopes inside earth. The rest is heat radiation from deep down of the center or from the middle zone of the Earth. Solar energy affects the energy sources of the ground down to 15 meters. (Helsingin kaupunki 2017.) In terms of expected human lifetime on planet Earth, Earth's inner geothermal energy in addition to radiant energy from the Sun is generally classified as renewable energy.

According to the U.S. Energy Information Administration, renewable energy is defined as energy source that is limitless in duration but flow-limited meaning that the availability of amount of energy per unit of time is limited (U.S. Energy Information Administration 2018). What comes to the geothermal energy sources; renewable capacity of the geothermal field must correspond to the power capacity equivalent of the conductive and convective natural heat recharge into the system (Sanyal 2005).

Geothermal energy can be stated as quite flow-limited source of energy due to high variability of adequacy depending on the geographical location. Particular geothermal plants can be depleted if the limited potential of the geothermal field is consumed too quickly compared to the so-called retention time of the ground (Cataldi 2001). But according to various numerical simulations, degradation of resources which is caused by general power plant with a life cycle of 30 years would recover within 100 to 300 years. In 30 the pressure level would return to its original level and the temperature of the resource within 300 years depending on the local convective heat recharge rate. This scenario only applies if the exploitation is done by the sustainable level meaning that the installed capacity is maintained economically and that the production rate is maintained below or equal to the level of maximum energy production of the certain geothermal system (Sanyal 2005.)

Numerical simulation model for a certain geothermal system is the best tool to quantify the renewability capacity of the system. The numerical simulation reproduces the state of the reservoir. To create such model and use it effectively adequate data is required on the natural state of the geothermal field and resources and the energy production history of it. The availability of the data of the geothermal field depends on the case which may forbid creating the numerical simulation model. (Sanyal 2005.)

When utilizing local geothermal energy by using ground source heat pump, it is most commonly used as a primary heating method. According to IEA dimensioning ground source heat pump to produce 50 to 70 percent of the peak heat demand, 85-98 % of annual heat demand is covered by ground source heat pump. The rest of the heat demand, which is not profitable or possible to produce with ground source heat pump, stands for the final heating of domestic hot water and space heating during the coldest days. This part of the total annual heat demand is mainly covered by electric heating. (Kärkkäinen 2008.) Due to this, part of the sustainability traits of the ground source heat pump is qualified by the source of electric energy.

3.2 General thermogeological features of Finland

Temperature of the bedrock varies with depth. The change in the temperature of the bedrock is approximately 3,0 °C per hundred meters when going deeper. In Finland, due to the geographical location, the temperature varies between 0,5 to 1,0 °C per hundred meters. (Helsingin kaupunki 2017.) Temperature difference between the hot interior of the Earth and cold surface produces ongoing heat flow from inside of the Earth towards to the surface. This occurrence is called geothermal heat flux and the average geothermal heat flux value in Finland is 42 mW/m^2. (Geological Survey of Finland 2018.)

Bedrock is the main source for geothermal energy in Finland (Helsingin kaupunki 2017). In addition to movement and amount of groundwater in bedrock, thermal conductivity of the rock has major effect on the transferability of the cooling and heating energy. Mineral composition, texture and porosity are some of the main elements which define the thermal conductivity of the rock. (Geological Survey of Finland 2018.) Bedrock in Finland was developed around 3 000 to 1 400 million years ago and today the bedrock in Finland is the most steady and oldest in the Europe. Nearest volcanic rock is located 1 000 - 1 500 kilometres away from Finland which has effected to the steadiness of the ground. The Finnish bedrock is also the thickest in the area of Europe being generally 40-65 kilometres thick but even 230 kilometres at the most. (Peura 2017.)

Geological Survey of Finland has created geoenergy potential map (Figure 4) of Finland according to the thickness of soil overlay, thermal conductivity of rock type and average temperature of the ground. (Suomen Geoenergiakeskus 2019.) It can be seen from the map that the geoenergy potential in Finland is not evenly distributed through the whole country. Red color represents high geoenergy potential and blue color represents weak potential rate. In Figure 4 waterways are white colored and striped areas are weathered bedrock areas. The best geoenergy potential in Finland is locating in southern and western Finland. The worst geoenergy potential according to GTK can be discovered to locate in the very northern parts of Finland.

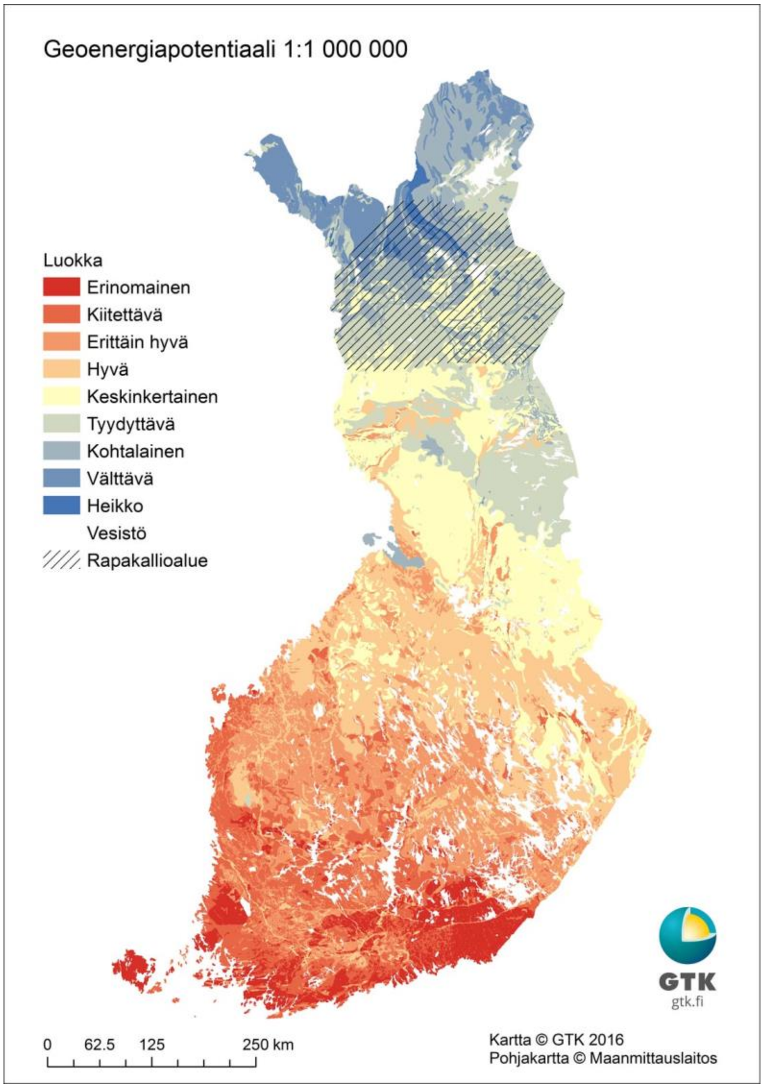

Figure 4. Geoenergy potential of Finland (Suomen Geoenergiakeskus 2019).

The bedrock in Finland is mainly composed of granite, gneiss, shales and other plutonic rocks. Density of the rocks varies usually between 2 600 to 2 800 kg/m^3 and the porosity is below 0,5 % which is low because of the crystalline bedrock. Because the mineral composition of bedrock affects thermogeological features, the crystalline bedrock and its low hydraulic conductivity of

$1x10^{-06}$ - $1x10^{-08}$ m/s resulting thermal conductivity values of 2,5-4 W/mK in Finland. (Peura 2017.) Due to the geographical differences in geothermal energy potential, the local geoenergy potential should be the basis to the geoenergy utilization planning.

3.3 Geothermal energy potential in Helsinki

GTK has made a model for geothermal energy sources in Helsinki that presents the suitability and local potential of the bedrock to exploit geothermal energy. Bedrock of Helsinki belongs to shale area of Uusimaa. The main rock types are gneiss, granite and metavolcanites, which compose migmatites that are typical for the area of South-Finland. Different rock species appear usually in zones where the shares of different species varies. Dark intrusive rock species are not typical for the bedrock area of Helsinki. (Peura 2017.)

Fracture zones, which are formed by to the movement of bedrock (Raudusmaa & Vänskä 2005), cross in the bedrock of the Helsinki City Centre from three main directions: north-west to south-east, east to west and north-east to south-west (Peura 2017). Fracture zones have significant impact on the building of tunnels and they complicate rock engineering (Raudusmaa & Vänskä 2005). For example, the most well-known fracture, fracture of Kluuvi, turned out to be very hard to permeate when building the metro tunnel causing several problems with the contract (Peura 2017).

Fracture zones, in addition to sand and gravel deposits in East-Helsinki, are important groundwater areas. The class 1 and other very important water resource areas are located in Vuosaari, Vartiokylänlahti and Tattariharju which quality of water is monitored. These water resource areas serve as backup storages of domestic water for exceptional situations. (Peura 2017.)

The GTK model is based on the rock samples that are collected from 51 different places around Helsinki. Samples were chosen to represent the most common type of the rock that appears in that specific location to find out the thermogeological features of Helsinki. Density, specific heat capacity and thermal conductivity were measured from all of the rock samples and according to the average of these values, diffusivity values were calculated. These averages for density, specific heat capacity and thermal conductivity of the six main rock species are presented in the Table 1.

Table 1. The average values for density, specific heat capacity and thermal conductivity of the main rock species of Helsinki

Rock	Number of samples	k [W/m*K]	C_p[J/kgK]	ρ [kg/m^3]
Amphibolite	10	2,66	731	2906
Gabbro	1	3,25	712	2804
Granite	16	3,2	721	2640
Grano- and quatzdiorite	12	3,17	731	2675
Mica gneiss	9	2,87	725	2707
Quartz-feldspar gneiss	2	3,1	723	2794

The 51 rock samples were categorized by closest representative rock specie from the rock specie map of Helsinki according to the specified rock specie of the sample. The original rock specie map of Helsinki was simplified by removing the littlest details. Simplified map of the rock species is presented below (Figure 5). (Geological Survey of Finland 2018.)

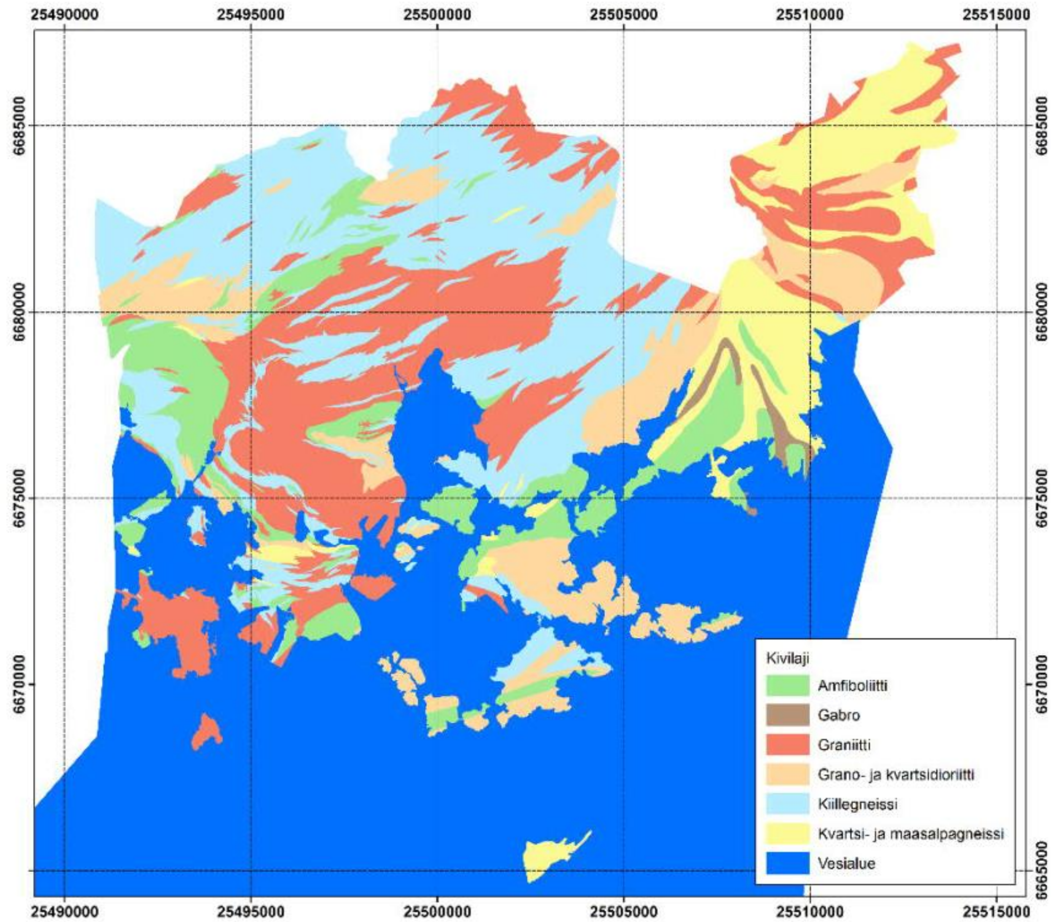

Figure 5. Simplified version of rock species in the area of Helsinki (Geological Survey of Finland 2018)

To estimate the thickness of the subgrade depth information of the clay areas and the drilling information of the Helsinki. According to the estimation (Figure 6), the thickness of the subgrade in the area of Helsinki is mainly under 10 meters. In the area around Kyläsaari and Arabianranta the thickness is 30 to 70 meters which is highest value in the area of Helsinki. (Geological Survey of Finland 2018.)

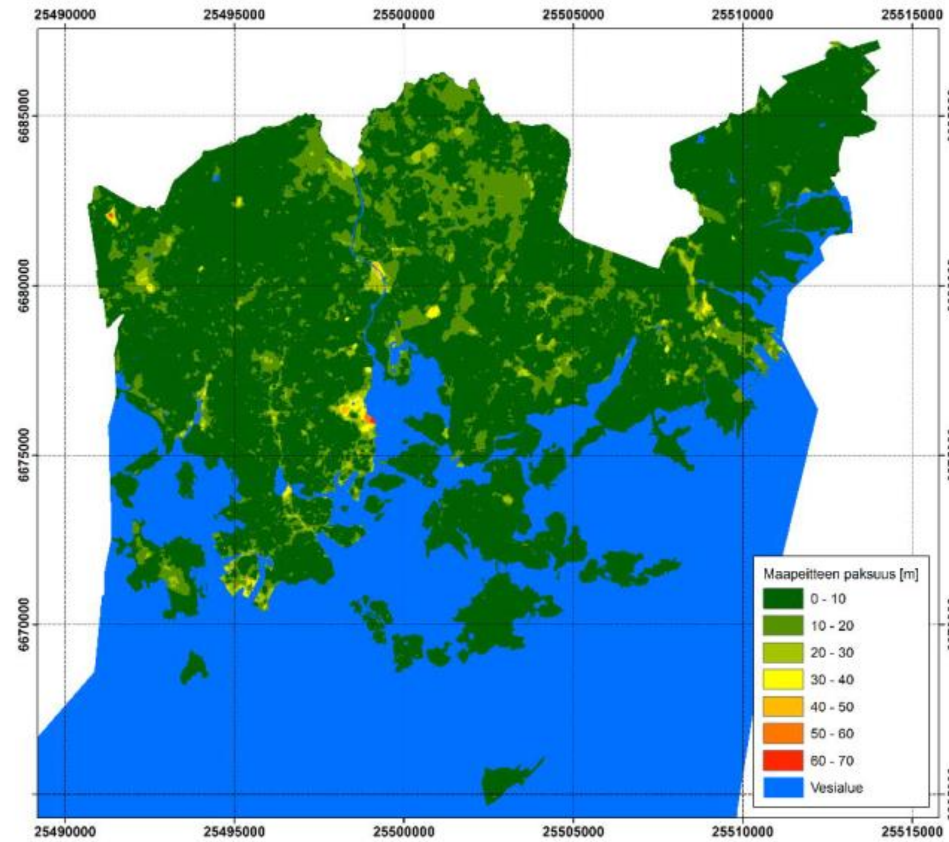

Figure 6. Thickness of the subgrade in Helsinki area (Geological Survey of Finland 2018).

Compilation of the results of the whole assessment about the thermal and geological features of the Helsinki area is presented below in Table 2.

Table 2. Compilation of the results (Geological Survey of Finland 2018).

Quantity	N	Minimum	Maximum	Average	Median	Mode
Thermal conductivity of the rocks [W/m*K]	239	2,66	3,25	3,01	3,10	2,87
Specific heat capacity of the rocks [J/kg*K]	239	712	731	725	725	725
Density of the rocks [kg/m^3]	239	2640	2906	2719	2707	2707
Specific heat capacity of the rocks [MJ/m^3*K]	239	1,90	2,12	1,97	1,96	1,96
Thermal diffusivity of the rocks [mm^2/s]	239	1,25	1,68	1,53	1,53	1,46
Average temperature of the ground [°C]	20 517	6,610	7,120	6,820	7,802	6,764
Geothermal heat flux [mW/m^2]	20 517	40,545	42,289	41,040	40,947	40,548
Geothermal gradient [K/hm]	20 517	1,27	1,56	1,37	1,34	1,27
Thickness of the subgrade [m]	2 091 338	0,0	67,0	5,1	3,4	0,0

Geothermal potential in Helsinki was modeled by calculating two different characteristics of geothermal potential: theoretical potential and technical potential. Theoretical potential corresponds the accumulated thermal heat energy of the bedrock. Technical potential is calculated by presuming the area of Helsinki as one big geothermal field where boreholes are located 20 meters away from each other. By calculating the technical potential, the maximum geothermal heat energy supply is clarified. Both theoretical and technical potential are calculated for three different depths of boreholes: 150, 300 and 1000 meters, and calculations were made by assuming that the heat exploitation period is 50 years. (Geological Survey of Finland 2018.)

Theoretical potential was calculated by using the equation 3.1.

$$Q = \rho \cdot C_p \cdot V \cdot (T_2 - T_1) \tag{3.1}$$

Heat energy amounts for the 100, 300 and 1000 meters were calculated at first and after that the heat energy amounts were divided by to 50 years long exploitation period. All of the geospatial data calculated before was taken into account when forming the geothermal potential maps. The result was three raster maps (Figure 7, 8 and 9) with a resolution of 100 m x 100 m for the three predetermined depths.

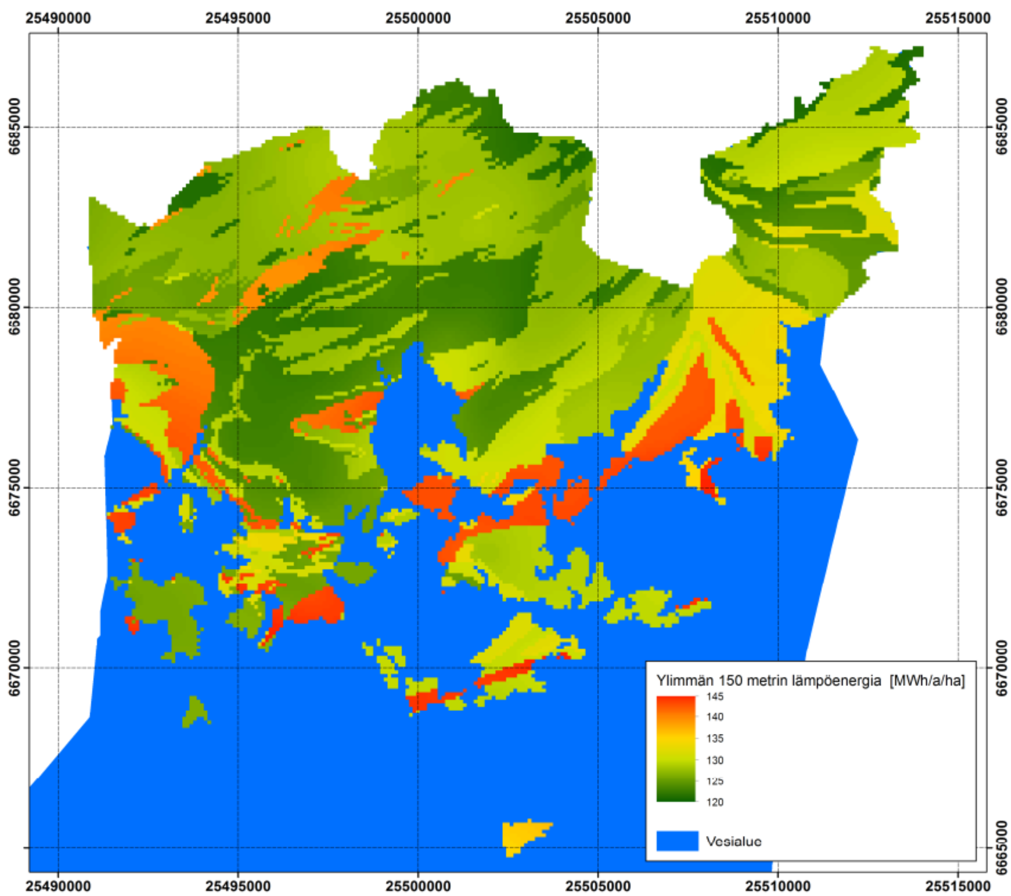

Figure 7. Exploitable theoretical geothermal heat energy potential in the 150 meters from the surface level (Geological Survey of Finland 2018).

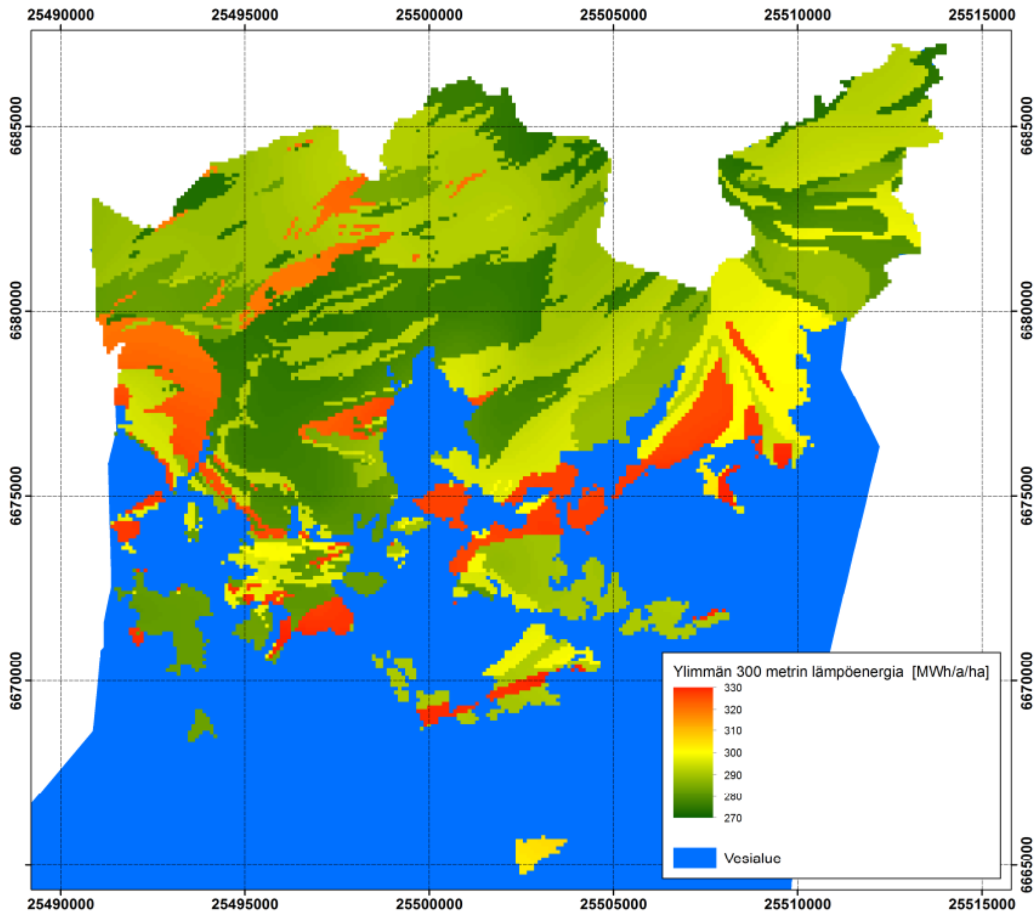

Figure 8. Exploitable theoretical geothermal heat energy potential in the 300 meters from the surface level (Geological Survey of Finland 2018).

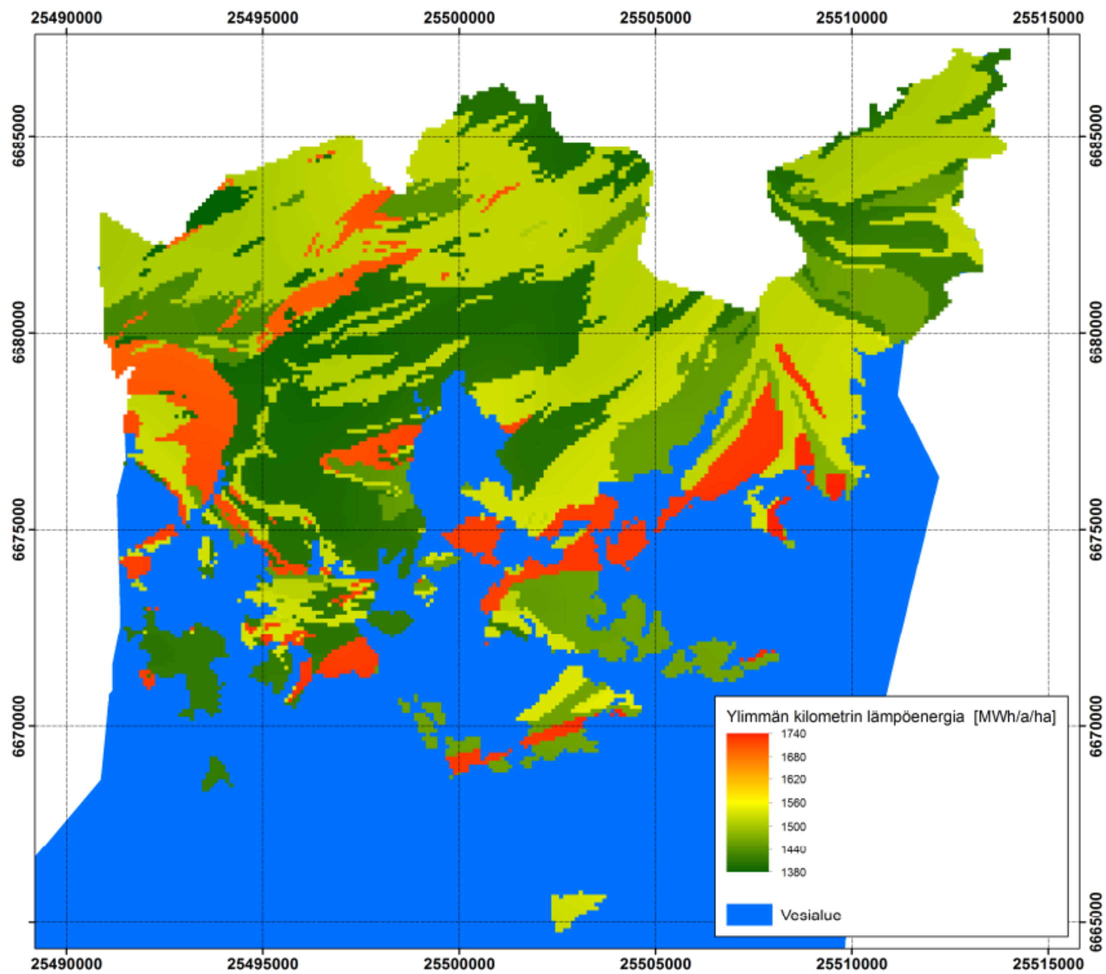

Figure 9. Exploitable theoretical geothermal heat energy potential in the 150 meters from the surface level (Geological Survey of Finland 2018).

According to GTK, the exploitable theoretical potential, assuming that temperatures of the energy wells would drop evenly to zero degrees at the end of the 50 years long period, would be 2,65 (150 m), 5,98 (300 m) and 30,71 (1000 m) TWh in a year. The assumption is impossible because of the inability of the energy wells to drop the temperature of bedrock evenly. (Geological Survey of Finland 2018.)

Technical potential was calculated by assuming the surface area of Helsinki as one big energy well field. The distance between the energy wells is 20 meters and heat energy is exploited from the wells through time period of 50 years. Heat energy is exploited as much as possible without dropping the temperature of the wells below zero degrees during the given time period. In other words, the exploitation is made sustainably within the limits of freezing the source. Joint effects of the energy wells are taken into account. Monthly energy consumption profiles were modelled with using monthly energy consumption reading from 16 different real estates. Results can be seen below in the Figures 10, 11 and 12.

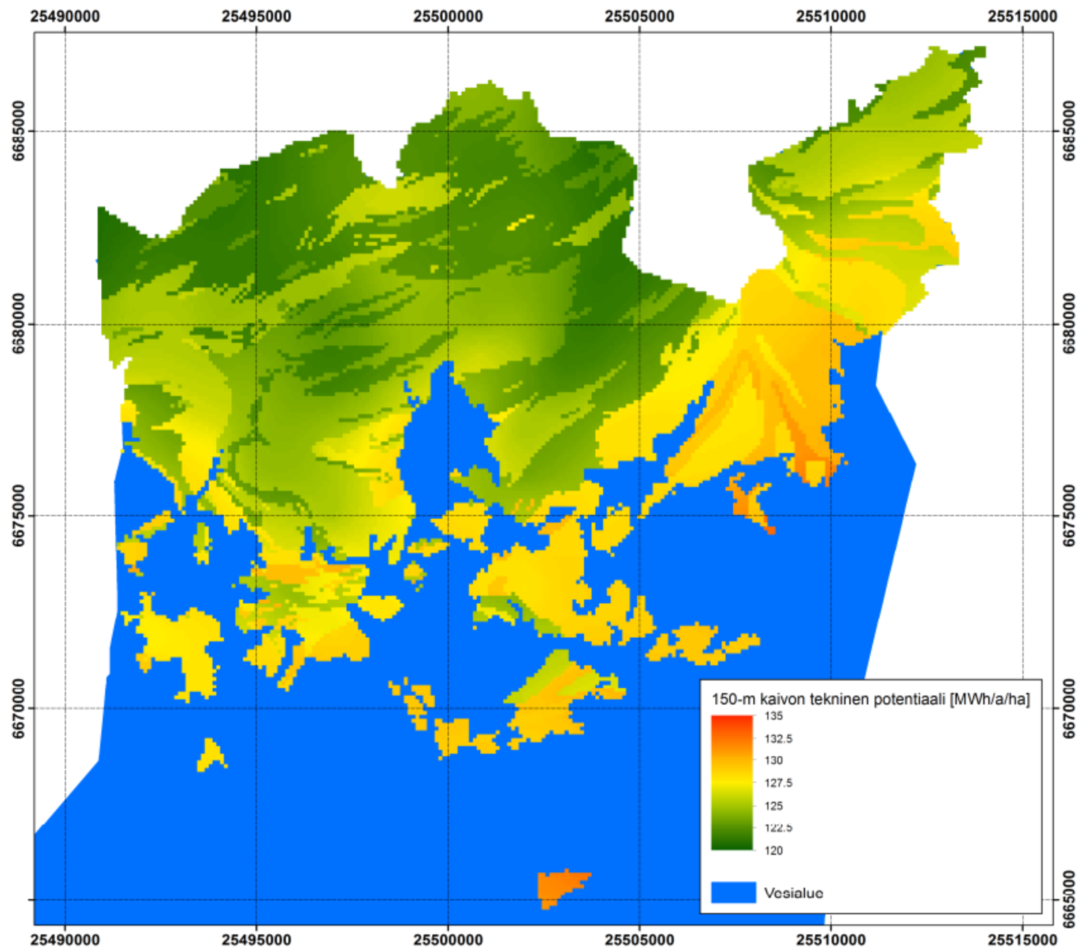

Figure 10. Exploitable technical geothermal heat energy potential in the 150 meters from the surface level (Geological Survey of Finland 2018).

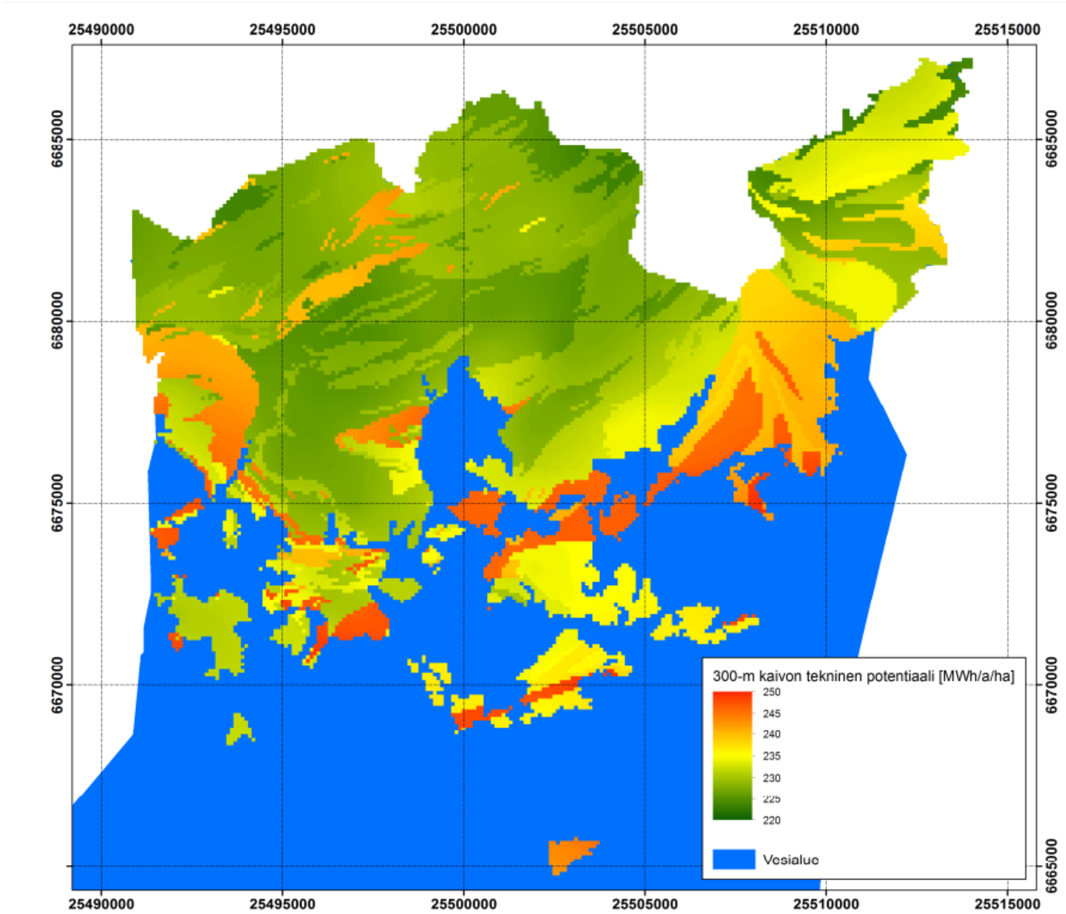

Figure 11. Exploitable technical geothermal heat energy potential in the 300 meters from the surface level (Geological Survey of Finland 2018).

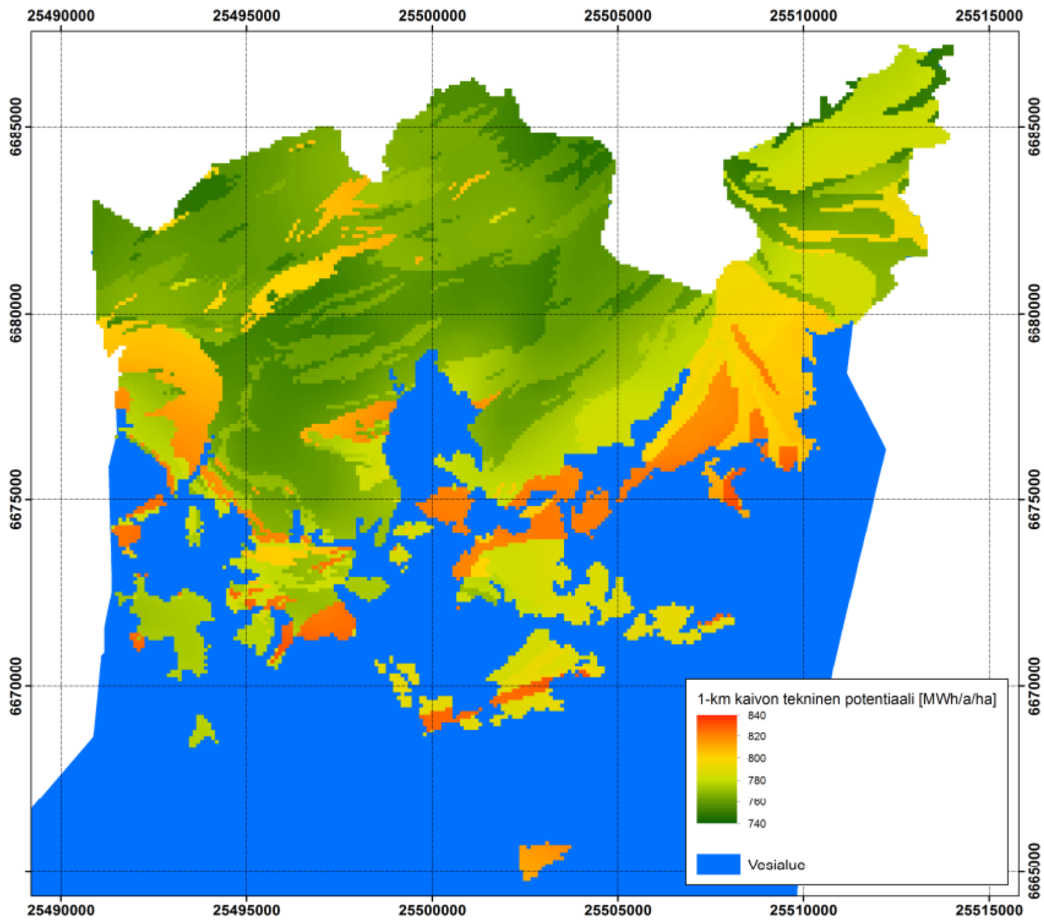

Figure 12. Exploitable technical geothermal heat energy potential in the 1000 meters from the surface level (Geological Survey of Finland 2018).

Exploitable technical geothermal energy potential from the whole area of Helsinki is 2,57 (150 m), 4,76 (300 m) and 15,91 (1000 m) TWh per year. All of the results for the theoretical and technical potential calculations are gathered to the Table 3 below. Results show that the theoretical energy potential of the bedrock is technically exploited the most effectively by using heat energy wells that are 150 meters deep with the efficiency of 97 %. Similar value for the maximum potential is 92 %. For the 300 and 1000 meters deep heat energy wells the efficiencies from the maximum theoretical potential are 75 % and 48 %. Theoretical and technical potentials are not fully comparable with each other because substitutive heat energy transfers, in addition to the ground below the heat wells, also from the ground surface. Shorter heat energy wells are more capable to evenly drop the temperature of the ground, which is the main reason for them being better at utilizing the geothermal energy potential than longer heat energy wells. (Geological Survey of Finland 2018.)

Table 3. Theoretical and technical geothermal energy potentials for the heat energy wells 150, 300 and 1000 meters deep (Geological Survey of Finland 2018).

Depth [m]	Potential	Minimum [MWh/a/ha]	Maximum [MWh/a/ha]	Average [MWh/a/ha]	Median [MWh/a/ha]	Mode [MWh/a/ha]	Total [TWh/a]
150	Theoretical	121	145	129	128	128	2,65
150	Technical	121	133	125	125	122	2,57
300	Theoretical	272	332	292	290	292	5,98
300	Technical	223	250	232	230	234	4,76
1000	Theoretical	1 381	1 744	1 498	1 507	1 518	30,71
1000	Technical	745	833	776	768	765	15,91

In Table 4 the results of how much geothermal heat energy can be exploited per meter are presented. The depth of heat well is not that significant when construing the receivable energy per one meter.

Table 4. Technical geothermal energy potential per one meter (Geological Survey of Finland 2018).

Depth of the heat well [m]	Minimum [kWh/m/a]	Maximum [kWh/m/a]	Average [kWh/m/a]	Median [kWh/m/a]	Mode [kWh/m/a]
150	32	35	33	33	33
300	30	33	31	31	31
1000	30	33	31	31	31

GTK also included the effects of one heat energy well to its surrounding soil. Effective distances were presented for the same three different depths and they are presented in the Figure 13. Red graphs present average temperature of the ground and blue graph presents the location of the temperature changes resulting from the usage of the heat well after 50 years from the time operation of the heat well started. According to this, 8 157 each 150 meters deep, 6 747 each 300 meters and 1000 meters deep heat wells would fit in the area of Helsinki. 150 meters deep heat wells that do not effect on each other could be theoretically installed with a maximum potential of 0,13 TWh/a within a time period of 50 years. The same receivable potential for 300 meters deep heat well would be 0,22 TWh in a year and for 1000 meters deep heat well 0,7 TWh in a year. (Geological Survey of Finland 2018.)

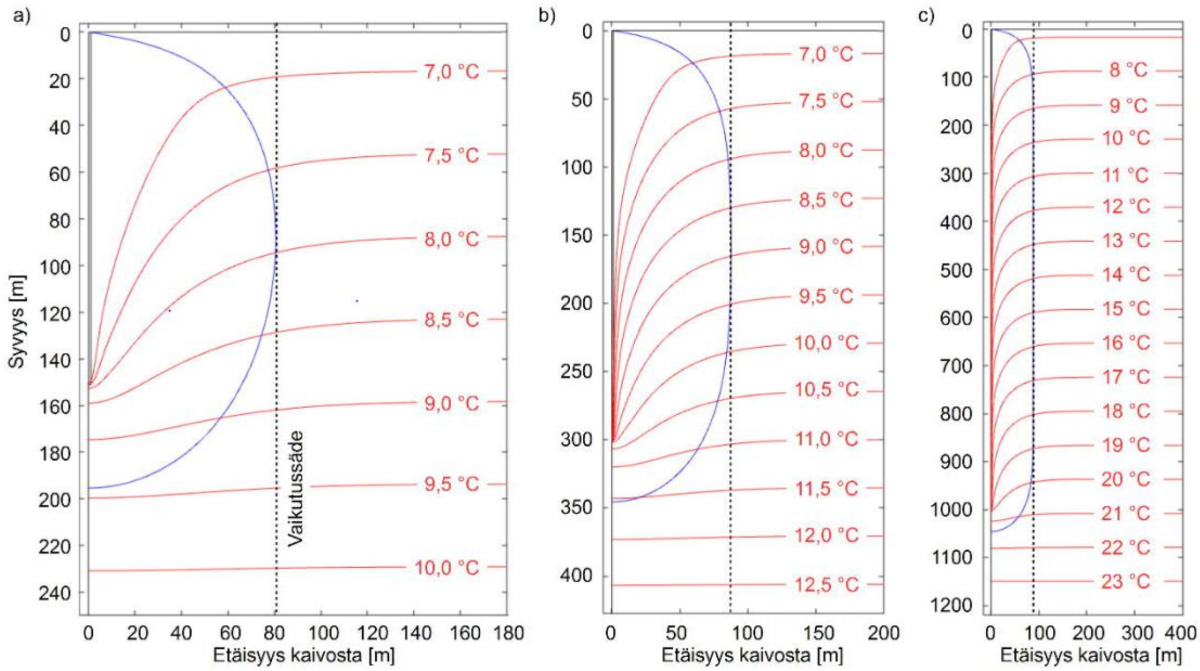

Figure 13. Effective distances for 150 (a), 300 (b) and 1000 (c) meters deep heat energy wells (Geological Survey of Finland 2018).

4 UTILIZATION OF THE GEOTHERMAL ENERGY

4.1 Laws and policies

In the 1970s and 1980s legislation had a minor role in the GSHP sector, while it was directed by high energy prices as a result from the energy crises, and internal factors of the heat pump industry like faulty technologies and installations. According to the study made by Pirjo Majuri, laws and policies have had a major effect on the Finnish GSHP industry from the 1990s when public attitudes and the market situation began to develop more beneficial direction for utilizing geothermal energy. At the end of the 1990s the GSHP industry in Finland started to recover after an adverse time period in the 1980s when small companies in the industry seriously harmed the reputation of the GSHP industry followed by them serving without consistent and proper standards or guidelines. Before that, in the mid-1970s, the industry of GSHP was steadily growing in Finland due to the first energy crisis and energy research funding. (Majuri 2016.)

Today in Finland the funding for ground source heat pump comes from the state government through tax credits for households. Installing ground source heat pump system as a heating system conversion is counted as household work which entitles to tax credit for household expenses. The tax credit is 2 400 € a year at maximum for a one person and the personal liability portion is 100 €. (Vero 2019.)

In Helsinki planning permission is needed when ground source heat pump system is installed to existing property. In the planning permission for example exact location information of the heat well and the possible risks are presented. (Helsingin kaupunki 2014.) Building capability report of the heat well (*maalämpökaivon rakennettavuusselvitys*) has to be prepared before applying planning permission for drilling of heat pipes. In the building capability report of the heat well possible limitations and barriers for drilling must be presented. Building capability report is made by reserving duct information report (*johtotietoselvitys*) from the city's underground duct and structure location services. (Helsinki 2018.) If the heat well is drilled when new property is built the permission of drilling is included to the building permission of the property (Helsingin kaupunki 2014).

The minimum distance instructed by the city administration between two boreholes is 15 meters in Helsinki. In this distance, the two boreholes do not effect on each other's amount of receivable energy by diminishing it. Also according to this regulation, the borehole must be located at least 7,5 meters from the borderline of the site to maintain equal rights and possibilities to neighbors. With a permission of the landowner of the adjacent site, the borehole can be drilled nearer than 7,5 meters from the borderline. (Helsinki 2018a.)

The city of Helsinki has also stated in their website about some possible environmental and health impacts and handicaps which have to be considered and prevented in the process of drilling the heat well. Possible risks of the project and the usage of the groundwater have be presented because drilling might effect on the quantity and quality of the groundwater. In addition, possible need of soil purification has to be investigated if the soil located near to the drilling spot is contaminated. In Helsinki, drilling of geothermal heat well is prohibited in important groundwater areas and also tunnels and reservations of tunnels can affect to the permission decision. (Helsinki 2018.)

Preventative actions, operating on environment and health, are the disposal of rock material and sludge from the drilling and restraining the leaks of heat carrier. Excess rock material and sludge from the drilling can't be deposit to waterways or the sewer. If the drilled site or trench is saturated with the sludge it has to be done by not causing any harm to neighbors or the environment, like waterlogging of the neighbor's site or clogging of trenches. The heat carrier, which flows in the heat pipes, should be the least injurious as possible to environment like ethanol which will degrade biologically in aerobic and anaerobic conditions. The possible leakage can cause contamination of groundwater and spoiling the groundwater areas is prohibited in the Environmental Protection Act 8 §. Leakages can be prevented by appropriate consolidation of the wells.

After drilling the borehole, inspection of the heat well by the city's authority is made to verify that the drilling is done according to the permission. (Helsinki 2018.)

4.2 Dimensioning and utilization technologies

When transporting heat from a heat source to a heat sink by using heat pump, external energy is needed. The same theory applies also for cooling. The characteristic of the heat (or cooling) source effects on the technical and economic performance of the heat pump. (Kärkkäinen 2018.) When the case considers ground source heat pumps, these characteristics are composition and structure of the ground for example (Juvonen & Lapinlampi 2013). Efficiency of the ground source heat pumps can be measured by values like coefficient of performance (COP) and seasonal coefficient of performance (SCOP). Coefficient of performance is defined as the ratio of electricity supplied to the compressor and the heat delivered to the heat sink by the heat pump (Kärkkäinen 2018) COP is usually for the heat pumps, when using them in the weather conditions of Finland, average 3. When comparing COP values of different heat pumps, the measurement conditions should be taken into account. (Juvonen & Lapinlampi 2013.) Seasonal coefficient of performance describes the efficiency of GSHP more practically. SCOP describes the annual efficiency of the heat pump because it takes into account the regional and seasonal differences in climate and outdoor temperature. (Nilan 2019.)

In Finland, the main source for locally utilized geothermal energy is the bedrock. Geothermal energy can be utilized in all types and sizes of buildings for heating and cooling. Energy is exploited from the bedrock by one or several heat wells depending on the heating or cooling demand of the building. Heat wells are usually vertical boreholes that are deep enough to achieve the wanted heat energy. Two heat pipes where heat carrier fluid flows are installed to boreholes and they are connected to each other with U-joint. Heat carrier fluid transports heat energy from the well to the heat pump that is located in the building. Well is usually 150 to 300 meters deep and its diameter is usually 115 mm. (Peura 2017.)

The temperature of 1-4 Celsius can be converted to temperature as high as 30-65 Celsius by a ground source heat pump. Energy in heat carrier fluid in the evaporator of the heat pump is transported to refrigerant loop when refrigerant is converted from liquid to gas. Evaporated refrigerant is pressed to high-pressure gas in compressor when its temperature rises. Electric energy used for pressing is converted to heat energy. In condenser heat energy is transferred from the refrigerant to heating system of the building while refrigerant is converted from gas back to liquid. After this, the refrigerant is transferred to the expansion valve where its pressure is lowered which also results temperature drop. (Peura 2017.)

Dimensioning and choosing well-suited heat pump are necessary to achieve fully functioning heating system for the real estate. Heat distribution system, specific requirements of the real estate, operating conditions and the location of the GSHP must be taken into account when choosing the heat pump (Tom Allen Sanera 2019). Dimensioning of the ground source heat pump system the heat demand of the building has to be calculated very accurately. Estimation or/and calculation of the space heating demand, heating power of radiators or underfloor heating system, heating demand for domestic hot water and efficiencies for all of the units in the heating system (Gebwell 2019a). In Finland dimensioning and modelling methods are still in a need of improvement and standardization because a lot of methods are based on general assumptions which may not be appropriate depending on the case. One reason for this may occur from the lack of education or degree studies in the geothermal industry. (Peura 2017.)

Ground source heat pumps are usually dimensioned to cover 60 to 100 percent of the maximum heat demand of the building. This means that usually GSHPs produce 85 to 100 percent from the annual heat energy demand. (Gebwell 2019.) When geothermal heat pump is being used in the part-power configuration it produces typically 60 to 85 percent of the power demand and 90 to 98 percent of the annual heating demand of the building (Juvonen & Lapinlampi 2013). If the maximum power of the GSHP is dimensioned to cover under 100 % of the heat demand, the remaining share is covered by using usually electric resistance heat or some other heating system. (Gebwell 2019a.) Approximately two of thirds of the energy produced by GSHP is “free” energy from the ground (Peura 2017). Power dimensioning of heat pump is also optimization of operating cost and investment cost (Juvonen & Lapinlampi 2013).

Ground source heat pump is the most suitable to connect with low temperature heat distribution systems like water underfloor heating or air heating (Peura 2017). To reach the best possible efficiency and the most optimal operation conditions, it's more advantageous if the temperature of the water, which is transferred to the heat distribution system, is as low as possible (Gebwell 2019a). Radiator heating can also be connected to GSHP system if the sizing of radiators is confirmed to cover needed heating capacity. Total surface or number of radiators might have to be added up because of the demand of bigger radiator surface as a consequence of low temperature of the water which can be achieved by the ground source heat pump system. (Peura 2017.)

In addition, the amount and depth of the energy wells are important part of the dimensioning of geothermal energy utilization system. Energy field as a whole system determines considerably the amount of utilizable energy from the ground. (Juvonen & Lapinlampi 2013.) Usually bigger real estates like apartment buildings require more than one energy well to utilize geothermal energy (Gebwell 2019b). The distance between heat wells can not be less than 15 meters or else the wells effect on each other by reducing the receivable energy. Even if the boreholes are diagonal the 15 meters-rule is valid for those parts of the boreholes that are less than 15 meters away from each other. Energy fields with ten or more boreholes should be inspected more carefully by surveying the characteristics of the bedrock because of the big thermal differences between different rock species. (Juvonen & Lapinlampi 2013.) Location and depth of heat wells should be defined according the quality and characteristics of the ground. According to Niina Leppäharju from Geological Survey of Finland, the most defining factor for the dimensioning the energy field is the geographical location of the field. (Gebwell 2019b.) Thermal conductivity of the ground can affect a lot on the number and depth of the boreholes. By optimizing the functionality of the energy field, incorrect dimensioning can be avoided. Energy fields are usually simulated to the time period of 10 to 30 years. (Juvonen & Lapinlampi 2013.)

There are some presumptions or standards that might be used when dimensioning energy field. One general standard is that approximately 100 kWh per meter is received from the energy well in a year. Ground source heating planner Miika Peltokorpi from Lapon Oy states that this presumption can be used when planning system with one or two energy wells. For one energy well 110-130 kWh/m can be assumed to receive in the southern Finland below Tampere. In North-Finland the same value can be assumed to be 70-90 kWh/m depending on the features of the bedrock. According to Tomi Mäkiaho, in South-Finland where the stable average temperature of the bedrock is between 7 and 9 degree Celsius the assumed received energy is usually not over 95 kWh/m from the active parts of the well, meaning the parts that stay below water level throughout the year. The equivalent value for the apartment houses is 85-75 kWh/m. (Gebwell 2019b.)

The biggest problems with functionality of the ground source heat pump systems and energy fields are usually resulted from the imprecise dimensioning or planning. If capacity of the energy well is not enough to heat the building, the energy well is usually undersized. Undersizing will cause cooling of the energy well under the designed parameters resulting low reclamation of heat energy from the well. In this case, the undeceived energy from the well is produced by electricity and that will result lower efficiency level of the GSHP. Usually problems caused by the undersized system are noticed after the implementation of the GSHP system from the electricity use that is higher than planned. These problems can be noticed not until after couple of years of full operation time. (Juvonen & Lapinlampi 2013.)

Like mentioned before, problems might occur also from the small distance between energy wells if the GSHP system reclaims energy from several energy wells. If the temperature in the heat well drops below zero Celsius, the heat well might freeze. In such cases the expanding ice crushes the collector pipes against each other. Resulting from this the circulation of the heat transfer liquid in the collector pipes is decelerated or fully restrained. (Juvonen & Lapinlampi 2013.) According to Peltokorpi, energy wells cool down the surrounding ground about within a

100 meter radius (Gebwell 2019b). The freezing is usually a consequence of unsuccessful dimensioning that results overloading of the energy well (Juvonen & Lapinlampi 2013).

Bending of the energy well towards undefined direction is possible because of the geological quantities of the ground, drilling equipment or the professional skills of the driller. It can be discovered from the survey about bending of ground source heat wells made by Real Estate Office of Helsinki City that effects of bending multiply the deeper the boreholes are drilled. In the depth of 100 meters bending is quite small but when drilling deeper, bending can be from tens of centimeters to several meters. The bending can’t be predicted in ground source heat wells until further notice. True location information of the well should be confirmed by measuring the location information through the whole depth of the well. (Peura 2017.)

More demand side flexibility is already needed for electricity and heat production. For district heating demand side management means modifying the timing of heat power demand without debasing the quality of the actual service. One of the main principles of demand side management is also not to limit customers heating demand. Demand side management is way to decrease the usage of the peak heating boilers or other expensive peak or reserve production to increase economic efficiency and decrease negative environmental impacts. (Energiateollisuus 2015.) As ground source heat pump being separated unit for heating or cooling utilization and covering both heating and cooling demands, it can be hypothesized to be suitable for demand response. High use of ground source heat pumps for cooling in summer peak times and for heating during peak times in winter can balance out the demand. Profitability of the heating by GSHP significantly decreases in very low temperatures because of the low COPs of heat pump, which causes the need of additional heating system like electricity or gas. (Kärkkäinen 2008.)

5 CO_2-EMISSIONS OF GEOTHERMAL ENERGY AND DISTRICT HEATING

In this chapter the basis of emissions for geothermal energy utilization and district heating are discussed. This chapter will operate as a foundation to the second empirical part of this study in which the possible carbon dioxide emission reduction potential of utilizing the local geothermal energy for years 2025 and 2035 is calculated as a substitution of heat energy source to district heating. This chapter is divided into two sections: in section one the CO_2-emissions of geothermal energy are discussed and in the other section the CO_2-emissions resulting from district heating are discussed. Emission of these are discussed at a current state and also outlooks to years 2025-2035 are studied.

5.1 Geothermal energy

Geothermal energy is renewable energy and can be stated as a carbon dioxide free or zero emission source of energy. Renewability of geothermal energy is discussed in the chapter 3.1 before more in depth. As geothermal energy is assumed to be carbon free source of energy, the emissions resulting from the utilization of it can be recognized. In this case utilization means ground source heat pumps. So the carbon dioxide emissions occurring form the utilization of geothermal energy are fully consisted of the emissions of used electricity.

According to Finnish Energy (Energiateollisuus ry) the emissions of production of electricity have been on the wane from the year 2013 in Finland (Figure 14). Total CO_2-emissions of the electricity production in 2018 were 7 Mt and the equivalent value for the year 2019 were 5,5 Mt. So, all in all the total emissions were reduced approximately 23 % in year. Specific CO_2-emission factor in 2018 was 107 gCO_2/kWh and in 2019 just 88 gCO_2/kWh. (Energiateollisuus 2020.) According to the same source of Finnish Energy, the reason for this emission reduction was mainly 1,7 % reduction of the use of electricity and the fact that carbon free electricity production is breaking records.

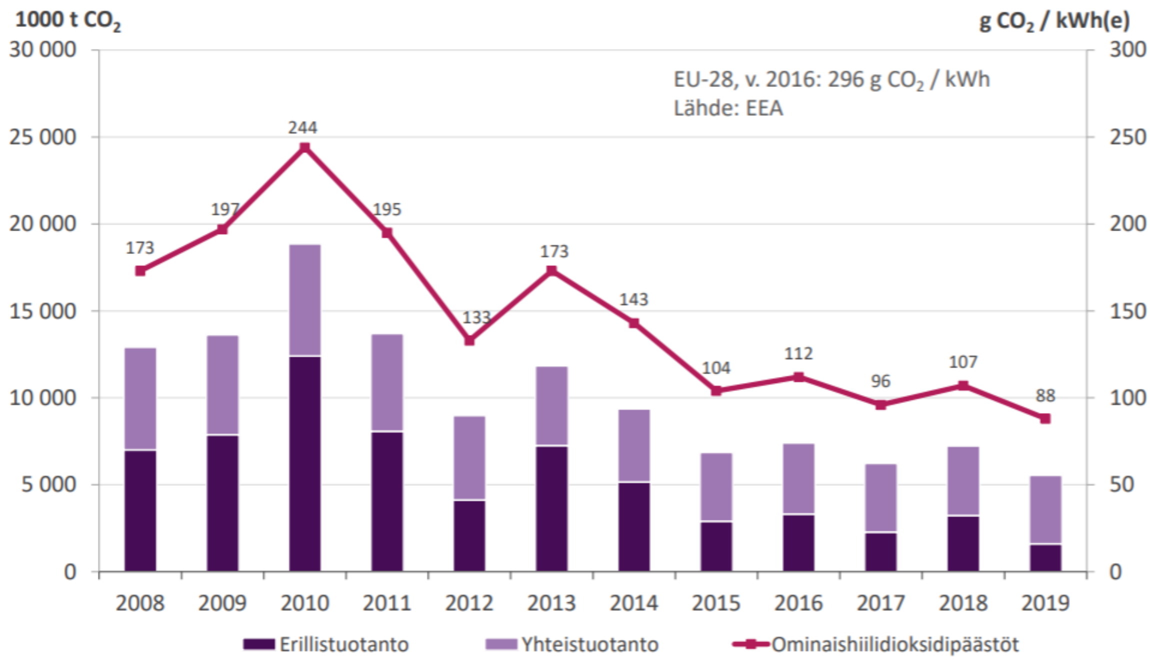

Figure 14. CO_2-emissions occurring from electricity production (Energiateollisuus 2020).

At monthly level, the fluctuation of the specific CO_2-emission factor of electricity can be noticeable. In Figure 15 are presented monthly values for specific CO_2-emission factors of electricity (Energiateollisuus 2019b). The fluctuation is depending on the demand of electricity that is itself very dependent on the season here in Finland. Another factor is current possibility of using hydropower as a stored power stock which is depending on the amount of rainfall. If hydropower is not available, the needed energy stock and flexibility can be covered by more carbon intensive energy source like carbon or peat condensing power. (Ilmasto-opas 2019.)

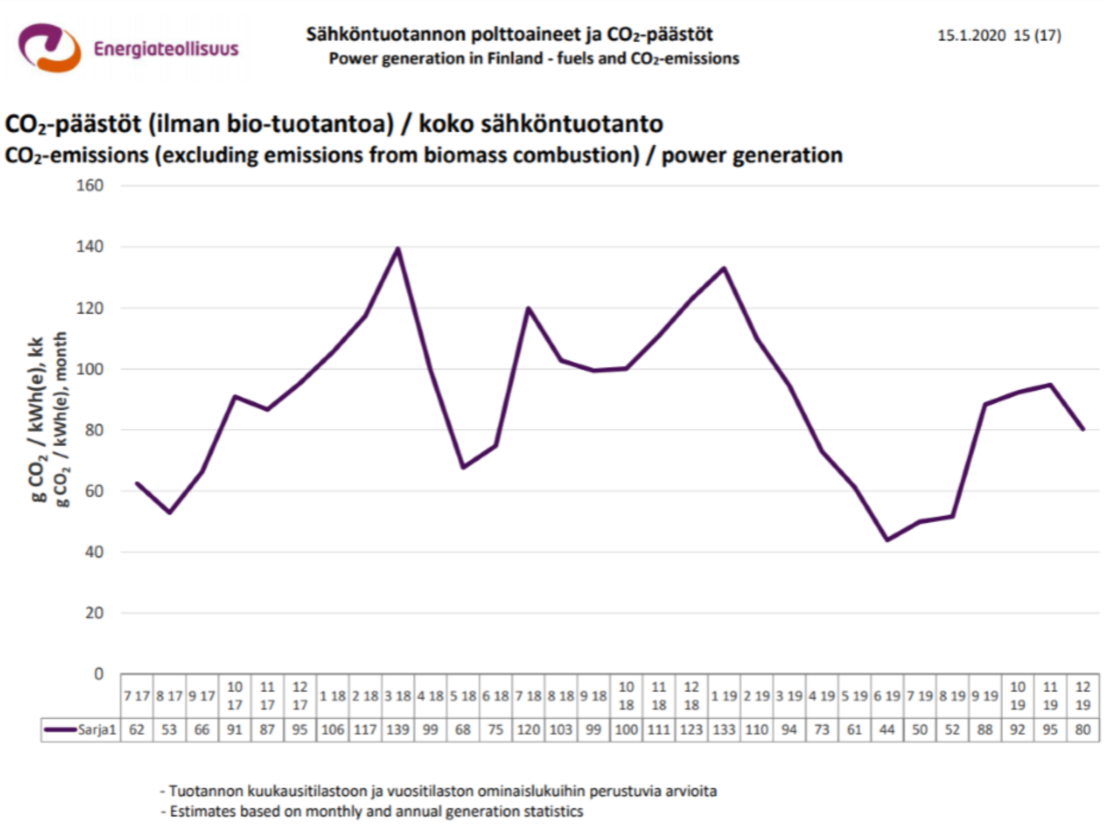

Figure 15. Monthly CO_2-emissions occurring from electricity production (Energiateollisuus 2019b).

According to the source used in report concerning future energy production 2030-2050 made by Ministry of Employment and the Economy of Finland, carbon neutral electricity production will take on the Nordic electricity production scheme even more strongly in upcoming decades (Figure 16) (Tekes 2017). It's safe to say that the emissions of electricity are still on downswing and according to the report of Carbon neutral Helsinki 2035 the CO_2-emissions of the electricity production will be 45 gCO_2/kWh (Helsingin kaupunki 2018b).

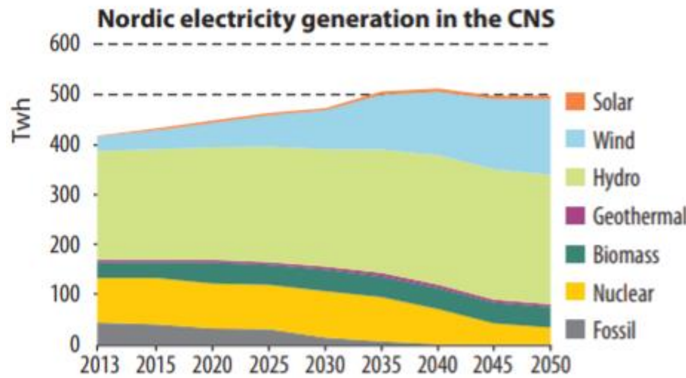

Figure 16. Nordic electricity generation from different energy sources in the future (Tekes 2017).

What comes to the emissions occurring as a result of utilizing geothermal energy by using ground source heat pumps, the emissions are linear to the COP of the heat pump. As the COP designates the required amount of electricity per exploited amount of heat energy. The COP values vary between different heat pumps and also circumstances effect on the temporal COP value. In the calculations of this report the used COP value for utilizing geothermal energy potential is chosen to be three at all times. For example, Gebwell states that according to the measurement demands of standard SFS-EN 14511 most of their ground source heat pumps can achieve the COP of 4-5 in the outdoor temperature of 0 Celsius degrees. (Gebwell 2019c.) Because in the calculations of this report, the geothermal energy is dimensioned to be utilized especially during the colder times the COP of three was regarded to be realistic. Also, it was somewhat challenging to find reliable and comprehensive studies about the seasonal fluctuation of COP values of ground source heat pump especially at cold circumstances.

5.2 District heating

Emissions of district heating are looked into from a production-point of view. The production structure of district heating in Helsinki is under a remarkable change. Some investments are already made by Helen to cover coal and yet so many options and possible solutions are still under a consideration and research. Because of this, these upcoming scenarios of the emissions of district heating energy production can't be introduced that deeply and some of the information behind these graphs are classified as secret information.

At the moment Helen utilizes efficiently combined heat and power production in power plants of Vuosaari, Hanasaari and Salmisaari. In Salmisaari also district cooling is produced that is based almost 80 % to the energy that would otherwise be unutilized. During coldest times of the year separated energy power plants are needed. Helen also has heat pump power plants locating under the parks of Katri Vala and Esplanadi. Stored heat is also very important factor to balance energy production. Helen Oy has heat and cooling storages locating at Vuosaari and Salmisaari with total power of 200 MW. (Helen Oy 2020a.) In 2018 the specific CO_2-emission factor of produced district heating was 158 gCO_2/kWh (Helen Oy 2020b). In 2018 53 % of the used fuels to produce district heating was coal. Natural gas represented 35 % share of the production. Other used fuels were heat pumps (8 %), biomass (3 %) and oil (1 %). (Helen Oy 2020c.)

According to the data received from the energy production control team of Helen, total emissions from the production of district heating was approximately 2 000 $ktCO_2$ in 2018 (Helen Oy 2019b). In Figure 17 is presented the cumulative growth of carbon dioxide emissions and production of district heating in 2018.

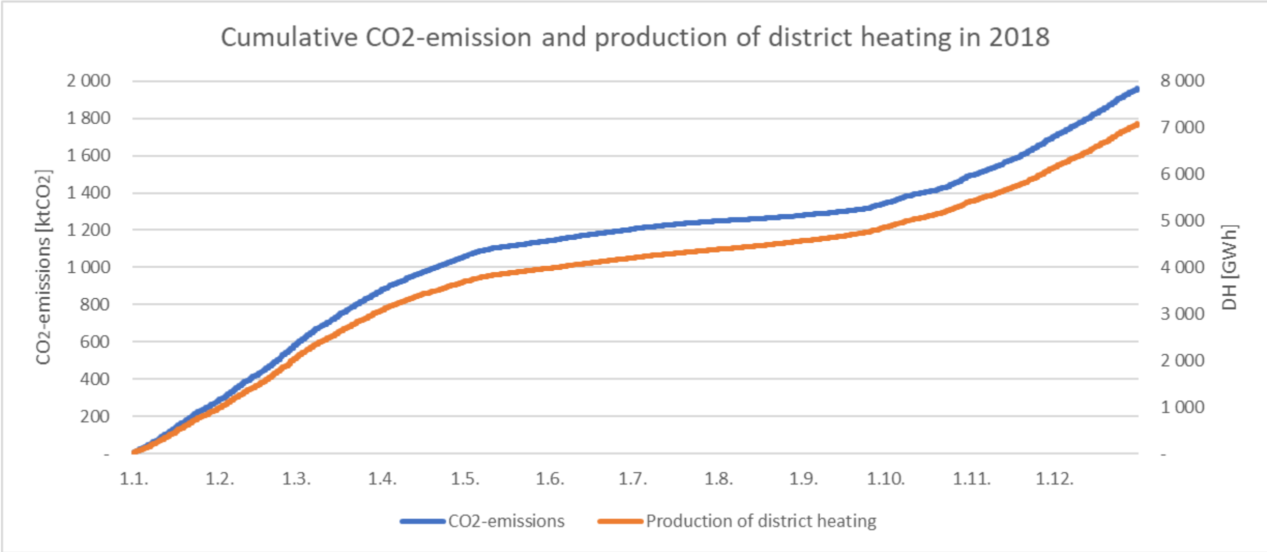

Figure 17. Cumulative carbon dioxide emissions of district heating in 2018 (Helen Oy 2019b).

As Helen is stated, it will reduce its emissions 40 % from the level of 1990 by 2025 by cutting coal usage to half. Renunciation from the coal will happen fully by the end of year 2029 and the operation of Helen Oy will be fully carbon neutral by 2035. (Helen Oy 2020d.) These goals are met by closing the power plant of Hanasaari in 2024 which will half the usage of coal. From the combined heat and power production of Hanasaari only heat production will be recompensated in Helsinki. Heat pump power plants under Katri Vala and Esplanadi are grown and around the power plant of Vuosaari another heat pump will be installed to utilize process heat and sea water. Also, powerplant that exploits biomass as a fuel is planned to Vuosaari. In addition, the usage of coal in power plant of Salmisaari has to be replaced by 2029. By the year 2035 natural gas, that is classified as a fossil fuel, should be decreased and compensatory actions should be decided. (Helen Oy 2019.)

Here in Figures 18 and 19 are presented the forecast of the emissions from district heating production in 2025, 2030 and 2035. This dataset is received from the energy production planning team of Helen. In the figures are shown that the emission reduction goals are fulfilled.

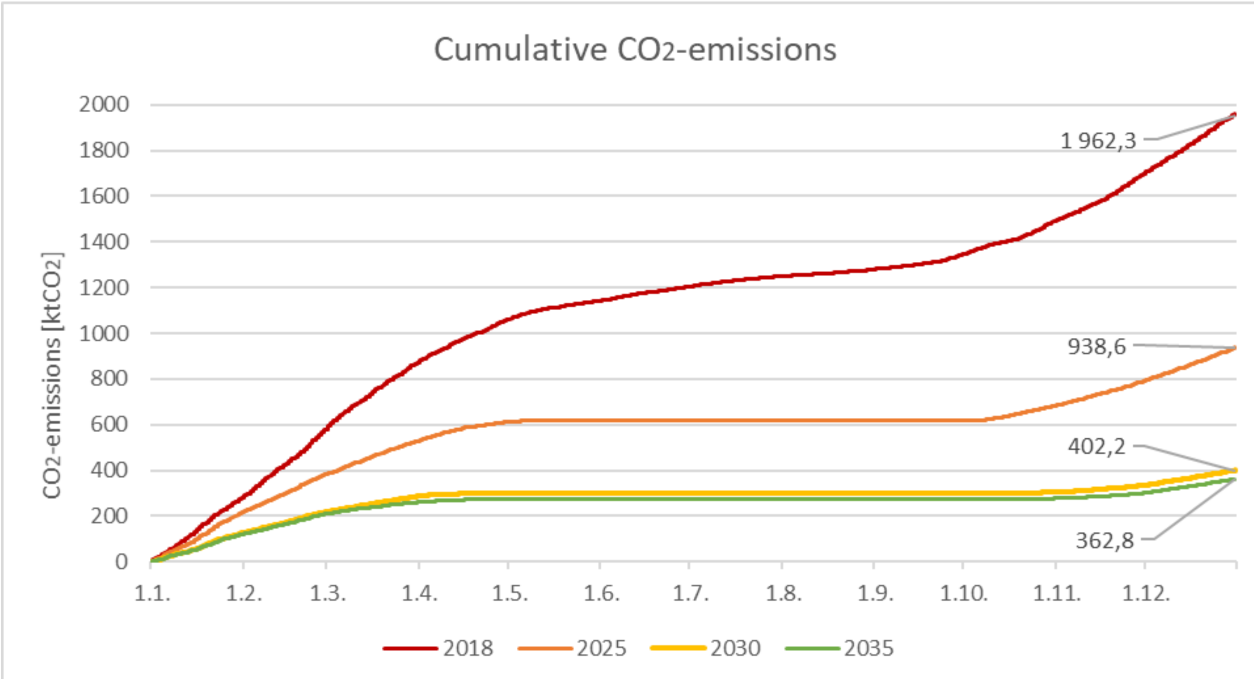

Figure 18. Cumulative carbon dioxide emissions of district heating in 2018, 2025, 2030 and 2035 (Helen Oy 2019b).

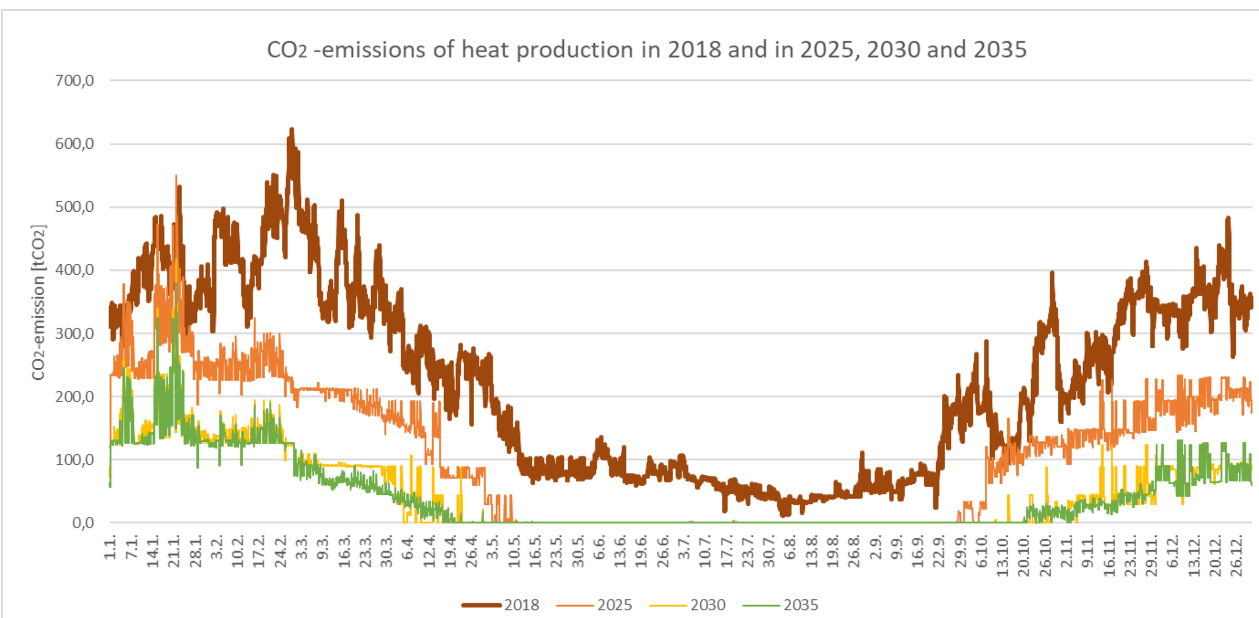

Figure 19. Carbon dioxide emissions of district heating production in 2018, 2025, 2030 and 2035 (Helen Oy 2019b).

It should be noted that waste heat energy sources are seen as zero emission energy sources. In the empirical part of this study there is calculated CO_2-emission factor to the waste heat according to the assumed emissions of electricity production. Used COP for waste heat is 3,5 according to the information from the energy production planning team of Helen Oy.

6 GEOTHERMAL ENERGY POTENTIAL AND HEAT ENERGY DEMAND

The calculation about the utilization possibilities of the geothermal energy potential in Helsinki is made by using free program called QGIS 3.8. QGIS is a program designed to analyse geographical information and data and to calculate certain numerical key ratios and characteristics linked to coordinate system. Combining geographical information from different data sources is possible by using programmes like QGIS and as a result of this integration of unique and newkind knowledge can be achieved (QGIS 2019).

The calculation is made to present current heat energy demand compared to local geothermal energy potential occurring at block areas and to present the relation between future (2050) heat energy demand and geothermal energy potential at grid layout areas.

6.1 Used data and data sources

Helsinki metropolitan cities have made regional data concerning, for example, about housing and constructed environment public since 2011 by Helsinki Region Infoshare web services (HRI). HRI allows easy access to numerous data sets for everyone interested freely. Opening data aims to support information based planning, decision-making and research. (HRI 2018.) Helsinki Map Service sustained by the city of Helsinki is the most updated data source concerning about geographic information of Helsinki (City of Helsinki 2019). The portal allows you to download most of the information in Shape or GeoPackage file format that can be easily exploited in the QGIS. The used data package that includes all the main geographic information about Helsinki in these QGIS calculations and modelling is shared through WFS vector layer interface (City of Helsinki 2015).

Geothermal energy locating at the area of Helsinki is calculated by GTK and the background of the calculation is introduced more precisely in the chapter 3.3. The data, to which the geothermal energy potential in the area of Helsinki report (Geological Survey of Finland 2019) is based on, was given by the GTK to utilize in this calculation. Only the data representing theoretical geothermal energy potential used in the calculation. Raster maps presenting theoretical geothermal energy potential are presented to three different depth of ground or boreholes; 150, 300 and 1 000 meters. So altogether, there are three different raster maps to represent geothermal energy potential that are used in these QGIS calculations and modelling.

Theoretical geothermal energy potential values are chosen to be assessed in this report. Theoretical potential takes into account only the existing amount of heat energy in the upper 150, 300 or 1000 meters from the ground if the energy is exploited fully during the time period of fifty years while the temperature of the ground in those three different depths would be lowered to zero Celsius degrees. In other words, theoretical geothermal energy potential values describe the bare maximum of the heat energy stored in the ground. Technical potential described in the report can be understood to represent maximum limit of exploitable heat energy in the area of Helsinki by using heat wells. Technical potential is calculated by supposing that the area of Helsinki is one big geothermal wellfield where the impact of heat wells to each other has been taken into account. Due to high frequency of built environment in the urban area, there is no possibility to utilize all existing technical geothermal energy potential wich is the reason why only theoretical potential is included to the calculations.

Data concerning about projection of total cumulative floor area in Helsinki area in 2050 according to the forecasted population growth and residential construction is also used in these calculations. By means of using this data, the heat energy demand in the long term can be modelled and its relation to the local existing geothermal energy storages. This data is produced by the City of Helsinki and it is given to Helen Oy to process inside Helen Oy only. Because of this, the data is not presented unrefined in this report. Dataset used in these calculations is from 2018 because the updated version for 2019 could not be acquired. This data is fitted to areas of grid plan and due to this the coverage rate of heat energy demand and local geothermal energy potential is examined at a level of grid plan areas.

Heat energy demand and other data of the buildings that are connected to the district heating network of Helen were available for this study. Especially monthly heat energy demand values based on the real measurements by hour is the type of information that is exclusively applicable by Helen and each district heating customer only. When combining these type of more exclusive data with public data, new-kind and unique information is generated.

For buildings that are not DH customers of Helen Oy, heat energy demand values are calculated separately from this project by software that Helen Oy had used for technical analysis. The calculation takes into account district heating consumption of different customer segments and creates heat energy demand values according to the learnt information to three building types: residential buildings, commercial buildings and the others. Heat energy demand values are calculated for non-district heating buildings in units of one kilowatt-hour per one cubic meter and for the whole building stock in 2050 in units of one kilowatt-hour per square meter. These values are presented below in the table 5.

Table 5. Heat energy demand values for non-DH buildings.

Building type	Energy demand 2018 [kWh/m^3/a]	Energy demand 2050 [kWh/m^2/a]
Residential	43,02	89,32
Commercial	28,80	59,97
Other	29,87	62,42

Buildings in the building register of Helsinki are sorted for three categories to match the heat energy demand classifications: residential buildings, public or office buildings as commercial buildings and non-labelled, labelled for other use and industrial buildings as the others. Buildings registered as outbuildings are ruled out from the calculations. Because the local geothermal energy potential is expressed in the unit of MWh/a/ha, heat energy demand values of buildings are also presented in the resolution of one year.

6.2 QGIS calculation

Working with QGIS software can be stated to be somehow challenging when the calculation and modelling are made by using several vector layers that include multiple polygons. In this case, the most used layers include polygons that represents: block areas, district heating account areas, remained block areas when the DH account areas are separated, buildings and segments of theoretical geothermal energy potential for three different depths in addition to areas of the city grid plan. Only itself DH account areas are presented in over 15 000 polygons. Because of such big amount of geospatial data the QGIS calculation process has demanded a lot of fixing invalid geometries and crashed calculation processing algorithms.

6.2.1 Existing geothermal energy potential and current heat energy demand at block areas

The amount existing geothermal energy potential in comparison to the heat energy demand of the building stock is calculated for each different city blocks. City blocks that include areas where district heating is engaged are separated to each district heating account areas using geoprocessing tools in QGIS. Data set that includes precise location of the district heating account areas is from Helen Oy and for each DH account area are linked the monthly heat energy consumption time series (based on the hourly consumption of district heating) from all months of the year 2018. The yearly heat energy demand of the DH account area in units of MWh/ha/a is calculated by dividing the total district heating energy demand from the year 2018 by the grid plan area of the DH account area.

Register information of the building stock in Helsinki is open data and that data package includes information like building type, total floor area, number of floors and volume of the building. For the city block areas that are not DH account areas of Helen Oy, the heat energy demand is calculated by recognizing buildings situating in those lot areas by combining these vector layers. These areas are called in this report remaining block areas. After selecting the buildings situating in blocks that are not counting as DH account area of Helen Oy, the heat energy demand is calculated by classifying type, floor areas and volumes of the buildings. With this information, yearly heat energy demand values are calculated for those areas with using the beforehand produced data of Helen Oy of heat energy demand values concerning buildings in three categories that are not connected to the district heating network of Helen Oy.

Theoretical geothermal energy potential fluctuation in the area of Helsinki is included to calculation process by, at first, transforming the raster maps from GTK to vector layers. The used coordination system in these calculations is ETRS-GK25 which is officially used in the area of Helsinki from the year 2012 (City of Helsinki 2019). After that, the three vector layers presenting geothermal energy potential existing in three different depths are each separated to segments so that later QGIS is able to recognise different potential values inside one city block and/or DH account area. The geothermal energy potential vector layers are separated to segments as follows:

- 150 meters deep theoretical potential to 125, 130, 135, 140 and 145 MWh/ha/a
- 300 meters deep theoretical potential to 280, 290, 300, 310, 320 and 330 MWh/ha/a
- 1 000 meters deep theoretical potential to 1 440, 1 500, 1 560, 1 720 and 1 740 MWh/ha/a

Reasonable range of variation is found by separating experimentally different energy potentials from the vector, thus ensuring that the variation is not too wide to assure calculation results as exact as possible. Local geothermal energy potential for the city block area vector layer and DH account area vector layer is calculated by using vector analysis tool called “overlapping analysis” in QGIS. The tool calculates area in units of m^2 and the percentual share of each segment of geothermal potential. Analysis is done for all three different depths and for theoretical potential layers separately as well. By using the percentual representation of each segment the local geothermal energy potential to each remaining block area and DH account area can be calculated after the area of each blocks (DH and non-DH) are calculated too.

When the local geothermal energy potential at city block area or DH account area is modelled and total yearly heat energy demand values on those areas are also calculated, the foregoing geospatial data is combined. For the DH account areas the relation between local geothermal energy potential is calculated by dividing the local geothermal energy potential; theoretical potential in depth of 150, 300 or 1 000 meters, by the yearly heat energy demand of the account area. For the city block areas, that are not featured as district heating customers of Helen Oy, the relation is also calculated by dividing the local geothermal energy potential by the yearly heat energy demand based on before explained assumptions and datasets.

6.2.2 Existing geothermal energy potential and heat energy demand in 2050 at grid plan

Heat energy demand in long-term planning is calculated by using the projection of total cumulative floor area in Helsinki in 2050 according to the forecasted population growth and residential construction for grid plan areas. Projection of total cumulative floor area is divided into three categories: residential, commercial and the others. According to this data set, heat energy demand for each grid plan area is calculated.

When calculating the heat energy demand to each grid plan area, current data from the district heated buildings is utilized. So the assumption is made, that at each grid plan area district heating is consumed as in the year 2018. Necessarily this assumption is not fully accurate, but it is seen to be more accurate information than if the heat demand of Helsinki in 2050 would be calculated only based by the estimation of heat demand for those three building types in units of $kWh/m^2/a$. So the heat energy demand calculation for each grid plan area is started by recognising the DH account areas at each grid plan area by using certain tools of QGIS. Before that, the district heating account area data must be enriched by the open data of Helsinki that includes floor areas of each building. This also needs an extra step of vector layers combining calculation where buildings locating at each DH account areas are combined.

After this each DH account areas are separated to those three construction type categories, to which the 2050 floor area scenarios categorize the floor area growth, based on the district heating account information of Helen. Helen has categorized each of their DH customer according to the dominant building type and application. In needs of this calculation, these categories are recategorized into three categories to fit into the scenario models of total cumulative floor area in Helsinki in 2050.

After the heat energy demand of DH account areas for three categories at each grid plan area is calculated the remainder of forecasted cumulative floor area is calculated. Heat energy demand values for the “non-DH” floor area is calculated by using estimated 2050 heat energy demand values in units of kWh/m^2/a. Because the estimation of 2050 heat energy demand values in units of kWh/m^2/a is also categorized according to building type, the remained “non-DH” floor area must be categorized into these three same categories (residential, commercial and others). More about the functions and assumptions to which that segmentation is made is presented in the next chapter where the calculation results are discussed.

Lastly, the amount of existing geothermal energy potential on each area of the grid plan compared to the heat energy demand in 2050 locating to that area is calculated by dividing geothermal heat energy potential by heat energy demand of area of the grid plan.

6.3 Calculation results

In this section, calculation results achieved by using QGIS are presented. Results are presented by numerical data and maps. At first, the results for calculation concerning current heat energy demand at block areas are presented and after that are discussed the calculation results of forecasted heat energy demand in 2050 and its relation to local geothermal energy stock at grid layout level.

6.3.1 Existing geothermal energy potential and current heat energy demand at block areas

In this chapter are presented the maps where relation between theoretical geothermal energy potential and heat energy demand is shown at block areas. Heat energy demand values are calculated according to the current yearly district heating energy consumption of district heating customers and as an estimate for the remaining block areas when district heating account areas are separated. Here in the Table 6 are separated total heat energy demand values for district heating account areas and other block areas that are not classified as DH account areas of Helen. Like mentioned before, heat energy demand for block areas that are connected to district heating network of Helen is based on the measured heat energy consumption. Heat energy demand calculations for remaining block areas are described in the chapter above.

Table 6. Calculated heat energy demand values and averages to them.

Type of field	**Heat energy demand [TWh/a]**	**Area [ha]**	**Average heat energy demand per area for one field [MWh/a/ha]**
DH account area	6,80	4 886,4	1 836,4
Remaining area of city block	0,77	2 611,4	416,2
Total	7,57	7 497,8	1 597,4

Also, the average heat energy demand per area for one field are calculated and presented in Table 6. Sizes of fields vary a lot, especially when assaying remaining block areas. The reason for this is that some DH account areas may cover the whole block area and some, for example just seven-eights of it. Due to this, there are many small swathes of block areas included to the calculation. This explains the somewhat big difference in heat energy demand averages between DH account areas and other block areas.

GTK has presented geothermal energy potential as the amount of yearly receivable underground heat energy per one hectare when temperature of ground is set down to zero Celsius degrees in fifty years. QGIS modelling shows that geothermal energy potential locating at the DH account areas and remaining block areas in total is considerably less than the total geothermal energy potential in the area of Helsinki presented, which was completely expected. Total geothermal energy potential in Helsinki, according to GTK, is 2,65 TWh/a in 150 meters (Geological Survey of Finland 2019). Local geothermal energy potential existing under block and DH account areas in total is 0,95 TWh/a, according to the QGIS calculation based on the potential maps and the size of the DH account area or remaining block area. Layout of the geothermal energy potential of block areas in 150 meters is presented in the map below (Figure 20).

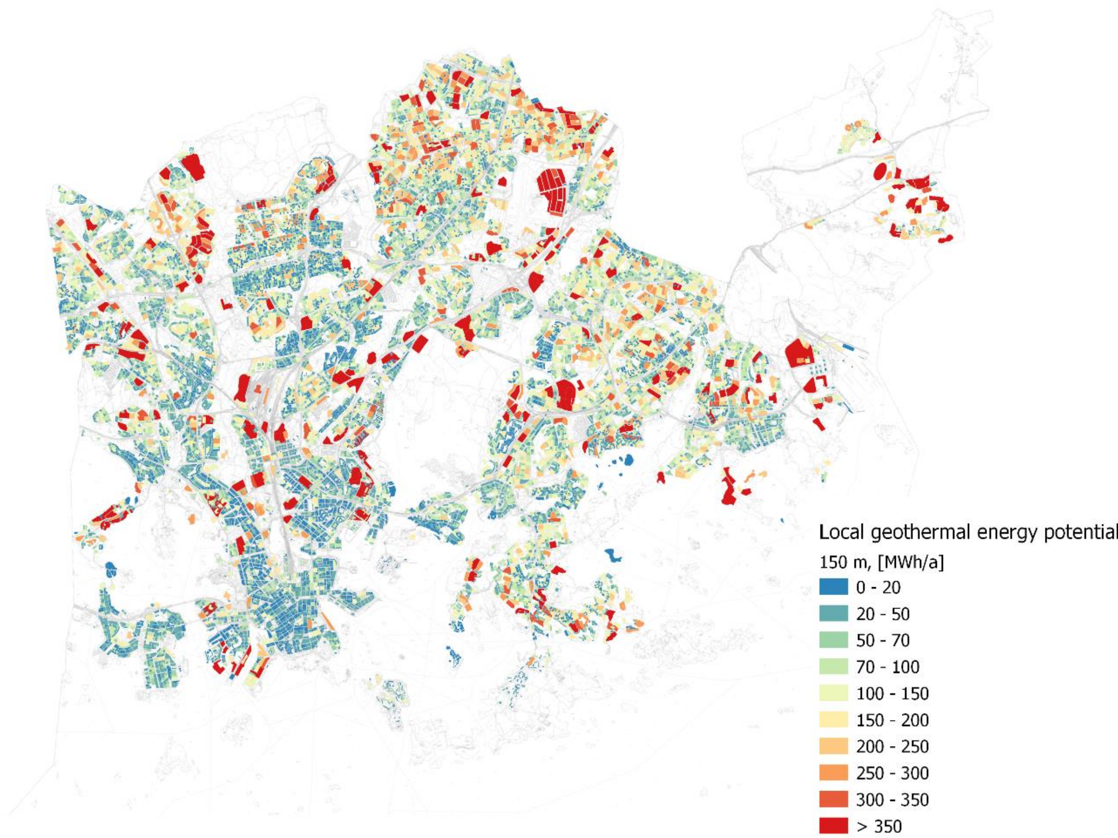

Figure 20. Geothermal energy potential at 150 meters locating at block areas.

Existing shallow geothermal energy potential in block areas can be considered as geothermal energy potential that is exploitable by the current building stock. Difference between geothermal energy potential of total Helsinki area and block areas is 1,7 TWh/a which is about 65 % of the total geothermal energy potential in Helsinki existing in the upper 150 meters. According to this, it can be addressed that most of the existing geothermal energy potential is locating under areas that are not block areas. These areas are, for example, public areas such as parks and road and street areas.

The same inference is valid also for the geothermal energy potential in 300 and 1 000 meters, because GTK has based the potential maps according to the same field researches about local rock species and their thermal conductivity (Geological Survey of Finland 2019). So, the difference of the potential maps is fully computational. Equal potential values for 300 and 1 000 meters are:

- 5,89 TWh for the whole area of Helsinki and 2,14 TWh for block areas in 300 meters
- and 30,71 TWh for the whole area of Helsinki and 11,10 TWh for block areas in 1 000 meters

The data about exploitable local geothermal energy potential and heat energy demand are combined and presented as heat energy coverage rate. Heat energy coverage rate states the threshold of existing potential and the demand. Figure 21 shows the coverage rate of thermal energy stock in upper 150 meters to heat energy demand of block areas.

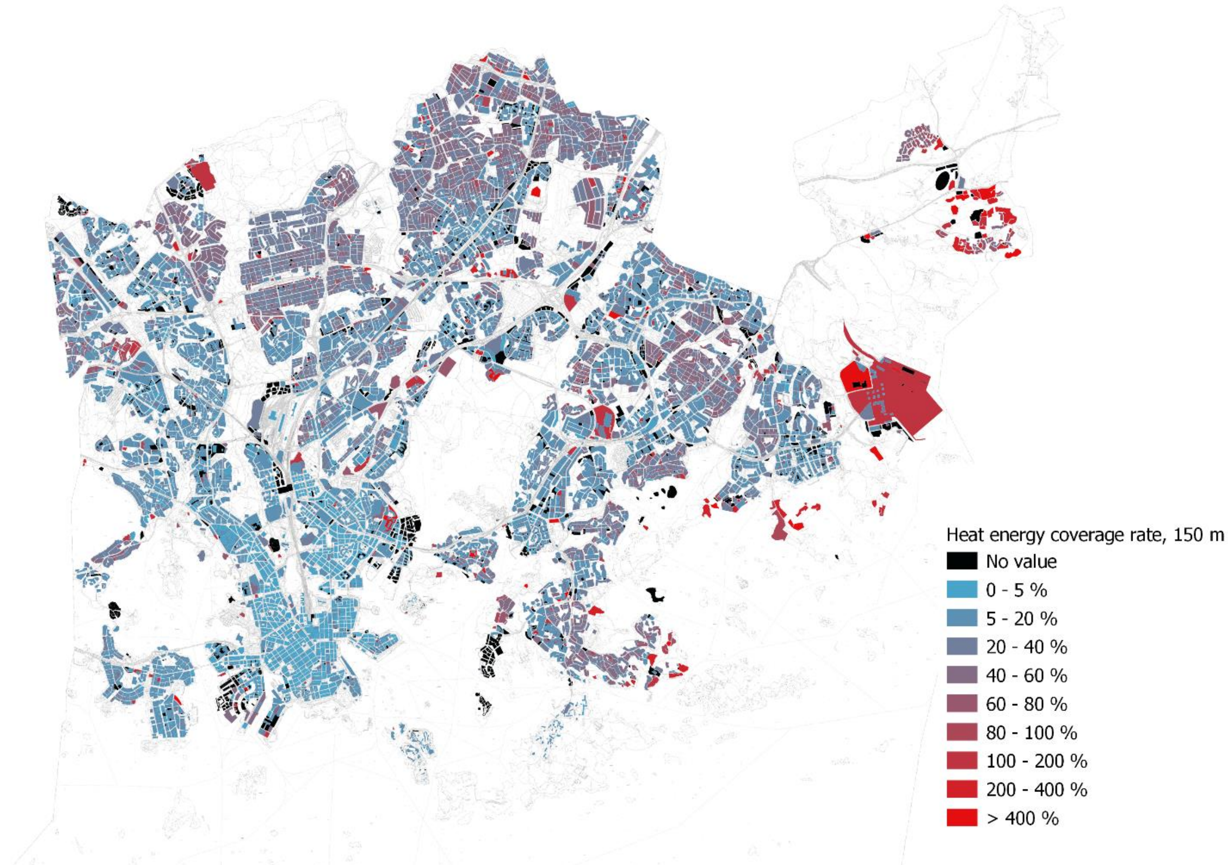

Figure 21. Heat energy coverage rate of local geothermal energy potential in 150 meters.

The map shows that in the centre of the city, the receivable heat energy in the upper 150 meters is five percent at maximum to cover existing yearly heat energy demand of the existing building stock. This can be partly explained by the fact that the land use and construction stock in that area is very dense. Also, the existing geothermal energy potential in that area is less compared to the other parts of the city.

The best coverage rate is locating in parts of the city that locate the furthermost from the city centre and main roads. As it can be seen from the map above, there are some DH account areas or parts of the city blocks which heat energy demand can be covered even over 80 % by the local geothermal energy potential, but clearly most of the existing 150 meters deep geothermal potential under block areas can cover under 60 percent of the local demand. Below is presented histogram of the same information than presented in the map (Figure 22).

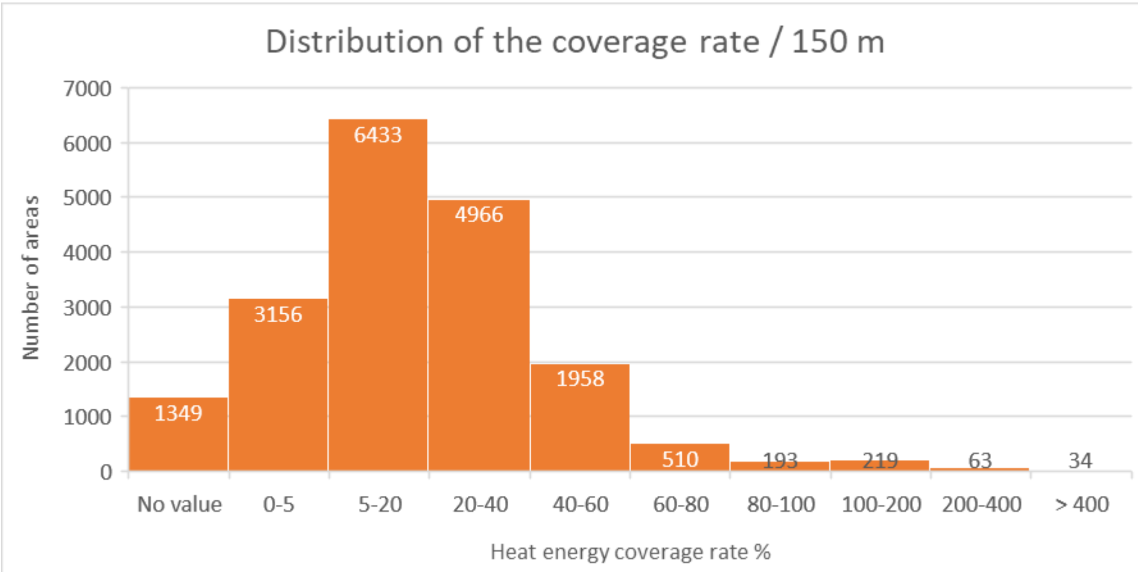

Figure 22. Histogram 150 m theoretical geothermal energy potential

According to the histogram, five to twenty percent coverage rate is clearly the most common when estimating 150 deep theoretical geothermal energy potential in relation to heat energy demand. Total number of areas in this calculation is 18 882. Coverage percent over 80 is occurring only in 509 areas which is being just 2,7 % of the total number of areas included to the calculation. Geothermal energy existing upper 150 meters can cover an average of 25,33 % of the heat energy demand of one block area or DH account area in Helsinki. For 1 349 blocks areas the local geothermal energy potential is not defined most likely as a result of original raster maps not covering the area. Due to this, local geothermal energy potential is zero. Or as a result of heat energy demand of the area being zero.

Overall, existing theoretical potential in depth of 150 meters locating to city block areas is 0,95 TWh which is exploitable yearly during the fifty-year-period, like mentioned before. According to the before explained calculations, the total heat energy demand for the block areas of Helsinki is 7,57 TWh with occurred consumption of district heating in 2018 and estimated heat energy demand values for remaining block areas based on the current buildings. From this total heat energy demand, 6,8 TWh represents yearly heating demand of district heating account areas and 0,77 TWh heating demand of other building locating at remaining block areas. According to this QGIS calculation, total 12,5 % of heat energy demand of the block areas can be covered by existing shallow theoretical geothermal energy potential from the upper 150 meters.

Because above presented results about heat coverage rate values do not perfectly describe the maximum amount of exploitable heat energy from the ground, a rough evaluation of the number of needed heat wells is also made to bring more dimension to processing of the calculation results. According to the GTK report, for 150 meters of depth the minimum amount of receivable energy per meter from well field is 0,032 MWh/a calculated by the technical geothermal energy potential in Helsinki. The used distance between each heat well in the heat well field model is 20 meters. GTK also studied receivable energy per meter from one single heat well in depth of 150 meter which is 0,108 MWh/a per meter. The single bore hole calculation model is based on the assumption that there does not exist another heat wells inside certain distance defined by the depth of the heat well. For the 150-meter-deep heat well the distance is 81 meters. (GTK.) Using these values, number of needed heat wells for each DH account area or block area is calculated. It is assumed that the amount of exploited heat energy from the well is two thirds of the heat energy demand of the area based on the chosen COP value of three of the imaginary heat pump system that enables the exploitation of the geothermal energy.

By multiplying the local heat energy demand by two-thirds and receivable energy from heat well and lastly dividing it by depth of heat well, the number of heat well for one block area is calculated. This calculation is made for all DH account areas and remaining block areas. Number of 150-meter-deep heat wells are averagely needed 60,1 per are if the area of Helsinki is imagined to be one coherent geothermal wellfield. Calculated median for the number of needed well in this case is 32,5. The average surface area of the DH account areas and remaining block areas used in this QGIS potential calculation model is 0,40 hectares. Because commonly such small lots and high density of built environment, it can be assumed that 60 or even half of it heat wells can’t be designed to suit into most of the block areas or DH account areas in Helsinki. Of course, the model of heat wellfield covering the whole city of Helsinki is not that accurate and even near to the reality because, like discovered earlier, about 65 % or the total land area of Helsinki is classified as non-block area where heat energy demand is not needed locally.

When studying statistics for the single well-systems equivalent number of needed wells are 17,8 as an average and 9,6 as a median. When distance where the effect of heat well for the ground is 81 meters for 150 meters deep heat well, at least area of 0,21 hectares is needed per one heat well. According to these statistic, not enough heat wells could not be suited into the most of DH account areas nor remaining block areas. There are approximately 1 600 parts of block areas, from what about half are DH account areas, that are size of a hectare or more. So there also exists bigger sized parts of block areas. According to QGIS calculation where buildings are excluded from the DH account areas and remaining block areas, the average of remaining area is 0,27 hectares. Of course, examining average values is not very accurately descriptive or precise analysis and because of this, no substantial conclusions should be made leaning on these presented numbers about heat wells.

For the depth of 300 meters, exploitable heat energy from the ground is presumably greater. Below in the Figure 23 heat energy coverage rate for geothermal energy potential in 300 meters is presented. Red and purple shades in the map reflect heat energy coverage rate greater than 60 % that are represented more quantitatively than in the map that presents situation of geothermal potential in the 150 meters. In the city center potential can be seen zero to five percent like in the 150 meters.

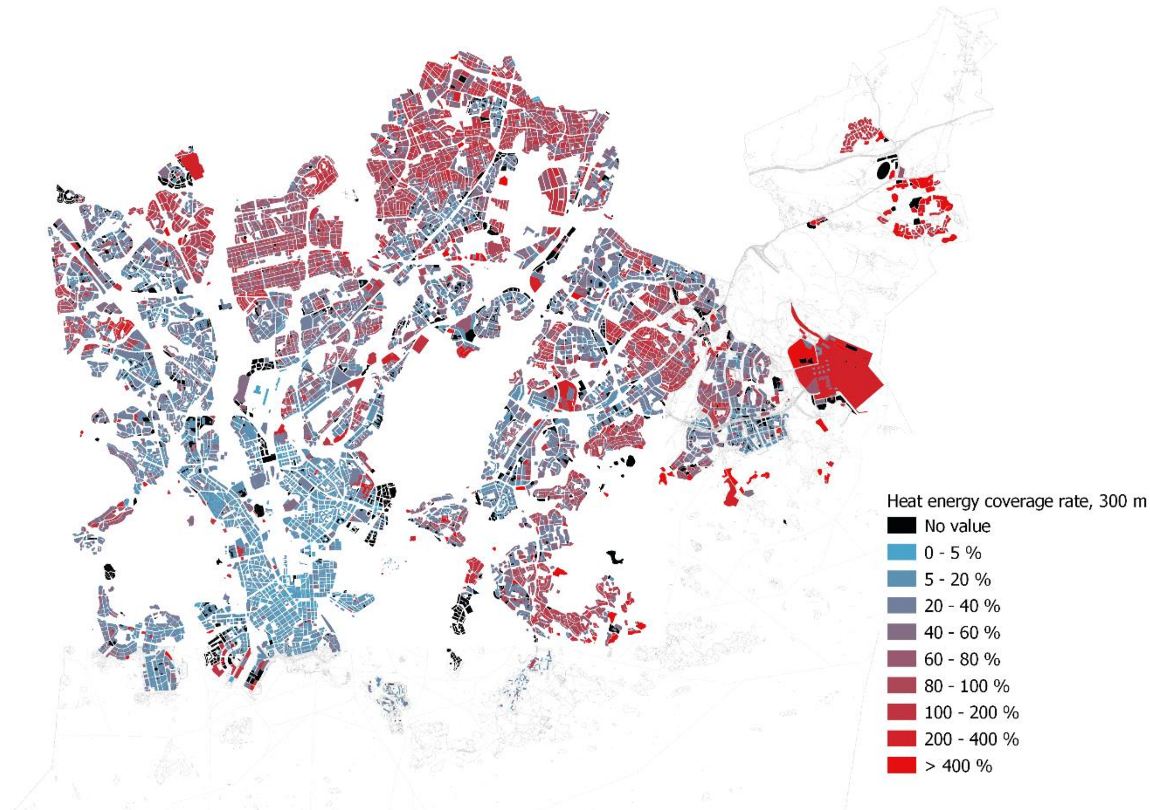

Figure 23. Heat energy coverage rate of local geothermal energy potential in 300 meters.

Histogram (Figure 24) shows that 5-20 percentage coverage rate of heat energy demand is dominant in the block areas. The situation is same for the 150-meters-deep geothermal energy potential. 80 % of heat energy demand of 32 % of all areas can be covered by local geothermal energy potential. For the depth of 150 meters, equivalent value was 2,7 %. About 12 % heat energy demand of the block areas of the calculations can be covered over 100 % by the local geopotential.

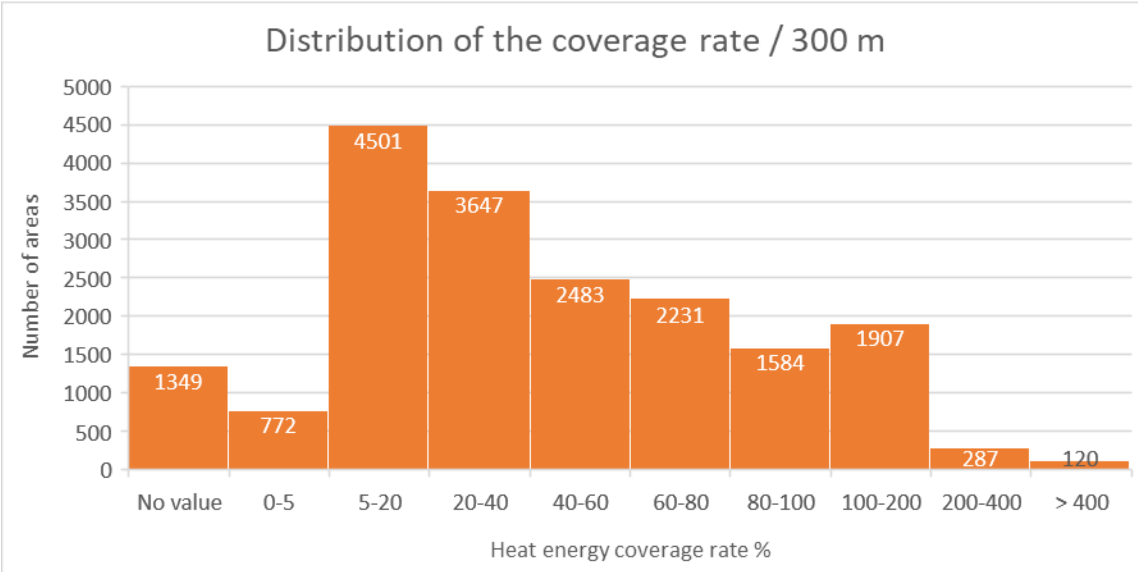

Figure 24. Histogram 300 m theoretical geothermal energy potential

Total coverage share of the geothermal energy potential for DH account areas is 21,0 %. Equivalent value for remaining block areas is 92,3 %. Average coverage rates are for DH account areas 46,6 % and for remaining block areas 133 %. Existing and exploitable geothermal energy potential at DH account areas and remaining block areas is totally 2,14 TWh/a. This can cover 28,3% of the total heat energy demand of the block areas.

When inspecting the exploitable energy per meter for imaginary heat wellfield covering the whole Helsinki and one single heat well, results are the following. According the GTK report, exploitable heat energy from 300 meters, in the case of wellfield offsetting the city, is 0,03 MWh per meter in one year. With the coefficient performance of three the average number of needed heat wells is 29,7 and median of 14,6 for the block areas. For one 300-meter-deep single heat well, with sanctuary approximately of 80 meters, the exploitable heat energy is 0,109 MWh per meter yearly. Number of needed heat wells by calculating this receivable heat energy is an average of 8,2 heat wells and a median of 4 heat wells.

For the examination of the geothermal energy potential at one kilometer compared to the local heat energy demand, the results are presented next. In the Figure 25 is seen the map of the coverage rate in this case. The city center is standing out in the map in this case too. Heat energy demand can be covered basically not even 50 % at that area even when talking about the heat energy existing down to one kilometer. Most of the other parts of Helsinki can be fully covered locally by the 1 000 meters deep geothermal energy. The difference between city center and other parts of the city is glaring.

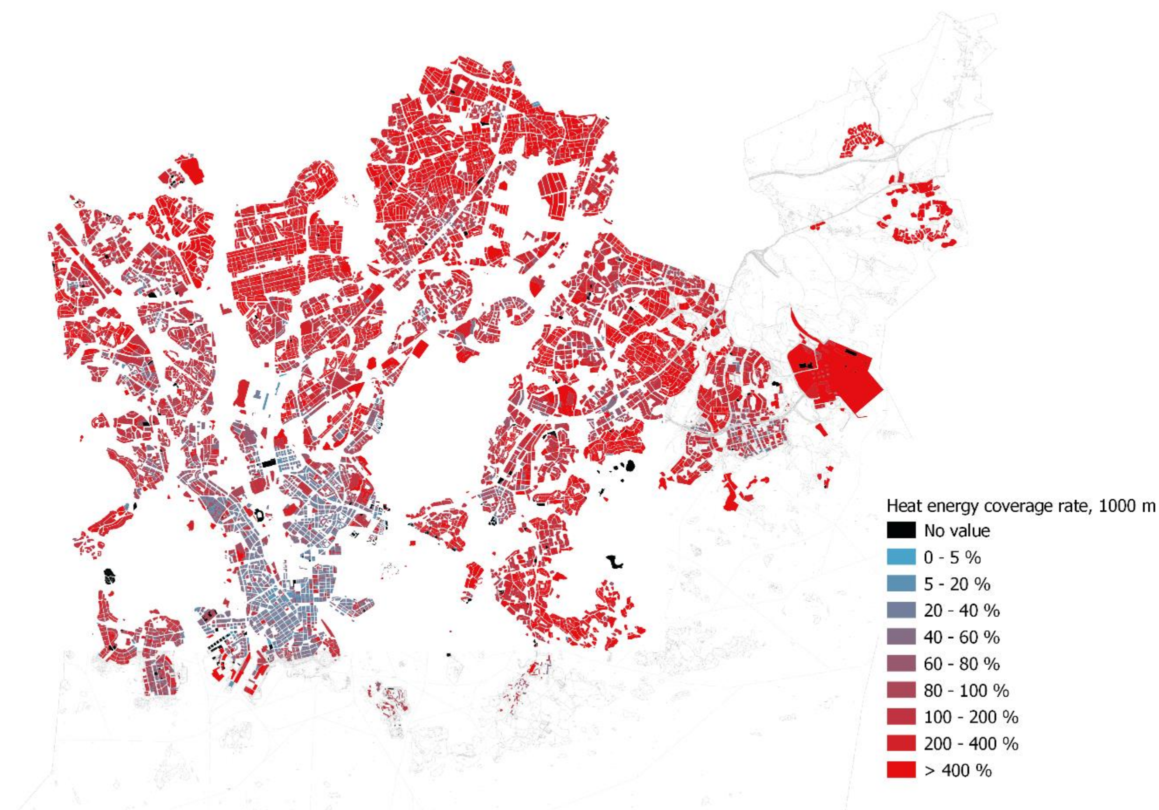

Figure 25. Heat energy coverage rate of local geothermal energy potential in 1 000 meters.

Histogram of the results are presented below in the Figure 26. It shows too that most of the block areas can be covered by the 1 000-meter-deep geothermal energy. 65 % of the all 18 882 DH account areas and remaining block areas can be fully covered by this geothermal energy. For DH account areas the existing geothermal potential is 7,4 TWh yearly in total with coverage rate of 108,8 % and for remaining block areas the yearly potential is calculated to be totally 3,7

TWh with coverage percent approximately 480 %. In total, when combining the demands and local potentials of DH account areas and remaining block areas, the coverage rate is 146,6 % in this case of 1 000-meter-deep geothermal energy potential.

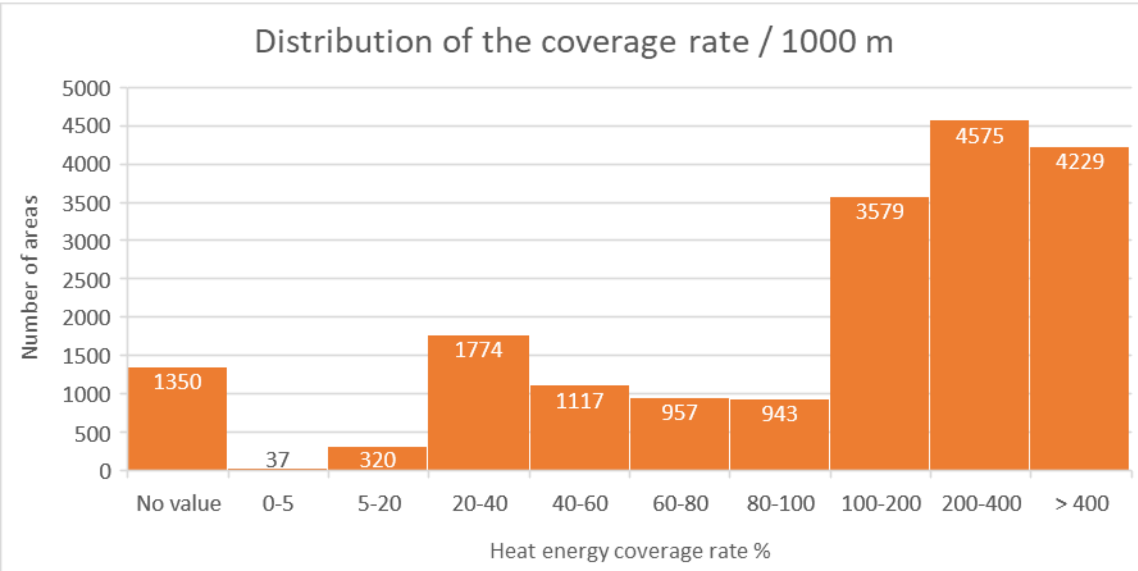

Figure 26. Histogram 1 000 m theoretical geothermal energy potential

If inspecting the potential and heat demand result of this case of one kilometer deep geothermal energy and reflecting them to the possible amount of needed heat wells, the results are following. The exploitable energy from the energy well field per one heat well would be 0,03 MWh/m/a for a 1 000 meters deep well. And receivable energy from a single heat well with a preservation distance of approximately 95 meters would be 0,109 MWh/m/a. Both of these values are calculated similarly than in the case of 150 and 300 meters deep wells and using the assumption from GTK report. With these values, the number of wells would be as follows for block areas:

- energy wellfield system: average of 8,9 and median of 4,4 heat wells
- single heat well system: average of 2,5 and median of 1,2 heat wells

The average and median number of 1 000 meters heat wells seems feasible for some cases but of course when discussing about deeper bore holes the more detailed planning is needed and more things have to be taken into notice. And of course, these values are just reference values based on the assessment of GTK of how much heat energy could be exploited per meter.

When evaluating the above results of the coverage share calculations it should be observed that local theoretical geothermal energy potential reflects the maximum attainable amount of exploitable heat energy. Individual possibilities of each DH account area or remaining block area of utilization technologies define the bare maximum of the achievable coverage share. Below in Table 7 is presented the compilation of the local theoretical geothermal energy potential and energy demands and relation of them for the all city block areas.

Table 7. Compilation of the results for theoretical geothermal energy potential compared to heat energy demand in 2018.

Depth [m]	Type of field	Local geothermal potential [TWh/a]	Total coverage share [%]
150	DH account area	0,63	9,3
	Remaining area of city block	0,32	59,6
	Total	0,95	12,5
300	DH account area	1,43	21,0
	Remaining area of city block	0,71	92,3
	Total	2,14	28,3
1 000	DH account area	7,40	108,8
	Remaining area of city block	3,70	479,8
	Total	11,10	146,6

6.3.2 Existing geothermal energy potential and heat energy demand in 2050 at grid plan

The calculation results of sufficiency of the geothermal energy stock compared to the heat energy demand in 2050 for areas of the grid plan are presented in this chapter. Calculations are based on two different floor area projection: scenario of residential construction and scenario of population growth in Helsinki. There are 1 790 areas in the grid plan which are used in this calculation and to which heat energy demand and local geothermal energy potential are calculated to. Heat energy demand is calculated by using both, residential construction and population growth scenarios.

When performing the first step of calculation; assessing the heat energy demand of each grid plan area, it was noticed that some areas of the grid plan turned out to represent negative growth of total floor area compared just to the current gross floor area of buildings that are district heating customers of Helen in 2018. The areas where negative growth is occurring are presented in Figure 27. Negative growth is stated by using the data of residential construction scenario. Negative growth of total floor area occurs in 191 areas that is 11 % of the total number of grid plan areas used in the calculation. The reason for this is hard to find because it is not known on what assumptions or studies the data concerning floor area scenarios received from exclusively from the city of Helsinki is based on.

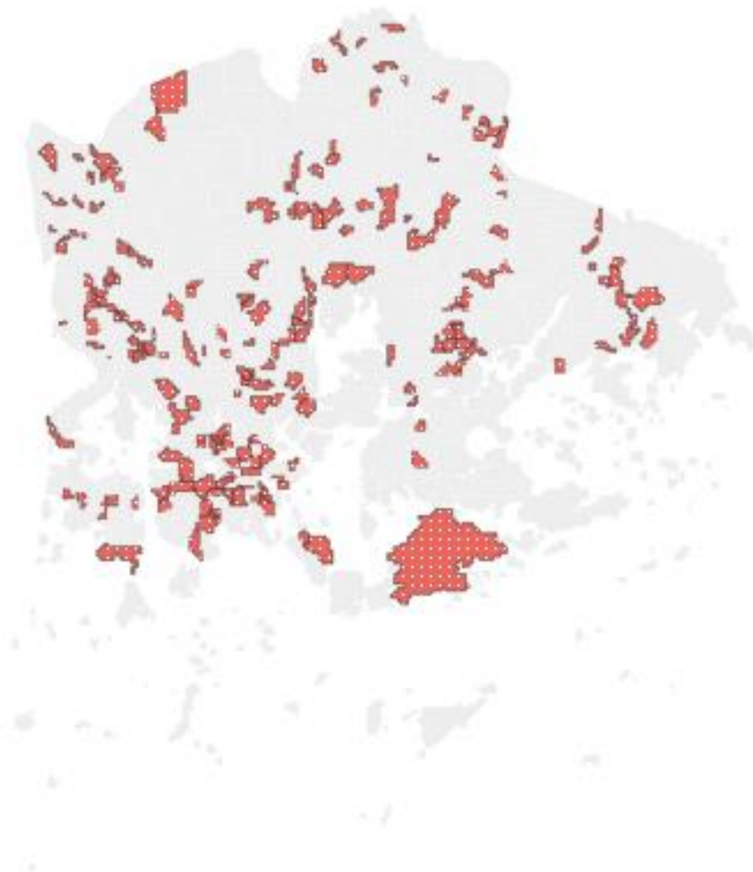

Figure 27. Negative growth of total floor area according to scenario of residential construction and current building stock connected to district heating.

Because the negative growth is occurring in over 10 % of the all studied grid plan areas and total floor area is being the base for the heat energy demand calculation, it is reasonable to consider what is the most sensible way to calculate and represent heat energy demand data for floor area scenarios presenting buildings that are not district heating customers of Helen. Floor area to present "non-DH" building for each grid plan area is calculated by decreasing the floor are of DH account areas locating at each grid plan areas from the forecasted cumulative gross floor area. Like presented above in the Figure 27, for some grid plan areas the forecasted floor area growth is in this case assumed to be negative. This occurs later on in this calculation process as a negative heat energy demand.

Negative heat energy demand was also noticed to occur for some other grid plan areas. The biggest reason that results assumed distortion in some areas is that the “non-district heating” square meters are shared to the three categories: residential, commercial and others, according to the assumption of how district heating square areas are shared to those three categories. And these don’t seem to fit to the idea of the same categories of the forecasted floor area growth in 2050.

As a result of this the amount of “non-DH”-floor area for these three different categories are calculated by two different ways. In calculation type 1 the gross floor area is calculated just by reducing the total gross floor area of DH account areas from the forecasted gross floor area for each category at each grid plan area. As seen from the Table 8 where the calculated floor areas are presented in total, “the others”-category is negative. According to this, it can be stated that when categorizing DH account areas to these three categories, the assumption about the category is not equivalent to the assumption to which 2050 floor area scenarios are based on. In calculation type 2 the percentage share for forecasted residential, commercial and other gross floor areas is calculated for each grid plan area and the remaining gross floor area, after reducing the local floor area of DH account areas, is separated to these three categories. These results are also presented in Table 8 below. All these mentioned calculations were made to both floor area scenarios of residential construction and population growth.

Table 8. Gross floor area for three building categories according to calculation type one and two.

<table>
<tr><th colspan="2">m²</th><th>Residential</th><th>Commercial</th><th>Others</th><th>Total</th></tr>
<tr><td colspan="2">KL</td><td>27 128 622</td><td>17 765 315</td><td>2 037 142</td><td>46 931 079</td></tr>
<tr><td rowspan="2">“non-DH” / Calculation type 1</td><td>Residential construction</td><td>22 104 102</td><td>7 705 642</td><td>-46 445 174</td><td>-16 635 431</td></tr>
<tr><td>Population growth</td><td>16 141 496</td><td>5 941 473</td><td>-46 445 174</td><td>-24 362 206</td></tr>
<tr><td rowspan="2">“non-DH” / Calculation type 2</td><td>Residential construction</td><td>18 503 138</td><td>9 572 751</td><td>182 618</td><td>28 258 506</td></tr>
<tr><td>Population growth</td><td>13 168 892</td><td>7 214 959</td><td>147 882</td><td>20 531 731</td></tr>
</table>

Heat energy demand values were calculated according to these above presented information about gross floor areas. For calculation type 1 it is chosen that if the heat energy demand, calculated by the specific heat demand values in unit of kWh/m^2 per year, is negative it is changed to zero. As a result, when combining to heat energy demand values of DH account areas the total heat energy demand in 2050 are calculated and presented in Table 9.

Table 9. Heat energy demand 2050 [TWh/a]

TWh/a	Residential construction	Population growth
Calculation Type 1	9,22	8,61
Calculation Type 2	8,78	8,16

From these two calculation types it was chosen to use the results based on the calculation type of two. In this case when the categorization of DH account areas don’t match enough with the categorization of the scenarios, it is better to calculate “non-DH” gross floor areas by using the percentual shares of the categorized forecasted gross floor areas. Heat energy demand of district heating account areas of each grid plan area is presented in the map below (Figure 28). It is reason to remember that the assumption is made that the consumption of district heating is remaining the same level of 2018 in the year of 2050.

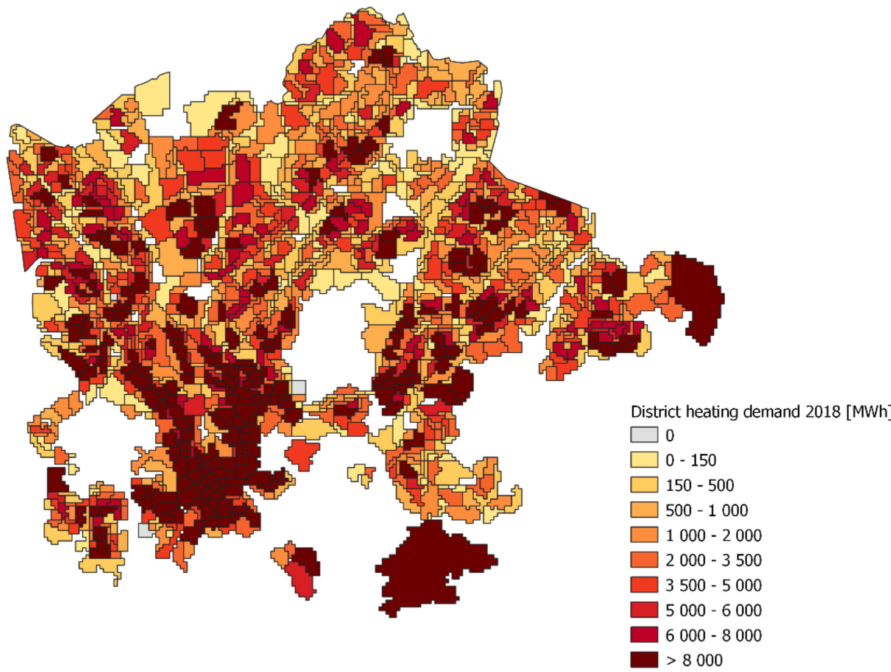

Figure 28. Heat energy demand of district heating account areas of each grid plan area.

Here in Figures 29 and 30 are presented heat energy demand values in 2050 according to the two square area scenarios made by residential construction and population growth. Total yearly heat energy demand according to the model made by residential construction scenario would be 8,78 TWh and according to the model made by population growth scenario 8,12 TWh.

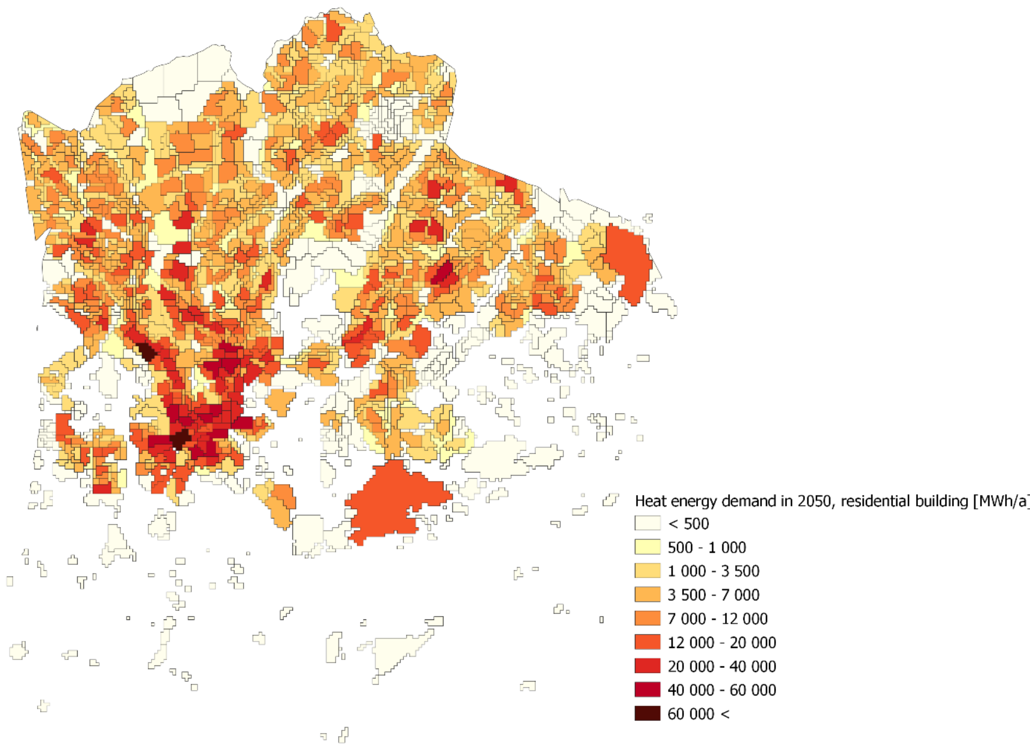

Figure 29. Heat energy demand of Helsinki 2050 according to projected residential building.

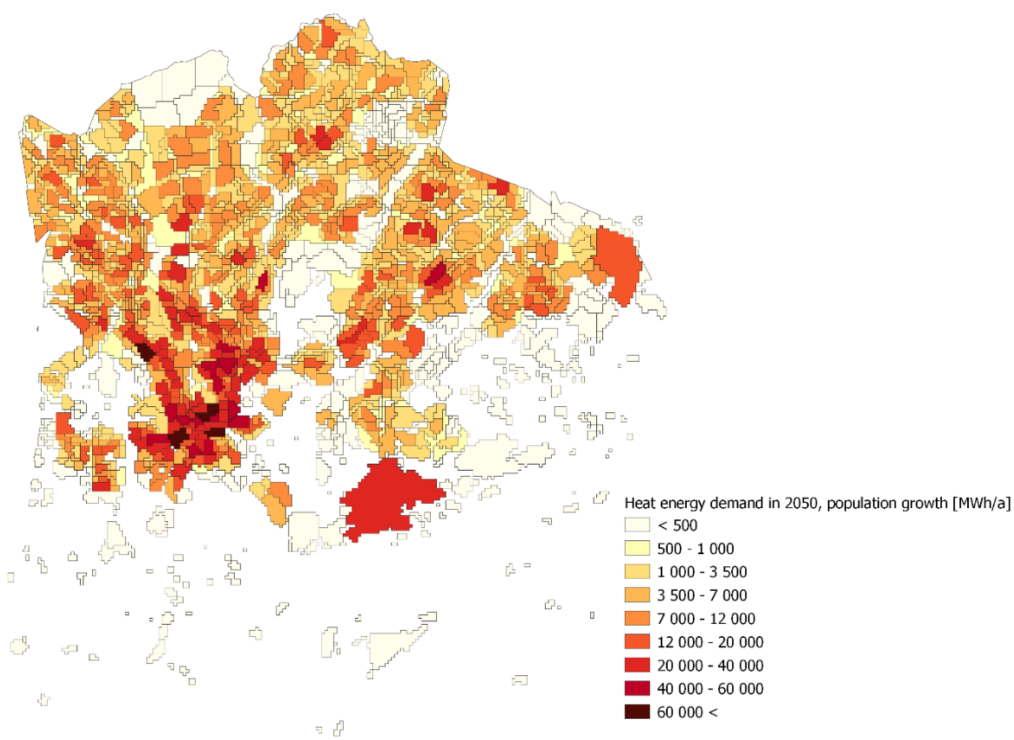

Figure 30. Heat energy demand of Helsinki 2050 according to projected population growth.

It can be noted that regional differences between these two scenarios are not occurring considerably. In the 2050 most of the heat energy is needed in the city centre like today. Santahamina island stands out with greater heating demand compared to the surrounding islands or, for example, the area of Laajasalo which can be explained by the big size of the calculation field of it.

Below in Table 10 are combined the total results of the potential calculations of 2050. Local geothermal energy potential existing at the grid plan areas in the depth of 150 meters is 2,35 TWh which is approximately 27 to 29 percent of the total heat energy demand of Helsinki. Equivalent coverage rates for the geothermal potential existing in 300 and 1 000 meters are 60-65 % and 313-337 % depending which scenario the calculation is based on. Coverage rate results differ so much from the results of before presented potential calculation of 2018 because the 2018 calculation is made for the block areas / DH account areas.

Table 10. Total coverage share for different depths.

Depth [m]	**Local geothermal energy potential [TWh/a]**	**Total coverage share [%]**	
		Residential construction	**Population growth**
150	2,35	26,76	28,79
300	5,30	60,33	64,92
1 000	27,50	313,12	336,91

The results are presented more specifically next by using map modelling and histograms. Like heat energy demand maps, also the coverage rate maps are very similar between scenarios of residential building and population growth. Due to this, map models representing the distribution of local geothermal energy potential compared to local heat energy demand for 150, 300 and 1 000 meters based to the scenario of population growth can be find from the attachments (Attachment 1, 2 and 3).

Figure 31 represents the geothermal energy potential existing in the upper 150 meters compared to the heat energy demand in 2050. Local geothermal energy potential is addressed to be 2,35 TWh yearly. It is seen from the Figure 31 that there are many areas in Helsinki where the coverage rate of local geothermal energy is zero to forty percent. In the city centre the coverage rate is similarly poor to the stated coverage rate in the block area model illustrating the relation of geopotential and heating demand in 2018.

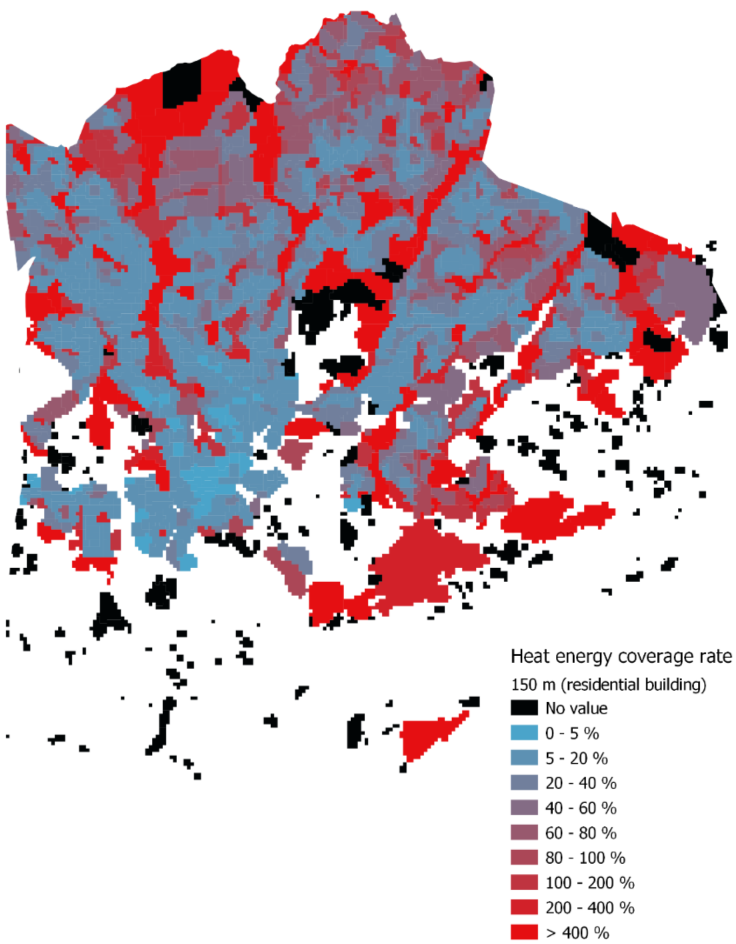

Figure 31. Relation between local geothermal energy potential (150 m) and heat energy demand in 2050 according to projected residential construction.

According to the Figure 32 representing the distribution of coverage rates for the calculation model based on potential in 150 meters and the residential construction scenario, in major part of the calculation areas, or in this case grid plan areas, the coverage rate is 5-20 %. About 14 % of the areas the sufficiency of existing geothermal energy potential is over 100 % compared to the local heat energy demand. In Figure 33 the similar histogram is presented but for the calculation results based on the population growth and the most popular coverage rate is same for that. Over 100 % of geothermal energy potential compared to the demand is occurring in 16 % of the areas in this case. From both Figures 32 and 33 it can be seen that 20-40 % is the second most dominant coverage rate for the areas of the grid plan.

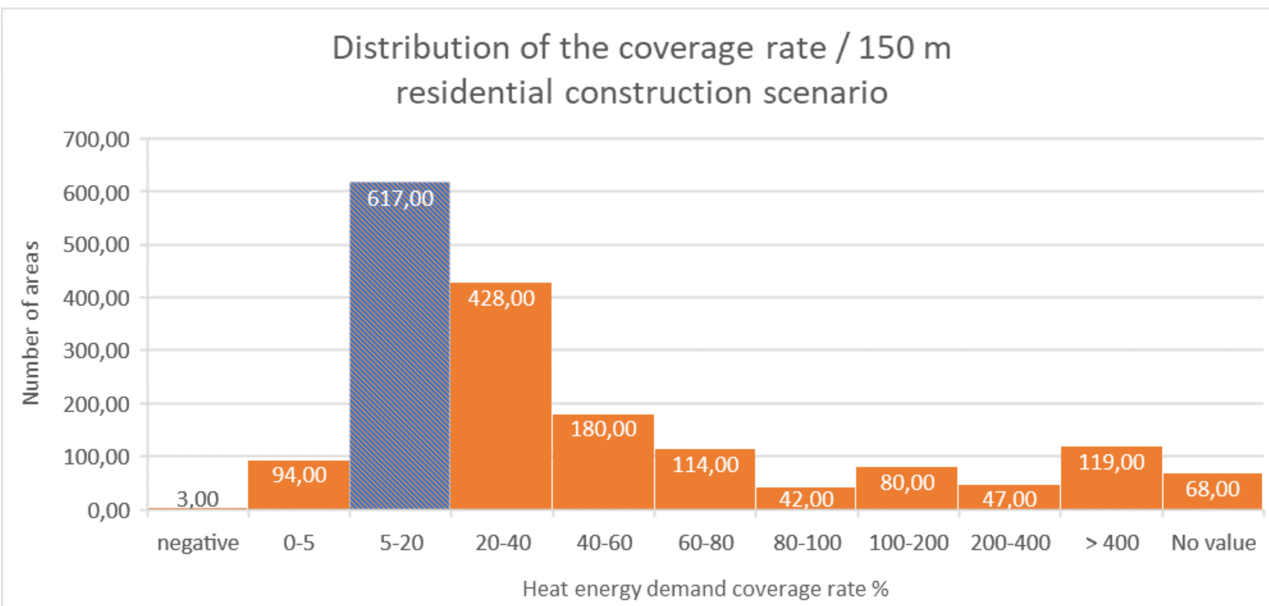

Figure 32. Distribution of the coverage rate in 150 meters according to the scenario of residential construction.

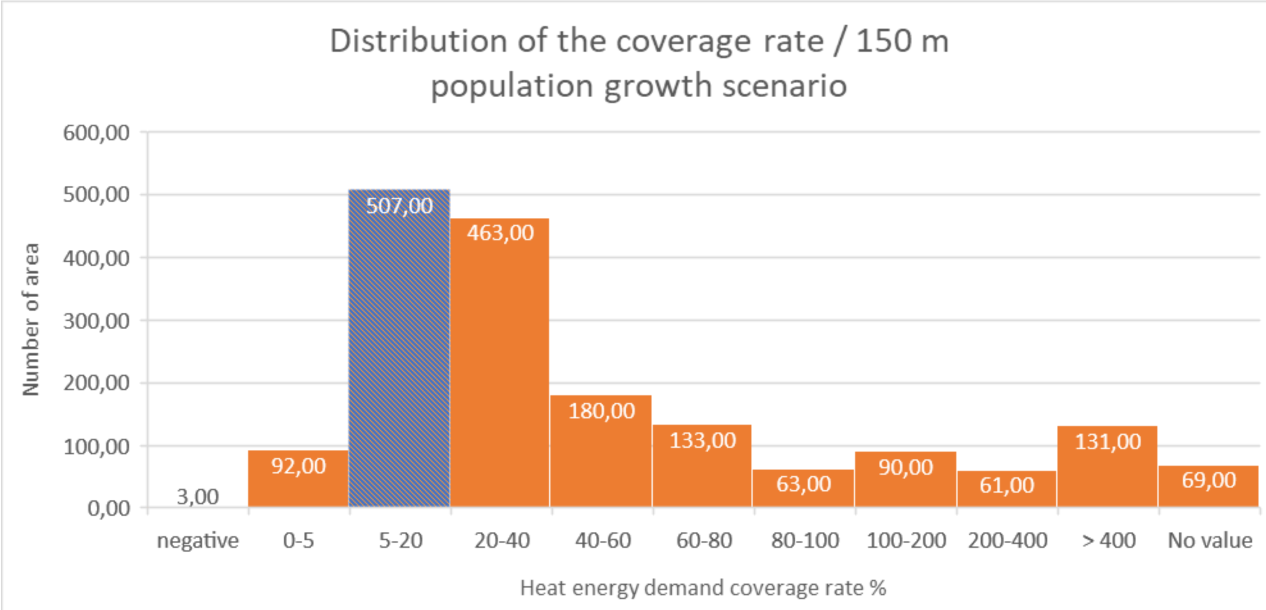

Figure 33. Distribution of the coverage rate in 150 meters according to the scenario of population growth.

Areas that are labelled as “no value” have undefined or zero heat energy demand or geothermal energy potential. Negative coverage rates were discovered to occur in three areas, where the total amount of prognosticated square meters were smaller compared to the total amount of square meters of district heating account areas locating at that grid plan areas, resulting that heat energy demand of “non-DH” classified square meters are also negative.

Figure 34 represents the potential situation when going deeper into the ground down to 300 meters. Still some blue areas can be noticed, but almost none 0-5 % areas can be seen. But the difference compared to the Figure 31 is big, due to that especially northern parts of Helsinki can be seen more red than blue or purple coloured.

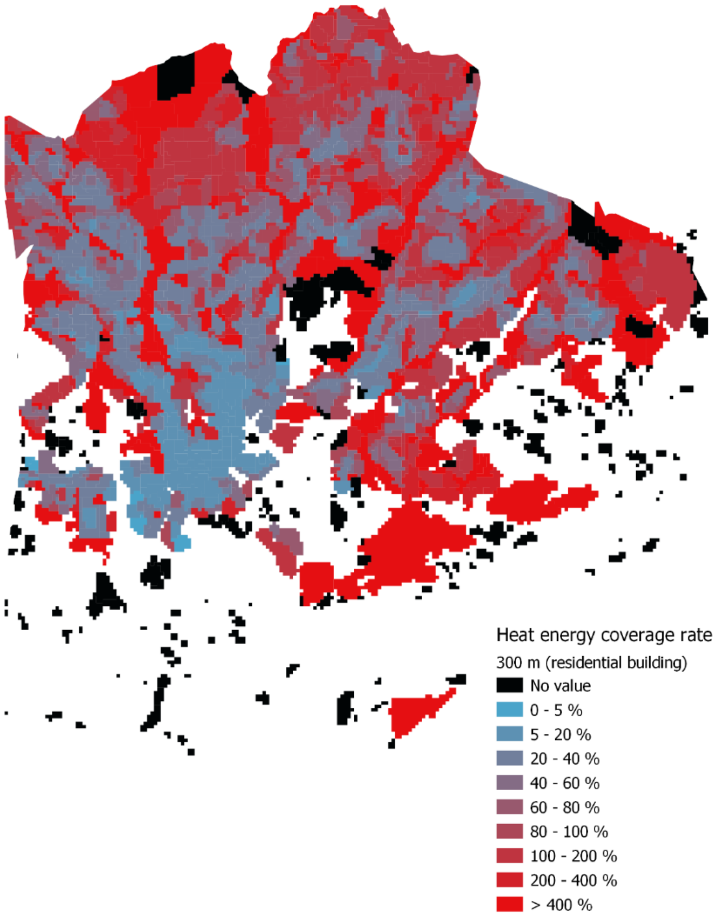

Figure 34. Relation between local geothermal energy potential (300 m) and heat energy demand in 2050 according to projected residential construction.

As seen from the histograms below (Figures 36 and 37), 20-40 % is the most presented coverage rate in both scenario cases. In the coverage calculation based on the population growth, the number of grid plan areas is almost the same for representing 20-40 % and 40-60% coverage rates. Over 100 % coverage rate is presented in approximately 30 % of the areas that are included in this calculation concerning both scenario cases.

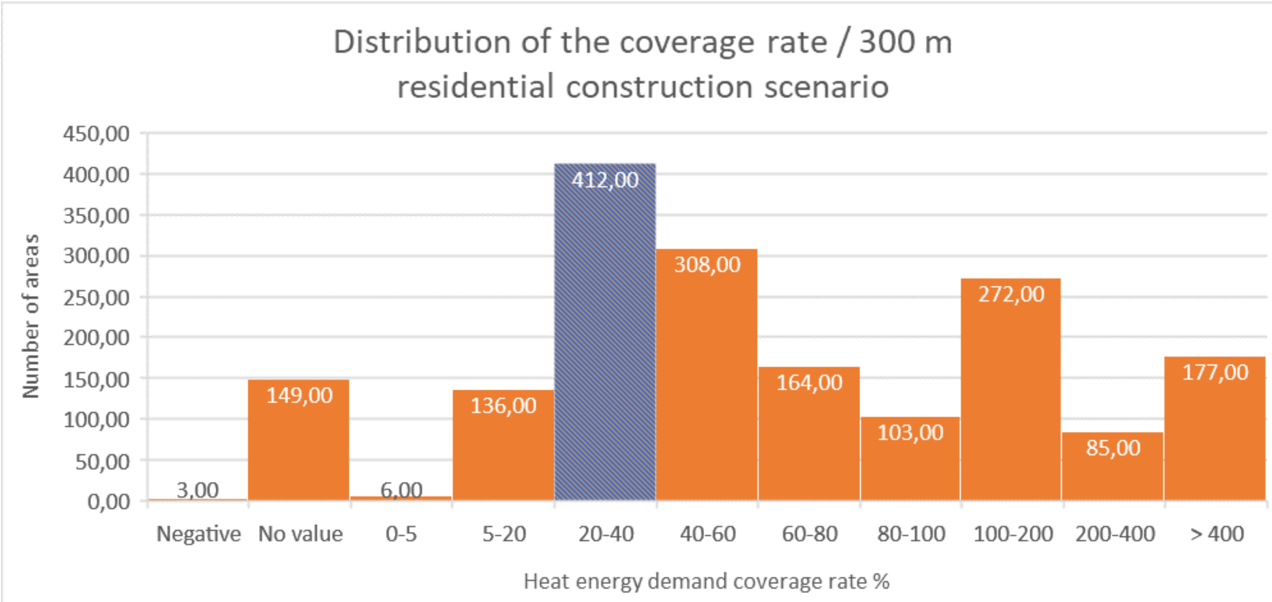

Figure 35. Distribution of the coverage rate in 300 meters according to the scenario of residential construction.

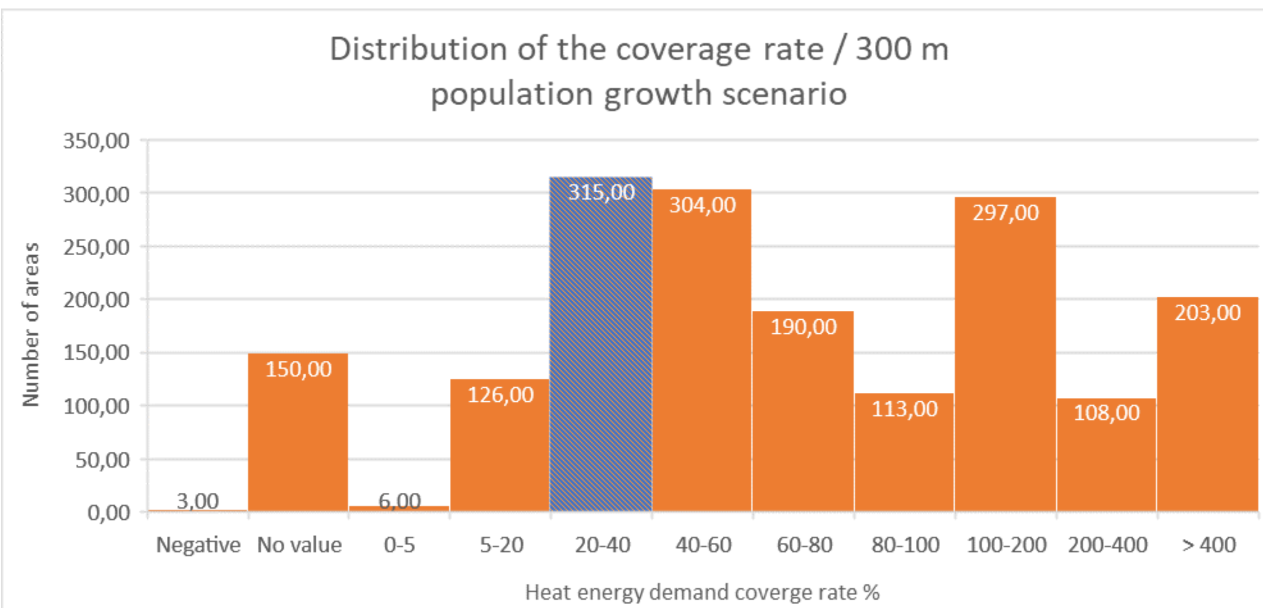

Figure 36. Distribution of the coverage rate in 300 meters according to the scenario of population growth.

The map model that represents the coverage rate of geothermal energy potential existing in upper kilometre compared to the assumed heat energy demand in 2050 is presented in Figure 38.

Difference between this and map models presenting the situation of coverage rates from 150 and 300 meters is even noticeable than the difference between 150 and 300 models. Major parts of Helsinki are labelled to have over 100 % of coverage rate that is shown as red colour in map. The area of city centre is blue-/purplish representing approximately the coverage rate of 20-80 %.

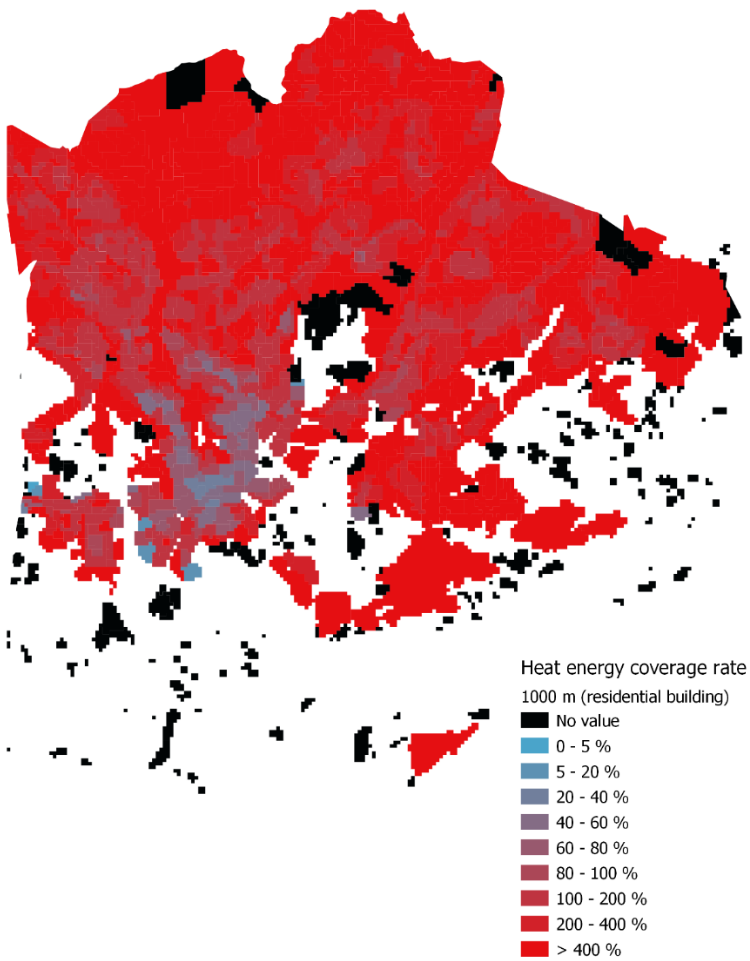

Figure 37. Relation between local geothermal energy potential (1 000 m) and heat energy demand in 2050 according to projected residential construction

Figures 39 and 40 show the same information but as a form of histograms, like for the models of 150 and 300 meters and for both scenarios of square area growth. For both cases it clear that most areas pf grid plan have over 100 % of coverage rate. Over 100 % coverage rate is occurring in 85 % of the areas in the case of residential construction scenario and 85 % in the case of population growth scenario. The results are similar for both cases. The bar representing coverage rate over 400 % is the greatest for both scenario cases.

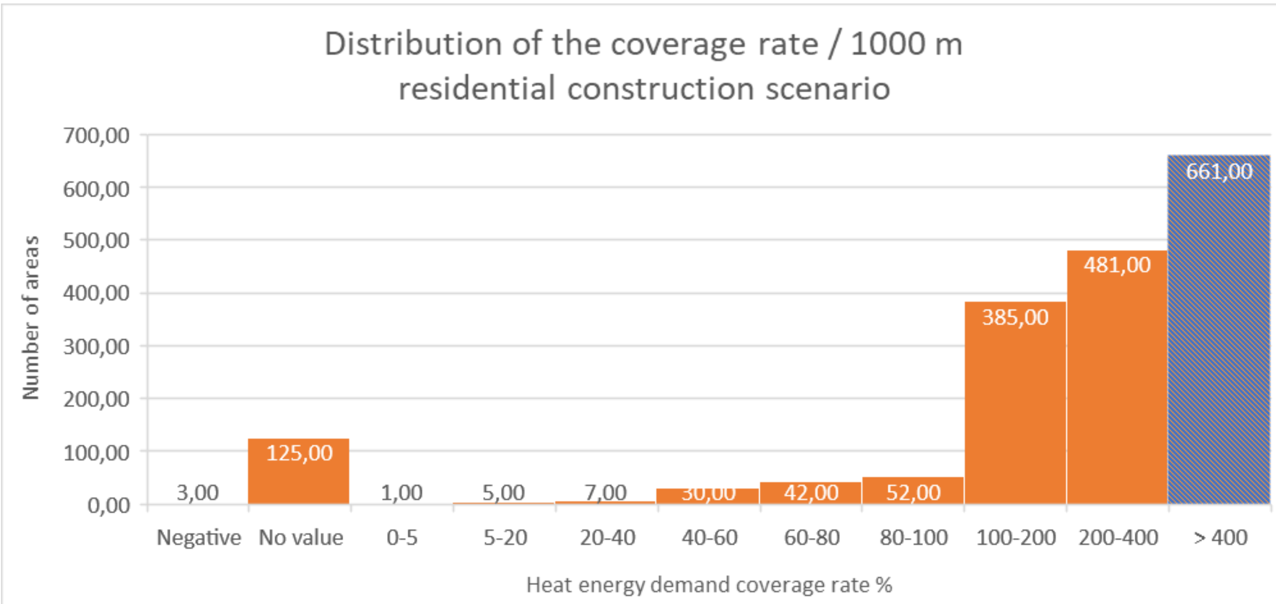

Figure 38. Distribution of the coverage rate in 1 000 meters according to the scenario of residential construction.

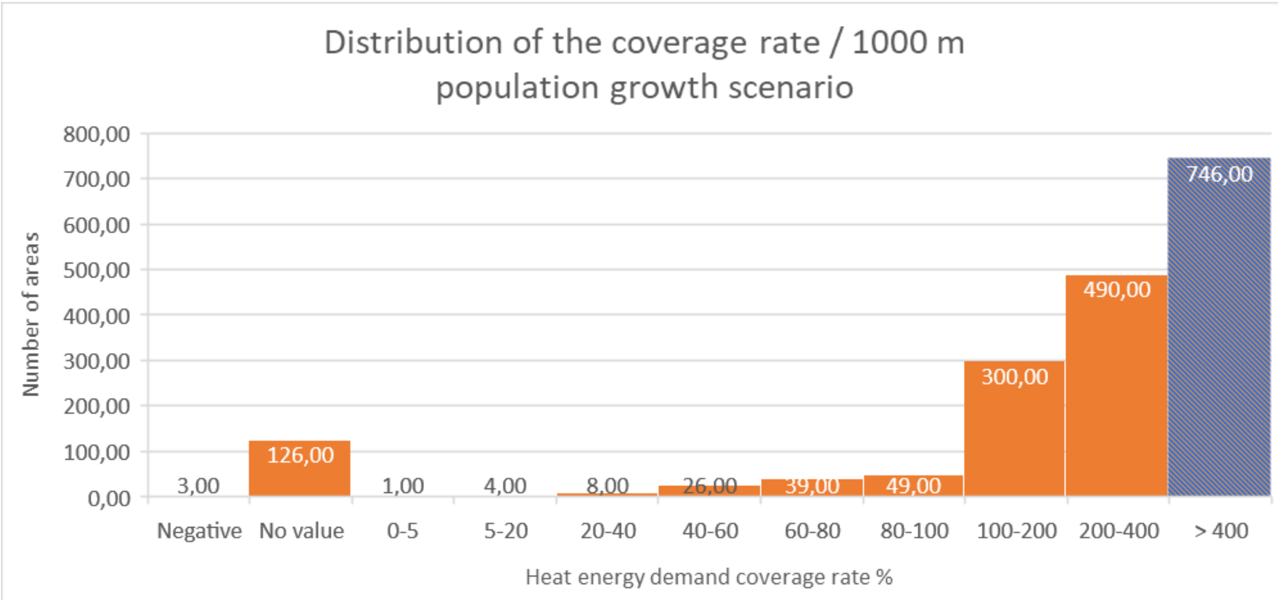

Figure 39. Distribution of the coverage rate in 1 000 meters according to the scenario of population growth.

As the reference, also the coverage percent for the total heat energy demand was calculated by assuming that existing theoretical geothermal heat energy demand is utilized by using heat pumps with coefficient performance of three. Coverage rate by this calculation method would be 40,1 % for the heating demand calculated by residential building scenario and 43,2 % when using population growth scenario in the demand calculation with the case of 150 deep geothermal potential. For models representing the situation with 300- and 1 000-meter-deep geothermal energy the results are following:

- 300 meters and model based on residential building scenario: 90,5 %
- 300 meters and model based on population growth scenario: 97,4 %
- 1 000 meters and model based on residential building scenario: 469,7 %
- 1 000 meters and model based on population growth scenario: 505,3 %

7 CO_2-EMISSION REDUCTION POTENTIAL

Another empirical part of this study is to survey the vicinity of CO_2-emission reduction potential when utilizing the existing geothermal energy potential beside district heating to cover heat energy demand of the Helsinki in the future. The main data used in this calculation is hourly projection of district heating consumption and CO_2-emissions from the heat production in 2025 and 2035 made by Helen and scenario of heat energy demand in 2035 also produced by Helen. This data is exhibited more elaborately in the chapter 5.2. In this chapter yearly CO_2-emission reduction potential is calculated by using these two different hourly projections of district heating consumption and emissions based on the future energy production structure prognosticated in end of 2019 by production planning team of Helen.

7.1 Calculation principles and background

Like discussed before, district heating network is well sustained and functional system with long history based on prominent made investments that is not seen to be discontinued to utilize. However, there has seen complexity in heat energy production from the year 2029 when coal will be a banned fuel in the energy production industry. Also, any type of burning is seen as a non-long-term option for energy production at this day and decentralized geothermal energy is seen as a potential option to partly substitute these energy sources.

In this calculation geothermal energy potential is seen as decentralized energy supply that is utilized when it is needed the most. This inspection is made by the emission-point of view meaning that the main driven factor for utilizing the existing geothermal heat energy stock is hourly specific CO_2-emission factor of district heating production. The most carbon intensive hours of district heating production are substituted by the shallow geothermal energy. As a result, it is seen how much the possible emission reduction potential is and when seasonally the district heating is the most emission-effective to be exploited.

7.1.1 Functions

Emissions of the planned district heating production

Because the amount of utilized geothermal energy is calculated based on the hourly specific CO_2-emission factor of the planned district heating production the emissions must be calculated at first for the planned production system for year 2025 and 2035. In the case of 2025 the hourly specific CO_2-emission factor is calculated according to the emissions of planned district heating output. And in the case of 2035 the emissions are calculated according to the hourly specific CO_2-emission factor of planned district heating output and the emissions coming from additional district heating production.

There are occurring hours for both reference years when emissions of planned district heating production are zero. To get more realistic comparison composition between emissions of district heating and geothermal energy, these zero emission hours are replaced by the emissions of assumed heat pump system that enables the “zero emission” heat energy. Emissions for these hours are assumed to be 100 % from the electricity of these heat pumps. The COP of the heat pump system is assumed to be the standard value of three. The emission of electricity are defined monthly and these values are described more detailed on the next chapter.

The hourly specific CO_2-emission factor of produced district heating output is made by dividing the CO_2-emissions from the heat production of the hour by the produced district heat. For the year 2025 the hourly specific CO_2-emission factor is simply the produced district heating energy divided by the tonnes of CO_2-emissions. For the year 2035 the total emissions must be calculated by summing up emissions from the district heating production and emissions from the additional district heating production. Like described before, the additional district heating energy is assumed to be waste heat energy that is, in this case, classified as limitless source of energy. Due to this, hourly values of additional district heating production are calculated by reducing the production of district heating from the heat energy demand projection for 2035. Emissions from utilizing this waste heat energy are calculated by assuming the COP of waste heat utilization system to be 3,5 and assuming the emissions of electricity in 2035 to be grown linearly from the year 2018. The summed-up emissions from that hour are divided by the hourly heat energy demand.

Geothermal and district heating energy

The main cause is to cover heat energy demand, otherwise covered by district heating, by utilizing geothermal energy potential when the hourly specific CO_2-emission factor of district heating overruns certain selected value of specific CO_2-emission factor. There is assumption made that the geothermal energy potential is exploited by heat pumps with chosen standard COP rate. The calculation is made by using excel. For each hour the used geothermal power is calculated as follows:

- if the hourly specific CO_2-emission factor of produced district heating output is greater than the selected value for CO_2-emission factor and if heat energy demand is greater than maximum dimension power of the geothermal heat pumps at that hour, the geothermal power for that hour is the maximum dimension power of the geothermal system
- if the hourly specific CO_2-emission factor of produced district heating output is smaller than the selected value for CO_2-emission factor, heat energy demand is fully covered by produced district heating on that hour.
- if the hourly specific CO_2-emission factor of produced district heating output is greater than the selected value for CO_2-emission factor and if the hourly heat energy demand is smaller than maximum dimension power of the geothermal heat pumps, the geothermal power for the hour is same as the heat energy demand.

In terms of the selected values of specific CO_2-emission factor, heat energy demand that is not covered by utilizing the geothermal energy stock is covered by district heating as designed. Hourly district heating power is calculated as follows:

- if utilized geothermal energy at that hour is zero, district heating output is occurring as designed.
- if utilized geothermal energy at that hour is not zero and if dimensioned power capacity value of the geothermal stock is being smaller than the heat energy demand / designed

district heating output of the hour, the district heating output is the difference of designed district heating output of the hour and the dimensioned power capacity value of the geothermal stock for that year.

- if utilized geothermal energy at that hour is not zero and if dimensioned power capacity value of the geothermal stock is being greater than the heat energy demand / designed district heating output of the hour, the district heating output is zero.

7.1.2 Default values and assumptions

Default values and assumptions that are affecting to the calculation results are presented in this chapter. Assumptions that are concerned are:

- CO_2-emissions of electricity in 2025 and 2035
- Chosen threshold values for CO2-emission factor for 2025 and 2035
- Rated capacity of geothermal stock
- Amount of exploited energy from the ground

Specific CO_2-emission factors of electricity monthly must be discovered to years 2025 and 2035 before going more into the emission reduction potential calculation of geothermal energy. In the chapter 5.1 CO_2-emissions of electricity were discussed and by using the projection of CO_2-emissions of electricity in 2035 and 2018 on monthly level from the document of Energiateollisuus ry (Energiateollisuus 2019b), carbon dioxide emissions for electricity are calculated monthly. Calculation is made for both reference years 2025 and 2035 by linearly and by using the ratio of monthly and yearly CO_2-emissions in 2018 (Energiateollisuus 2020). The ratio factor is calculated for each month by dividing the specific emission factor of the month by the specific emission factor of 2018, that is 107 gCO_2/kWh. According to the Carbon neutral Helsinki-report, evaluated specific CO_2-emission factor for electricity in 2035 is 50 gCO_2/kWh (Helsingin kaupunki 2018b). When assuming that, the carbon intensity of electricity is linearly decreasing, the yearly change in specific emission factor is 3,65 gCO_2/kWh negative. According to that, below are presented specific CO_2-emission factor of electricity for each month for years

2025 and 2035 (Table 11 and 12). These monthly based specific CO_2-emission factors of electricity are also used to calculate emissions for utilizing the waste heat source and to replace zero emission hours in the planned district heating production.

Table 11. Monthly specific emission factor for electricity in 2025.

Month	Specific emission factor for electricity in 2025 [gCO_2/kWh]
January	80,7
February	89,1
March	105,8
April	75,4
May	51,8
June	57,1
July	91,4
August	78,4
September	75,4
October	76,1
November	84,5
December	93,7

Table 12. Monthly specific emission factor for electricity in 2035.

Month	Specific emission factor for electricity in 2035 [gCO_2/kWh]
January	44,6
February	49,2
March	58,5
April	41,6
May	28,6
June	31,5
July	50,5
August	43,3
September	41,6
October	42,1
November	46,7
December	51,7

Threshold values for CO_2-emission factor for each year are selected by using median values of the hourly CO_2-emission factors for the planned district heating production in the reference years. Chosen threshold values for CO_2-emission factor for each year are:

- 2025: 0,141 tCO_2/MWh
- 2035: 0,022 tCO_2/MWh

Rated capacity of geothermal stock is calculated by evaluating the full load hours for the geothermal energy stock and potential geothermal energy based on the first empirical part of this study. In this calculation the most suitable value to represent existing geothermal energy potential is the total potential locating on the district heating account areas and in the depth of 300 meters. According to GTK local geothermal energy potential from the 300 meters can be utilized by the rate of 80 % when this utilization rate is just 52 % for 1 000 meters deep heat wells (Geological Survey of Finland 2019). And if the utilization would be made by using 150 meter deed geothermal energy greater amount of heat wells are needed which may decrease the implementation possibilities in the more dense built areas.

Full load hours of utilizing the geothermal energy stock are chosen to be 3 600 hours which is a raw estimation of hours covering most of the intense heating season. Rated capacity of geothermal stock for the three reference years are calculated by using equation 7.1.

$$Rated\ capacity_{\ geo} = \frac{Geothermal\ energy\ potential}{Full\ load\ hours_{geo}} \tag{7.1}$$

$$Rated\ capacity_{\ geo} = \frac{1\ 430\ 000\ MWh}{3\ 600\ h} = 397{,}2\ \text{MW}$$

In addition to the potential emission reduction, also the amount of exploited energy from the ground is compared to the discovered geothermal energy potential. Exploited heat energy for the reference years are calculated by summing up the calculated power from each hour the geothermal energy is chosen to be utilized and then reducing one third of it according to assumption of the standard COP of 3 for ground source heat pump system. Carbon dioxide of the utilized geothermal energy is simply calculated by assuming that 100 % of the emissions are from used electricity with the standard COP.

7.2 Calculation results

In this chapter the results from the emission calculation are presented and discussed. The results are calculated as explained in the previous chapter and presented comprehensively in the Table 13.

Table 13. Compilation of the results concerning emission reduction potential calculation.

	2025	**2035**
Planned district heating production [TWh]	6,77	6,38
CO_2-emissions of the planned district heating production [tCO_2]	973 650	399 002
Used geothermal energy to cover planned DH output [TWh]	1,72	1,60
Exploited energy from the geothermal energy stock (COP 3) [TWh]	***1,15***	***1,07***
Remaining DH output [TWh]	5,05	4,78
CO_2-emissions of the exploiting geothermal energy potential [tCO_2]	50 599	26 174
CO_2-emissions of the remaining DH output [tCO_2]	686 361	269 740
CO_2-emissions total for the hybrid scenario [tCO_2]	736 959	295 913
CO_2-emission reduction potential in total [tCO_2]	***236 691***	***103 089***

7.2.1 2025

With 0,141 tCO_2/MWh emission limit and 397,2 MW rated capacity of geothermal energy most of the geothermal capacity is utilized from October to April in 2025. This monthly distribution is presented in Figure 41. The amount of geothermal energy that is covering district heating demand is calculated to be 1,72 TWh and exploited geothermal energy would be 1,15 TWh with coefficient performance of three of the imagined heat pump system that enables the utilization of geothermal energy stock. Used district heating energy in this case would be 5,05 TWh.

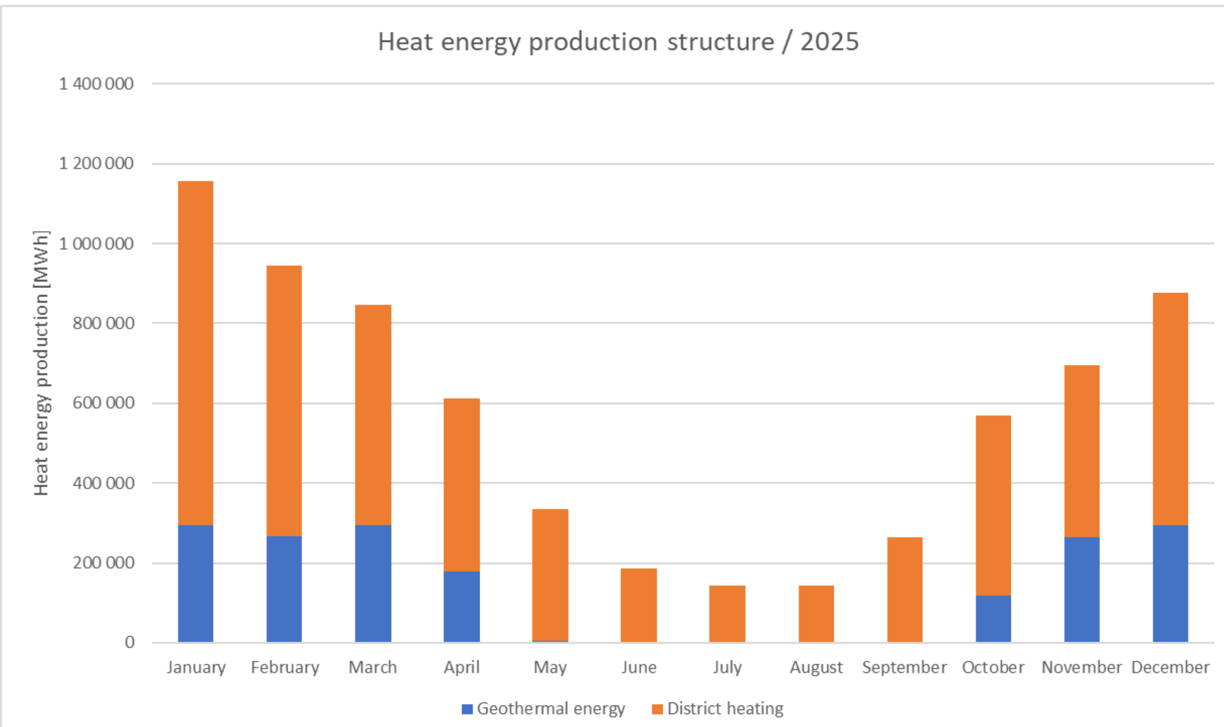

Figure 40. Calculated heat energy production structure in 2025.

According to the calculations, there is remarkable carbon dioxide emission reduction potential in utilizing geothermal energy potential to cover some of the district heating in the most emission intensive hours of the production. With these made assumptions and used functions, the emission reduction potential would be approximately 237 000 tCO_2 which is 24 % of the emissions occurring from the projected district heating production without utilizing distributed geothermal energy potential. According to the data set of Helen, the emissions from heat production total in year 2025 would be 973 650 tCO_2.

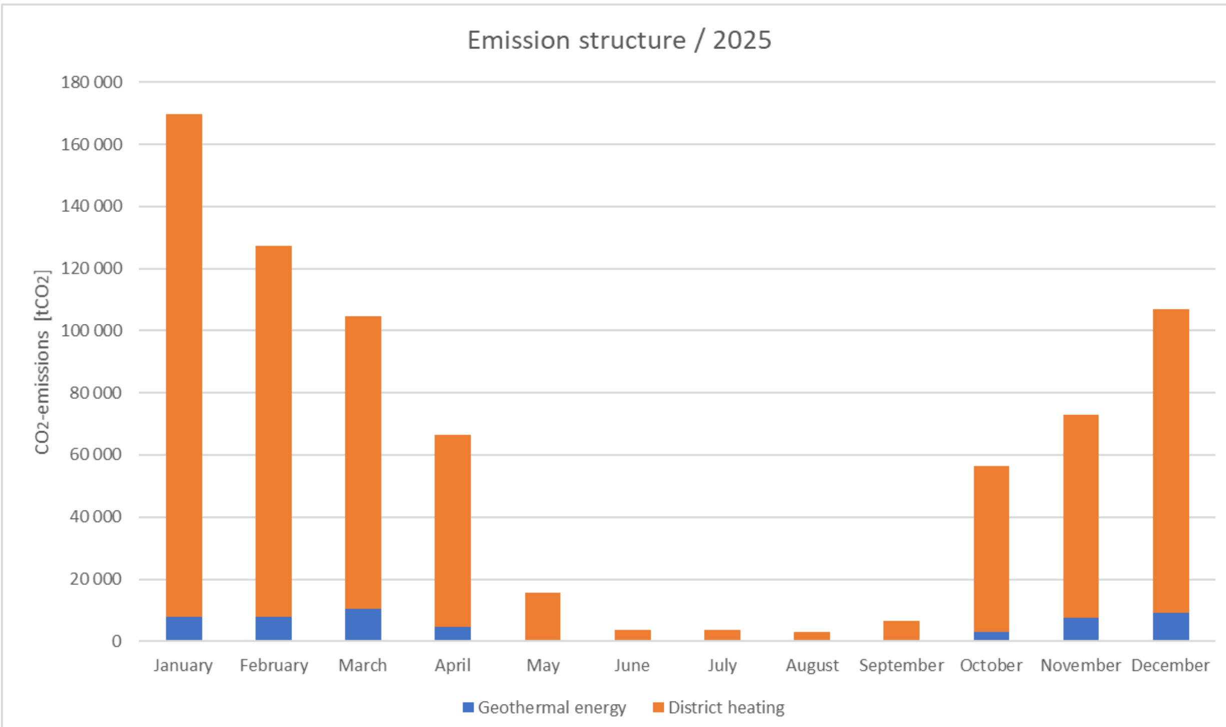

Figure 41. Calculated emissions occurring from the heat energy production in 2025.

The yearly amount of exploited geothermal energy (1,15 TWh) is very well reachable compared to the local geothermal energy potential locating at district heating account area which was discovered to be 1,43 TWh in a year in a depth of 300 meters. Due to this fact, this model would be somehow realistic. Because the originally planned emissions from projected district heating production are reasonable big compared to the emissions in 2035, the emission reduction potential is greater for this reference year.

7.2.2 2035

In the Figure 43 is presented the heat energy production structure for the year 2035 when part of the planned district heating production is covered by geothermal energy.

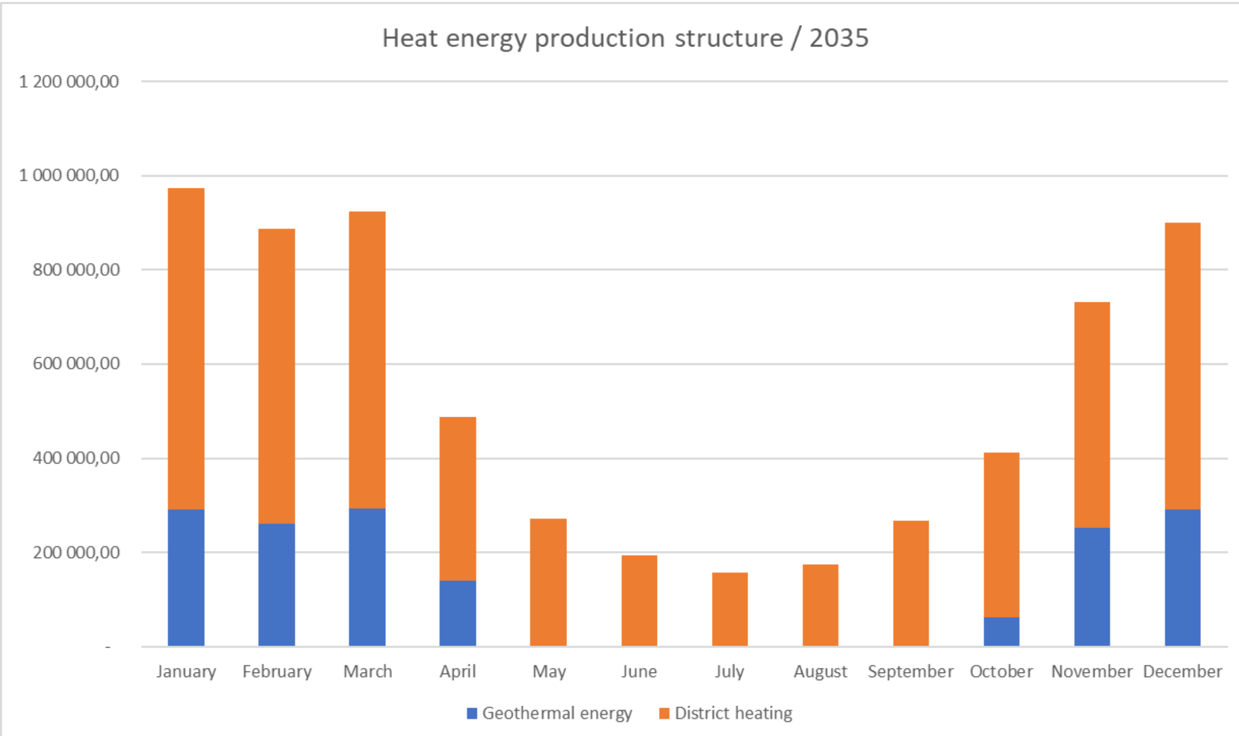

Figure 42. Calculated heat energy production structure in 2035.

Like district heating production, naturally also the emissions of it are smaller in the production scenario of 2035 compared to the year 2025. Ten years from the 2025 the emissions are supposed to drop 39,4 % according to the emissions of production planning. The main factor to cause such huge drop in the emission levels of planned district heating production is the major change in the heat production structure, even without the utilization of geothermal energy stock. Emissions from projected district heating production (without the additional waste heat energy source) is 374 441 tCO_2 and emissions from the utilization of waste heat energy source is 24 621 tCO_2. Like the amount of emissions, the calculated amount of exploited geothermal energy would also be less compared to the utilized stock in the model of 2025.

In 2035, with emission threshold rate of 0,022 tCO_2/MWh, the yearly amount of exploited energy from the ground would be 1,07 terawatt hours. And based on the emission scenarios of electricity, the possible emission reduction potential, according to this utilization rate, would be 103 089 tCO_2 in a year which means 26 % emission reduction. Depending on the local utilization possibilities, according to these results it would seem to be fully manageable to reach utilization rate of 1,07 TWh of geothermal energy in Helsinki that would lead to emission reduction of over 100 000 tCO_2 per year.

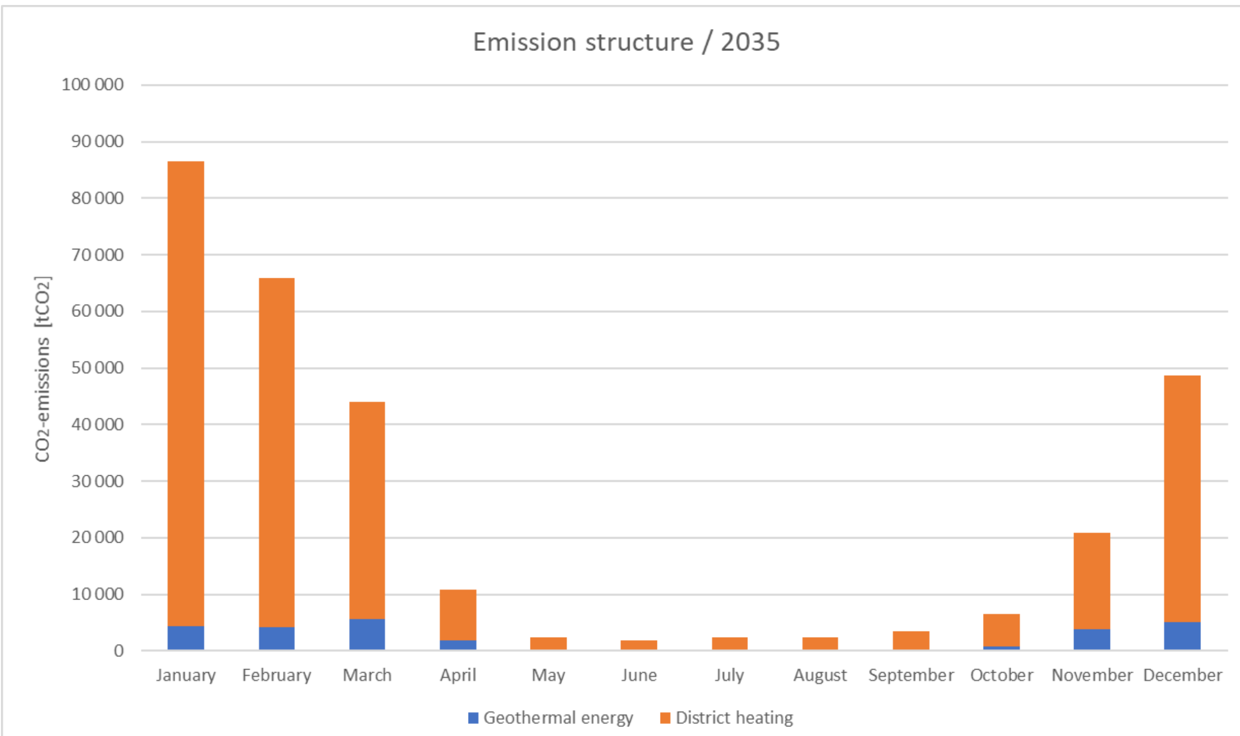

Figure 43. Calculated emissions occurring from the heat energy production in 2035.

The main factors effecting to the emission reduction potential are predictions about the emission progress of electricity, selected threshold values of specific CO_2-emission factor and of course the chosen COP values of ground source heat pump system and pump which enables utilization of the waste heat source. One thing that is reasonable to point out especially when comparing results from these two reference years is that hourly heat emissions from the district heating production (without the geothermal utilization) are calculated differently for them like mentioned and explained before.

8 CONCLUSIONS AND DISCUSSION

The aim of this research was to find out the sufficiency of local geothermal energy potential compared to current heat energy demand and also to estimated heat energy demand in 2050 in Helsinki. Another object of this thesis was to estimate what could be the possible CO_2-emission reduction potential if part of the produced district heating would be covered by the utilization of geothermal energy potential which was determined in the first empirical part of the study. This study was made for Helen Oy that is currently searching options to cover heat energy demand of Helsinki after 2029 coal exit and exploring ways to meet their ambitious sustainability goals concerning energy production.

At the first part of the empirical study where local geothermal energy potential was compared to heat energy demand for three different ground depths the results showed that especially in the outskirts of town the coverage share of geothermal energy potential is greatest and much more promising than in the city center due to dense building stock. This result can be made from both geopotential calculations; the one where current coverage share was examined at block areas and the one where coverage share was examined in the light of estimated heat energy demand in 2050 of grid plan areas. Current heat energy demand of Helsinki can be covered by the 300-meters deep geothermal energy potential at block areas with rate of 28,3 %. Coverage rate for the one-kilometer deep geothermal energy is calculated to be 146,6 %. The equivalent rate for the geothermal energy stock at 150 meters is only 12,5 %. It was found out that heat energy demand of district heating account areas can be covered by the local one-kilometer deep geothermal energy with rate of 108,8 %.

For the whole area of Helsinki, geothermal energy potential compared to the heat energy demand of estimated building stock in 2050 was calculated by using two scenarios of total cumulative floor area based on the forecasted residential building and population growth. Results of the calculations based on both scenarios are not that different. Because the investigated area in total was much bigger in the 2050 calculation case the coverage rate is greater in this case. In the depth of one kilometer the geothermal energy is covering over 300 % of the estimated heat energy demand of the year 2050. Equivalent coverage rates for 300 and 150 meters were discovered to be 60-65 % and 27-29%. These potential calculations were made only by investigating the existing geothermal energy stock and the utilization of it was not discussed but very briefly. Of course, in this grid plan area based model that represents the 2050 circumstances and basically covers the whole Helsinki, it is not as probable to have capability to utilize all of the existing potential than in the block area based model due to urban infrastructure like road network.

The most effective factor for these results is the data that was chosen to be used in the calculation process. The used datasets in the calculation, mainly concerning about the estimated heat energy demand to represent other building stock than buildings that use district heating (because that data is stated to be based on real consumption measurements), are based on assumptions and estimations especially the datasets that represent future circumstances. Data that was chosen to be used in these geopotential calculations is the most suitable data that was achievable to use in this calculation at this moment. Results that represent the future circumstances in 2050 are based on the district heating consumption information from 2018. So, the effects of possible energy efficiency actions during upcoming decades are not included in the calculation which can change the results substantially. It is recommended to in the further research untangle more specifically how consumption structure of district heating will change and do geopotential coverage rate calculations based on that. But with these datasets the result of the first empirical part of the research is that total coverage rate of local geothermal energy compared to heat energy demand varies for in the case of current heat energy demand from 13 to 147 % on block areas and in the case of 2050 estimated heat energy demand from 25 to 337 % on the approximately whole are of Helsinki depending on the depth that is examined. Other thing that was noted is that the coverage rate varies enormously in the different areas of the city. Like current heat energy demand, also in 2050 heat energy demand will be densest in the city center.

In the second empirical part of the study possible emission reduction rate was examined for the years 2025 and 2035 in the case of 300 meters deep geothermal energy existing at district heating account areas. The main data used in this calculation was emission and district heat production amounts provided by the production planning team of Helen. The calculation was made based on the assembly that geothermal energy stock would be used during the most CO_2-emission intensive times. Results were promising and according to the calculations for both reference years 25 % of emission reduction potential could be achieved. In this empirical part of the study too the utilization of geothermal energy was discussed only briefly by assuming that geothermal energy is exploited by using ground source heat pump systems with a stable COP of three at all times. Also recharging of the local geothermal stocks by cooling solutions were not included to the study.

Results of the second empirical study are approximate and also in this case the results are mostly depended on the assumptions and used datasets. In the emission reduction potential calculation the chosen COP value and threshold values for hourly specific CO_2-emission factors can be noted the most significant in terms of the results. In this case it is recommendable to make more comprehensive calculations by using different values to reach more extensive results concerning emission reduction potential of local geothermal energy. But all in all, with these made assumptions, the result is that even the district heating production will be more emission dense in the future, there is possibility to cover heat energy demand of building stock with even less CO_2-emission intensive energy and the possibilities are local due to diverse variety of local geothermal potential in the city and utilization possibilities resulting from land use planning for example. Other made observation is that district heating will have an important role also in the future to cover heat energy demand of building stock.

This research is made specifically for Helen Oy and the calculations are made based on the data concerning the area of Helsinki so it is quite improbable that any other company would benefit from this. The City of Helsinki might have a usage of the content and results of this thesis, but it is under the decision of Helen Oy how they consider to utilize and share the information that is discovered in this thesis. Like mentioned before, geothermal energy and especially utilization of it can be very complex and much depend on the local circumstances so the results occurring from this research are objective and are not suitable to apply to single cases of examining geothermal energy potential at more specific level.

9 SUMMARY

This thesis research was managed by the Helen Oy, local energy corporation of Helsinki, that is currently looking for solutions to cover heat energy demand at this current time of energy revolution. One of the possible solutions to produce carbon neutral heat energy is utilization of local geothermal energy. The aim of this study was to figure out the relation between current and future (2050) heat energy demand of Helsinki and compare it to the local geothermal energy potential. Other aim was to discuss what is the possible emission reduction potential of the usage of geothermal energy potential at district heating account areas in year 2025 and 2035.

Theory part of this study examined different aspects that concern utilizing geothermal energy in urban environment. Topics that were touch on for example were the main characteristics of urbanization and built environment like aspects of land use planning and typical aspects that should be considered when considering utilizing the local geothermal energy. The most important parts of the theory parts in terms of the empirical part were chapter three where the research of GTK, that considered features of geothermal energy existing under Helsinki, was referenced, and chapter five in which factor that effect on CO_2-emission calculations for geothermal energy and district heating currently and in the future circumstances are discussed.

The first part of the empirical part concerned the local geothermal energy potential compared to the heat energy demand, at current state in block areas and at the estimated circumstances of 2050 divided into grid plan areas totally covering the whole area of Helsinki. The used data and calculation methods were presented which had major effect on the results. Results were presented in the form of maps which showed the variety of geothermal coverage rate at different parts of Helsinki and as a numerical form. Calculations were made by using programme called QGIS that allowed combining different geospatial data and create new-kind information as a result. Calculation results from this part showed that coverage rate varies very much in different parts of the city and depending on how deep from the ground geothermal energy is exploited.

Fully coverage rate (over 100 %) was achieved in both cases, when examining the whole geothermal stock and heat energy demand, that studied 1 000-meter deep geothermal energy stock.

The second empirical part studied the potential emission reduction potential when comparing the district heating production plans for the year 2025 and 2035. The study was limited to concern only district heating account areas (2018 dataset) and existing geothermal energy potential in the depth of 300 meters. Calculation was based on the point of view that usage of planned district heating was covered by existing geothermal energy potential during the most emission intensive times of district heating production. Results showed for both reference years that with made assumptions and used data there is 25 % of emission reduction potential.

Significant and possible emission reduction potential in the utilization of geothermal energy potential was discovered even the emissions of district heating in 2025 and 2035 are significantly smaller compared to current emissions of district heating. But it is almost impossible to cover the whole district heating production by local geothermal energy because the heat energy demand of district heating account areas could be fully covered only by the deeper utilization of geothermal energy stock. And in especially in the city centre the coverage share of existing potential and heat demand seems to be insufficient. Due to this district heating can be stated as important heating system for building stock of Helsinki even in the future circumstances.

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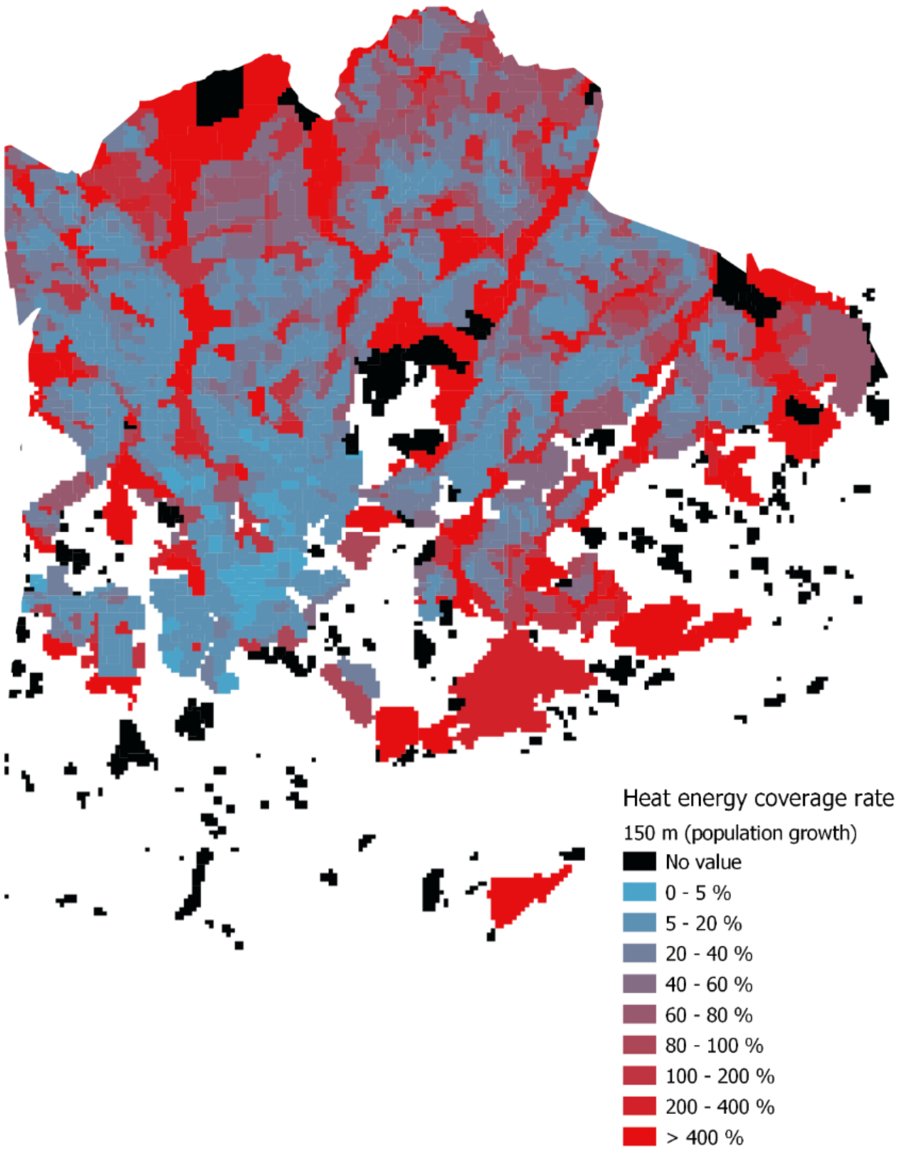
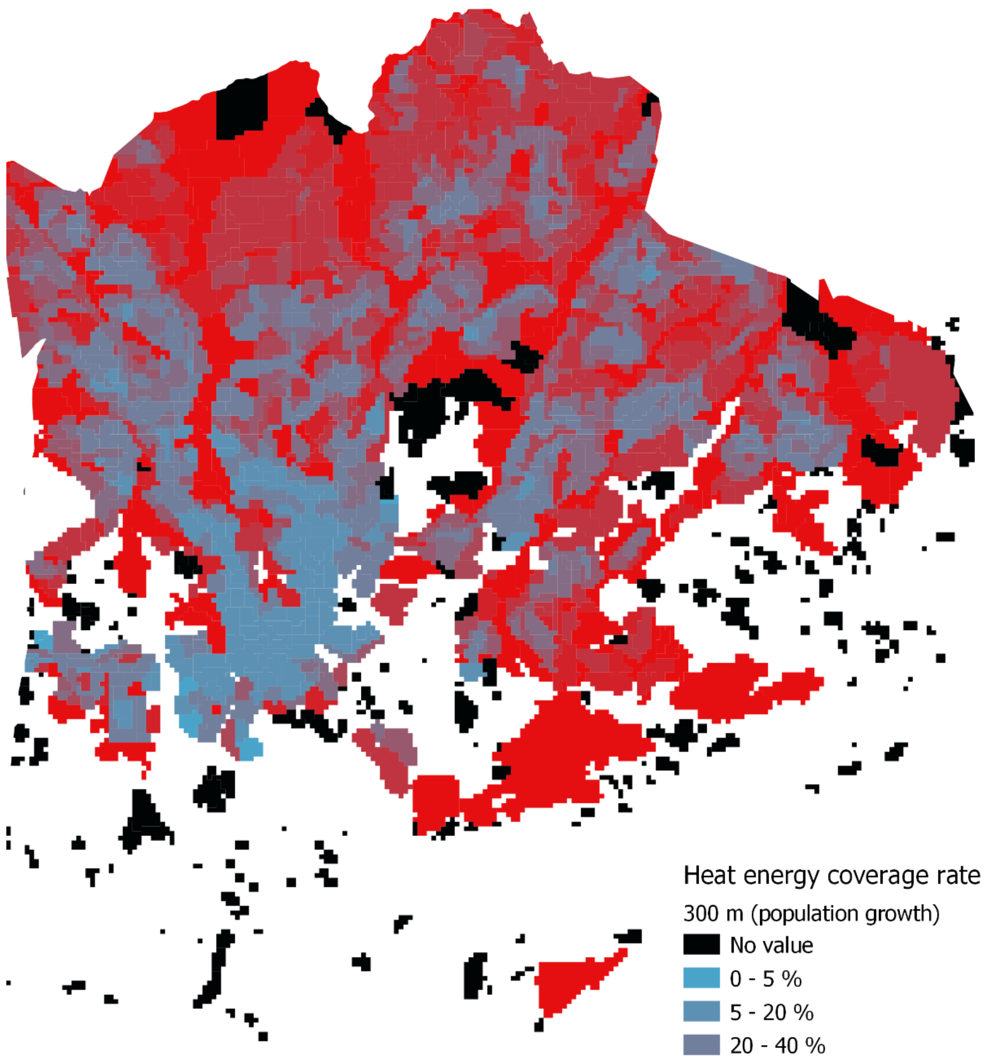
Relation between local geothermal energy potential (150 m) and heat energy demand in 2050 according to projected population growth



Relation between local geothermal energy potential (300 m) and heat energy demand in 2050 according to projected population growth



Relation between local geothermal energy potential (1 000 m) and heat energy demand in 2050 according to projected population growth