LAPPEENRANTA–LAHTI UNIVERSITY OF TECHNOLOGY LUT
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POSSIBILITIES OF DISTRICT HEATING AND GROUND SOURCE HEAT COMBINATION IN HELSINKI AREA

Examiners: Professor, D. Sc. (Tech.) Risto Soukka
D. Sc. (Tech.) Mika Luoranen

Instructor: M. Sc. (Tech.) Jouni Kivirinne

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
School of Energy Systems
Ympäristötekniikan koulutusohjelma
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Kaukolämmön ja maalämmön yhdistelmän mahdollisuudet Helsingin alueella

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Työn tarkastaja: Professori, TkT Risto Soukka
Tutkijaopettaja, TkT Mika Luoranen
Työn ohjaaja: DI Jouni Kivirinne (Helen Oy)

Hakusanat**:** CO_2-optimointi, maalämpö, kaukolämpö, ilmanvaihdon jäteilman lämmöntalteenotto

Helsingin kaupungin kokonaispäästöt vuonna 2020 olivat 2360 t CO_2, josta puolet olivat lämmityksen aiheuttamia. Suurin osa Helsingin alueen lämmityksestä on Helen Oy:n tuottamaa. Helen Oy:n tavoite on olla hiilineutraali vuoteen 2030 mennessä. Kaukolämpöverkko on mainio alusta tulevaisuuden energiaratkaisuille. Tämä diplomityö on tehty Helen Oy:lle ja työn tavoitteena on analysoida CO_2-ohjatun kaukolämmön ja maalämmön yhdistelmän mahdollisuuksia, jossa on lisälämmön lähde. Tutkimus alue on Vattuniemi Helsingin alueelta. Tutkimuskysymyksiin vastataan vertaamalla erilaisia kaukolämmön ja maalämmön yhdistelmä kokoonpanoja, joiden aukkokohtia ja rajoitteita etsitään Tableau simulation toolin avulla. Yhdeksää muodostettua energia klusteria tutkitaan Vattuniemen alueelta, joita simuloidaan vuodesta 2025 vuoteen 2075. Simulaation mukaan CO_2-optimoitu kaukolämmön ja maalämmön yhdistelmä korttelitason energiajärjestelmässä hukkalämmön talteenotolla ja vapaajäähdytyksellä on pieni päästöisin vaihtoehto. Tavallisella tavalla simuloituun kaukolämmön ja maalämmön yhdistelmään verrattuna, se vähentää CO_2-päästöjä jopa 47 %. Tehomitoitetulla maalämpöpumpulla saadaan paremmat tulokset kaikilla osa-alueilla verrattuna energia mitoitettuun maalämpöpumppuun. Systeemiin lisätty ilmanvaihdon jäteilman lämmöntalteenotto lisälämmönlähteenä parantaa systeemin energiapeittoa, pienentää päästöjä ja maalämpökaivojen vaikutusta toisiinsa.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT
LUT School of Energy Systems
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Sustainability Science and Solutions

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Possibilities of district heating and ground heat combination in Helsinki area

Master's thesis

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82 pages, 29 figures and 15 tables

Examiners: Professor, D. Sc. (Tech.) Risto Soukka
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Keywords: CO_2-Optimization, Ground Source Heat, District Heating, Waste Heat Recovery from Ventilation Exhaust Air

The total GHG emissions of Helsinki city in year 2020 were 2360 t CO_2 from which half were from heating. Most of the heating in Helsinki area is produced by Helen Oy. The goal of Helen Oy is to be carbon neutral by the end of year 2030. District heating grid is a great platform for future energy solutions. This thesis is made for Helen Oy. The aim of this master's thesis is to analyze district heating and ground source heat combination that has CO_2-optimization as well as additional heating system attached to it. The case area is Vattuniemi area from Helsinki city. The research questions are answered by comparing different kind of set ups of the district heating and ground source heat combination and finding limitations and observations with using the Tableau Simulation Tool. Nine energy clusters were made from Vattuniemi area and simulated together from the year 2025 to year 2075. Based on the simulations done, a CO_2-optimized district heating and ground source heat combination in a cluster-based energy system with waste heat recovery from ventilation exhaust air and cooling service utilization has the smallest environmental impact compared to the other set ups simulated. It reduces CO_2-emissions almost 47% compared to ordinary way optimized district heating and ground source heating system. Also, with power dimensioned ground source heat pump results are better in every mean compared to energy dimensioned heat pump results. Added waste heat recovery from ventilation exhaust air improves the systems energy coverage, decreases CO_2-emissions, and reduces ground source heating well impact on each other.

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In Helsinki 30 November 2021

Sonja Merinen

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SYMBOLS AND ABBREVIATIONS

CHP	Combined heat and power
COP	Coefficient of performance
EU	European Union
GHG	Greenhouse gas emissions
GSHP	Ground source heat pump
GTK	Geological survey of Finland
IPCC	Intergovernmental Panel on Climate Change
AHP	Waste heat recovery from ventilation exhaust air (Air Heat Pump)
CO_2	Carbon dioxide

1 INTRODUCTION

It is known that climate change is caused by emissions made by human. The GHG emissions known also as greenhouse gas emissions has already changed the climate and the environment more than was expected. The global average temperature has risen 1,1 ^{o}C compared to pre-industrial times. The probability of extreme weather conditions has increased, and continental glacier changes are already irrevocable. Now, by decreasing GHG emissions rapidly, humans can reduce the extent of ongoing changes. According to the IPCC report from year 2021, European Union must cut more than 55% of its greenhouse gas emissions known also as GHG emissions by the end of year 2030 to make an impact on the ongoing situation. This goal is written to EU’s climate goals as well as the goal to be carbon neutral by the end of year 2050. The whole energy industry must change rapidly towards more sustainable. (Ympäristöministeriö 2021.) (European union 2021.)

Most of the GHG emissions in Finland and in Helsinki come from the energy sector. In year 2020 the emissions from energy sector in Finland were about 34,7 million t CO_2 ekv. which covers 75% of the Finland’s total GHG emissions. The whole energy sector in Finland is trying to decrease their GHG emission rates. For example, GHG emissions decreased 11% compared to the 2019-year level. GHG emissions from energy sector have dropped approximately to half from the year 2003 level. In year 2003 the GHG emissions from energy sector has been highest between years 1990- and 2020-time gap. (Tilastokeskus 2021.) The total GHG emissions of Helsinki city in year 2020 was 2360 t CO_2 from which half were from heating. (Helsingin kaupunki 2021.) Most of the heating in Helsinki area is produced by Helen Oy.

The energy system in Helsinki is very flexible which means that different projects towards clean energy systems are possible. District heat grid is a great platform for future energy solutions. It is possible to implement waste heat recovery applications and ground source heat pumps to the district heat grid to decrease GHG emissions from heating. It should be remembered that the infrastructure for heating is already there and there is no need to replace new infrastructure for heating if the already existing infrastructure can be implemented.

1.1 Background of the study

The government of Finland is committed to the European union’s goal to stop the world average temperature to rise over 1,5 °C. Finland has legislation that guides companies to be carbon neutral by the end of year 2035. They have set high taxation for fossil fuels which makes fossil fuels loss-making energy resource compared to renewable energy resources. This has already led many energy companies to think about other energy solutions, especially Helen Oy, which energy production is still heavily dependent on coal and natural gas. The goal of Helen Oy is to be carbon neutral by the end of year 2030. On 29 September 2021 Helsinki city changed its goal to be carbon neutral by the end of year 2030 and to be zero emission city by the end on year 2040. This meant that also Helen Oy had to advance its goals from year 2035 to year 2030. Nevertheless, it did not affect the goal of being coal free by the end of year 2029. Now, most of Helsinki city’s GHG emissions come from Helen Oy actions. (Valtioneuvosto ja ministeriöt 2021.)

Helsinki city has drafted an operational program to reach the goal of being carbon neutral by the end of year 2030. It includes restrictions requiring new constructions that are going to be built to have a low energy consumption rate compared to the today’s energy consumption levels. According to the operational program, the local renewable energy production should also increase, and decentralized heat production GHG emissions decrease significantly. The program is divided to eight categories that are seen below. This study is trying to find a solution for the category “construction and building use”:

1. Traffic
2. Construction and building use
3. Consumption, acquisition, circular economy
4. Smart and clean growth
5. Helen’s development program
6. Carbon sinks and emission compensation
7. Communication and involvement
8. Climate work coordination, monitoring and evaluation

(Rajatie et al. 2019, 4.)

There is wide district heating infrastructure in Finland which should be implemented to the new energy solutions. District heating is delivered by different companies regarding in what area the housing locates. In Helsinki area the district heat supplier is Helen Oy. It is the biggest district heating company with the largest district heating grid in the whole Finland. There are various district heating products available for different client segments for example recycled heat for companies and renewable district heat for all. Renewable district heat is heat produced from renewable energy resources, for example by pellet combustion. Because most of the district heating is still produced by fossil fuels, Helen Oy is doing research on new more sustainable solutions to produce environmentally friendly heat for the whole Helsinki area. Besides heat, Helen Oy is also focused on green energy solution like solar energy and wind power and invests to sustainable energy innovation projects. Also, usage of geothermal energy is recognized as an environmentally friendly energy resource that can be used in Finland’s circumstances. (Helen Oy 2021d.)

Geothermal energy can be utilized together with district heating. Geothermal energy is a renewable energy resource that can be used to make electricity, heat, or both at the same time. Renewable resource reflects a resource that can replenish itself at a similar rate to its used by people. The heat generated inside the earth is called geothermal energy. (National Geographic 2021.) In Helsinki area geothermal energy is already utilized as a heating source.

With new cluster-based energy concept, it is possible to reach almost 70% reduction on heating related CO_2-emissions depending on the location. Principle of the cluster-based energy system thinking is that the cluster formed from the chosen plots has its own heat delivery center for the whole cluster from where the energy is distributed inside the clusters energy system network. Also, CO_2-optimization of district heating and ground source heating can approximately bring 20% reduction on CO_2-emissions when it is compared to ordinary way of optimizing the ground source heat pump (GSHP) use. CO_2-optimization is a way to optimize district heating and ground source heat combination a way that causes the lowest possible CO_2-emissions from energy use for constructions. Added waste heat recovery can support this heating system and improve it depending on the energy entity used. The usability of different waste heat recovery technologies depends on location and energy system. For example, depending on the intended use, liquid cooler, wastewater heat recovery and exhaust waste heat recovery can be used, but the benefits and costs depend on the system's sustainability choice. (Kopra et al. 2021, 5.)

1.2 Objectives and limitations

This thesis is made for Helen Oy. Because Helen Oy has the widest district heating network in Finland, they have a major impact on Helsinki city's overall CO_2-emissions as well as the whole Finland's CO_2-emissions.

The goal of this master's thesis is to analyze the possibilities of CO_2-optimized district heating and ground heat combination that has an additional heating system attached to it. This master's thesis aims to present district heating as a part of the future energy system as a reasonable choice from environmental point of view. Heating can be a combination of different heating solutions with low CO_2-emission rate and this way can decrease buildings use phase CO_2-emissions. A new perspective towards heating should be established, where multiple heating solutions are combined to achieve the best solution in terms of reducing GHG emissions.

The system that is studied is a district heating and ground source heat combination that is CO_2-optimized. Waste heat technology and other heat capture solutions are considered as heat resources connected to the system. One of the presented additional waste heat recovery systems is chosen to the tableau simulation. The case study is focused on densely built urban area. Case area in this study is Vattuniemi that is in Lauttasaari area in Helsinki city. There is preliminary research already done about district heating and ground heat combination optimization that is used in this thesis.

Helen Oy has ordered reports from Ramboll according to the heating combinations and cluster-based energy system solutions. Concerning these reports, Ramboll has done a simulation tool to simulate different set ups of the heating systems. This simulation tool is Tableau simulation in where cluster level energy systems are built detailed which considers all the detail from how the waste heat energy technology machines function to all the details affecting the system dynamics that includes district heating and ground source heat combination. (Kopra et al. 2021, 6.) Limitation of this simulation is that the data sources are not opened. Results from the simulation should be viewed critically due to possible errors.

This study is limited to big construction in Helsinki area. Cooling as a restocking element for the geothermal energy stock is considered in this study. Only use phase energy use GHG emissions are included. GHG emissions from constructing phase energy use of the buildings are not considered. To minimize the environmental impact of heating in big constructions at urban area, the primary heat supply system should be waste heat energy, as a secondary heat supply system should be geothermal energy and third heat supply system district heating. The research questions are answered by using the simulation as a tool and already existing information towards the topic. The research questions are:

-What is the impact of the chosen waste heat recovery technology to an energy system where district heating and ground heat combination is used?

-What is the impact of the geothermal wells on each other in a cluster-based energy system?

- What are the differences between energy and power dimensioned ground source heat pumps?

-Which heating combination has the smallest impact on environment in Vattuniemi area?

1.3 Methods and materials

The client's perspective is included by interpreting an interview conducted by Helen Oy for its client about the hybrids. District heating and ground source heat system with and without waste heat recovery are compared from emission perspective. Also, other comparisons are made to answer the research questions. Results will be presented in a form of how much emissions in t CO_2 are emitted by each technology combination. The time span for this study is 50 years from year 2025 which means that the future emission values for electricity and district heating are used.

First, some theoretical background for this study is presented about district heating, geothermal heat and heat demand and supply mainly in Helsinki area. Some different kinds of waste heat energy technologies are presented as well in the theory part. Some future projects and an overview to CO_2-emissions from district heating and geothermal energy are presented as well as the customer side perspective on the study. Then, the methods and materials used for the case study are presented and after that the Vattuniemi area description and its results are presented. The results are analyzed and compared to each other in the discussion and conclusion's part where conclusions from the results are drawn as well.

2 DISTRICT HEATING IN HELSINKI AREA

District heating is based on hot water delivered from the power plant via piping to the customers fixed district heating distribution center that scatters domestic water heated up with district heating water to all over the housing via radiator system. Domestic hot water is also heated up with district heating water. When the district heat water does not have any heating value, it is led back through piping to the power plant to be heated up again. (Gebwell 2021.) In this section, district heating of Helsinki city is presented.

2.1 District heating grid

District heating grid is growing in agglomerations. In 2019 there was 15 430 kilometers of district heat piping's in the whole Finland that is 290 kilometers more than in year 2018. There are 174 municipalities in Finland where district heat companies sell district heating. In Finland, the district heat grid is owned by the city where the grid is located. The opportunities of expansion of the whole Finnish district heat grid are dependent piping's location. For example, if the company get a chance to expand their grid, they must calculate is it profitable. District heat is mostly available in big cities and municipalities in Finland and is the most common way to heat buildings. (Aaltonen 2020.)

In Helsinki area, district heating has a rather long history. It is used from the year 1955 when the first district heating piping's were installed under Helsinki ground. Now, there are 1400 kilometers of district heating lines which means that there are 2800 kilometers of district heating piping owned by Helen Oy under the Helsinki ground alone. There are also 80 kilometers of district cooling lines installed. The large district heating piping's are positioned in tunnels. The grid is built in an annular way which makes it possible to deliver heat from alternative routes. Annular grid reduces the need of preparation of the grid and distribution interruptions due to remediation. In figure 1 the Helen Oy district heating grid is seen. It is seen that the grid is very densely constructed especially in the center area of Helsinki city which is in the coastal area. (Aaltonen 2020.)

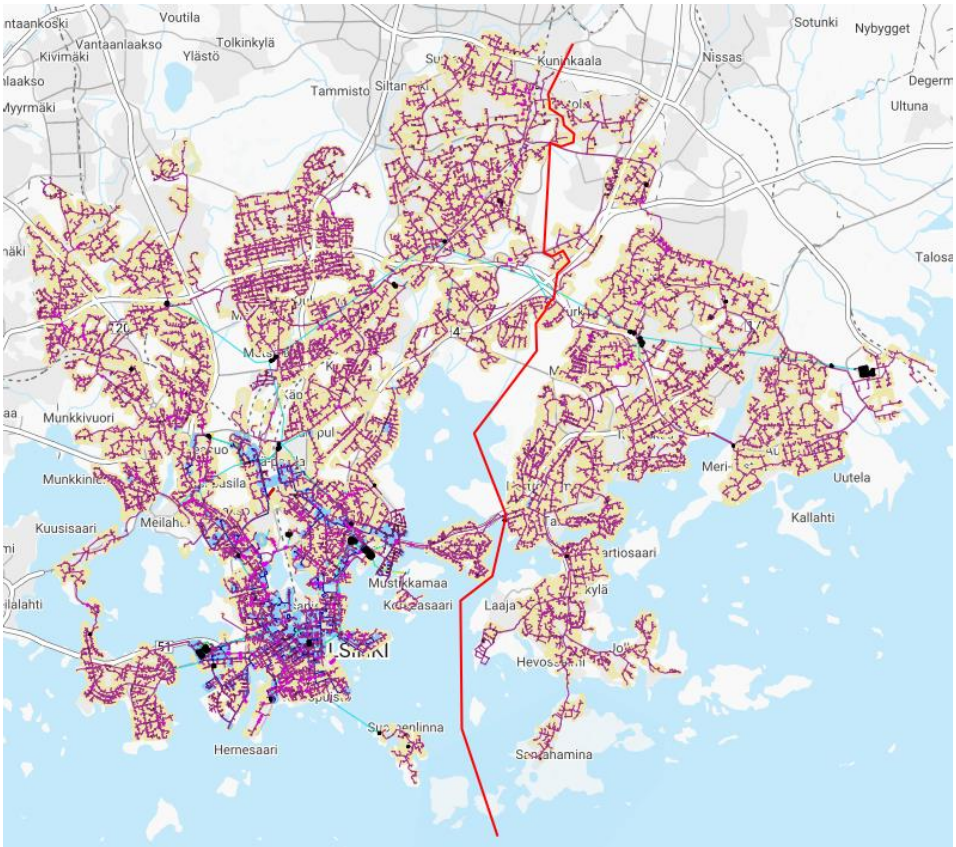

Figure 1. Helen Oy district heating grid (Helen Oy, Key DH 2021)

The district heating sales have increased all the time, but it might start to decrease after year 2030. There are many new heating companies at the heating markets. Still, some of the new heating system companies need district heating grid to deliver their heat produced. District heating industry must change to more flexible from its behavior and from the technical point of view in a way where other heat systems can be implemented to the grid easier. According to Energiateollisuus, district heating companies should take customer into account more as an active partner in designing the heating systems just for their property. (Energiateollisuus 2013, 5.)

2.2 District heat production

Helen Oy produces energy in heating plants and power plants. In Vuosaari, Hanasaari and Salmisaari, the combined heat and power known as CHP is used due to maximize the efficiency of heat and electricity production. District heat used in Helsinki area is mainly produced with CHP production (average 90% of all energy produced). Besides CHP, Helen

Oy also uses trigeneration method in Salmisaari power plant. It means that besides electricity and district heat, district cooling is produced there from which 80% is district heat recovery that would not be otherwise used if not recovered. (Helen Oy 2020a.)

CHP is based on electricity and heat production in the same process. Heat in this context is thermal energy on-site. It means that heat appeared in electricity production is recovered and used for heating up the district heat water. According to U.S department of energy, CHP improves the energy efficiency, decreases energy costs, enchange energy resiliency, reduces risk from uncertain energy prices and increases economic competitiveness. As the CHP production lays on incineration, there is an opportunity to use renewable energy resources by replacing natural gas with biogas. There are two common ways to do CHP: with combustion turbine or reciprocating engine, with heat recovery unit or steam boiler with steam turbine. Since district heat is mainly produced with CHP process at Helen Oy, there are many ways to calculate the origin and emissions for only district heating. (U.S. Department of energy 2017.)

Finland is forerunner at using the CHP process in electricity and heat production. According to Finnish energy, about 75% of district heat production is made in CHP process and 34% of electricity is made with it as well. The same number for EU is only 10% of electricity. The future energy system planning is trying to get rapidly rid of the combustion-based energy production methods. CHP process in future planning as a future energy production method is often forgotten as it is combustion-based technology since combustion causes GHG emissions. (Finnish energy 2021.)

In figure 2, it is seen how major of district heat is made in CHP process in Finland. Heat recovery has been a newcomer from the year 2010 and it is becoming more common around Finland especially in big cities. (Statistics Finland 2019.)

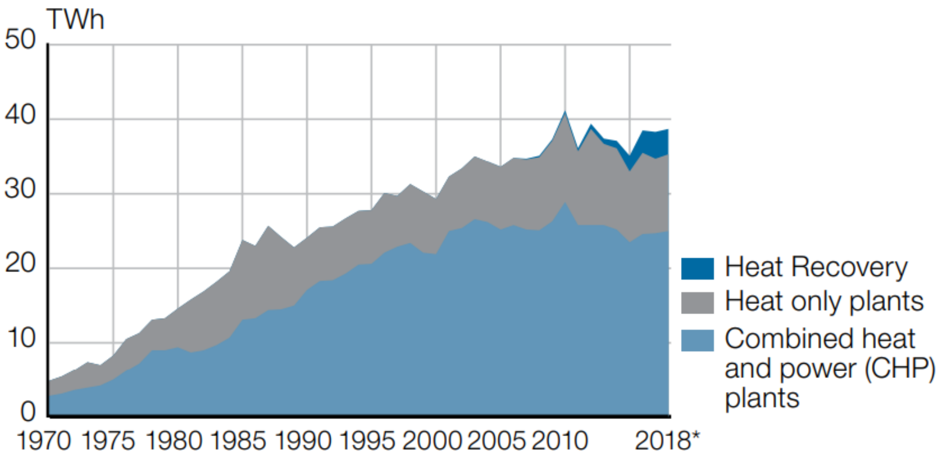

Figure 2. Production of district heat 1970-2018* (Statistics Finland 2019, 15.)

The heating peaks that CHP plants can not cover are covered by heating plants. Heating plants are on use when there is need for heat in a very cold outside temperature. The usage period of heating plants is usually very short. Heating plants ensures the local heat supply in exceptional events. For example, if the heat delivery from CHP power plants is stopped, heating plants can produce energy for use. There are 11 heating plants all over the Helsinki and they are in use when needed. (Helen Oy 2020a.)

Beneath Katri Vala and Esplanadi park there are heat pump facilities that produces district heating and cooling. Heat energy from wastewater and solar heat collectors are imported through pipeline from constructions to the Katri Vala facility. The facility can cover the whole heat demand in Helsinki in summertime which is for domestic hot water heating. Under 50 meters of Esplanadi park there is also a district cooling storage as well as heat pump facility that together forms Esplanadi park heating and cooling facility. (Helen Oy 2020a.)

Heat demand changes during the day. For example, in daytime there is more need for heat than in nighttime, which means that energy produced at nighttime in CHP power plants is stored. Helen Oy stores its produced heat in water tanks at nighttime so the stored heat can be used at morning. These heat storages are in Vuosaari and Salmisaari and their power together is around 200 MWh. District cooling water can be also stored. District cooling storages are located beneath Esplanadi park and Pasila. (Helen Oy 2020a.)

2.3 Energy resources

According to Helen Oy, in year 2020 the origin of its whole district heat energy resources was coal 46,1%, bio 3,4%, natural gas 42,3%, oil 0,5% and heat pumps 7,7%. In year 2019 the origin of Helen Oy's district heat was 56% coal, 3% bio, natural gas 32%, oil 1% and heat pumps 8%. It is notable that the usage of coal in one year has already decreased rapidly. Helen Oy is trying to fulfill its goal to be coal free by the end of 2029 and be carbon neutral by the end of year 2030. Below, in figure 3 Helen Oy district heat energy resources in year 2020 are presented. It is seen that most of the district heating is produced with coal and natural gas. (Helen Oy 2020c.)

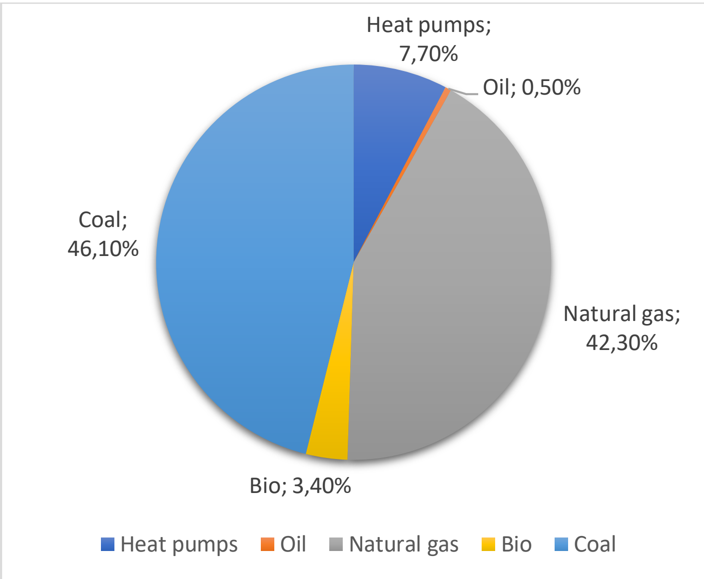

Figure 3. Helen Oy's district heat energy resources in year 2020 (Helen Oy 2020c.)

Compared to year 2019, the share of renewable energy resource is increased meaning that the direction is right. In figure 4 the source of district heat energy in GWh is seen for Helsinki city. Helen Oy is the only district heat provider in Helsinki area, which means that the district heat values for Helsinki city are the values for Helen Oy. It is also seen that coal use in 2020 has decreased compared to year 2019 and the usage of heat pumps have increased. Nevertheless, the drive towards carbon free district heat seems to be slow. For example, one can see that in 2008 and in 2015 there has been less district heat made with coal than in year 2020. Still, there might be many explanations for this for example outside temperature. (HSY 2021.)

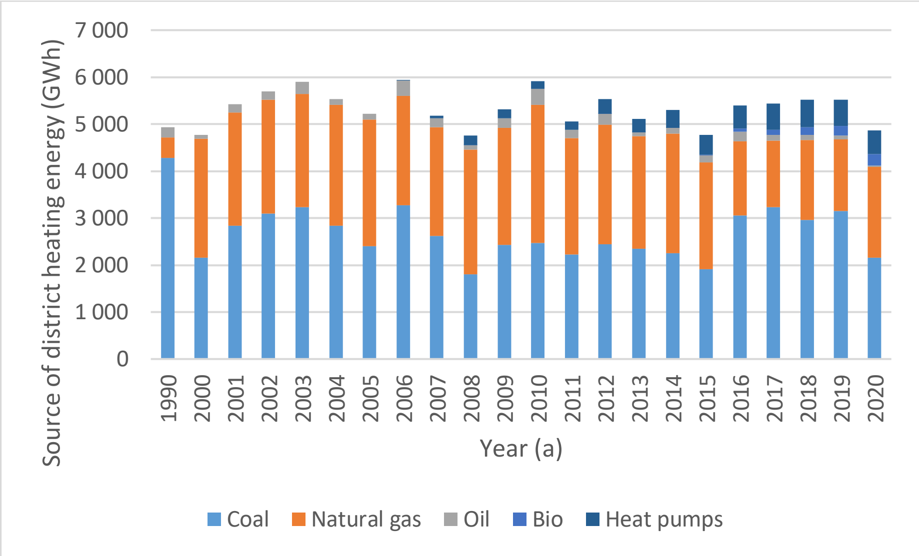

Figure 4. Energy resources of district heating in Helsinki area 1990-2020 (HSY 2021.)

Today, Helen Oy uses coal together with renewable energy resource. For example, wood pellets are used at Hanasaari and Salmisaari CHP power plants. Coal is used for its stable price and the easy possibility to store it for exceptional situations. Helen Oy requires the coal supplier to be committed to the practices of responsible business, at least to the UN Global Compact principles. Now, the coal is bought from Russia. (Helen Oy 2020f.)

Usage of wood pellets is going to increase when the Finland's largest pellet-fired heating plant in Vuosaari is built. In year 2020, most of the wood pellets, used by Helen Oy were made in Finland from by-products of the sawmill and wood processing industry. Helen Oy also bought wood pellet from Estonia and Russia in year 2020 which were also made from by-products of sawmills and wood processing industries. Helen Oy requires a sustainability certification from wood pellet suppliers, but only 68% of the wood pellets in year 2020 were certificated. (Helen Oy 2020f.)

Helen Oy buys a significant amount of natural gas (42,3%) from Western Siberia. There are natural gas pipelines from Western Siberia to the power plants where the natural gas is returned to electricity and heat. Natural gas is used at Vuosaari power plants and in a few heating plants around Helsinki. (Helen Oy 2020e.)

Excess heat and sea water are very important part of reaching the goal of carbon neutrality in year 2030. With heat pumps, waste energy is processed into district heat and cooling making them more environmentally friendly. Heat is produced from excess heat of purified wastewater and the return water of district cooling at the Katri Vala heating and cooling plant. This kind of process is also in Salmisaari cooling plant. Oil used in heating plants was bought from Finnish or Nordic refineries. (Helen Oy 2020e.) (Helen Oy 2020f.)

2.4 Temperature rates of district heat water

When customer's district heating device is working correctly, the district heat water cools down in the customers fixed district heating distribution center when the district heat water releases heat for housings heating network's water. The temperature difference between supply water and return water is different in summer and winter time. According to Helen Oy, optimal temperature difference between district heating supply water and return water is 15-30 ^{o}C, in summertime and in wintertime 50-70 ^{o}C. In some buildings the difference can be 80 ^{o}C depending on construction type of the building. (Helen Oy 2020b.)

The district heating supply water temperatures vary in different outside temperatures between 65-115 ^{o}C degrees. The colder the outside temperature is, the warmer the supply water is. Figure 5 shows the supply water that is distributed to the client in each outside temperature. It is seen that when the outside temperature is colder the warmer supply water is distributed to the client. There is 10 ^{o}C degree range on the supply water because the housing type change. For old buildings the supply water temperature is different than for the new buildings (Helen Oy 2020b.)

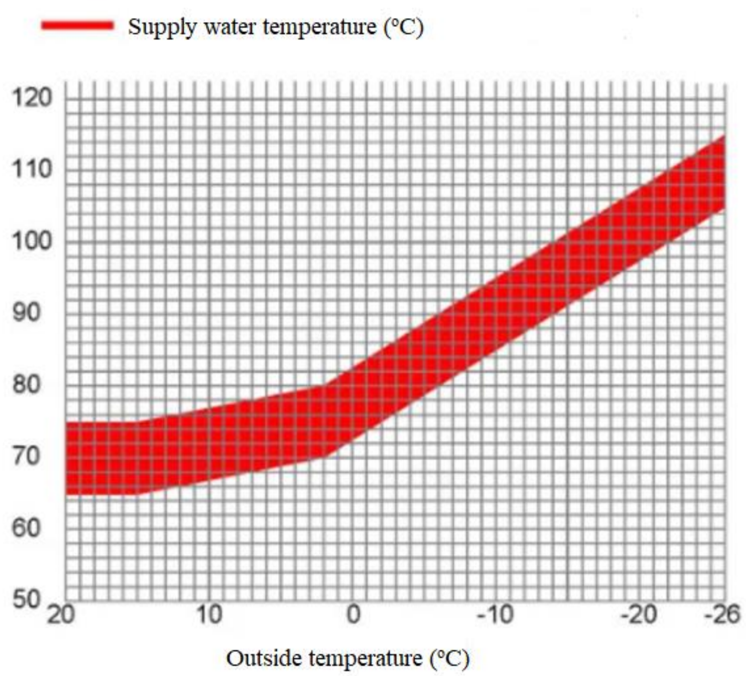

Figure 5. Supply water temperature (Helen Oy 2020b.)

In the future, the district heating supply water is expected to be under 70 ^oC which eases hybrid solution implementation to the district heat network. It is easier to adapt other systems like wastewater heat pumps and ground source heat pumps to district heating network that has low temperatures. Model of a low temperature district heating system supports the heating system transition towards renewable energy resources and other ecological way of capture heat and producing heat. (Pesola et al. 2011, 34.)

For the low temperature district heating the optimal heat distribution system inside the housing would be floor heating distribution system because it can be used with lower temperatures than in radiator network. Also, its wide area and flow controlling is its benefits. Model of a low temperature district heating system especially fits to new buildings. If the system is implemented to already existing buildings, its investment costs can be too high. (Pöyry Oy 2016.)

2.5 Climate goals and action of Helen Oy

There are many operations that Helen Oy is going to do, and it has already done to reduce its CO_2-emissions. Nevertheless, the carbon neutrality goals are different compared to other companies due to the size and production methods Helen Oy uses. It is easier to make changes in a smaller company than in a big corporation like Helen Oy. Still, Helen Oy has managed to do remarkable changes to its energy production CO_2-emissions and is still doing investigation to find better ways to produce heat for Helsinki City and electricity for whole Finland. Below in figure 6, the carbon neutrality goals of some Finnish energy companies are seen. It is seen that Helen Oy goal is ambitious when the size difference of the company to others is considered.

Figure 6. Carbon neutrality goals of Finnish energy companies (Vantaan energia 2021.) (Lappeenrannan energia 2021.) (Keravan energia 2021.) (Fortum 2020.)

There are few differences between the terms carbon neutrality and zero emission. Finnish climate panel determines carbon neutrality as a space where all the CO_2- net emissions are every year zero, which means that CO_2-emissions are emitted only an amount that can be bind. Together with decreasing own CO_2-emissions, compensating the CO_2-emissions that cannot be bind are related to carbon neutrality term. Compensations can be acquisition of emitting rights and investing to the projects that improves the state of the environment. Zero emission means that no CO_2-emissions occur outside the system at all. (Bruce-Hyrkäs et al. 2020.)

In the figure 7 below the total GHG emissions of Helen Oy are presented. Values used are based on the values from annual reports of Helen Oy and on the values from production and CO_2-emission calculations. It is seen that the emission reduction has been changing between years 1990 and 2010. The annual GHG emissions between years 1990 and 2010 have been rapid because natural gas usage has increased when Vuosaari A-power plant that uses natural gas was opened. Also, several GHG emission reduction technologies were implanted to old power plant facilities that also decreased the annual GHG emissions between the years 1990 and 2010. Investment to hydropower plants decreased the annual GHG emissions. From year 2010 the reduction has been slow but still happening. It is seen also that very rapid emission reductions must be done before the year 2050 and it is still open how much there is going to be reduction on GHG emissions in the future which is why the figure is directive from the year 2021. (Tolonen 2021.)

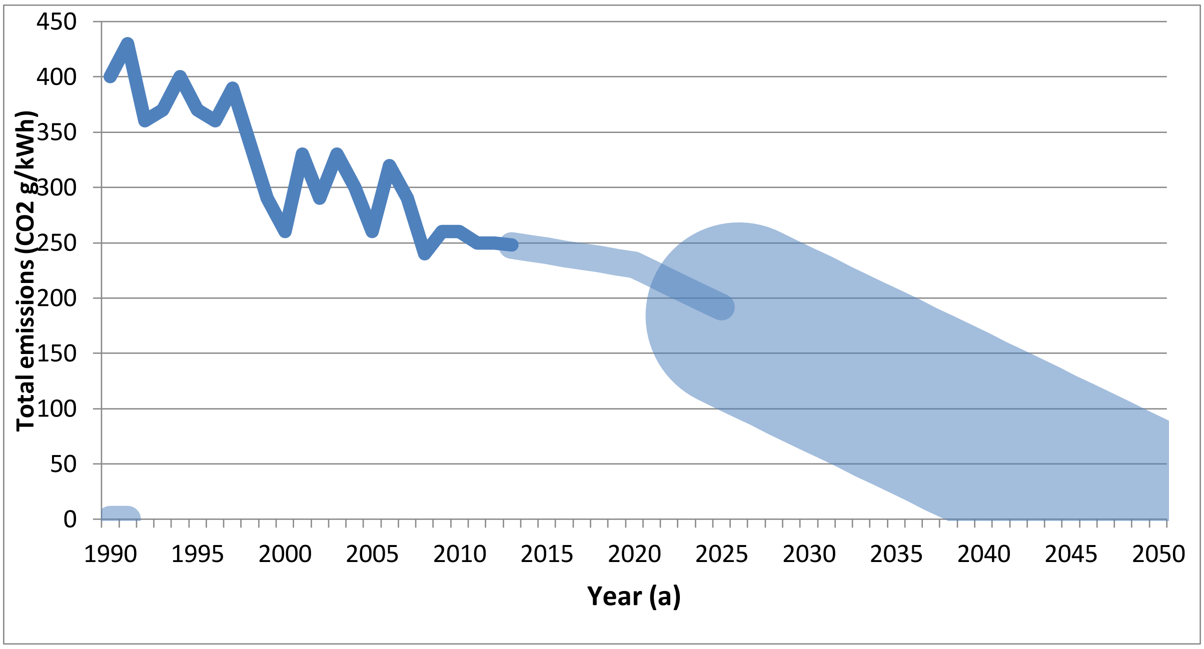

Figure 7. Total GHG emissions of Helen Oy (Tolonen 2021).

The taxation Finnish government has set for fossil fuels is very effective way to impact on companies' carbon neutral goals. For example, Helen oy is going to close Hanasaari power plant before the planned time for its closing that was 2024. Hanasaari is going to be closed already in 4th of April 2023 because it is more profitable to close it before the year 2024. This has impact on the carbon neutrality goal of Helsinki city as well when its CO_2-emissions reduces by 20%. Hanasaari production is replaced with heat pumps, heat stocks, biomass, and heat trade. The possibilities of closing the Salmisari power plant is also under consideration. (Helen Oy 2021a.)

Helen Oy has also other goals. One of its goals is to reduce CO_2-emissions by the end of year 2025 by 40% compared to years 1990 level. Also, Helen oy is going to add renewable energy share by 25% and halve its coal use. The company will resign coal use entirely by the end of year 2029 or even earlier. Vuosaari biomass CHP power plant is going to be ready in year 2022-2023. Its power is going to be 260 MW and will reduce 330 000 tons of CO_2-emissions. There is going to be heat pump installed to Vuosaari power plants that uses its own cooling circle and sea water heat as a heat source. Its power is 13 MW for district heat and for district cooling 9,5 MW. (Helen Oy 2021b.)

In figure 8, one can see the most important carbon neutrality projects that Helen Oy is going to have in future and project happening currently. The first important project is Katri Vala's heat pump facilities capacities lift before year 2021. The next project is to open the sixth heat pump to Katri Vala before year 2022 and establish the heat stocks (cave heat acuumulator) to Mustikkamaa. Close to the year change 2022 there should be new wind parks established, Vuosaari heat pump established and Ruoskeasuo's geothermal heat energy facility pilot ready to be tested. Before the year 2023 Salmisaari's cooling facility should be ready and Vuosaari's biomass CHP power plant should be ready to be tested. Also, one important project has appeared: Hanasaari coal CHP power plant closing before year 2024. Before year 2024 there is going to be seventh heat pump in Katri Vala's. (Helen Oy 2021b.)

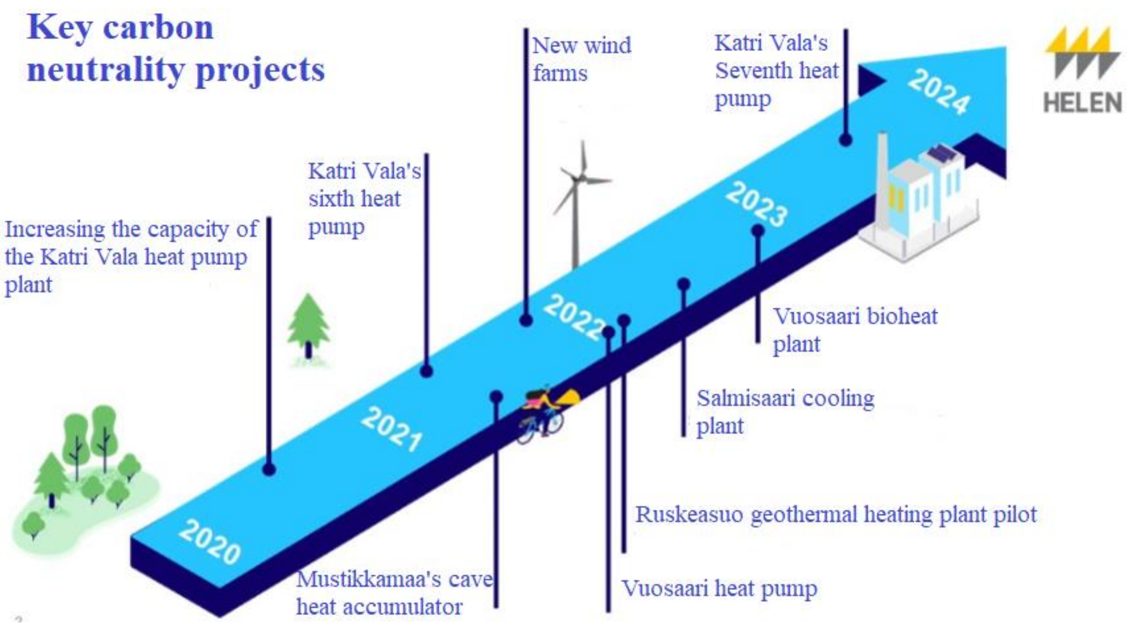

Figure 8. Key carbon neutrality projects (Helen Oy 2021b.)

2.6 CO_2-emissions

The CO_2-emissions from district heat production depends on what energy resources are used. For example, if coal and natural gas are used CO_2-emissions from district heat production are rather high but if other solutions like heat pumps and wastewater utilization are used in a big scale the CO_2-emissions would be smaller. (Kopra et al. 2021, 19.)

It is seen from the future CO_2-emission simulation for district heating that the annual and monthly CO_2-emissions are going to decrease remarkable. The review period is 2025-2045. The impact of closing of Hanasaari earlier than planned is not considered in this simulation model. The model is based on Helen's plans which leads to CO_2-emission factor decrease on years, 2025, 2030 and 2035. It does not consider the new goal of being carbon neutral by the end of year 2030.

Below in figure 9, the monthly CO_2-emission factors month by month is seen for years 2025, 2030 and 2035. The monthly CO_2-emission factor is in kg/MWh. One can see that the CO_2-emissions will not drop significantly for summer months. The significant difference is in the winter period when the CO_2-emissions are changing in future. The blue line represents CO_2-emissions in year 2025 per every month, dark green light is year 2030 and lighter green line is presenting the year 2035. This model of CO_2-emissions for district heating is used in the simulation presented in section materials and methods. (Kopra et al. 2021, 19.)

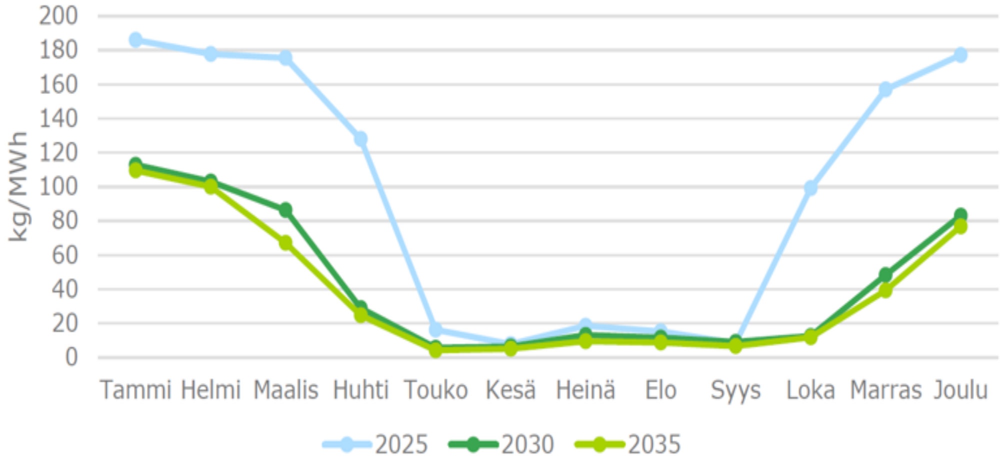

Figure 9. The monthly CO_2-emission factor levels for district heating (Kopra et al. 2021, 20.)

3 GEOTHERMAL ENERGY IN HELSINKI AREA

Geothermal energy as a heating system fits best for buildings that has floor heating system or radiator heating system inside the building. Geothermal energy can be used in apartments that uses district heating that also requires radiator heating system or floor heating. The advantage of exploiting geothermal energy as a source of heat is its low use phase costs. Only cost in the use phase is the repairing costs and electricity used by compressor costs. Investment costs for ground source heat pump is still rather high. Geothermal energy is environmentally friendly option for heating system if the electricity needed for the ground source heat pump to function is from renewable resources. (Motiva 2020a.)

Ground source heat pumps collects heat that is charged to the ground, to rock or sun energy stored in water. The source of the extracted heat can also be sun that has warmed the ground surface. The most common source of the heat that GSHP that is ground source heat pump collects is geothermal energy. Geothermal energy results from breakdown of radioactive isotopes inside the earth and from heat radiation from the center of the earth. The main source in Finland for locally utilized geothermal energy in is bedrock. Most of the geothermal energy collection in Finland is carried out by heat wells especially in southern Finland. Usually, the heat wells are vertical boreholes that are 200-400-meter-deep with diameter of 115-165mm. Depending on the location, the boreholes can be deeper. In the borehole there are two heat pipes installed with heat collecting substance that are connected to each other with U-joint. In the heat pump the temperature is converted from 1-4 ^{o}C to 30-65 ^{o}C. As a heat collecting substance 30 percent bioethanol blend with -17 ^{o}C freezing point can be used. (Motiva 2020a.) Ground source heat pump's compressor needs electricity to function. It is noticeable that two thirds of the energy produced by ground source heat pump is from geothermal energy and one thirds of the heat energy is made with electricity. (Motiva 2020b.)

3.1 Geothermal energy potential

There is access to geothermal energy especially in Southern Finland, which means that ground source heat is a realistic option to be utilized as an energy resource for the heating system especially in Helsinki area. The temperature of bedrock varies in Finland about 0,5-

1 ºC per hundred meters. There is a heat flow from hot interior to the surface that is called geothermal heat flux. Geothermal heat flux average in Finland is 42 mW/m2 which is the average for Scandinavia area. As mentioned before, in Finland the main source of geothermal energy is bedrock that is the thickest, steadiest, and oldest one in Europe. The elements of bedrock that contributes to the thermal conductivity of rock are its mineral composition, texture, and porosity. (Geological Survey of Finland 2019.)

The figure 10 below is geo energy potential map of Finland made by Geological Survey of Finland. The map is based on the thickness of soil overlay, average temperature of the ground and thermal conductivity of rock type. The red area represents high geo energy potential when blue area represents low potential. It is seen in that geothermal energy potential in Southern Finland is notable and in northern parts it is very low. (Suomen geoenergiakeskus. 2019.)

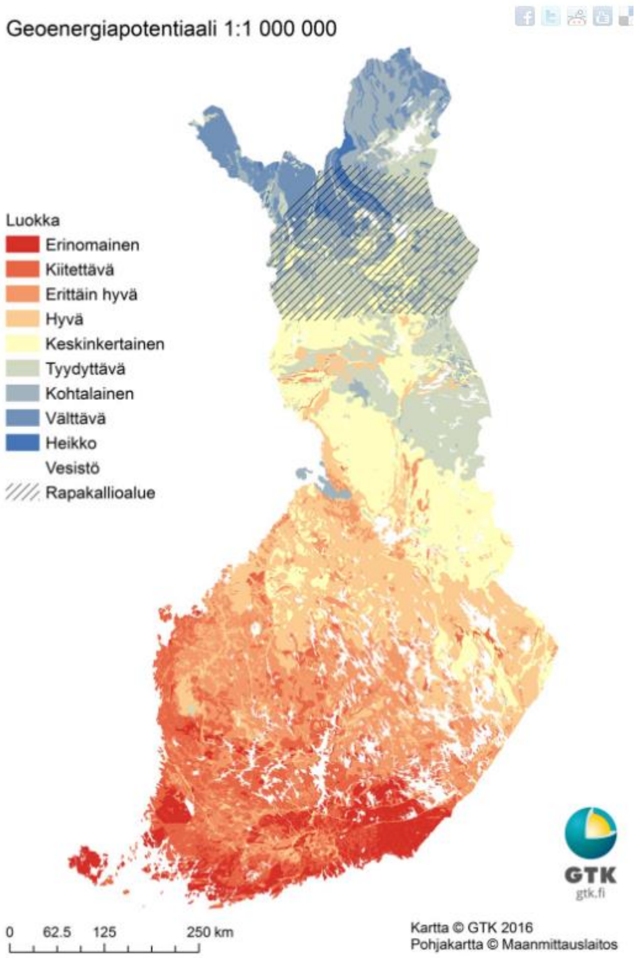

Figure 10. Geoenergy potential in Finland (Suomen geoenergiakeskus 2019.)

According to GTK the local geothermal energy potential that can be utilized is the most optimal for Helsinki city from 300-meter-deep ground source heat wells. For 300-meter-deep wells the energy potential can be used by the rate of 80%. For one kilometer deep it is 52% and for 150-meter-deep wells, there would be a need for several wells, which can cause problems in a densely populated area. This means that 300-meter-deep wells can cover the heat demand in Helsinki area depending on the area where the wells are at. (Geological Survey of Finland 2019.)

In Helsinki the main rock types are gneiss, granite and metavolcanites. The figure below is made by GTK that created the figure to determine the suitability of geothermal energy use for Helsinki and potential of bedrock to exploit geothermal energy from them. The model is based on rock types found from different areas of Helsinki city. Different rock types of density and specific heat capacity were measured, and model made based on the values gotten. Below, the figure 11 presents the theoretical geothermal heat energy 300 meters below the surface. (Geological Survey of Finland 2019.)

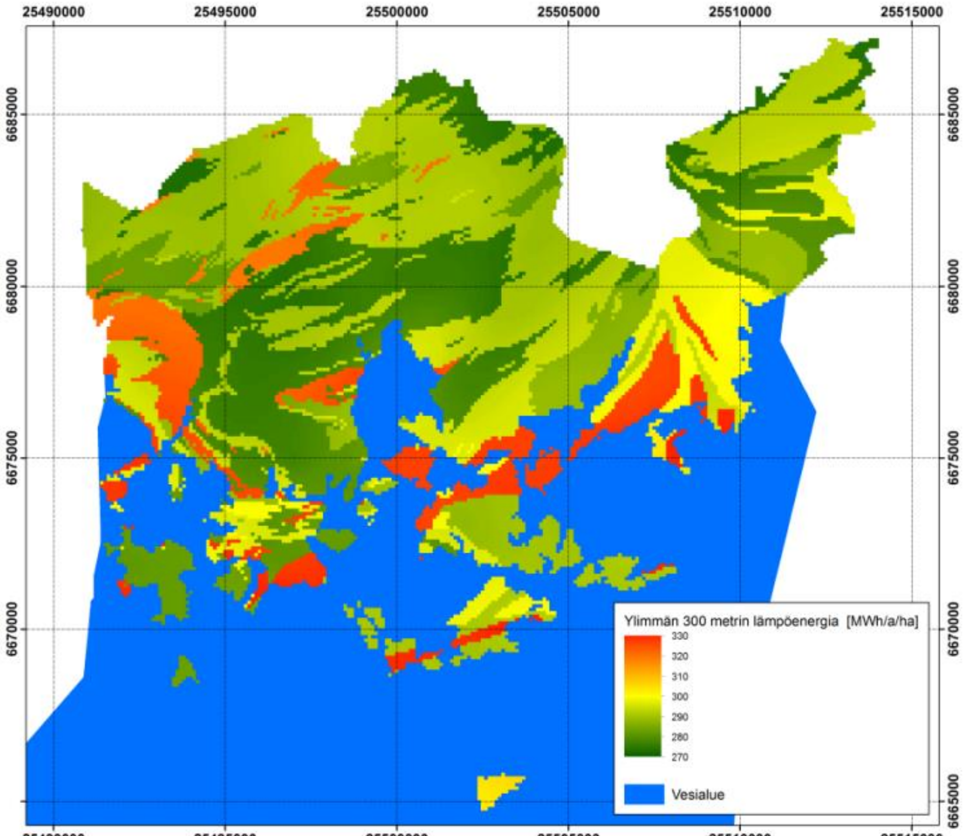

Figure 11. Theoretical geothermal heat energy 300 meter below the surface (Geological Survey of Finland 2019.)

When investigating the area of Lauttasaari where Vattuniemi is located, there is one potential area there where the geothermal energy potential is high, but it is not in Vattuniemi. Still, geothermal energy is a realistic opportunity in the area that is studied. The exploitable theoretical potential with this model made, if temperature of the energy wells would drop evenly to zero degrees by the end of 50-year long period would be 2,65 TWh (150m) and 5,98 TWh (300m). One should notice that the temperature drop in bedrock does not happen evenly. (Geological Survey of Finland 2019.)

3.2 Geothermal capacity limitations

When planning where to drill the geothermal heat wells, there are few prohibitions, where drilling is not possible. For example, drilling of geothermal heat well is prohibited in important groundwater areas in Helsinki area. Also, tunnels and reservations of tunnels can affect to the permission to drill ground source heating wells in Helsinki. (Helsinki 2018).

The main limitation for geothermal heat is the impact of other wells in a location chosen. There is also a significant impact on energy consumption and CO_2-emissions when it comes to the amount of ground source heat wells. The location where wells are replaced impacts to the CO_2-emission rate as well as to the energy that can be utilized. It is also important to choose the right number of wells to each location. (Kopra et al. 2021, 34.)

Figure 12 shows ground source heat pumps specific heat production per well meter during a 20-year period with different amount of wells. The ground source heat pumps specific heat production reflects the heating energy which the ground source heat pump can take per drilled well meter. The system is a system where the ground source heat is alone without any additional heat systems implemented on it. It is seen that the amount of ground source heat wells impact on the specific output of the ground source heating system. 25 wells model (green line) where heat pumps specific heat production reaches the level 80 kWh/m in 20 years in the most typical number that is used in ground source heat dimensioning. It is seen that the smaller well field (5 wells) has the biggest specific production in year 1 and the biggest field (40 wells) has the smallest production. There are many aspects that has an impact on this phenomenon. The interaction of the wells with each other’s is a one thing that impacts on the specific production of a heat well field. Smaller heating well fields have little impact between the field's wells and the wells don't steal energy from other wells. In well fields with higher number of heating wells the field's wells steal energy from its own wells which decreases the specific heat gotten from the ground. Also, the ground source heat fields configuration that means replacement of the wells effects the specific heat production. When there are too many wells according to the heat demand, the well is not overloaded, and this way over dimensioned for the heat demand. (Kopra et al. 2021, 34.)

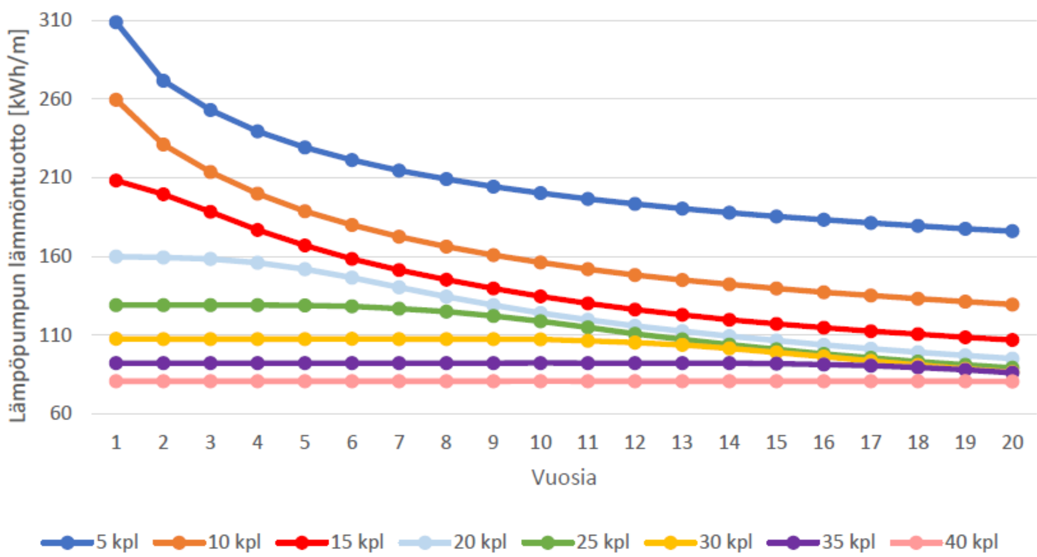

Figure 12. Specific heat production per well meter in 20-year period (Kopra et al. 2021, 34.)

3.3 Geothermal projects of Helen Oy

Geothermal energy and geoenergy differs from each other. Geothermal energy is energy from deep down (1 km or deeper) from the earth's depth and geoenergy is energy from earth surface where the heat from the sun is stored (150-300 m). In the surface there is geothermal energy mixed to the solar heat energy. What comes to geothermal energy, Helen has started its first medium deep geothermal well drilling piloting project in Ruskeasuo which goal is to test and develop drilling technique and other technical aspects. The heat well is going to be 2,5 km deep, and it should produce 1,8 GWh district heat and 0,8 GWh district cooling in a year which should be enough heat and cooling for 180 apartment buildings. In 2,5 km deep the earth temperature is 40 °C. In the heating drill the water is circulated and when the water comes to the heat pump the water is heated about 10-15 °C that is heated up to be hot enough to the district heat network by the help of heat pumps. The district heat grid is obligatory so the heat and cooling made in the geothermal heating facility can be distributed to the customers. The electricity needed for the heat pumps to function is made partly by solar energy. All the electricity needed cannot be fully made with the 100 solar panels and electricity from the electricity grid is needed. According to Arola from Helen Oy, the geothermal energy could be driven straight to the district heating grid if the heat from ground is 75-100 ^{o}C. If it is 150-160 ^{o}C, it can be used in electricity production where high temperatures are used. These kinds of projects are not new, but it is the first big geothermal energy project of Helen Oy. (Helen Oy 2021c.)

3.4 CO_2-emissions

Geothermal energy is classified as a renewable energy resource, which means that it has low CO_2-emission. The only CO_2-emissions for geothermal energy are the electricity use of GSHP's compressor. Electricity's monthly variance in CO_2-emissions is based on Finnish electricity grid emissions from year 2018. The CO_2-emission data from Helen Oy for electricity is also used for creating the CO_2-emission factor overview of electricity. It should be noted that heat pumps efficiency is roughly 3, which means that ground source heat pumps electricity CO_2-emission is one of third. In figure 13, it is seen that CO_2-emission factors will drop evenly every year. This model of CO_2-emissions for ground source heating pump's electricity consumption is used in the simulation presented in section materials and methods. (Kopra et al. 2021, 19.)

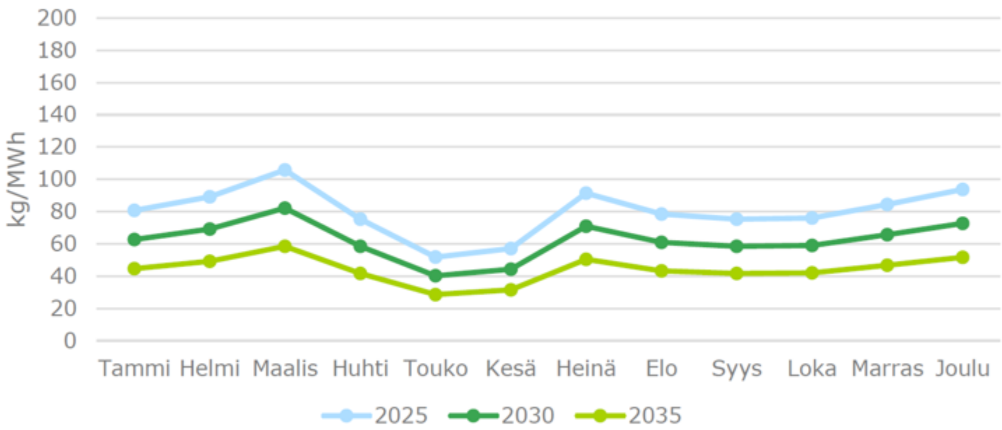

Figure 13. The monthly CO_2-emission factor levels for electricity (Kopra et al. 2021, 20.)

4 WASTE HEAT RECOVERY AS AN ADDITIONAL HEATING SYSTEM

Waste heat should be recovered in the urban area because that is easy to implement to the already existing heating system and district heat grid. It also decreases heating costs, and it is environmentally friendly. Wastewater heat recovery, liquid cooler and waste heat recovery from ventilation exhaust air fits the best in a construction set that is in an urban area like Helsinki city. Even the waste heat recovery technologies have benefits in specific system solutions, it increases the use of electricity. (Kopra et al. 2021, 38.)

The additional heating systems like waste heat recovery technologies are a great support for ground source heating system. The less there are geothermal heating wells the more dramatic the impact of additional heating system is to the whole ground source heating system. It means that he additional heating systems like waste heat recovery from exhaust air and other waste heat systems fits the best to the systems where there is possibility to drill only a few ground source heating wells. In urban areas the plot areas are rather small, so sometimes there is lack of space on the ground to replace ground source heating wells when additional heating system might be needed. (Kopra et al. 2021, 21.)

4.1 Wastewater heat recovery

Almost 40% of heat demand is for domestic hot water. Used domestic hot water is directed to the wastewater treatment facility and the waste heat from it is not recovered. Some of the waste heat energy of wastewater can be recovered with wastewater heat recovery machine. Katri Vala’s heat pump facility is using already buildings wastewater heat recovery to make heat. Wastewater heat recovery machine usually consists of heat transfer and heat pump. Wastewater heat recovery machine can locate in blocks centralised energy centre where all the wastewater is guided. It means that pressure drainage is needed where is also a pump transferring the wastewater. Energy centre has the heat transfer that recovers the heat energy from wastewater and transfers the heat to the centralised heat pump systems evaporator. When wastewater heat recovery is used with GSHP, it improves its efficiency. Because it increases the amount of energy from GSHP, it decreases the demand of district heat. The waste heat from wastewater heat recovery is recovered around the year and the heat recovery is stable due to domestic hot water's stable usage all over the year. The number of waste heat recovery machines is determined area by area according to the possible amount of wastewater formed. Nevertheless, big wastewater masses are needed for this system, and it would not fit in a scattered residential area where house specific heating systems are used. (Kopra et al. 2021, 16-17.)

4.2 Liquid cooler

The other way to recover heat is to capture heat from air. Liquid cooler is a heat transfer machine that captures heat from outside air to the system. Although its name is liquid cooler it is used for heating. Naturally, the warmer weather it is outside the more heat energy is captured from it. It means that liquid cooler is used mostly in summertime. When the temperatures fall under the temperature of GSHP's heat collecting substance, the liquid cooler cannot be used. The same heat collecting substance that is used in GSHP is also used in liquid cooler. The liquid cooler functions by taking the heat energy from the air and feeding the heat energy to the energy centre's heat pumps. When heat demand is low liquid cooler is used to charge the ground field. Charging the ground source fields increases the efficiency of the GSHP and increases the heat energy gotten from the pumps and decreases the use of district heat similar way that wastewater heat recovery does. The number of liquid coolers is determined area by area. One of the disadvantages of liquid cooler it is the noise it causes. (Kopra et al. 2021, 17-18.)

4.3 Waste heat recovery from ventilation exhaust air

Waste heat recovery from ventilation exhaust air is an additional heat source that supports ground source heat pump energy production in a similar way that liquid cooled, or wastewater heat recovery does. In ventilation machines there is a cooling radiator that can cool the supply air. The cooling energy is taken from the geothermal field when it loads heat to energy wells. In ventilation machines there is also heat transfer in exhaust air channel after heat recovery radiator. From this heat transfer the heat energy from exhaust air is recovered. Exhaust air heat recovery radiator is installed to the same piping that produces supply air cooling. Thus, the same cooling body piping is utilized both for supply air cooling and for exhaust air heat recovery. It should be remembered that cooling is not always available because it can run out. Ventilation exhaust air is warmest in summertime which means that the amount of heat recovered is also high. The ventilation air cooling is mostly happening in summertime. Below, one can see simplified figure 14 of schematic diagram of exhaust air ventilation heat recovery system that is connected to the cluster-based energy system. (Kopra et al. 2021, 38-39.)

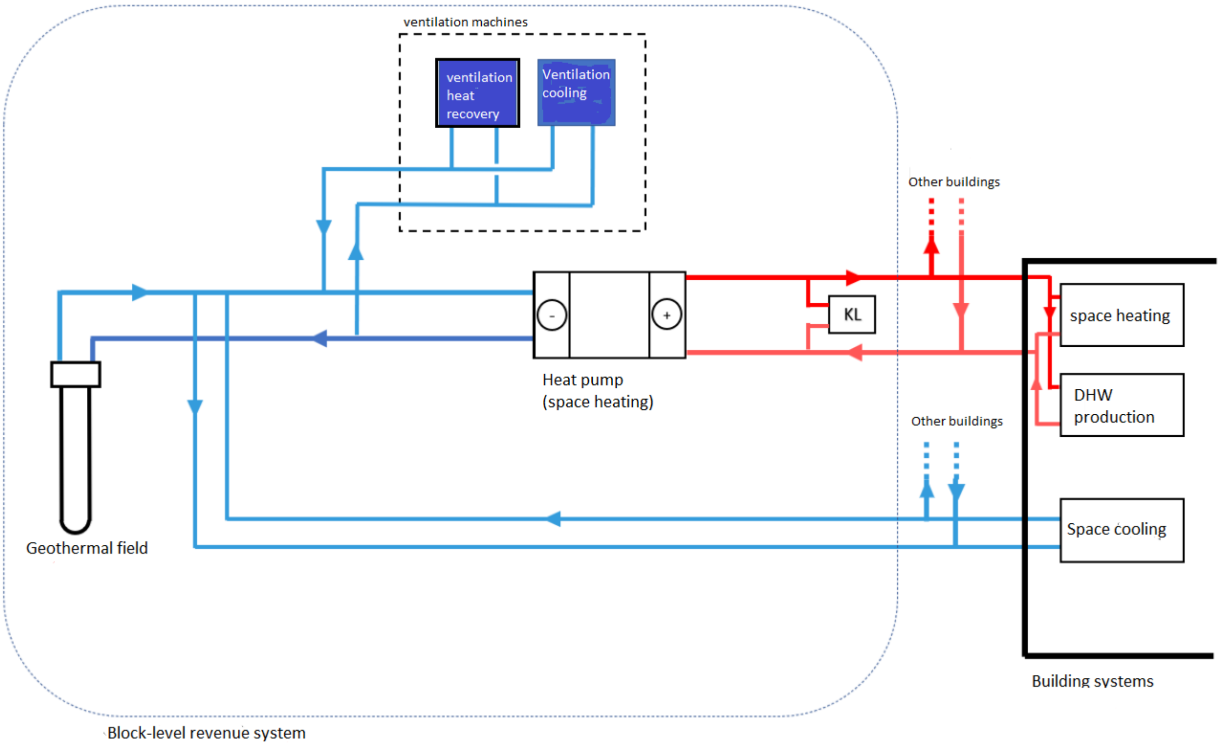

Figure 14. Simple model of waste heat recovery from ventilation system connection to the cluster energy system (Kopra et al. 2021, 39.)

Regarding on the size of the GSHP, waste heat recovery can cause CO_2-emission reductions of combined to the GSHP system. In large GSHP systems where there are many heat wells, the heat recovered and loaded to the ground heat system is not carrying out any CO_2-emission reductions, but in a small cluster energy system where there are not so many heat wells there is emission reductions noticed from waste heat recovery that is loaded to ground heat system to support the system significantly. (Kopra et al. 2021, 28.)

5 HEAT DEMAND AND HEAT SUPPLY

The heat demand in buildings changes among the months. In wintertime there is naturally more energy usage because the buildings must be heated and in summer there is less energy usage because energy is only used for heating domestic hot water. Domestic hot water energy use can be covered with other ways than geothermal energy or district heating. For example, wastewater heat recovery, liquid cooler or exhaust air heat recovery can cover domestic hot water energy use fully if used. If these waste heat recovery technologies are used, it decreases CO_2-emissions of the building's energy use, which means it decreases buildings use phase CO_2-emissions. (HSY 2021.)

5.1 Heat demand in an urban area

In metropolitan area of Finland that Vantaa, Espoo, Helsinki and Kauniainen forms, the energy consumption differs from the energy consumption of sparsely populated areas where most of the energy consumption is from industrial areas. Below in the figure 15 it is seen how residential buildings of the metropolitan area consumes energy. Metropolitan area is mostly densely populated urban area and that is why it includes many residential buildings. Overall energy usage in metropolitan area has not change during the period 1990-2020. Most of the energy is used in services, the public sector and in households. Heat demand can be estimated based on the consumption. (HSY 2021.)

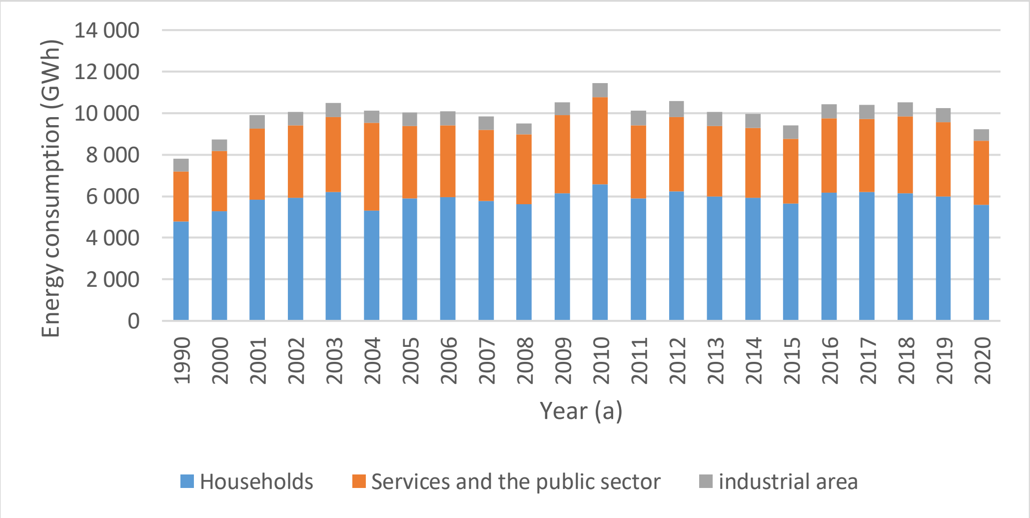

Figure 15. Energy consumption of Metropolitan area in Finland. (HSY 2021.)

Because most of the energy consumption of metropolitan area is from households, it means that most of the CO_2-emissions from energy usage are from households when the CO_2-emissions are viewed from the sector point of view.

5.2 Monthly energy use

Monthly energy use behaviour for households is mostly the same for all households over the Finland so almost any values for monthly heat demand changes for households can be used when the household is building of blocks. The figure 16 below includes the energy needed for space and air condition heating, space and air condition cooling and domestic water heating. The energy demand of 50 apartments build between years 2013-2018 is seen. For domestic hot water, one building domestic hot water usage in 30 minutes gap is used to make an average for 50 apartments domestic hot water usage. Monthly variance can be seen below with months in x axel and energy demand in y axel. DHW is domestic hot water. It is seen that the heat demand is naturally higher in wintertime than in summertime. Domestic hot water need is almost same in every month. Need for cooling is only in summer months. The energy demand for one year would be for space heating 50 kWh/m^2, for domestic hot water 35 kWh/m^2 and for space cooling it would be 4 kWh/m^2. (Kopra et al. 2021, 7.)

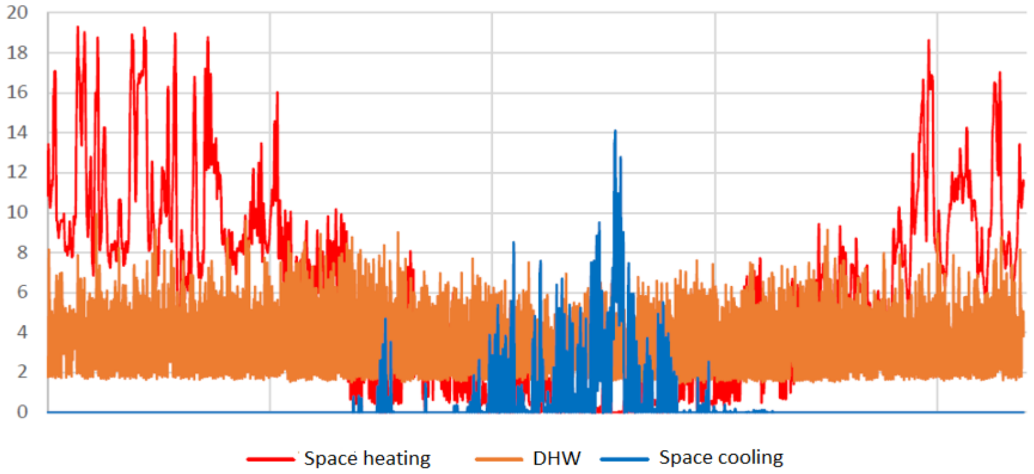

Figure 16. Square based space heating, domestic hot water, and space cooling. (Kopra et al. 2021, 7.)

5.3 Heat supply in different areas

Usually, companies have decided what is the longest distances between the clients building and district heating grid that they agree to sell district heat. District heat is sold for buildings that are rather close to the district heat grid and where the piping is easy to build. Nevertheless, if there is a client that would bring lots of revenues for the company, district heating is sold to the client even construction the piping would be hard.

In figure 17, the orange dots shows where district heat companies are located. The sparsely populated areas are in yellow and cities in purple are seen. Orange areas seen are the core of rural municipalities. It is seen that district heating is mostly available in cities and in big municipalities. In sparsely populated area other heating solutions are used. District heating is a common way of heating in cities of Finland. (Energiateollisuus 2019.)

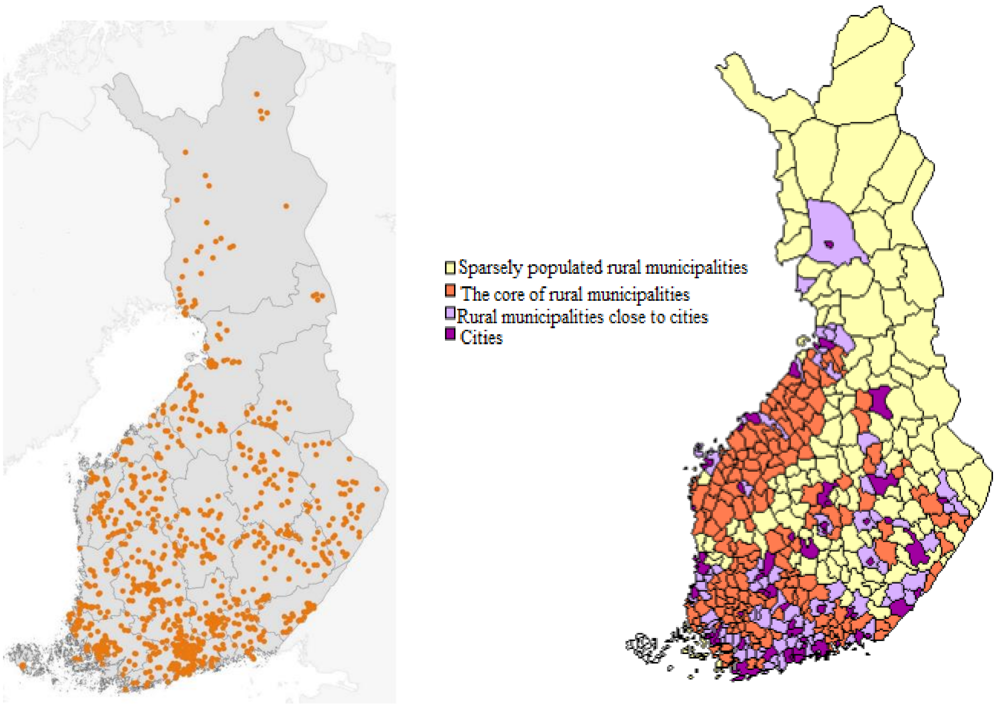

Figure 17. District heating companies and population density (Energiateollisuus 2019.) (Tilastokeskus 2003.)

In sparsely populated areas, buildings usually have a house-specific heating, when district heat is not always available. Some house-specific heating systems that buildings in rural areas use are fireplaces, different kinds of boilers, heat pumps like ground source heat pumps or electricity heating like electricity radiators. In agglomerations district heating is used. Heat is produced centrally. District heating plant, heat plant or geothermal pump that can be used regionally to produce heating for the buildings. (Lappalainen 2010.)

In sparsely populated areas and in some town houses district heating is recognized to be uneconomical. One of the reasons to this is low energy usage that is for town houses approximately 15 000 kWh per one year. It is uneconomical for district heating company to construct the piping to housing with this low energy usage. It is also hard to provide so little energy when there is heat loss in piping's. (Lappalainen 2010.)

5.4 E-number

When the E-number came to be a part of the energy efficiency calculations in the building restrictions, it meant that the choice of the form of heating affected the energy class of a building as well. Insulation is one aspect that affects this. Building that does not fulfill the goals of the regulation, would not be subjected for building permit. E-number describes the calculated annual consumption of the building's purchasing energy, weighted by a factor specific to the energy form. The factor has been determined separately for fossil fuels, electricity, district heating, renewable energy, and for district heating. (Seppänen 2014.)

E- number is calculated energy efficiency benchmark that is also known as the total energy consumption. It is coefficients weighted by energy factors, annual purchased energy consumption per net area heated by standardized use of the building type. In e-number calculation the energy demand, technical systems, heating system and energy form is considered. Usually, E-number is needed when buildings energy accounting or energy certificate is made. For new constructions the limit for e-number is dependent on construction type. The limit value for new construction is calculated according to regulation's 1010/2017 4§ calculation formulas. For smaller housing like detached houses the area of the house impacts on the limit value and for log houses there are own values. Thus, E-number does not depend on the real consumption, and it is usually better for big constructions than for smaller houses. (Arkkitehtitoimisto tilasto 2021.)

So, E-number is determined by adding together the calculated annual purchasing energy and income of coefficients of energy forms per net area heated by chosen energy form. Renewable self-sufficient energy does not have factors in E-number calculations like purchasing energy (district heating, electricity) because it reduces the need for purchasing energy. In this case, renewable self-sufficient energy is renewable energy produced from local renewable energy sources by equipment that belongs to the building which E-number is calculated excluding renewable energy resources like biogas and other. Renewable self-sufficient energy that is not considered in E-number calculation is for example solar panel, solar collectors, waste heat pumps and other waste heat recovery technologies that are presented in this thesis. (Ympäristöministeriön asetus rakennuksen energiatodistuksesta, 27 February 2013/176)

The part of renewable self-sufficient energy that is considered in E-number calculations is only the part of the energy that can be utilized at the building. It is the same part that minimizes the use of purchasing energy. The energy produced by the machines in the building that the building does not need to use and what is returned to the network is not considered in e-number calculations. (Ympäristöministeriön asetus rakennuksen energiatodistuksesta, 27 February 2013/176) This might cause problems when calculating a systems E-number where waste heat is not used immediately but loaded to the GSHP system so it can be used in colder periods of the year.

5.5 Client’s perspective on heating systems

Helen Oy has done an interview to different client segments about the hybrid heat solutions. In this case hybrid means district heating and ground source heat combination hybrid. The internal presentation about the interview included information about hybrid heat customer value and role in the heat sales, a sub-report on the overall development of the heat supply and customer understanding summary. Mostly builders, property owners and members of the board of a housing association were interviewed. It is noticeable that owners and builder views hybrids from the new constructing perspective when members of housing share company views hybrids from an already existing building’s perspective. The main questions that were attempted to be answered were, what clients wait from the hybrid heat solution, what kind of pricing model is the best for chosen clients, what kind of motives drives the builder in choosing the heating system and are builder interested in hybrid solutions in any way. (Helen Oy 2021d.)

The different client segments were asked what their preferences are towards ground source heating, district heating and hybrids. Based on the interview, for housing companies ground source heat and hybrid solutions are more attractive heating options than district heating. Whereas for builders, district heating is the main choice when choosing a heating system to the new buildings. For property owners all the choices were equally attractive choices. (Helen Oy 2021d.)

Some general observations were made based on the interviews. For example, that housing companies has a very short project planning horizon (2-5 years) whereas builders have very long (about 50 years) project planning horizon. The changes on E-number and regulation directs builders to the path to think about also other energy solutions than district heating. Also, the building size increase and versatile use of the future buildings needs versatile energy solutions and new ankle on reflecting energy sources for a building. It means that builders need an energy provider that has the possibility to produce versatile all-inclusive energy solutions with compatibility and easiness of the systems control. Because of the tightening regulation ground source heat is a worthy heating solutions choice in some level in new construction projects. Still, the most important aspect in new constructing is the easiness of implementing the system and reproducibility of the energy solution. From this point of view, district heating is then the best choice, because its well-known and safe solution without complicated agreements. For already existing buildings it is more important how the new solution fits the old system. (Helen Oy 2021d.)

It was noticed that the existence and the intended use of the building impact to the energy system choosing. If the buildings are built to be sold, hybrids are not seen as luring option to be chosen but if it is built not for sale (for example municipality-owned buildings etc.) the hybrids are seen as a choice for enabling to follow the E-number and optimization of the buildings operating costs. If the building is already existing the hybrid is seen as a good choice. Hybrids are not seen as a choice if energy efficiency is not on the list to be develop. (Helen Oy 2021d.)

When the interviewees were asked about what they are waiting from the hybrid solution, the opinion had radical differences depending on what kind of client were asked. For example, housing companies saw hybrids as a fine choice because they might decrease heating costs. All the interviewees believes that district heating costs will not going to decrease. Builders did not see hybrids as a good choice because of its complexity and due to maintenance responsibilities. Builders appreciate systems ease of use and reliability. They also need more evidence about hybrids solutions. For property owners hybrids are also seen as too complex and expensive solutions with too small evidence of its functionality in practise. (Helen Oy 2021d.)

The importance of the energy efficiency and carbon neutrality rose when owners of dwelling houses and institutional buildings were interviewed. For them the carbon neutrality is partly important because of the goals Helsinki city has and certificates that must be fulfilled. Because builders review building projects with almost 50-year time span, they talk about a transition phase towards carbon neutrality. Many things impact on choosing the energy solution. For example, the area, zoning (is ground source heat an option), location (is there recycled energy resources available) is the building going to be sold or is it built for own use, its intended use and loan impact remarkable to the energy solution choosing of a building. (Helen Oy 2021d.)

In conclusion, for builder’s hybrid solutions are not familiar and they are seen expensive. Builders need more evidence about the hybrid’s functionality. Energy solutions are bought as a one-off investment without complex energy contracts. For construction developers that build construction for their own use, have the same output than builders. District heating is seen as the best choice. For construction developers that build construction the city or institutions, the strategy and needs controls the builder for example carbon neutrality goals and certificates. They see hybrids as a good solution because carbon neutrality is pursued in these complex buildings. (Helen Oy 2021d.)

6 MATERIALS AND METHODS

In this chapter, the Tableau simulation tool that is used for simulating different configurations is presented. First, the simulation tool and values that are used in it are presented. Mostly the values are based on Ramboll's own investigations and data they have gathered. After this, the cluster-based energy concept is presented. Then, the differences between ordinary optimization of district heating and GSHP combination and CO_2-emission optimization of the combination. The geothermal well replacement is presented separately with the limitations regarding it. The impact of chosen waste heat energy sources to ground source wellfield is presented and after that, the CO_2-emission input data used in the simulation are presented. Also, methods used are presented in the end regarding what is done and how.

6.1 Tableau simulation tool

Tableau simulation tool is a simulation tool to simulate different kind of energy system set ups. The simulation tool includes Ramboll's own data sources and calculations. Also, some data is from Helen Oy for example data about CO_2-emissions from district heating. This simulation tool is in a crucial role because all the results of this study are based on the outcome of this simulation tool. The cluster level energy systems are built detailed to the simulation which considers all the information from how the waste heat energy technology machines function to details affecting the system dynamics. Simulation models are attempted to be as realistic as possible by the individual components and by using detailed data about the different technologies used in cluster level energy system performance. For example, there is a mathematic model just for this case to model the behavior of the technologies when they are connected. Some errors were found from the simulation during this thesis, but they do not affect the results. (Kopra et al. 2021, 6.)

There is no impact in cluster energy net demand from used energy production system, which is why the buildings energy consumption is considered in this simulation as a static consumption profile. This was modelled with IDA ICE v4.8 software's advanced level. According to Equa Simulations, IDA ICE (Indoor Climate and Energy) is a simulation tool that models accurately the building, its systems, and controllers. It is built for studying thermal indoor climate and energy consumption of a building. (EQUA Simulations 2020.) For investigating how different system set up operate, there was 10 minutes time steps used to build the simulation. The used time span in the simulation is almost 50 years, because it is important to consider the changing CO_2-emission factors for energy production and ground heat fields energy content. The first year (year 1) is the year 2025 where the simulation is done 50 years forward to the future. It simulates the time between years 2025 and 2055. The geothermal heat fields were simulated by using IDA ICE Boreholds components which is a mathematic model that simulates the geothermal heat fields. (Kopra et al. 2021, 6.)

There are two different ways in the simulation that GSHP is dimensioned. One is power dimensioning way and other is energy dimensioning way. GSHP's energy dimensioning means that the heat pump is dimensioned in a way where is taken evenly from the wells. GSHP's power dimensioning in turn means that all the energy available is taken from the well field. In practice it is 30 W/m. Therefore, power dimensioning way gives results that has better energy amount of energy intake than energy dimensioning. Power dimensioning and energy dimensioning of the GSHP are used so that it is seen if it is more rational to take heat evenly over the life cycle (energy dimensioning) or always take as much heat from the well as you can (power dimensioning). (Kopra et al. 2021, 6.)

6.2 Cluster based energy system concept

The energy system studied includes geothermal energy, district heating and waste heat energy recovery technology. An energy system that includes many energy sources is easier to consider as a solution for an area than only for one building or one plot. The cluster-based energy system concept is based on the geothermal energy and district heating combination as a primary energy source. This cluster-based energy system concept's principle is that the cluster formed from the chosen plots has its own heat delivery center for the whole formed cluster from where the energy is distributed inside the clusters energy system network to the buildings. This cluster-based energy system concept enables heat production and cooling inside the formed cluster system. Cluster system would also include a smart CO_2-emission control device that optimize and chooses the best heat production system in each month based on which of the system causes the least CO_2-emission in each month. In a cluster-based energy system concept the energy demand and energy coverage are calculated due to the whole clusters energy demand. (Siren and Kopra 2021, 3.)

6.3 Ordinary optimization and CO_2-emission-based optimization

CO_2-emission-based ground heat district heat combination optimization differs from the ordinary way of optimizing the combination where ground source heat is used as a primary energy source and district heat an auxiliary heating according to the ongoing month. CO_2-emission-based optimized ground source heat and district heat combination optimizes the use of energy source used in an emission point of view. (Siren and Kopra 2021, 4.)

Ordinary way of optimizing the ground source heat goal is to maximize the ground source heat field's energy production. It means that GSHP is used evenly through the whole year. The goal is to cover the heat demand and produce heat as much as possible to cover it. District heat is used only to cover the peak power demand. (Siren and Kopra 2021, 4.)

CO_2-optimization directs GSHP and district heat in a way that minimizes the CO_2-emissions from buildings use phase where energy is used. In this model district heat cover only the additional heating power and ground source heat that prioritized in heating covers all the rest. When district heating has smaller CO_2-emissions that ground source heat, district heating is used, and GSHP are in a standing mode. This leads to that ground source heating is used at cold periods of the year and district heating is used at warmest periods of the year. In this simulation GSHP were not used actively between the time 1st of May to 31 of September when district heat is used that produces less CO_2-emissions than GSHP. Because GSHP's are not used actively in warmer periods, they are more effective in cold periods with all the energy that is loaded there in warmer periods. This is the main advantage of the CO_2-optimized system. (Kopra et al. 2021, 15-16.)

Below in figure 18 it is seen that energy usage can be covered in both ways. CO_2-emission way of optimization is the environmentally friendly choice one. These figures are based on the simulation that is used in this study. It is a simulation from Vattuniemi area's chosen clusters. If AHP is included to this system, it reduces even more the usage of district heating in summer periods. It reduces CO_2-emissions also more if it is implemented to CO_2-optimized system. (Kopra et al. 2021, 18.)

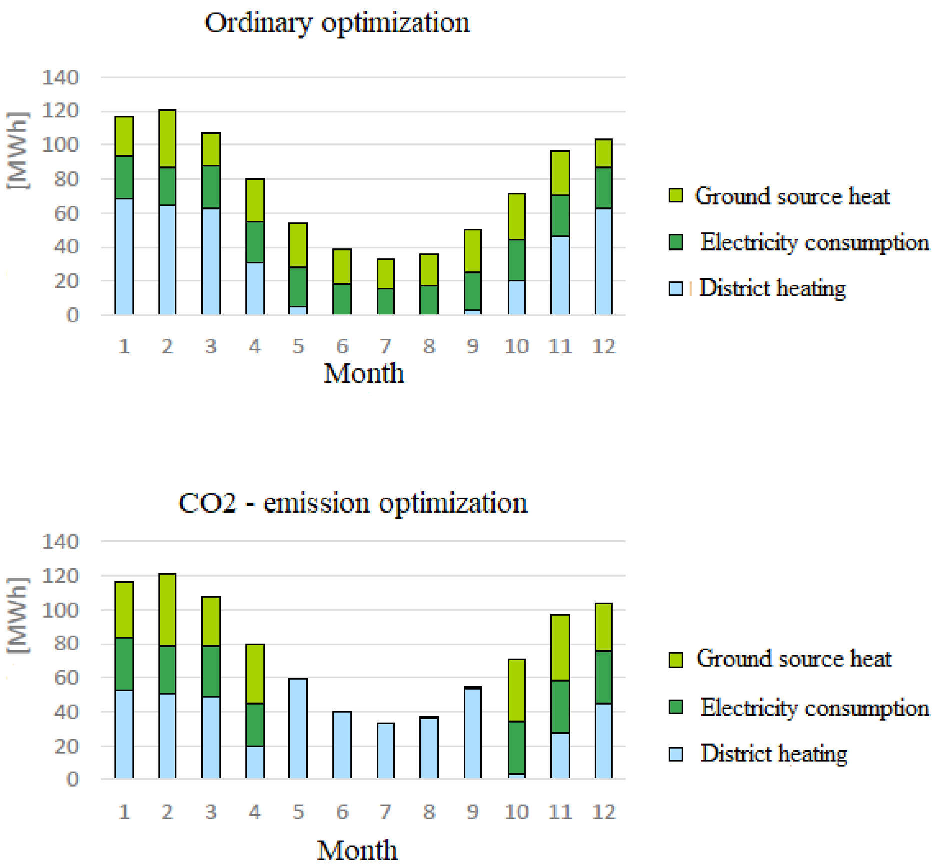

Figure 18. Ordinary and CO_2-optimized district heating and ground source heat combination (Siren and Kopra 2021, 18.)

CO_2-optimization impacts on the life cycle emission rate from energy use of the district heating and ground source heat combination but not the investment costs. It is seen from the figure 19 that the investment costs are the same for ordinary optimized system and for CO_2-optimized system. The graph below is indicative graph of the CO_2-optimized system and of ordinary optimized system. The impact of CO_2-optimization is largest for medium size ground source heat well fields (15,20,25 wells) where it decreases life cycle emissions from energy use by approximately 17% compared to the ordinary optimization. It is also seen that the more there are wells the less there is life cycle emissions from energy use. Nevertheless, the investment costs increases when the well number of the system goes up. (Kopra et al. 2021, 36.)

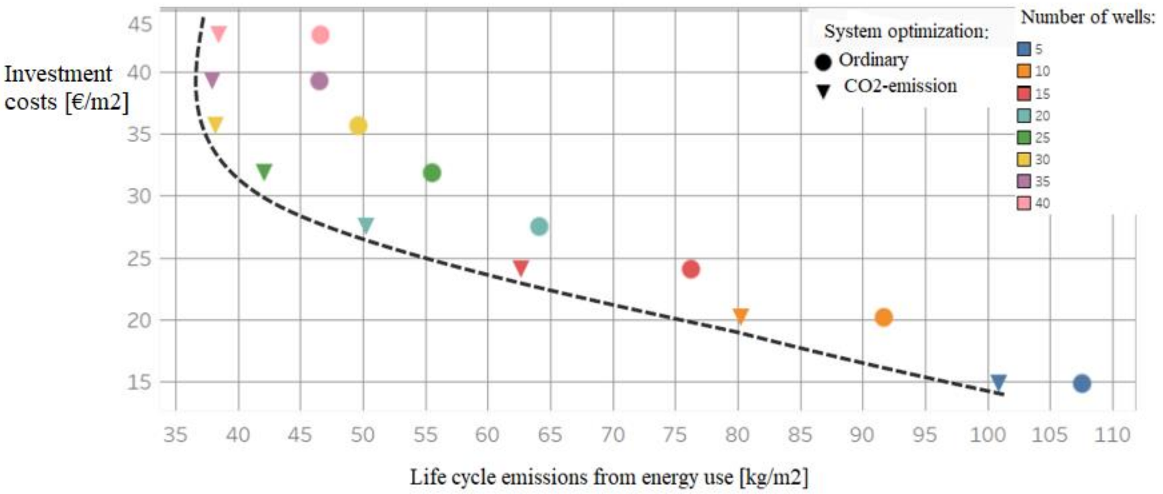

Figure 19. Life cycle emissions in kgCO_2/m^2 from energy use of the two different optimization methods (Kopra et al. 2021, 36.)

6.4 Chosen additional heating system

There are many reasons why waste heat recovery from ventilation exhaust air was chosen to be the additional heating source in this study. There are some technological and investment-based problems in the other presented waste heat recovery if they are added to the case area's heating system. For example, the problems of the wastewater heat recovery systems appear from the wastewater itself. It requires pressure drainage with separate pumping for wastewater transfer. When the investments of the separate pumping system are included to the life cycle cost estimations, the costs are higher than the benefits. This makes the system unprofitable when added to the district heating and ground source heat system. Also, liquid cooler requires additional machines. Liquid cooler might also cause unwanted noise nuisance. Wastewater heat recovery and liquid coolers pumps electricity usage is higher than exhaust air waste heat recoveries which also causes more expenses. (Kopra et al. 2021,17-8,28.)

Waste heat recovery from ventilation exhaust air that is added to the system reduces CO_2-emissions remarkably and it is more affordable additional heating system compared to other systems like liquid coolers or wastewater heat recovery systems. According to the Ramboll's research, it had the best CO_2-emission impact potential compared to other systems. Still, exhaust air waste heat capture system is not always the best choice for all the buildings. It is project-specific that which additional heating system fits the best for each location. Ventilation exhaust air waste heat recovery is a light and affordable system device that is easy to install if the ventilation for supply air cooling is already there. (Kopra et al. 2021, 41.) In this study ventilation exhaust air waste heat recovery is known as AHP (appreviation from word Air Heat Pump).

6.5 Values and placement of geothermal wells

Floor area of the buildings impacts on how much energy is consumed. Plot's area impacts on how many ground source heating wells must be drilled to the ground. In this study, the distance used between the wells is 15 meters and the distance between two different energy clusters is 7,5 meters. It is assumed that heating wells can be replaced awry under the buildings. If a well is replaced awry has its upper part approximately 3 meters away from buildings outer wall and approximately 5 meters away from another well. The ground source heating wells used in the simulation were 300 meters deep wells. Heat demand is considered when dimensioning the well fields. The wells are primary dimensioned according to the heat demand. Still, they are under dimensioned due to the plot efficiency. It is assumed that wells can be evaporated in areas where there are underground living spaces. The assumptions that were used in the simulation for ground source heat were the type values of ground source heat and the GSHP dimensions are based on them as well which are (Siren & Kopra 2021, 8.):

-The system power is 30 W/drill meter (inc. ground source heat pump's electricity)
-Well depths are 300 meters
-Average heat pump efficiency is 3 (COP=3)
-Ground source heat system is equipped with antifreeze automation, which limits the power of the heat pump if necessary.
-The specific energy output of ground source heat energy in kWh/m varies depending on the system solution (Siren & Kopra 2021, 8.)

The number of ground source heat wells and their configuration impact very significantly to the energy system used and this way to results. Also, bedrock properties are a significant factor. The bedrock property values in this simulation are based on TRT measurement data, in which based on the parameter that describes thermal properties of the bedrock were chosen. The parameters below that were used are slightly pessimistic values (Kopra et al. 2021, 9.):

-thermal conductivity: 2,8 W/mK
-undisturbed temperature: 8,4 °C
-borehole thermal resistance: 0,1 (Kopra et al. 2021, 9.)

6.6 CO_2- emission input data at simulation

In modelling the CO_2-emissions for electricity's and district heating's CO_2-emissions the development scenarios that considers monthly variation as well as long-term development till the end of year 2045 is used. (Kopra et al. 2021, 19.) Because when this simulation was made, Helen Oy's goal was to be carbon neutral by the end of year 2035 it assumes that the CO_2-emissions from district heating would be stable when they should be stable from the year 2030.

Electricity's monthly CO_2-emissions rates are based on the last four years averages and the projected development of the CO_2-emission factor is based on an estimate by the Ministry of the Environment. District heating values are based on the data from Helen Oy. Below in figure 20, years 2025 predicted CO_2-emissions are interpret and afterwards years 2035 energy CO_2-emission rates as well that were used in the simulation. (Siren & Kopra 2021, 4.)

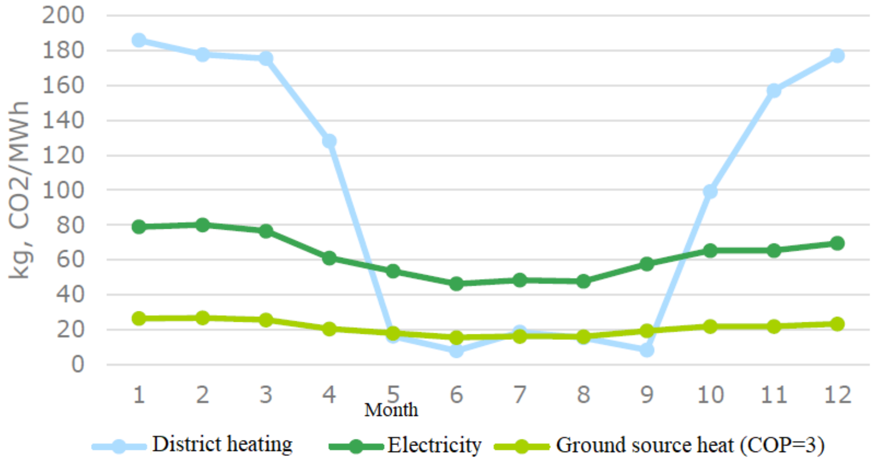

Figure 20. Energy CO_2-emissions of the year 2025 (Siren & Kopra 2021, 4.)

It is seen from the figure 21 below that the future CO_2-emissions according to the Helen Oy values that were used are much smaller for district heating than the values of the year 2025 that were seen in the figure above. Th electricity CO_2-emission rates are not going to drop as significantly as district heating's values, but still dropping by half compared to the year 2025.

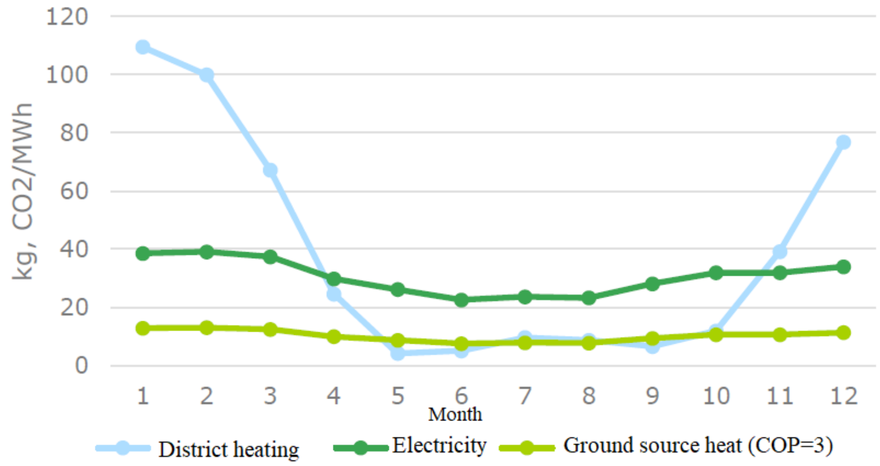

Figure 21. Energy CO_2-emissions of the year 2035 (Siren & Kopra 2021, 4.)

6.7 Methods

The results that are analyzed are from the simulation that is used as a tool for answering the research questions. There are many simulations but for this review the simulation results with smallest CO_2-emissions for whole time span are introduced. These results are compared to other scenarios chosen to show the benefits of each application. For example, it is presented how exhaust air waste heat capture or cooling service utilization decreases total CO_2-emissions of the Vattuniemi area. The focus of the simulations is on function of the energy production system evaluation. It is possible to simulate only one chosen cluster, but separate clusters alone were not simulated. Simulations focused on all the formed clusters together and in the impact on all the clusters together.

Any values or number were not added to the simulation because the values for Vattuniemi were installed already to the system. Only decision of what of the scenarios should be presented was made. It was possible to choose for each addition to be on or off the result scene of the simulation. The first scenario that is chosen to be presented in the results is a scenario where one can see the heat production, energy coverage and total CO_2-emissions differences between a cluster-based energy system that is ordinary optimized and CO_2-optimized. Then the impact of adding the AHP to the cluster-based energy system with CO_2-optimization is simulated by comparing it to the system without AHP. After that also the impact of the AHP that is added to the ordinary system is simulated, so the importance of adding it to the system is seen. Also, the impact of how the clusters impact on each other is possible to be simulated and is simulated because it presents that the results differs if only one cluster at a time is investigated and not the whole area. Adding the cooling service utilization to the system is simulated because it impacts on all results significantly and the benefit of it should be presented. It means the cooling that can be used when GSHP is part of the energy system. In summertime the GSHP can produce cooling for the housing.

7 SIMULATION RESULTS OF VATTUNIEMI

In this chapter the case area description and the results from the simulation are presented.

7.1 Case area description

The area of Vattuniemi is planning complementary new constructions. It is noticed that the energy system can be renewed in this point towards more environmentally friendly one. It is also noticed that this is a great platform for testing the new way of optimizing ground source heat production and district heating with additional heating system to reduce overall CO_2-emissions. Vattuniemi area consists of buildings that has office space, business premises and residential houses in the same building. It means that there is a need for different kinds of cooling and heating solutions inside one building. For example, if building has a small market downstairs, it needs a large amount of cooling and the upstairs living spaces need heating. (Siren and Kopra 2021, 4.)

In this study there are 15 plots chosen from Vattuniemi area that were combined to so called clusters. Below in figure 22. the 15 chosen plots are seen from which the clusters were formed. These plots were chosen because they fitted to the system best. It is also seen that the chosen plots are very close to each other that might have an impact on GSHP installation and its energy coverage rate. (Siren and Kopra 2021, 5.)

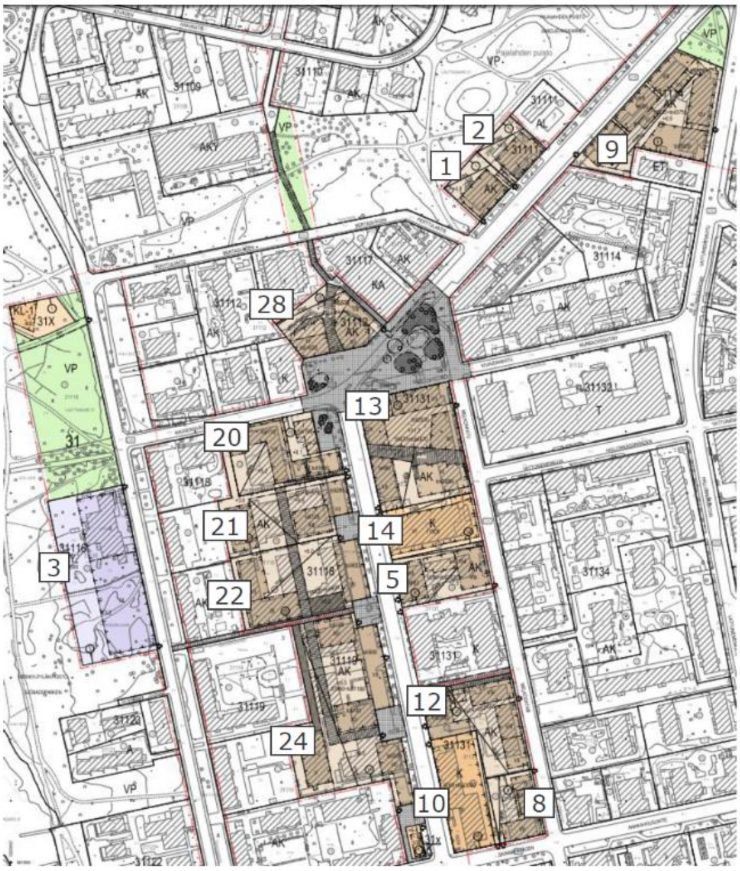

Figure 22. Plots and their numbers (Siren and Kopra 2021, 5.)

In table 1. the floor square meter information of the chosen plots are presented. The information about the plots is based on the information gathered on December 18, 2020. In plot number 3 there is an 8000-floor square meter (kem^2) school and no apartment buildings nor offices and retail buildings. Plot number 24 has the most floor area with 29 050 kem^2 and plot number 8 has the least of them with 1466 kem^2. (Siren and Kopra 2021, 5.)

Table 1. Plot floor area information (Siren and Kopra 2021, 5.)

Plot number	Apartment building floor area [kem2]	Ofiice and retail floor area [kem2]	School [kem2]
1	2 560	-	-
2	2 560	-	-
3	-	-	8 000
5	6 286	2 037	-
8	318	1 148	-
9	10 835	3 750	-
10	-	9 000	-
12	7 474	2 492	-
13	19 470	4 870	-
14	-	11 500	-
20	7 128	2 370	-
21	14 400	400	-
22	12 400	400	-
24	27 950	1 100	-
28	6 590	2 200	-

Below in table 2. the information about the formed clusters is seen that were used in the simulation. There are 9 clusters made. Each cluster has its own centralized energy system only for the cluster itself. Some clusters formed includes only one plot and some clusters includes three plots or two. Table 2 shows that which clusters includes which plots. It is seen that there are not only apartment buildings but offices and retail floor areas as well almost in every cluster made. The cluster 1 includes a school. Cluster 2 has the biggest heat energy demand from all the other 8 clusters left. It also has the most floor area.

Table 2. Plot floor area information (Tableau simulation 2021)

Clusters	Plot number	Plot efficiency	Apartment building [kem2]	Office and retail [kem2]	School [kem2]	Heat energy demand [MWh]	Peak heating in-use power [kW]
1	3	0,95	-	-	8 000	726	306
2	20/21/22	2,39	33 928	3 170	-	3085	1338
3	24	2,79	27 950	1 100	-	2501	1026
4	13	3,50	19 470	4 870	-	1853	922
5	14/5	3,29	6 286	13 537	-	923	903
6	8/10/12	2,03	7 792	12 640	-	1031	910
7	28	2,81	6 590	2 200	-	642	340
8	1/2	1,65	5 120	-	-	453	178
9	9	2,20	10 835	3 750	-	1059	566

In figure 23 the locations of the formed clusters are seen. It is seen that clusters made are close to each other and locate in densely build area. In the simulation, there is possibility to choose one of the 9 different cluster but in this study all the 9 clusters are simulated together at once. (Siren and Kopra 2021, 6.)

Figure 23. Chosen clusters and their numbers (Tableau simulation 2021)

In Vattuniemi area the groundwater source is noticed to be close to the base plates of the buildings in the area. This is considered with drainage pipes under buildings which ensures that groundwater does not rise to the level of manhole covers. It is recommended to have waterproof caps for geothermal plans. (Siren and Kopra 2021, 9.)

In the simulation, the energy system fills the buildings energy demand. The energy demand model that is used in the simulation is the same that is presented in heat demand and monthly energy use sections. The energy system that is considered in the simulation includes space and air condition heating and cooling as well as domestic hot water heating. These energy numbers were formed to square-based consumption hour series (W/m^2) which based on cluster's entire energy consumption was determined. In the simulation every year has the same energy consumption profile. It is noticed that there is a need for cooling in the future and demand for heating is going to decrease due to climate change. Nevertheless, the change is not considered in the simulation because it was not essential in this simulation. (Kopra et al. 2021, 8.)

7.2 Ordinary optimization and CO_2-optimization

In this review, all the 9 clusters are chosen to be studied together as a whole system. The whole area and all the clusters are reviewed as non-isolated clusters. It means that the Vattuniemi areas clusters consider the effect of other clusters nearby, which can affect the energy yield from the well field. When the systems clusters are non-isolated from other clusters, it considers how the well fields impact to each other and how the well number might affect the energy yield also.

From the table 3 one can see the choices that are made for the simulation. It is chosen that ordinary optimized and CO_2-optimized systems are seen in the simulation figures as well as power dimensioned and energy dimensioned heat pumps so they can be compared to each other. As it is seen, there are 4 different scenarios. The scenario 2 is where GSHP is power dimensioned and optimized in an ordinary way. The scenario 4 is otherwise the same but the optimization of district heating and ground source heating is done with CO_2-optimization. For scenario 14 the GSHP is done with energy dimensioning way and with ordinary optimization when scenario 16 is otherwise the same but has the CO_2-optimization. The color of the scenario number's background shows which scenario is seen in which color in the figure where heat production and energy coverage are seen.

Table 3. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Heat pump power dimensioning	Heat pump energy dimensioning	CO_2-optimization	Ordinary optimization	Non-isolated clusters
2	x			x	x
4	x		x		x
14		x		x	x
16		x	x		x

From figure 24. the simulation done is seen. It is seen that the scenario 2 has the best heat production and energy coverage in year 1 as well as the scenario 4. They both have power dimensioned GSHP which affect the results because all the ground source energy available is taken from ground. Scenarios 2 and 14 that has the ordinary optimization. It is seen that heat production and energy coverage in year 1 is lower when CO_2-optimization is used. In year 50 all the scenarios have almost the same heat production and energy coverage. The energy coverage drops rather fast in all scenarios but when the heat pump is power dimensioned (scenarios 2 and 4) the drop is even more dramatic. Scenario 2 the best life cycle energy coverage.

For CO_2-emissions, the pink pillar presents the CO_2-emissions from district heating for the whole period studied (approximately 50 years forward from year 2025) and the grey pillar represent the CO_2-emissions from GSHP's electricity use. Scenarios 4 and 16 have the smallest CO_2-emissions because they have CO_2-optimized systems. Energy emissions are presented scenario by scenario and it is seen that the scenario 4 has the smallest CO_2-emissions. Each line in the pillar, shows each of the nine clusters total CO_2-emissions. For example, the first part of the pillar shows cluster 1 CO_2-emissions from district heating in each scenario. Also, the plot efficiency inside each cluster is slightly different which impacts on the emission results.

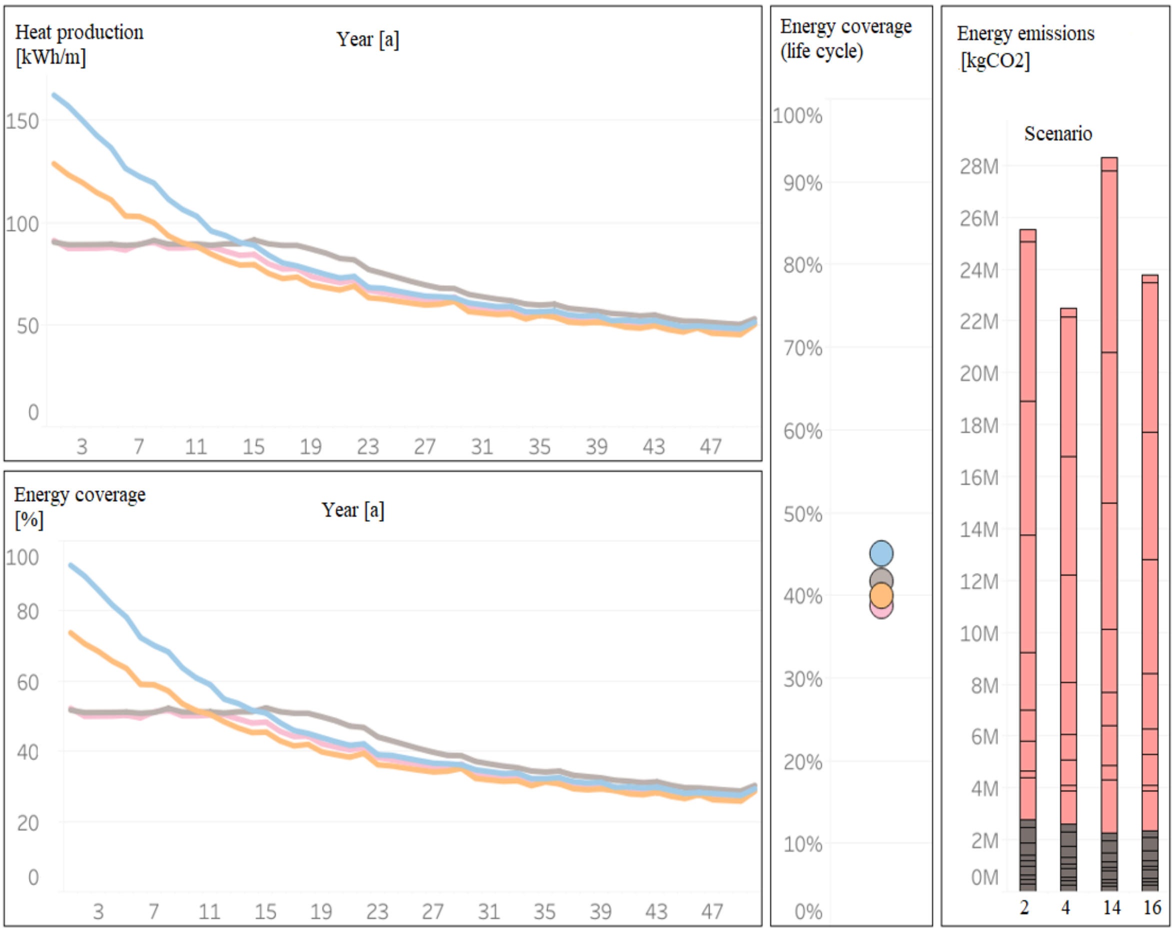

Figure 24. Simulation of CO_2-optimization and ordinary optimization differences (Tableau simulation 2021).

In table 4. the CO_2-emission of each scenario is seen in unit t CO_2. If the area would have been heated only with district heating the CO_2-emissions for 50-year period from year 2025 would be approximately 45 300 t CO_2. District heat CO_2-emissions are based on the average yearly CO_2-emissions of the area that is 906 t CO_2. Energy coverage, the CO_2-emissions from district heating, CO_2-emissions from electricity use and total of the CO_2-emissions of each scenario are seen. It is seen that with CO_2-optimization it is possible to reduce CO_2-emissions by 12-14 % compared to normal optimization. Scenario 2 that had ordinary optimization life cycle energy coverage is highest with the rate of 45%.

Table 4. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating (t CO_2)	CO_2-emissions electricity (t CO_2)	CO_2-emission total (t CO_2)
2	45	22 749	2 764	25 513
4	40	19 891	2 582	22 474
14	42	25 532	2 249	27 782
16	39	21 431	2 349	23 780
District heating	-	45 300	-	45 300

7.3 Waste heat recovery from ventilation exhaust air and CO_2-optimization

In this simulation, all the scenarios have CO_2-optimization, and clusters are non-isolated from each other's impact like in the first simulation. In this simulation the impact of AHP that is exhaust air waste heat recovery is seen. In scenario 10 (green line) and scenario 22 (blue line) there are AHP implemented to the system. In scenario 4 (orange line) and scenario 16 (pink line) there are only CO_2-optimization like in scenarios 4 and 10.

Table 5. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Heat pump power dimensioning	Heat pump energy dimensioning	AHP	CO_2-optimization	Non-isolated clusters
4	x			x	x
10	x		x	x	x
16		x		x	x
22		x	x	x	x

Implementing AHP to the system have significant changes to the energy coverage as well as to the CO_2-emission rates. It is seen from the figure 25 that scenarios 10 and 22 that had AHP added to the system have better energy production and energy coverage during the 50-year period that the scenarios 4 and 16 that had only CO_2-optimizated system. Scenario 4 energy production drops in 50 years almost 100 kWh/m and its energy coverage drop almost

40 %-units during 50-year period. It is rather a big change compared to scenario 10 where energy production drop at the same time is only 10 kWh/m if any and energy coverage drop is 10 %-units. Also, scenarios 10 and 22 have significantly higher life cycle energy coverage (61% and 44%) than scenarios 4 and 16 (36% and 35%). CO_2-emissions decreases when AHP system is implemented to the CO_2-optimized system with almost 18% for energy dimensioned heat pump and 35% for power dimensioned heat pump. The only thing that increases in systems with AHP compared to system without it is the CO_2-emissions from electricity use. Scenarios 10 and 16 have more CO_2-emissions from electricity than scenarios 4 and 16 that have no electricity need for AHP.

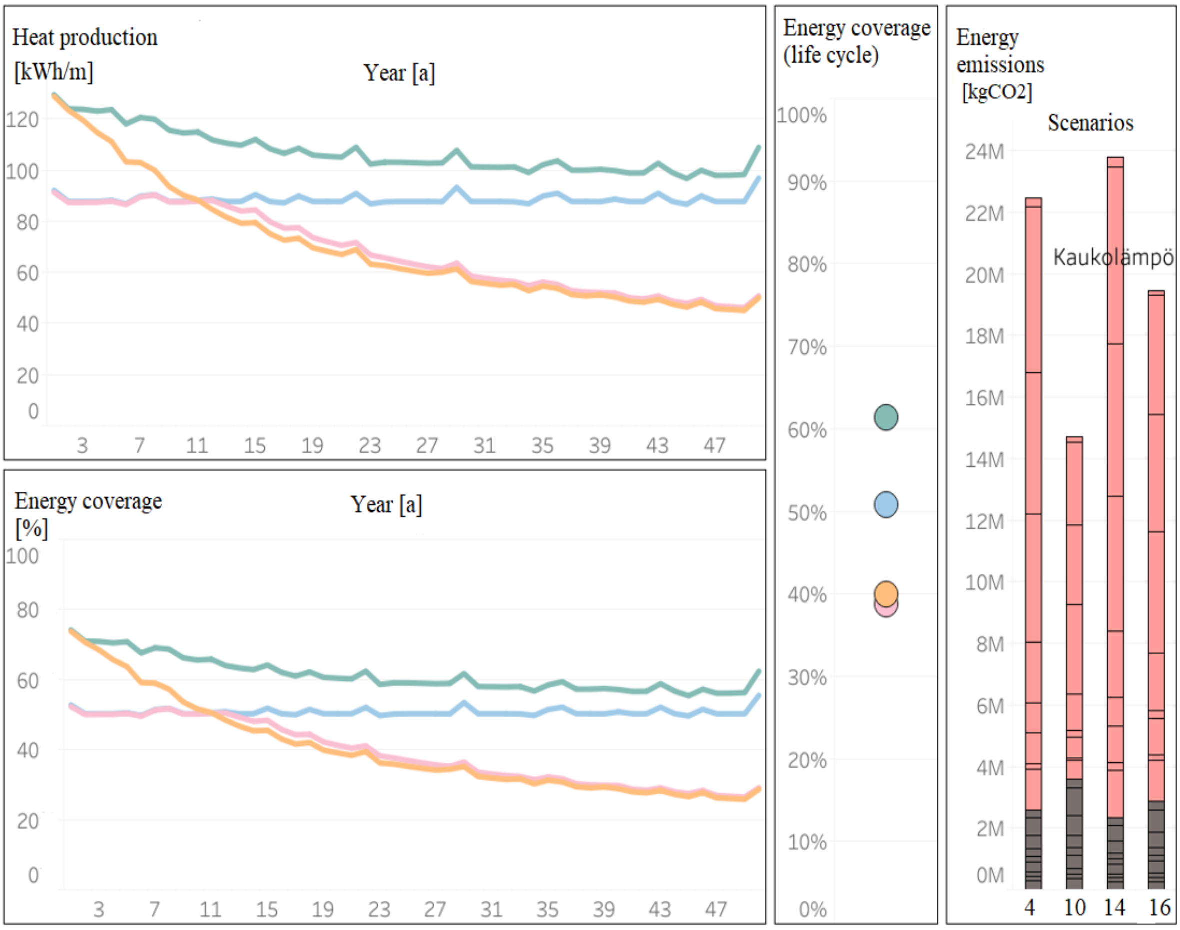

Figure 25. Simulation of CO_2-optimized system with and without AHP (Tableau simulation 2021).

Life cycle energy coverage for systems with AHP (scenarios 10 and 22) has better coverage than systems without AHP (scenarios 4 and 16). Scenarios with AHP emits more CO_2-emissions from electricity than the scenarios without AHP. Still, the total CO_2-emissions from scenarios with AHP are lot lower. It is possible to decrease CO_2-optimized systems

CO_2-emissions by implementing AHP system to it by 18-35% depending on how the heat pump is dimensioned. Below in the table 6 the CO2-emissions of these scenarios are seen.

Table 6. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating (t CO_2)	CO_2-emissions electricity (t CO_2)	CO_2-emission total (t CO_2)
4	40	19 891	2 583	22 474
10	61	11 109	3 582	14 691
16	39	21 431	2 349	23 780
22	51	16 604	2 856	19 460
District heating	-	45 300	-	45 300

If the AHP is connected to the system that has ordinary optimization the results would be different. Below in table 7 the explanations of each line of the simulation figure are seen. The scenarios 8 and 20 are ordinary optimizes systems with AHP and scenarios 10 and 22 are CO_2-optimized systems with AHP.

Table 7. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Heat pump power dimensioning	Heat pump energy dimensioning	AHP	CO_2-optimization	Ordinary optimization	Non-isolated clusters
8	x		x		x	x
10	x		x	x		x
20		x	x		x	x
22		x	x	x		x

It is seen from the figure 26 that if AHP is connected to the ordinary optimized system, the power dimensioned heat pump would have better energy production and energy coverage compared to system that has CO_2-optimization. Nevertheless, more CO_2-emissions would be emitted this way than with CO_2-optimized choice.

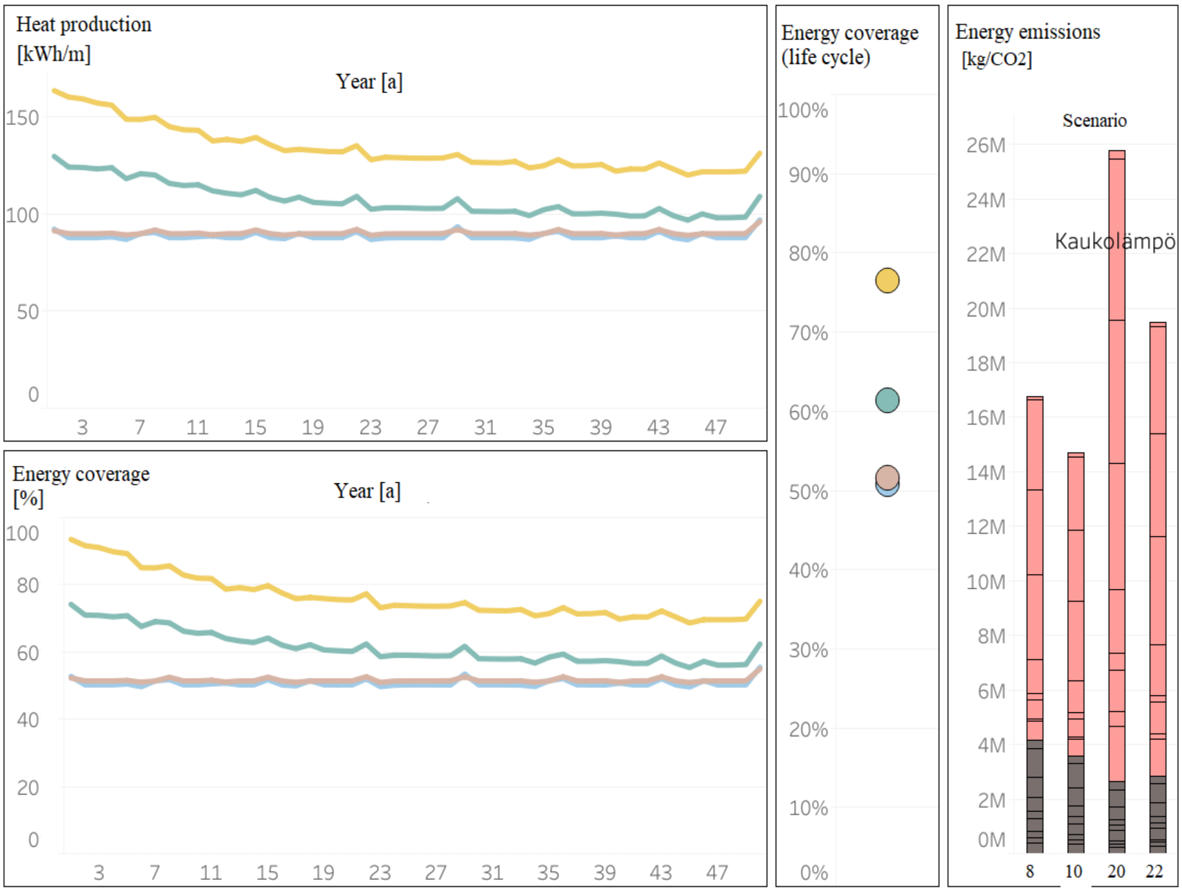

Figure 26. Simulation of AHP in ordinary optimization and in CO_2-optimized system (Tableau simulation 2021).

From table 8 it is seen that the scenario 8 has extremely high energy coverage (76%) and rather small CO_2-emissions (16 657 tCO_2). Nevertheless, scenario 10 has even smaller CO_2-emission rate (14 691 tCO_2).

Table 8. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating ($t\ CO_2$)	CO_2-emissions electricity ($t\ CO_2$)	CO_2-emission total ($t\ CO_2$)
8	76	12 498	3 639	16 657
10	61	11 109	3 582	14 691
20	52	23 137	2 632	25 769
22	51	16 604	2 856	19 460
District heating	-	45 300	-	45 300

The APH is recommended to be used due to maximize building efficiency in Vattuniemi area. There should be additional heating sources supporting the GSHP so it could cover the heat needed. (Siren & Kopra 2021, 4.)

7.4 Non-isolated and isolated clusters in the area

There are some differences when clusters are simulated as isolated clusters and as non-isolated clusters. In this case it means that when the scenarios are simulated with clusters that are isolated from other clusters around it does not consider the impact of other cluster's heat wells when non-isolated considers the impact of other clusters wells. Below in table 9, the choices made for the scenarios are presented. In these simulations, CO_2-optimization, and APH are considered in all the simulations. Scenarios 10 and 22 have non-isolated clusters and scenarios 9 and 21 have isolated clusters.

Table 9. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Heat pump power dimensioning	Heat pump energy dimensioning	Non-isolated clusters	Isolated clusters	AHP	CO_2-optimization
9	x			x	x	x
10	x		x		x	x
21		x		x	x	x
22		x	x		x	x

If the heat pump is power dimensioned, one can see from the figure 27 that there is a difference between system when the clusters inside the Vattuniemi area are considered as isolated cluster energy systems and as non-isolated cluster energy systems. Scenario 9 has better heat production, energy coverage and smaller CO_2-emisions than scenario 10. If the heat pump is dimensioned based on the energy, then there is no difference in heat production, energy coverage or CO_2-emissions rather the clusters are isolated from each other's impact.

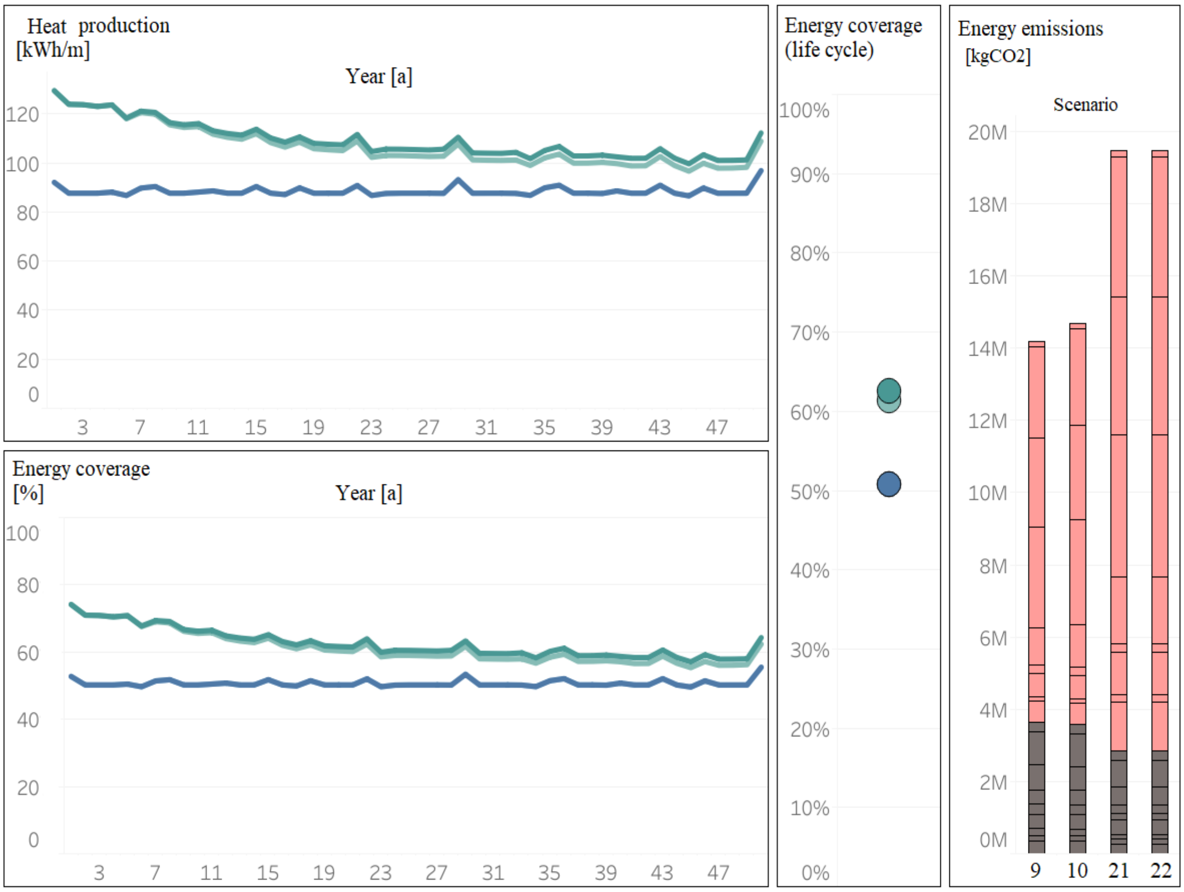

Figure 27. Simulation of non-isolated clusters and isolated clusters difference (Tableau simulation 2021).

It is seen from the table 10 the CO_2-emission results that if the clusters are isolated from each other's impact, the CO_2-emissions for the whole scenario will drop, but only by 3,5%.

Table 10. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating (t CO_2)	CO_2-emissions electricity (t CO_2)	CO_2-emission total (t CO_2)
9	63	10 547	3 639	14 184
10	61	11 109	3 582	14 691
21	51	16 604	2 856	19 460
22	51	16 604	2 856	19 460
District heating	-	45 300	-	45 300

The results above had all the 9 clusters of the area considered but when clusters are chosen differently the results will be different. For example, when choosing clusters that are close to each other the difference of clusters that are isolated or non-isolated is more dramatic. When choosing clusters with long distance between each other, the impact of cluster is naturally smaller. For example, if clusters 7-9 are reviewed, the results between isolated and non-isolated clusters are small, because clusters 7-9 are not so close to each other. When clusters 2-5 are chosen there is more impact from the clusters, because these clusters are close to each other. It is because also the heat wells are nearby impacting to each other. The importance of applied APH increases here. When APH is applied to the cluster-based energy system the impact of nearness of clusters to the well field decreases.

7.5 Cooling service utilization

The effect of cooling that is added to the system by adding it to the GSHP is simulated. This system includes CO_2-optimization, AHP and considers clusters as non-isolated from the impact of other clusters inside the studied area. Below in table 11 the choices made are seen. Scenarios 12 and 24 have cooling service utilization and scenarios 10 and 22 do not have. Scenarios 10 and 12 have power dimensioned heat pumps and scenarios 22 and 24 energy dimensioned ones.

Table 11. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Cooling service	Heat pump power dimensioning	Heat pump energy dimensioning	AHP	CO2-optimization	Non-isolated clusters
10		x		x	x	x
12	x	x		x	x	x
22			x	x	x	x
24	x		x	x	x	x

According to the figure 28 below, there are no differences between scenarios 22 and 24 (heat pump energy dimensioned) when cooling service utilization is added. Scenarios 10 and 12 have some differences, that shows implementing cooling service utilization to the GSHP system increases the heat production of the system as well as the energy coverage evenly for the whole 50-year period.

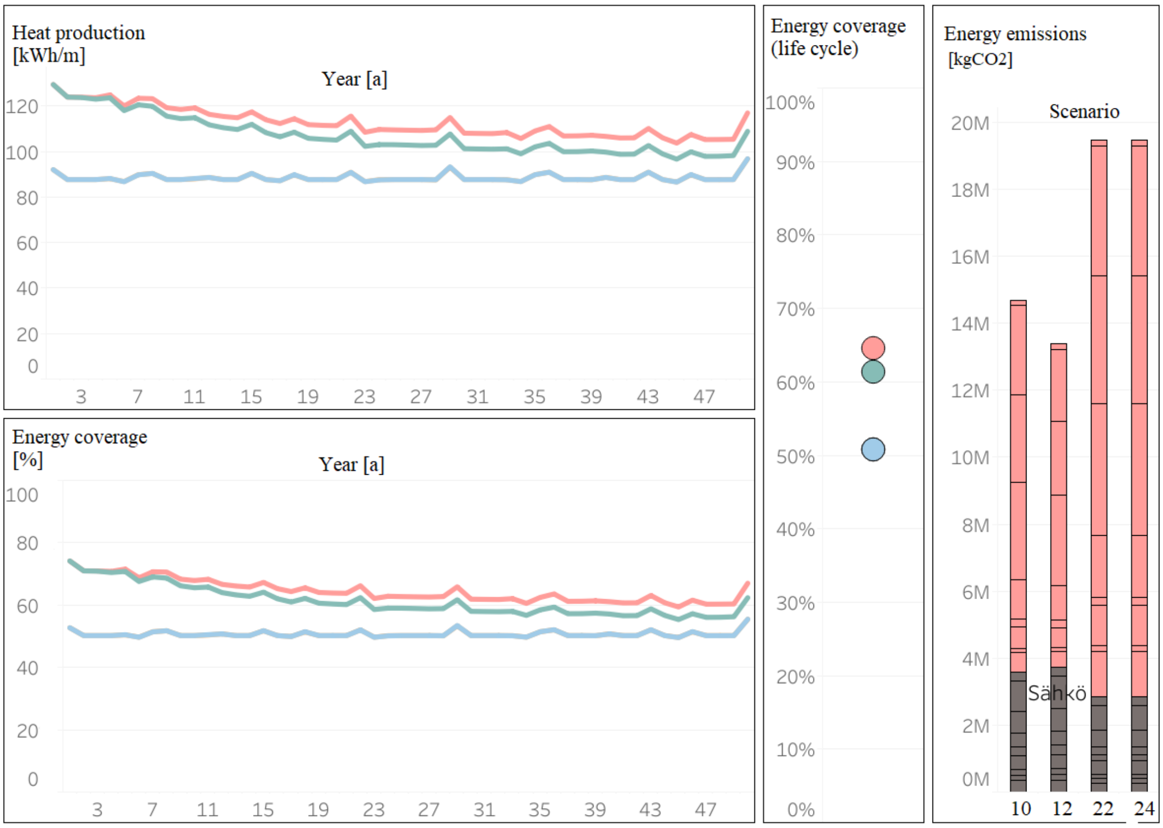

Figure 28. Cooling service utilization as a part of the CO_2-optimized system (Tableau simulation 2021)

It is seen from the table 12 that implementing the cooling service utilization decreases the total CO_2-emission. Scenario 12 that has cooling service utilization and power dimensioned GSHP has the smallest CO_2-emissions compared to any scenario presented above. Cooling service utilization reduces the whole energy system's CO_2-emissions 8,9% that has power dimensioned GSHP. For energy dimensioned GSHP cooling service utilization decreases the CO_2-emissions only by 0,8% compared to system without it.

Table 12. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating (t CO_2)	CO_2-emissions electricity (t CO_2)	CO_2-emission total (t CO_2)
10	61	11 109	3 582	14 691
12	65	9 640	3 736	13 376
22	51	16 604	2 856	19 460
24	51	16 446	2 856	19 302
District heating	-	45 300	-	45 300

7.6 Overall results

The differences in heat production in each scenario that were compared to each other are interesting. In the table 13 there are 3 different year's (year 1, 25 and 50) heat production readings seen from power dimensioned heat pump scenarios and energy dimensioned heat pump scenarios. The differences between these readings from scenarios that were compared to each other is seen. It is seen that when CO_2-optimization is added it decreases the heat production compared to ordinary optimized system. Still, the CO_2-emission reductions were remarkable when CO_2-optimization was compared to the ordinary optimization. It is seen also that when AHP is added to the CO_2-optimized system the heat production increases remarkable in year 1, 25 and in year 50. The increase in heat production means that AHP improves the heat production the most compared to other additions. The negative number shows if ordinary optimization is changed to CO_2-optimization, how much on kWh/m it decreases the heat production in year 1, 25 and 50. Nevertheless, this addition would decrease total CO_2-emissions.

Table 13. Heat production of different simulations (Tableau simulation 2021).

	Power dimensioned heat pump heat production [kWh/m]	**Energy dimensioned heat pump heat production [kWh/m]**
YEAR 1		
CO_2-optimization	-306,4	0
AHP	6,4	7,6
Isolated clusters	0,2	0,5
Cooling service	0	0
YEAR 25		
CO_2-optimization	-72,5	-76,2
AHP	346,3	149
Isolated clusters	22,8	0
Cooling service	53,2	0
YEAR 50		
CO_2-optimization	-29,8	0
AHP	501,7	332,7
Isolated clusters	31,2	0,6
Cooling service	67,6	0

In the table 14. it is seen what each scenario that were presented includes. If there is no mark in AHP it means that the scenario does not have exhaust air waste heat recovery system and if there is no mark on CO_2-optimization it means that the scenario has ordinary optimization. If there is no mark on isolated clusters, it means that the scenarios clusters are considered as non-isolated clusters.

Table 14. Explanation of the simulation curves (Tableau simulation 2021).

Scenario	Heat pump power dimensioned	Heat pump energy dimensioned	AHP	CO_2-optimization	Isolated clusters	Cooling service
2	x					
4	x			x		
9	x		x	x	x	
10	x		x	x		
12	x		x	x		x
14		x				
16		x		x		
21		x	x	x	x	
22		x	x	x		
24		x	x	x		x

In the table 15, the total CO_2-emissions from each scenario are seen. The CO_2-emission total in t CO_2 includes the emissions of the whole scenario of 50-year period. Each scenario's emissions from district heating and electricity are presented separately. Energy coverage is also presented. Scenario 12 has the smallest CO_2-rate. The best life cycle energy coverage is also for the scenario 12.

Table 15. CO_2-emissions of the simulations (Tableau simulation 2021).

Scenario	Energy coverage (life cycle %)	CO_2-emissions district heating (t CO_2)	CO_2-emissions electricity (t CO_2)	CO_2-emission total (t CO_2)
2	45	22 749	2 764	25 514
4	40	19 891	2 583	22 474
9	63	10 547	3 639	14 184
10	61	11 109	3 582	14 691
12	65	9 640	3 736	13 376
14	42	25 532	2 250	27 782
16	39	21 431	2 349	23 780
21	51	16 604	2 856	19 460
22	51	16 604	2 856	19 460
24	51	16 446	2 856	19 302
District heating	-	45 300	-	45 300

Below in figure 29 it is seen that all scenarios reduce CO_2-emissions when they are compared to the system where only district heating is used. Scenarios 2-12 have power dimensioned GSHP and scenarios 14-24 energy dimensioned. Each improvement to the system decreases the CO_2-emissions. For example, it is seen that scenario 4 (CO_2-optimization added) decreases the CO_2-emissions by 12% compared to scenario 2. When AHP is added to the system it reduced the emissions by 35% (difference between scenario 4 and 10). When cooling service utilization is added it reduces the emissions by 9% (difference between scenario 10 and 12). The reduction between scenarios 2 and 12 is 48%. It means that by adding CO_2-optimization, AHP and cooling service utilization to the district heating and ground source heat combination system that has power dimensioned GSHP one can reduce CO_2-emissions by 48%.

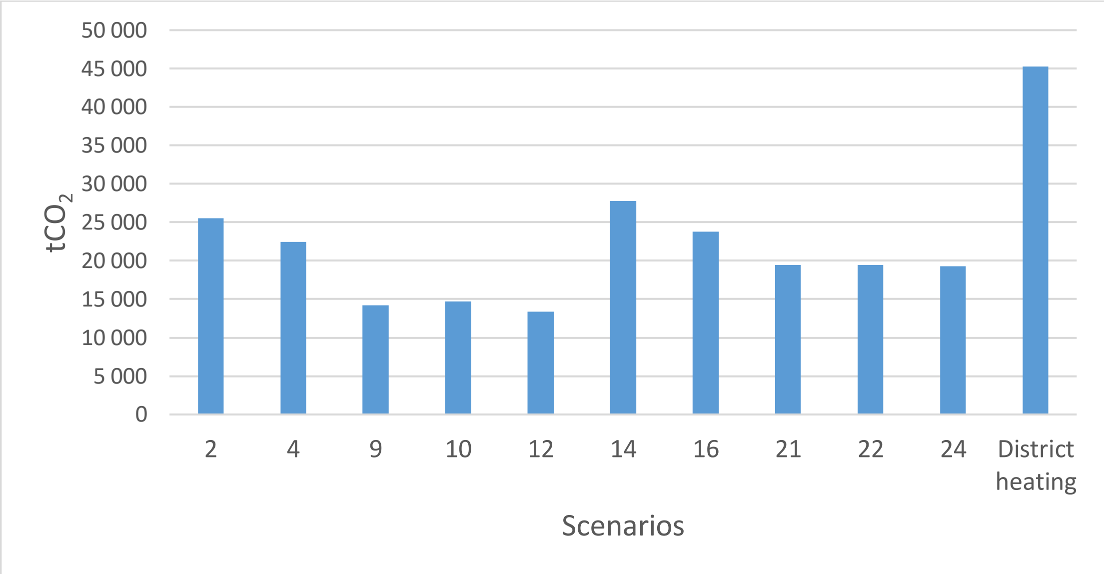

Figure 29. Total CO_2-emissions results from each scenario. (Tableau simulation 2021.)

The results that are from power dimensioned heat pumps are in general better than result from energy dimensioned heat pumps. For example, all the scenarios that had power dimensioned heat pump had life cycle energy coverage between 40-78% when the same number for energy dimensioned heat pumps were in ration 39-52%. Also, the heat production results were better for power dimensioned heat pumps than for energy dimensioned ones. For example, for power dimensioned heat pump's heat production in year 1 was between 140-160 kWh/m for all scenarios when for energy dimensioned, it was about 100 kWh/m. In the end (year 50) the heat production results for power dimensioned heat pump were between 50-140 kWh/m for all scenarios and for energy dimensioned they were about 50-100 kWh/m. This applies for the CO_2-emission rates as well. The lowest emission rates came from the scenarios that had power dimensioned heat pumps. Like mentioned before, the power dimensioning gives better results because when GSHP is power dimensioned, it takes all the energy available from the well field which is in practice 30 W/m when energy dimensioning recovers energy evenly from the geothermal heat wells. (Kopra et al. 2021, 6.)

8 DISCUSSION AND CONCLUSIONS

During this master's thesis, in September 2021 Helsinki city changed its carbon neutrality goal from year 2035 to the year 2030. This affected Helen Oy that emits most of the Helsinki city's GHG emissions by using fossil fuels in its CHP production. To be in line with Helsinki city's goal, Helen Oy had to change its goal of being carbon neutral by the end of year 2035 to the year 2030. The simulation was done by considering that Helen Oy is going to be carbon neutral by the end of year 2035. The simulation that simulated the district heating emissions were put to be leveled off by the end of year 2035 not by the year 2030. Also, the simulation did not consider that the Hanasaari is going to be closed earlier than it was planned. Nevertheless, this will affect the overall results only a little and it will not change the outcome of the study. It must be remembered that this study focuses on the future and the plans in the future can change rapidly. The simulation used gives enough reliable results of the future regarding all the changes on climate goals and actions that might be done in the future. In this study the construction phase was not considered. Only use phase of buildings was studied. There are much GHG emissions formed in construction phase that was not considered. If GHG emissions from constructing would have been considered, the outcome of the total GHG emissions would be totally different.

Cluster-based approach to energy system planning is more competitive than current energy systems where only one solution at a time is considered for only one building. Based on the results, the best option for cluster-based energy system is a CO_2-optimized district heat and ground source heat combination that includes waste heat recovery from ventilation exhaust air as an additional heat source and utilization of the GSHP cooling service. It is seen from the results that adding waste heat recovery from ventilation exhaust air ensures that there is enough energy available in long term by increasing the energy coverage rate for the whole 50-year time. From this system simulated the CO_2-emission were the lowest compared to the other simulations.

In the long run ground source heat alone is not sustainable choice in an urban area where the cluster-based energy systems ground source heat depends on how close the clusters are each other. From the results of the clusters considered as non-isolated and isolated, the impact of the geothermal wells on each other was seen. It was seen that it depends on how close the well fields are from each other and the size of the well fields. Therefore, heating systems should be considered now as an entity rather than a one building or one plots solution so that the well impact would be considered in the calculations. This is something that housing companies should consider when they are planning the heating system change from district heating to the ground source heat. It should be also remembered that Helsinki is densely built area. When considering the increasing plot efficiency in city areas there might not be enough area to drill geothermal wells to cover the whole energy demand of the plot. The energy demand could be covered if the depth of the wells would be drilled deeper, but there are still many problems with drilling deep wells in a densely build area with a high plot efficiency. This is one of the reasons why combinations of different heating solutions are important to be considered as an option.

The importance of dimensioning the GSHP correctly became clear, either it was power dimensioned, or energy dimensioned. It was seen from the section 3.2 figure that if the number of the wells rise, the heat production of the GSHP will not increase but drop. It is more cost efficient and environmentally friendly to dimension the wells according to the energy demand and not by the maximum energy that can be recovered from the ground. When considering the heating system as an entity and not only one buildings solution the surrounding buildings create new possibilities. For example, if there is close by business premises that produce a lot of waste heat, the nearby buildings could utilize this heat to heat up their living spaces. The absolute advantage of ground source heating system is the ability to load surplus heat to the wells, which can be utilized in cold winter periods. Also, the advantage of the ground source heating system as a part of the whole entity is cooling that can be utilized at the summertime.

The CO_2-optimization of the district heating and GSHP combination in a cluster-based energy system simulations gave very promising results when it was compared to the ordinary optimized system. The main difference between these two optimization methods is that the CO_2-optimization chooses the source of energy by the emission rate of the energy source when ordinary optimization tries to maximize the ground source heat energy usage. In conclusion, CO_2-optimized system uses district heating in summertime and other times ground source heat. Therefore, the energy coverage from district heating and ground source heating combination that has CO_2-optimization is smaller if it does not have exhaust air waste heat recovery. Nevertheless, CO_2-optimization enables better usability in wintertime. CO_2-optimized system usability is better than ordinary optimized systems usability because in summertime it can load energy to the ground source heating wells while it is using district heating to heat up the domestic hot water. For example, if waste heat recovery is used, the recovered waste energy can be loaded to the ground source heating wells. In ordinary system this kind of loading is not possible because it uses ground source heat through summer, and therefore the ground source heating system cannot be loaded through the summer. Also, depending on the system and intended use the waste heat recovery, it can increase CO_2-optimized systems energy coverage compared to ordinary optimized system. Still, the greatest meaning of CO_2-optimization is that because district heating's emission factors change over the year, increased use of GSHP at wintertime decreases the whole energy system's CO_2-emissions even ground source heat energy coverage is smaller compared to the ordinary optimized system. When adding cooling service utilization to the system it reduces CO_2-emissions even more and makes the life cycle energy coverage the best one with 65% coverage. It should be remembered that in these systems ground source heating and other additional heating methods are for supporting district heat and to for decreasing its use at the same time. The already exiting district heating grid is a great platform for different hybrids and it should be used in the future as a part of buildings energy system. (Siren & Kopra 2021, 18.)

The low carbon cluster-based energy concept can reach markable emission reduction in Vattuniemi's centre area. Nevertheless, the cost of the system is one of the most important factors for owners and construction builders when discussion about the options. The investment costs vary between different combinations of waste heat energy technologies and between how many energy wells there would be for one energy cluster. (Siren & Kopra 2021, 4.) Some research is done towards energy efficiency improvement and its costs. For example, according to Knuutila et al. building's energy related costs decrease approximately 30-40% and CO_2-emissions decreases approximately by 60-80% when active energy efficiency improvements like heat production change to heat pumps and solar panel installation and waste heat recovery efficiency is improved in a building. This research was done in Lappeenranta area where district heating is more affordable than in Helsinki. (Knuutila et al. 2021.) Still, there is no research like this done about the areas in Helsinki which has the heating systems studied in this thesis it is noticed that for the further research the optimizations of the investment cost and use phase costs of the studied heating combinations should be researched.

In every scenario that were presented in this study had rather high CO_2-emissions from district heating because Helen Oy district heating is produced mainly by using fossil fuels. It should be remembered that district heating from CHP process is waste heat energy from electricity production. If district heating was mostly produced from waste heat, the CO_2-emissions would have been smaller. For example, if the waste heat from Kilpilahti factory area that is directed to the ocean now would have been recovered to the Helen Oy district heating network, it would have covered almost ¼ of energy demand of the whole metropolitan area (Helen Oy 2020 g). If the research had been done in different location the results of CO_2-emissions might be also different. Nevertheless, if only district heating alone is used the CO_2-emissions would be even higher. Because the Vattuniemi area that was studied is in Helsinki, it possible to apply the simulations used to other parts of Helsinki if needed.

The difference between energy dimensioning and power dimensioning of the heating wells should be noted in this study because the way of dimensioning the GSHP impacts the results significantly. It was noticed from the result that systems that included power dimensioned GSHP generates better results than the energy dimensioned way. It is noticed that the best way to dimension the GSHP’s would be a way that implements both, energy dimensioning and power dimensioning. Nevertheless, all the results from power dimensioning GSHP were better that energy dimensioned ones, which means that GSHP should be dimensioned due to power. Power dimensioned GHSP might also be more profitable than energy from energy dimensioned, but this needs some further research.

9 SUMMARY

This thesis is made for Helen Oy that is looking for new solutions to cover the heat demand in Helsinki area. Helen Oy is a local energy company in Helsinki area which has the widest district heating grid in the whole Finland. One of the solutions is a district heating and ground source heating combination in an urban area. The aim of this master's thesis was to analyze district heating and ground heat combination in Helsinki area that has CO_2-optimization as well as additional heating system attached to it. The aim was to present district heating as a part of future energy system as a reasonable choice from environmental view. The case area in this study was Vattuniemi area in Lauttasaari that locates in Helsinki city coast.

The energy system is reviewed as a cluster-based energy system which means that buildings on formed cluster has the same heating center from where energy is delivered to the buildings through internal network. It makes both heating and cooling production possible inside the cluster system. This study was focusing on use phase CO_2-emissions of buildings in urban area. The constructing phase would cause emissions, but it was not considered in this study. The research questions were: What is the impact of the chosen waste heat recovery technology to an energy system where district heating and ground heat combination is used, what is the impact of the geothermal wells on each other in a cluster-based energy system, what are the differences between energy and power dimensioned ground source heat pumps and which heating combination has the smallest impact on environment in Vattuniemi area? The answer for the research questions were answered with using the Tableau simulation Tool.

The theory part of this study presented some theoretical background of district heating, geothermal heat and heat demand and supply in Helsinki area. Also, the heat demand and waste heat energy technology were presented. The customer side perspective in this thesis was viewed via interview that Helen Oy had done about hybrids for different customer segments.

The empirical part of this study presented the Tableau simulation tool that is used to simulate different set ups of district heating and ground source heat combinations. The data and the case area Vattuniemi were interpret. Nine energy clusters were made that were simulated from the year 2025 to year 2075. CO_2-optimized system and ordinary way optimized system were compared. Then AHP was added to CO_2-optimized system and compared to system without AHP. Also, ordinary optimized system with and without AHP was simulated as well as system with CO_2-opimization and AHP that had clusters considered as non-isolated and isolated from the impact of each other's ground source heating wells. At last, a system with CO_2-optimization and AHP with and without cooling service utilization was simulated.

The results that came out from the simulation were then discussed and compared. Based on this study a CO_2-optimized district heating and ground source heat combination in a cluster-based energy system with waste heat recovery from ventilation exhaust air and with cooling service utilization has the smallest environmental impact compared to the other set ups. It reduces CO_2-emissions almost 47% compared to ordinary optimized district heating and ground source heating system. According to the simulation results, added ventilation exhaust air waste heat recovery improves the systems energy coverage and decreases CO_2-emissions of the studied combination. Geothermal wells have an impact on each other can be reduced also by adding the ventilation exhaust air waste heat recovery to the system. When the system's GHSP is dimensioned according to the power, the results are better in every mean compared to the system with energy dimensioned GSHP. Therefore, according to the result, GSHP should be dimensioned due to its power.

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