LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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FUTURE ROLE OF MEDIUM ENERGY PRODUCTION UNITS IN HEATING AND COOLING SYSTEMS IN A LARGE ENERGY COMPANY IN FINLAND

Examiners:	1st Professor, D. Sc. (Tech.) Risto Soukka
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Instructors:	Suvi Karaste, M. Sc. (Chemistry)
	Lauri Valkonen, M. Sc. (Tech.)

ABSTRACT

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Future role of medium energy production units in heating and cooling systems in a large energy company in Finland

Master's thesis

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97 pages, 23 figures, 24 tables and 1 appendix

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Keywords: MCP-directive, MCP-decree, PiPo-decree, district heating and cooling, DHC, medium combustion plants, peak load units, demand-side management

The MCP-directive was published by the European Union in 2015 and was implemented to the Finnish legislation in the end of 2017. The scope units of the MCP-directive are energy production units with a thermal power of 1 MW or more but less than 50 MW. The main objective of this thesis was to study whether Fortum's units in the scope in Finland are in line with the MCP-decree. And if not, what action paths there is to fulfil the requirements. Basic information, emission levels, emission limit values and monitoring requirements of the units in the scope were examined and part of the scope units were registered to the environmental authorities' data systems.

In the existing situation majority of the units studied in this thesis fulfilled the requirements set by the MCP-decree. Because of the reorganised production structure in the Joensuu district heating system it was studied what kind of action paths there is if the role of a case unit is changed and the MCP-decree's emission limit values are applied. Scenarios chosen to be studied were primary methods to decrease emissions in the case of operating hours increasing, switching the fuel to bio oil and utilising demand-side management to replace all or part of the operating hours of the case unit and thus avoid the applying of MCP emission limit values.

Also the utilisation of the exemption concerning horse manure combustion in medium energy production units unit was studied in a case unit. It was identified that requirements are possible to reach, but the incentive to add horse manure to the fuel mix is needed in addition to the exemption itself.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
LUT School of Energy Systems
Ympäristötekniikan koulutusohjelma

Elina Seppä

Keskisuurten energiantuotantoyksiköiden rooli tulevaisuuden kaukolämmitys- ja kaukojäähdytysjärjestelmissä suuressa energiayhtiössä Suomessa

Diplomityö

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Asiasanat: MCP-direktiivi, MCP-asetus, PiPo-asetus, kaukolämmitys, kaukojäähdytys, DHC, keskikokoiset energiantuotantoyksiköt, huippukuormalaitokset, kysyntäjousto

Euroopan Unionin MCP-direktiivi julkaistiin vuonna 2015. Suomen lainsäädäntöön MCP-direktiivin vaatimukset sisällytettiin loppuvuonna 2017. MCP-direktiivi säätelee polttoaineteholtaan 1 MW tai yli mutta alle 50 MW energiantuotantoyksiköiden toimintaa. Tämän työn tavoitteena oli tutkia täyttävätkö Fortumin energiantuotantoyksiköt Suomessa MCP-asetuksen vaatimukset, ja jos eivät, minkälaisilla toimenpiteillä vaatimukset voitaisiin täyttää. Laitosten perustiedot, päästötasot, raja-arvot ja päästömittausvaatimukset käytiin läpi ja osa laitoksista myös rekisteröitiin ympäristöviranomaisten tietokantoihin työn aikana.

Nykyisessä tilanteessa valtaosa Fortumin energiantuotantoyksiköistä täyttää MCP-asetuksen vaatimukset. Joensuun kaukolämpöverkkoa ja tuotantoyksiköitä on viime vuosina järjestelty uudelleen, jonka vuoksi eräälle energiantuotantoyksikölle tarvittavia toimenpiteitä tutkittiin tilanteessa, jossa sen rooli kaukolämpöjärjestelmässä muuttuu ja käyttötuntien kasvaessa MCP-päästörajoja sovellettaisiin. Läpikäytäviä toimenpiteitä olivat primääriset menetelmät päästöjen pienentämiseksi käyttötuntien kasvaessa, mahdollisuus polttoaineen vaihtamiseen bioöljyyn sekä kysyntäjouston hyödyntäminen laitoksen käyttötuntien vähentämiseksi tai korvaamiseksi jotta MCP-rajojen soveltaminen vältettäisiin.

Työssä tutkittiin lisäksi hevosenlannan polttoa keskisuuressa energiantuotantoyksikössä helpottavan poikkeuksen hyödyntämistä eräässä yksikössä. Case-tutkimuksessa todettiin, että päästövaatimukset ovat saavutettavissa mutta kannattavuuden puolesta hevosenlannan poltolle tulisi olla jokin muu perustelu kuin poikkeus.

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Over six years ago I started my studies as a freshmen in LUT and never did I expect what a great experience it would be. Now I can say that going to Lappeenranta was one of the best decisions in my life so far. During my studies I had the privilege to meet amazing people from LUT and also from other universities. I gained a lot of unforgettable memories and also succeeded to found my own fields of interests.

This master thesis was conducted to Fortum Power and Heat Oy. I want to thank everyone involved for providing me the opportunity to write this thesis. Special thanks to my advisors, Suvi Karaste and Lauri Valkonen, for all the conversations, comments and guidance during this project. In challenging situations you were always ready to help, from which I can't be more grateful. I also want to thank all colleagues with whom I had the privilege to discuss for the expertise and professional answers to my questions. Thanks to my examiners, Risto Soukka and Mika Luoranen, from your enlightening comments and from the academic view-point. Writing this thesis has taught me a lot from the energy sector and yet now I only know how much there is to learn. Even though these acknowledgements denote the goodbye to my studies, hopefully learning will never end.

Thanks to all my friends for always being there for me. Especially thanks for 'Ymte-tytöt' for all the support and good company during studies. Special thanks to my mother and father for always encouraging me to study and aim towards my goals. Finally, I want to thank you Tommi for all your support, inspiring conversations and great company.

In Helsinki 10.12.2018

Elina Seppä

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SYMBOLS AND ABBREVIATIONS

Abbreviations

CHP = Combined heat and power

DSM = Demand-side management

ETS = Emission trading scheme

EU = European Union

HOB = Heat-only boiler

MCP = Medium combustion plant

NEC = National emissions ceiling

P = Power

PM = Particulate matter, dust

Chemical formulas and elements

CH_4 = methane

CO = Carbon monoxide

CO_2 = Carbon dioxide

NO = Nitrogen oxide

NO_X = Nitrogen oxides

SO_2 = Sulphur dioxide

1 INTRODUCTION

1.1 Background of the study

Climate change, development of new technologies, digitalisation and increased awareness of consumers are forcing all energy producers to reduce their environmental impacts worldwide. Digitalisation and novel technologies enable new, competitive energy solutions to the markets and challenge the status quo of the energy sector. Global guidelines, directives and national legislation set stricter targets to achieve decreased environmental impacts, which reflects as pressures to develop the energy sector to be more sustainable. Energy end-users are more aware of the environmental aspects and impacts of the products and services they are using, and also expect and demand more sustainable solutions. Moreover, the increasing amount of energy consumed worldwide is setting challenges to all energy systems.

The European Union (EU) has several instruments in use aiming to reduce the total amount of gaseous emissions to the atmosphere from energy sector. The emission trading scheme (ETS) is the most well-known of these instruments and is used in multiple industries, including energy production. The ETS has been in use since 2005 and focuses on reducing the absolute amount of carbon dioxide emissions to the atmosphere. The ETS works on the "cap and trade"-principle: it sets a maximum cap on the absolute amount of greenhouse gases, which is allocated to or bought by companies producing greenhouse gases. The total amount of allowances (the cap) is reduced over time so, that the total amount of greenhouse gases emitted from the industries within the ETS decreases. Companies can also trade allowances with each other. The target of the ETS is to have 21 % lower greenhouse gas emissions in 2020 and 43 % lower greenhouse gas emissions in 2030 from the sectors covered, base year is 2005. (European Commission 2018c.)

In addition to the ETS, there is the Clean Air Policy Package currently applied in the EU. The Clean Air Policy Package was adopted on 18th of December 2013. The aim of the Clean Air Policy Package and its instruments is to improve the air quality in cities across Europe with cost-effective methods and technologies. The Clean Air Policy Package includes the Clean air programme for Europe, the National emissions ceiling directive (NEC-directive), the Gothenburg protocol and the Medium combustion plants directive (MCP-directive). (Finnish ministry of economic affairs and employment 2017.)

The Clean air programme for Europe sets air quality improvement objectives for years 2020 and 2030. The main legislative instrument to reach the Clean air programme's objectives is the NEC-directive. The NEC-directive was latest revised in 2016 (2016/2284/EU). The NEC-directive sets reduction targets for the EU member countries for six air pollutants: sulphur oxides (SO_2), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), particulate matter (PM) in size smaller than 2,5 μm and methane (CH_4) and is used in multiple industries. The NEC-directive requires all governments to draft national air protection plans. National air protection plans must describe the development of emission levels of different pollutants during years 1990–2016. Furthermore, air protection plans shall present development paths of emission levels and air quality, and present the impacts of these both until the year 2030. (European Commission 2018a; European Commission 2018b; European Council 2018; Suoheimo et al. 2015, 8–9.) In Finland the national air protection plan is currently under preparation (Syke 2018). The Gothenburg protocol is part of the Clean air policy package. It is a proposal to approve international rules on long-range transboundary air pollution, which is not a problem in Finland. The Gothenburg protocol will reduce pollution especially areas in Eastern Europe, Caucasus and Central Asia. (European Commission 2016.)

The MCP-directive is one tool used to reduce the amount of gaseous emissions from energy sector in the EU. The MCP-directive sets air protection requirements for energy production units with a thermal input of more than 1 MW but less than or equal to 50 MW. It was published in the Official Journal of the European Union on 25th of November 2015. The MCP-directive sets emission limit values for SO_2, NO_X and dust from medium energy combustion plants. The ETS and the Clean Air Policy Package presented in this section are briefly summarised in figure 1.

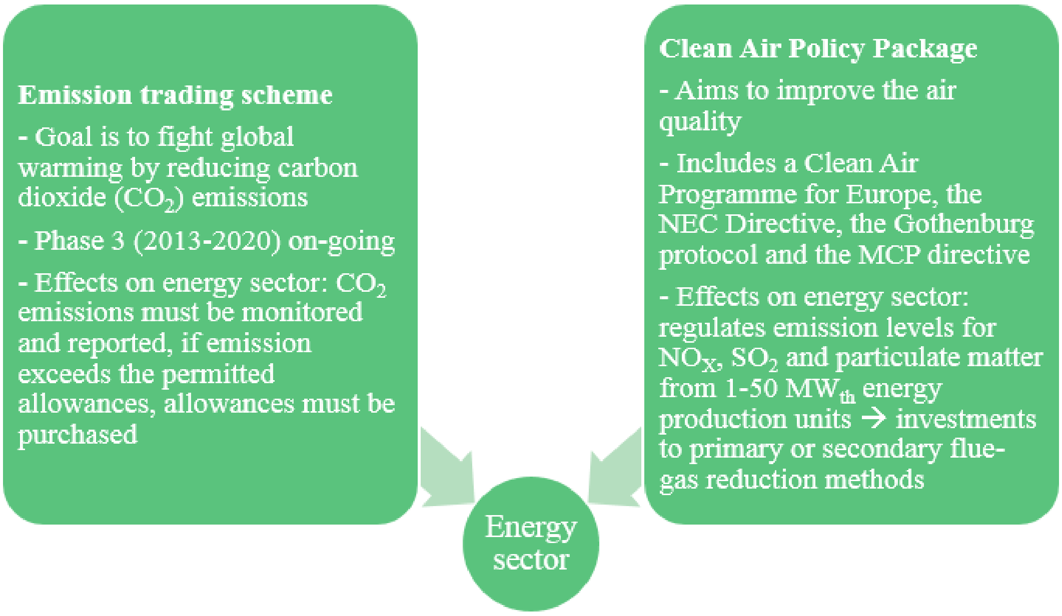

Figure 1. Summary of the EU's agreements affecting to the energy sector.

Directives and other legislative requirements aiming to decrease the total amount of gaseous emissions and other pollutants affect to the district heating and cooling industries across the EU. In Finland the effect is significant since about a half of all Finnish households, offices and public buildings have district heating as their main heating method. Although the ongoing trend is to utilise more renewable fuels and surplus heat inputs into the district heating systems, a significant percentage of district heating in Finland is still produced with fossil fuels. In the 2017 the shares were: 35 % of the total amount with coal, oil and natural gas and 14 % with peat. (Finnish Energy 2018a.)

Often the ongoing utilisation of increasing amount of renewable resources into the energy systems is referred as the energy system transition. One purpose of the energy system transition is to end firing of fossil fuels and also to reduce the combustion of primary fuels altogether. And thus result in to a smaller environmental impacts. New solutions and technologies, such as demand-side management (DSM), are transforming the production structure in the existing district heating and cooling systems. Traditionally district heating system has been operated to answer to the demands from customers, but demand-side management aims to change also the behaviour and consumption of customers and optimise the overall system.

This thesis studies the effects of the MCP-decree and the energy sector transition to a case company, Fortum, which is the biggest energy company in Finland. Fortum has multiple energy production units in the MCP-scope in it's district heating and cooling systems in Finland, and it aims to increase sustainability in its district heating and cooling production. The key driver to this thesis was the MCP-decree publication in Finland, but also sustainable solutions to district heating production were studied.

1.2 Objectives

The objectives of this thesis are approached by two research questions, which are stated as follow:

- How the MCP-decree is affecting to the existing energy production units in the case company? Are there any modification needed and how to perform them most effectively?
- How the peak load could be produced more sustainably in the case company?

The main objective of this thesis is to study whether all Fortum's existing energy production units in Finland in the MCP-scope fulfil the minimum requirements for gaseous emissions set by the MCP-decree. The first step in this study is to verify that all of the basic environmental requirements are fulfilled. If not, the second step is to study what kind of action paths there are to fulfil the requirements and how feasible are they. Furthermore, the third step is to study the possible action paths to increase the amount of renewable fuels in the selected case units. This includes a review of demand-side management utilisation to avoid gas oil usage in the peak load units. Also the possibility of pyrolysis oil or horse manure usage instead of primary fuels is studied on account of more sustainable production.

1.3 Limitations

From Fortum's existing energy production units in Finland only those units which are regulated by the MCP-decree are studied in this thesis. This includes a review of 44 energy production units located in Espoo, Kirkkonummi, Tuusula, Järvenpää and Joensuu areas. Only emissions regulated by the MCP-decree are studied in this thesis. The ETS and the amount of CO_2-emissions are not studied widely, but regarding to the discussion about the future of the district heating and cooling systems also the targets for the carbon dioxide reduction and renewable energy increase are discussed since they are in key role in the whole energy system.

This thesis concentrates only on the air pollution originated from energy production units in the scope. Air pollution requirements consist of flue gas emission limit values and monitoring requirements during and after the transition period. This thesis does not cover other requirements than flue gas requirements set by the MCP-decree, such as waste and wastewater processing. Legislative requirements are studied for existing energy production units only. Solutions proposed can be technical or techno-economical solutions e.g. limitation of the operating times or changing of the fuel type or quality.

1.4 Structure, methods and materials

This thesis includes theory and empiric parts. The theory part includes the theoretical background of the study, which consist of the basic theory of district heating and cooling systems and its current situation in the case company. The section includes a discussion of the future prospects of district heating and cooling systems. Fortum mainly uses its units in the scope to cover peak load needs, thus a special emphasis is put on the peak load production. The second theory part presents the legislational framework of the operation of MCP-units. The legislational review consist of a review of air protection requirements in Finland set by the MCP-decree and discusses the changes due to the implementation of the MCP-directive to the Finnish legislation.

In the empiric part the emission limit values and emission levels of the existing energy production units are studied before the MCP-decree implementation, during the transition periods and after the transition periods. As an output a complete up-to-date list with all relevant information of the units and their requirements will be produced. Also during the execution of this thesis a part of the units were registered in the environmental authorities data systems. Different scenarios are studied from environmental and economic perspective. DSM is one key scenario studied on account of decreasing the operation hours of fossil fuel-based boilers used to cover demand peaks in district heating systems. Scenarios chosen to be studied are based on Fortum's interests and internal calculation tools are used to model the production.

Information concerning Fortum's energy production units and production structure is based on the environmental permits and registration forms of energy production units, emission reports and the information from Fortum's employees and company's internal material. National and international articles and publications about energy systems have been used to examine national and global situation of district heating and cooling. The future possibilities have been studied already in multiple studies, master's thesis's, licentiate and doctoral dissertations, which have been used to constitute a comprehensive view of the future possibilities and challenges of district heating and cooling systems in northern countries. Internal material and insights have been available during the execution of this thesis and have been exploited widely.

2 DISTRICT HEATING AND COOLING

2.1 Introduction to district heating

District heating is the dominant heating method in Finland: currently the share of all the buildings connected to the district heating networks is nearly 50 % of all the residential, commercial and public buildings. District heating is the most popular heating method in new buildings. The sources of district heating vary from fossil and renewable fuels, such as coal and wooden fuels, to resources that will otherwise be wasted e.g. surplus heat from industrial processes. Even though the ongoing trend is to increase the amount of surplus heat utilised in all district heating systems, the current situation is that it represents only a tenth of all district heating sources in Finland. The sources of district heating and their shares in Finnish systems in the year 2017 are presented in figure 2. (Finnish Energy 2018a.)

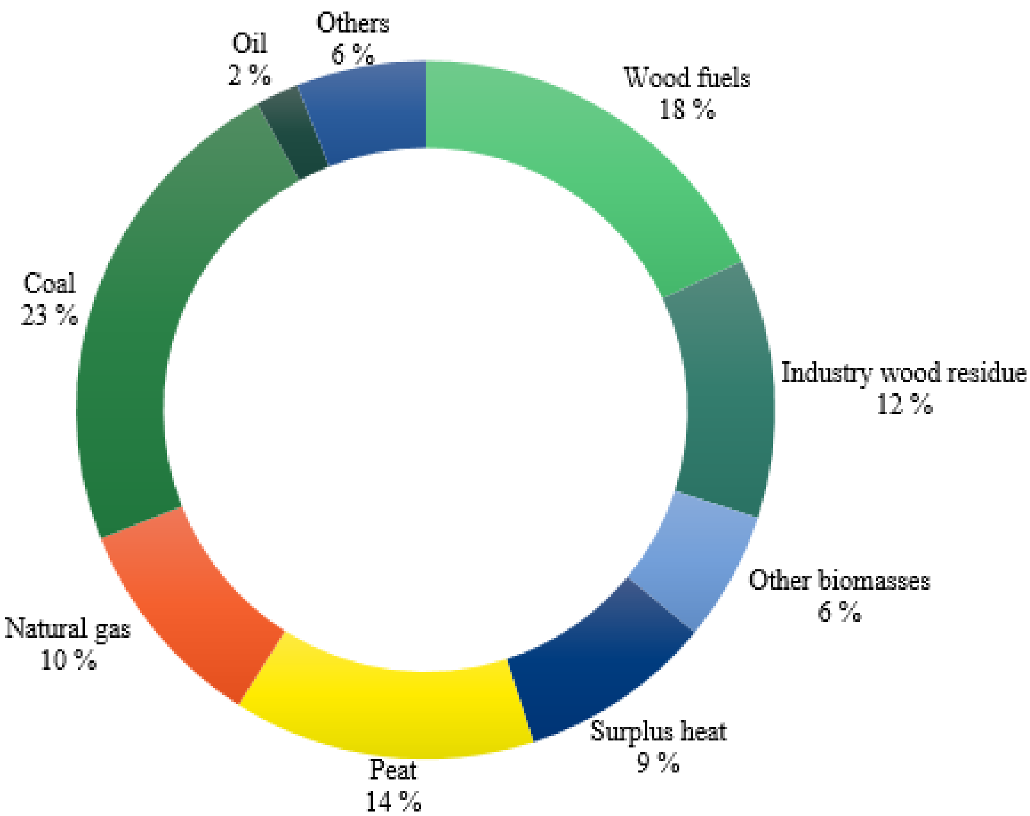

Figure 2. District heating sources in Finland in 2017 (Finnish Energy 2018a).

The basic principle of district heating system is to arrange the heat energy production in a centralised way and provide the heat energy to end-users via water flowing in distribution pipelines. Traditionally the circulating water in the district heating distribution pipelines is heated in boilers by combusting different fuels. The energy content from the fuel is transferred to the water in different kind of boilers. (Koskelainen et al. 2006, 282.) Surplus heat as an energy input does not require combusting of fuels, but depending on the temperature it might need heat pumps to increase the temperature of the water to be adequate to be utilised in the network.

Production and distribution of district heating are controlled usually by a company and the heat energy is sold to the customers. To work properly and profitably district heating systems require a suitable and affordable energy source or sources, demands from markets and pipelines to connect the production with the demand. The density of customers' location is a crucial factor and it's not feasible to build an entire network for only a few customers. Also the district heating pipelines have thermal losses. The best performance of a district heating system can be found in dense urban areas. The end-users use district heating to keep the indoor temperatures pleasantly warm and to heat the domestic water. Industrial customers can use district heating also to industrial processes. Furthermore, district heating can be used for example to maintain football fields or streets warm and unfrozen during cold months. (Frederiksen & Werner 2013, 21, 43; Skagestad & Mildensten 2002, 13.)

2.2 Production of district heating

The district heating demands vary significantly both seasonally and daily. The seasonal varying origins from the outdoor temperature changes: the heat energy needed to maintain pleasant indoor conditions increases when the outside temperature decreases. (Frederiksen & Werner 2013, 87.) At the summertime district heating is mainly used for production of domestic hot water and the total district heating demand can be less than 10 % of the winter peak capacity. The peak capacity refers to the highest district heating production possible in the specific district heating system. (Koskelainen & Saarela 2006, 41.) An example of the seasonal variation in the district heating system is presented in figure 3. This example is based on the Fortum's yearly production of district heating in the Espoo area. The x-axis starts from the 1st of January and the highest demands can be found from the beginning of the curve, when the outdoor temperature drops to –20 °C. Summertime consumption presented in the middle of the figure is clearly lower comparing to the sides presenting other seasons. As seen from the temperature curve in figure 3 during the reference year the temperatures were quite warm troughout the whole winter and the district heating production remained quite low.

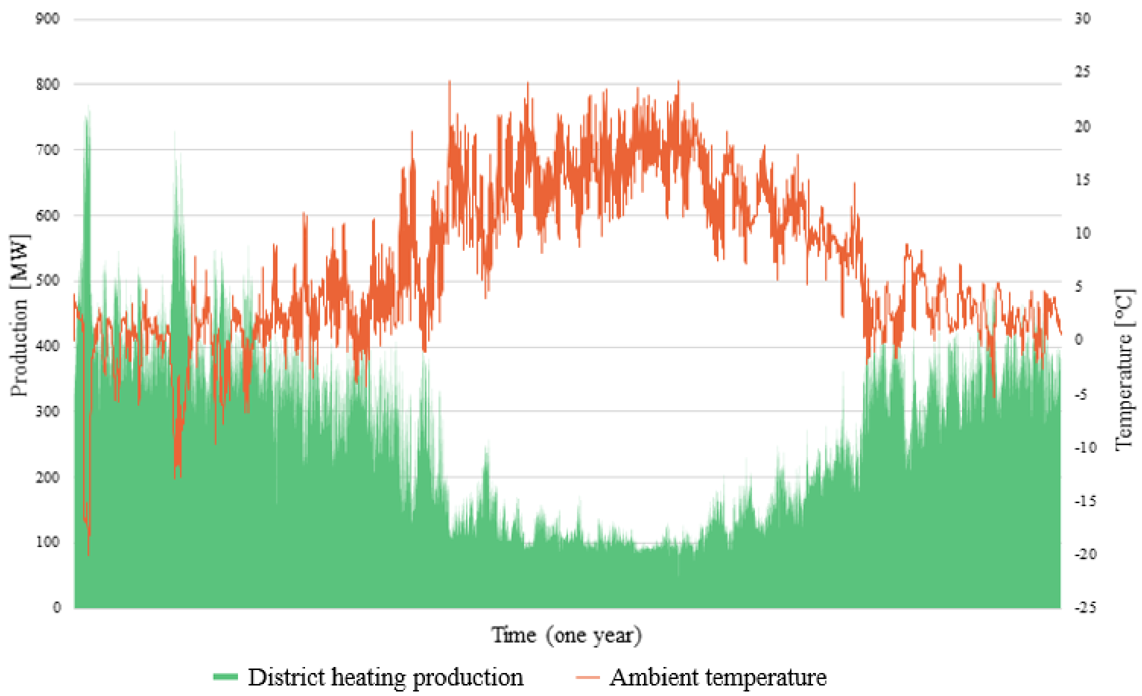

Figure 3. Correlation between the production of district heating and the ambient temperature in the Espoo district heating system during one year.

The daily variation in the district heating demands origins from the behaviour patterns of people. This phenomena is sometimes referred as "the social factor". The social factor causes increasing in the demands in weekday mornings when people wake up and start their morning routines and also in the afternoon when people come home from school or work. The daily district heating demand patterns differ based on the type of the building: apartments, offices, hospitals and warehouses all have different district heating demand patterns. (Frederiksen & Werner 2013, 87, 92.)

Figure 4 represents an example of the heat demand pattern in an apartment building in Sweden during one week in different seasons. Notable in this figure is that the daily variation is the highest during autumn and spring (red and purple lines) because of the high ambient temperature difference between day and night. At summertime the district heating demands are the most balanced. During wintertime the overall consumption of district heating is the highest, but the daily variation is smaller than during autumn and spring. (Gadd & Werner 2013, 179.)

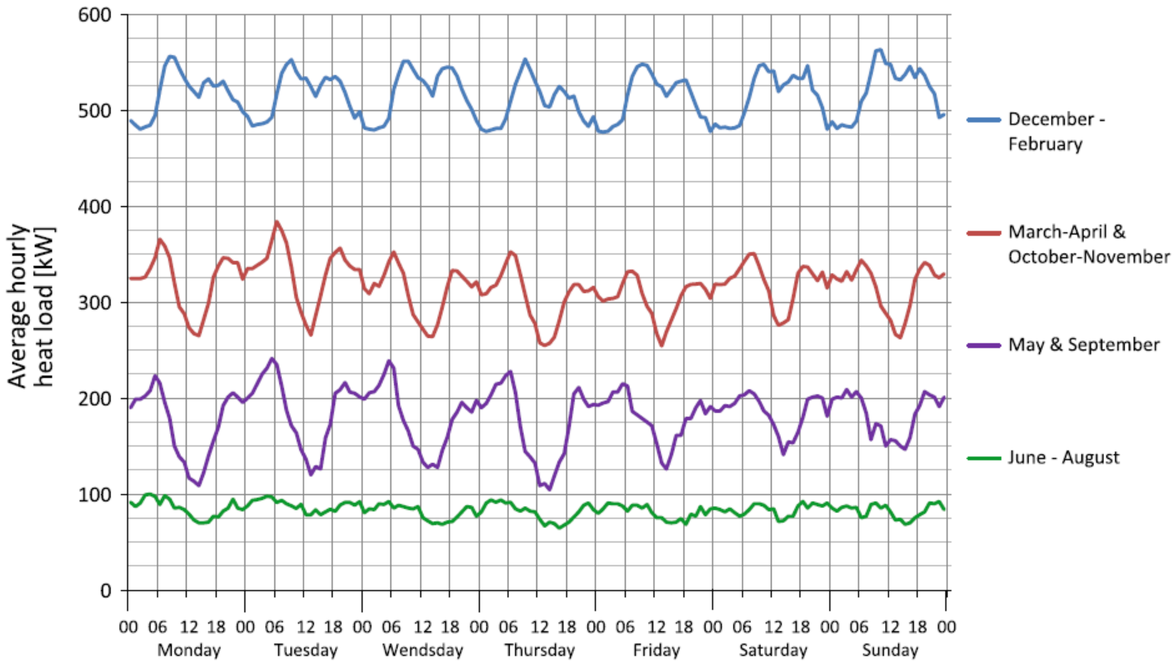

Figure 4. The heat load fluctuation during one week at different seasons of the year (Gadd & Werner 2013, 179).

Due to the seasonal and daily heat demand variation in centralised district heating systems it is feasible to divide production structure into several different loads: base load, mid load, peak load and reserve load. In smaller district heating systems this dividing might not be reasonable since there may not be multiple production units available to use. The alignment between different loads is not strict nor based on any exact thermal power, but the basic characteristics can be identified. The base load is according to its name the base of the production and is operated constantly as much as needed. The mid load is used to cover the fluctuating demands when the base load production capacity is not enough. It is also used during disturbances and revision times. The peak load units are used especially during the high consumption times, but can be used to cover disturbances and revisions. (Koskelainen & Saarela 2006, 42, 259.)

One simple tool to demonstrate yearly variation in the district heating production and different loads is the duration curve. An example of the duration curve is presented in figure

5. In this example the district heating production is presented as percentage of the total maximum district heating output. The referred year is the same than in figure 3, but the hours of one year are organised based on the hourly production of district heating from highest to lowest. The peak load units are in this example defined to be used when demands are 60 % or higher of the district heating capacity and also during the warmest hours during the year, which are in this curve in the end between 8000 and 8760 hours. The mid load units are used when the consumption is between 40 % and 60 % of the maximum district heating capacity and the rest is defined as the base load. The ambient temperature and its weekly rolling average are presented to clarify the dependency between the ambient temperature and the district heating demands.

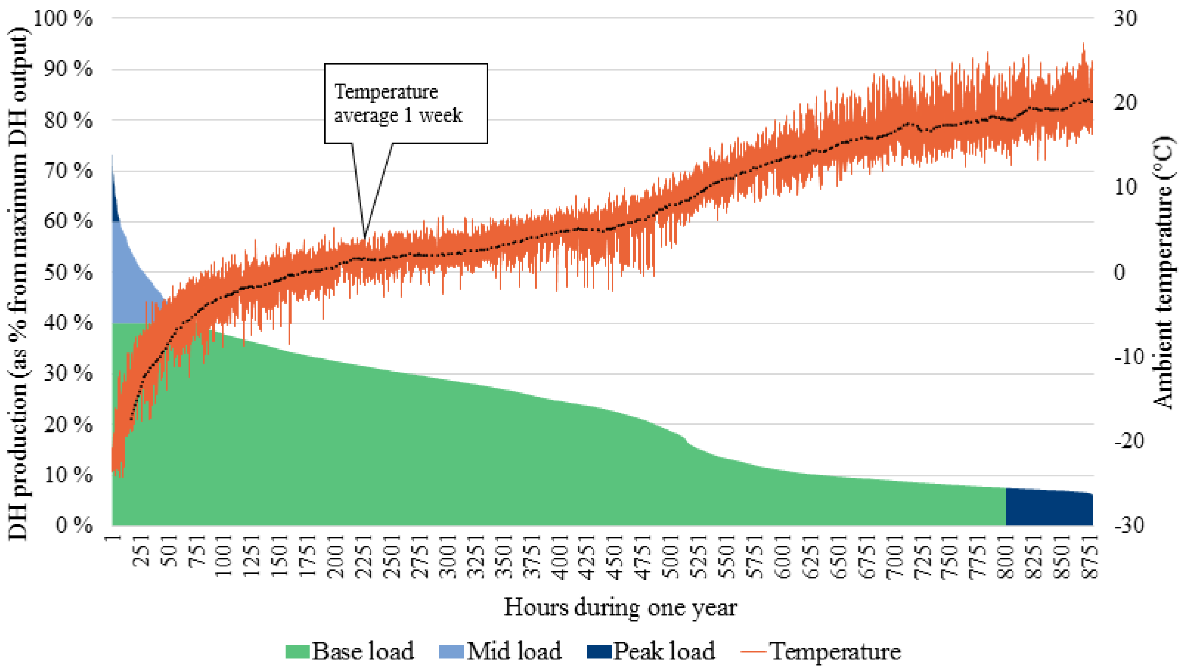

Figure 5. The district heating duration curve representing district heating production in the Espoo system during one year.

Typically energy production units used to produce the base load have high usability and low operating costs. If surplus heat is available to be utilised to the district heating system it is operated as base load. Surplus heat refers to heat which originates as a by-product from processes in which there is no possibilities to utilise it to any purpose. Without utilisation to district heating system, surplus heat might be conveyed to the atmosphere or to water areas, such as seas and rivers. Surplus heat is often produced constantly from industrial processes, thus it is the most reasonable to utilise to the district heating production as a base load. (Koskelainen & Saarela 2006, 259.)

The operating time of mid-load units is less than the operating time of base load units. One characteristic of a mid-load unit is, that it is often cost-effective also when using only part of the unit's maximum power. The peak and reserve load units have low investment costs and they are easy and fast to start, but their operating costs are typically higher comparing to the base load and mid-load units. The leading principle of the district heating production structure with different units is to start the units based on the needs arising from customers and based on the merit order. (Koskelainen & Saarela 2006, 259.)

Combustion-based district heating can be produced in heat-only boilers or in combined heat and power (CHP) units. According to the name a heat-only boiler (HOB) produces only heat energy. Multiple HOBs form a heating plant. HOBs can vary in size from less than one MW to hundreds of MWs. Typically energy production units with a thermal power less than 50 MW are HOBs. Depending on the size and characteristics of the district heating system HOBs can operate as a base load, mid-load or peak and reserve load units. HOB can be the only unit in an individual district heating system or support other energy production units in the system. The thermal efficiency of a HOB depends on the fuel used, technology, the sizing and the role of the boiler. Also solutions such as flue gas condensing can increase the thermal efficiency of a HOB (and also a CHP-unit). HOBs are built to one permanent location, but there are also small movable HOBs in use to cover temporary needs in the network. Temporary needs arise e.g. from disturbances in the system, bottlenecks in the distribution network or planned revisions of energy production units. (Mäkelä & Tuunanen 2015, 25–26; Jalovaara et al. 2003, 22; Koskelainen & Saarela 2006, 282.)

In the year 2017 in Finland approximately 30 % of the combustion-based district heating was produced with HOBs and 70 % was produced with CHP-units (Finnish Energy 2018a). CHP-units are combustion-based energy production units which can produce both electricity and heat energy in the same process. Electricity production in CHP-units is more efficient comparing to the separate electricity production by combustion. This is because if produced only electricity, after a turbine the partly cooled steam has to be condensed e.g. by using sea or river water or cooling towers instead of utilising the heat content. A significant amount of heat energy is lost in this process. In CHP-unit the heat content from the steam can be used in district heating after a turbine, and combined less inputs are needed comparing to the separate production of heat and electricity. (Mäkelä & Tuunanen 2015, 12–13.) Utilisation of the heat content requires that heating needs are present. The difference between cogeneration and separate heat and electricity production is illustrated in figure 6 by presenting the amount of the energy inputs of the both production ways. The difference between the cogenerated heat and electricity and the separate production by combustion is, that production of same amount of heat and electricity in CHP unit requires less energy inputs (35 energy units) than separate production. (Rajala et al. 2010, 21.)

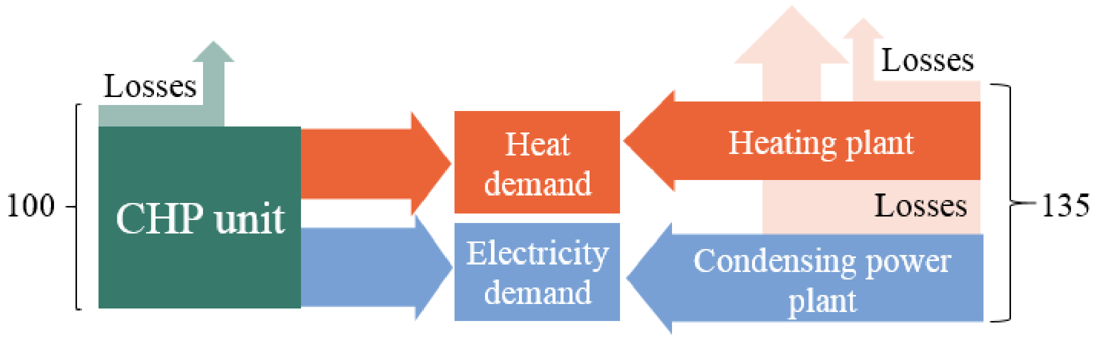

Figure 6. The difference between cogenerated and separate heat and electricity production by combustion (Adapted from Rajala et al. 2010).

Both CHP-units and HOBs can vary in size, but generally it can be said that CHP-units are larger in size than HOBs. According to Nock et al. (2012) CHP-units can be divided to three different categories based on their size; large, small and micro-sized units. There is no exact limit values for the size, but the total power of a large CHP-unit is measured in tens or hundreds of megawatts. Micro-sized CHP-units can have a total power of only tens of kilowatts and small CHP-units land on between large and micro-sized CHP-units. (Nock et al. 2012.) In larger district heating systems CHP-units are traditionally sized to cover the base load needs and HOBs are sized to cover the momentary peak load needs. Gas oil or natural gas-fired HOBs are faster to start than CHP-units using solid fuels in urgent needs.

In addition to the traditional combustion-derived energy production the district heating systems can include newer solutions: heat accumulators to short-term heat storing and large heat pumps to recover surplus heat from different sources. Heat accumulators offer flexibility to the district heating production, for example excess heat can be stored during nights when the domestic hot water consumption is low and then be used during the peak hours in the morning. Heat accumulators help to balance the energy load profile, and with large heat accumulators it could be possible to utilise all base load production even though the consumption does not occur simultaneously. (Paiho et al. 2016, 15–16.) Large heat pumps can recover the surplus heat e.g. from sewage water. Some district heating companies in Finland use heat accumulators integrated to the district heating systems. Fortum's heat accumulator located in Suomenoja area can store approximately 800 MWh heat energy in a 20 000 m^3 tank of water. (Fortum 2015.)

2.3 Distribution of district heating

The heat transfer substance used in the district heating distribution systems is steam or water. In the European district heating systems water is the most common way to transfer the heat energy from one place to another. Typically in Finland the district heating distribution pipeline is a two-way insulated pipeline: one pipeline is for supply water and another one is for return water. Majority of the district heating distribution pipelines in Finland are built underground which makes the distribution convenient and unvisible in the cityscape. In special cases distribution pipelines are built under buildings, above the ground or into the structures of bridges. (Mäkelä & Tuunanen 2015, 50.) A simplified basic principle of the district heating distribution system is presented in figure 7. The figure presents supply (red) and return (blue) district heating distribution pipelines and the inside circulation system of one house.

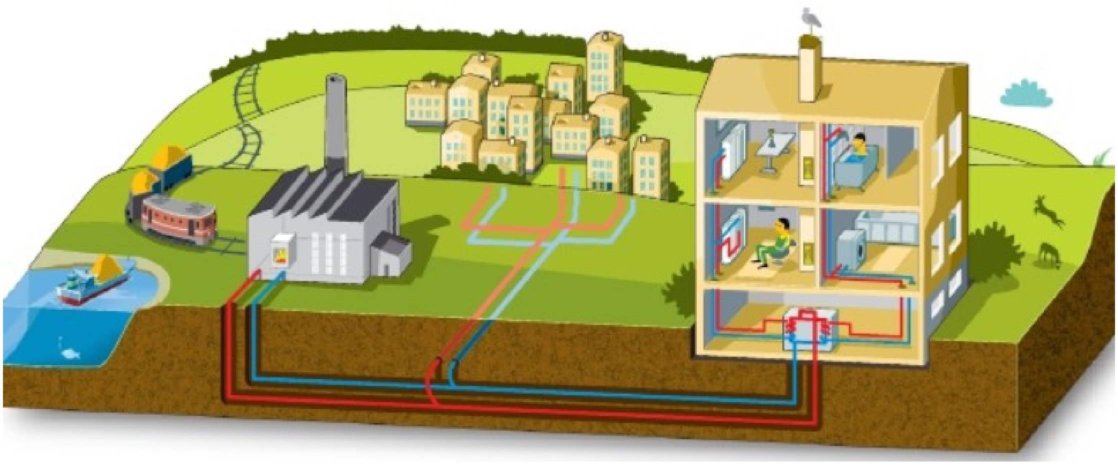

Figure 7. The basic principle of the Finnish district heating system (Fortum internal material).

The district heating distribution system inludes primary and secondary circulation systems. The heat transfer substance circulates from the production sites to the end-user sites in the primary network. Water in the primary cicrculation system is heated in the energy production units' boilers and pumped to the customer sites. At the customer site in the heat substation the heat energy is transferred from the primary distribution pipeline to the house-specific circulation systems. House-specific system is the secondary side of the distribution system. In the secondary system the heat is used to warm the building and to the domestic hot water production. When the heat is transferred from the primary side to the secondary side the temperature in the primary side decreases. Cooled water is then recirculated back to the energy production units to be heated again. (Mäkelä & Tuunanen 2015, 11; Fredericksen & Werner 2013, 57.)

The district heating producer controls the temperature of the supply water based on the outdoor temperature. Common temperatures used in the district heating supply vary, but typically the temperature is between 70–120 °C. The highest supply temperatures occur during wintertime, because when the outdoor temperature decreases, more heat energy is needed to maintain the warm indoor conditions. Higher temperature in the supply water enables longer transport distances and higher heat content to be utilised in the house heating. When outdoor temperatures decrease, in the customer heat substation more energy is transferred from the supply water to the house-specific circulation system and the temperature of the return water decreases. Thus the temperature difference between return and supply water is increased, and more energy is demanded from the boiler. Thermal losses in the pipeline increase if temperature difference between ambient temperature and pipeline temperature increases. (Koskelainen et al., 2006, 29; Mäkelä & Tuunanen 2015, 50.) Thermal losses in district heating pipelines are approximated to be 4–10 % in larger pipelines and 10–20 % in smaller pipelines. Smaller pipelines have bigger thermal losses because there is more surface compared to the transform capacity of the pipeline. (Koskelainen et al. 2006, 203.)

2.4 District cooling

Currently district cooling demand in Finland is about one hundredth compared to the district heating demands, but the consumption of district cooling has been growing rapidly during last 15 years. During 2017 the district cooling sales were approximately 223 GWh, when in

2003 the sales were approximately 20 GWh. (Finnish Energy 2018b.) Both district heating and district cooling are distributed via a two-way insulated distribution pipelines from the production sites to the consumers. District cooling is used for example in office buildings, hotels and public buildings to cool down the indoors for more pleasant surroundings. District cooling is also used in different industrial processes. A growing trend is to cool residential buildings, thus the district cooling demands are predicted to grow even more in the future. (Koskelainen & Saarela 2006, 26.)

District cooling is mainly produced with refrigerant machines using absorption, with heat pumps, with compressor driven chillers or by free cooling. The sources of district cooling can be e.g. electricity, sea water or river water. The shares of the district cooling methods used in 2017 Finland are presented in figure 8. (Finnish Energy 2018b.)

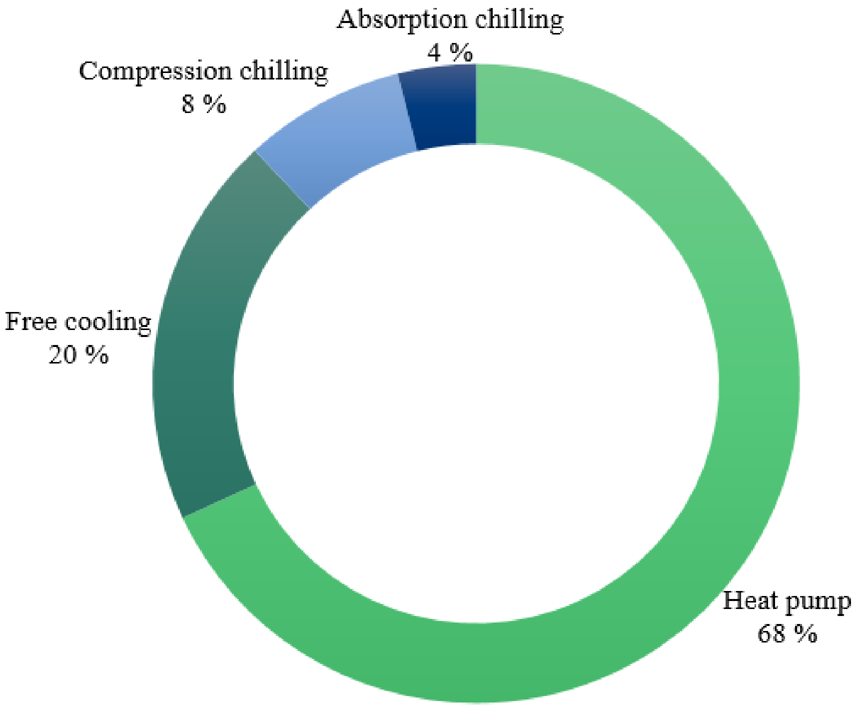

Figure 8. The district cooling production methods in Finland in 2017 (Finnish Energy 2018b).

Heat pumps in the district heating and cooling systems are usually originally invested to be used for surplus heat recovery to the district heating system. Same heat pumps can be used also to produce district cooling. Without the waste heat recovery the amount of heat pumps used in the district cooling production would not be so high. Heat pumps are used to recover the heat from low-heat sources and transfer the heat to its destination in a higher temperature than in its source. Heat pumps can be based on absorption or mechanical work. Main parts of mechanical heat pumps are evaporator, condenser, compressor and a refrigerant which circulates in the process. In the evaporator the pressure of the refrigerant is decreased, which causes the refrigerant to evaporate. The energy needed for the evaporation process is received from the heat source. Energy transfer causes the temperature to decrease in the heat source. In the compressor the pressure of the refrigerant is increased causing the refrigerant to transform back to liquid phase. The process from vapour phase to liquid phase releases the heat energy to destination. (Maaskola & Kataikko 2014, 15–16.)

In compression chilling an electricity-driven compressor is used to produce cooling. Heat pumps and compression chillers have similar processes, but in this classification heat pumps' condensation heat is utilised to the district heating systems, while the condensation heat from the compression chilling is not utilised to any purpose. (Laitinen et al. 2016, 8.)

Absorption chilling utilises heat which can be originated as surplus heat from industries or from the heat production (Werner 2017, 8). The absorption process is based on two liquids: the solvent and the absorbent and their behaviour as a substance pair. In a certain pressure and temperature there is a balance between the vapour and the gas absorbed to liquid. When the temperature or pressure changes, vapour is released or bonded. The heat-binging process is used to produce cooling. (Laitinen et al. 2016, 19.)

Free cooling utilises natural cold sources, such as sea water or cold air, to cooling purposes. Utilisation of free cooling requires the cold source to be cold enough. Free cooling is used mostly for process cooling and office cooling during wintertime. Free cooling itself can be the only cooling source when the source temperature is lower than the required process temperature or the indoor temperature. During warmer seasons other solutions are required if efficient cooling is pursued. (Koskelainen et al. 2006, 531.) Seasonal cold storages could be used to store cold water from colder season and utilise it to the district cooling system during summertime (Werner 2017, 8).

2.5 Profitability of district heating and cooling

District heating and cooling in Finland is operated in the form of business. District heating and cooling companies sell their product, district heating and/or district cooling, to customers with a profit margin. Operational costs from the district heating and cooling production and distribution origin e.g. from the maintenance needs in the district heating and cooling systems and from fuel procurement. Operational costs could be reduced e.g. with more efficient energy production or with lower priced fuels. If there is multiple energy production unit used in one district heating and cooling system, existing units are started up based on the merit order. The merit order is formed based on the production costs of each different unit and the aim is to produce district heating and cooling as cost-effectively as possible. The factors affecting to the merit order are the type and efficiency of the unit (CHP or HOB), the fuels used and the size of the unit. (Koskelainen et al. 2006, 25–26; Sun et al. 2016, 325.)

There is some characteristics of monopolies in the district heating and cooling systems and they can be referred as natural or regional monopolies. These characteristics of monopolies origin from the massive investments to district heating and cooling production units and distribution pipelines regionally: there is no possibility to support multiple systems in the same area without losing the scale benefits. Because of this there is no real competition between the district heating and cooling companies in traditional district heating and cooling sales. Customers still can choose their heating method freely: heat pumps or electricity heating can be used to provide all or part of the heating or cooling needed in the house. (Koskelainen et al 2006, 29–30.) When located in one district heating company's area there is no possibility to join to another company's district heating system.

Pricing of district heating is usually implemented in multiple parts: it can include connection fee, energy fee and capacity fee. The connection fee is paid when a new customer is connected into the network. In Fortum the energy fee is based on the consumption and the capacity fee is a yearly fee based on the connection capacity. The energy fee can be the same all year round, season-specific or month-specific. Fortum's district heating prices vary monthly. (Fortum 2018f.)

2.6 Possibilities and challenges of district heating and cooling

The strenghts of district heating are energy efficient combined heat and power production and the possibility to utilise multiple different heat sources into the same district heating distribution system. For the consumers district heating is an easy and carefree solution to fulfil their space heating and domestic water needs. (Koskelainen et al. 2006, 25.) Also the smooth operation and reliability is the foundation of the success of district heating system (Finnish Energy 2013, 6.). There are synergies between the district heating and the district cooling systems and it is possible to utilise the waste heat from cooled buildings to the district heating production with heat pumps. The synergies between the systems leads to more efficient systems. (Jing et al. 2014, 414.)

Constant development is needed if the traditional district heating companies want to keep up in rapidly changing markets. Even though in Finland the traditional district heating distribution network is sometimes seen as old-fashioned and unflexible way to transfer heat, it is identified also as an enabler in the energy system transition. This is because the existing networks provide a possibility to utilise multiple different heat sources into the same, already existing distribution network. (Hakkarainen & Paiho 2018.) In the best case surplus heat or geothermal heat can be utilised to the district heating distribution network without any additional investments. This requires that district heating pipelines are located close. Digitalisation brings possibilities and challenges for district heating companies. Improving energy efficiency in new buildings and availability of alternative heating methods decrease the need for traditional district heating.

Digitalisation enables development of new products and services for the customers and optimisation of the production and distribution. (Deloitte 2016, 6.) New solutions can be totally new solutions or services, which decrease the effort required from the customer (Finnish Energy 2013, 6). One example of a new service is Fortum Liisi, which is a leasing service in which only monthly fee is paid by the customer and no investment for heat transfer station is needed. Fortum takes care of the maintenance of the heat transfer station and no effort is required from the customer.

The challenges in the district heating systems origin from significant investment costs to the production units and to the distribution pipelines. Partly same aspects (large centralised CHP-units) which are traditionally identified as strenghts can appear also as rising challenges. As big investments are made to the energy production units and to the distribution pipes, major system changes are expensive to execute. Other challenges origin from the thermal losses in distribution pipelines which cause district heating and cooling not to be a feasible solution for sparsely populated areas. (Koskelainen et al. 2006, 25.)

Tightening environmental requirements set challenges to the district heating producers. The district heating systems with multiple combustion based units will face challenges due the stricter emission limit demands from legislation. Also the Finnish climate targets to make the society coal-free set pressures for energy producers, but will bring competitive advantage in export when new solutions are needed around the world. To achieve all of the targets there is major investment pressures to the existing energy systems and for cleaner technologies. The aim of the instruments such as the ETS is to promote investments to low-carbon technologies with robust carbon price and thus guide the energy producers to more climate-friendly solutions. (European Commission 2018c.)

2.7 District heating and cooling in the case company

Fortum has a vision called "for a cleaner world" and its mission is to engage the customers and the society to drive the change towards a cleaner world. Fortum has four strategic priorities (figure 9), which are to pursue operational excellence and increased flexibility, to ensure value creation from investments and portfolio optimisation, to drive focused growth in the power value chain and to build option for significant new businesses. (Fortum 2018c.)

Figure 9. Fortum's strategic cornerstones (Fortum 2018c).

Fortum has core operations in 10 countries worldwide. These are Finland, Sweden, Norway, Russia, Poland, Lithuania, Latvia, Estonia, India and Denmark. Fortum's organisation consist of four business divisions: Generation, City Solutions, Consumer solutions and Russia divisions. In addition to the divisions, Fortum has two development units focusing on growing new businesses: first one is called "Technology and New Ventures" and second one is called "M&A and Solar and Wind Development". Fortum's services and solutions are electricity retail sales, district heating and cooling, services for smart living, electric vehicle charging solutions, recycling and waste solutions, products and services for nuclear and thermal power plants and power trading services for energy-intensive industries. (Fortum 2018a; Fortum 2018b.)

Fortum's district heating and cooling business is a part of Fortum City Solutions division. City Solutions division aims to develop sustainable city solutions into a growing business. City Solutions division comprises of district heating and cooling, waste-to-energy solutions and other circular economy solutions. Fortum has district heating operations in Finland, Sweden, Latvia, Lithuania, Estonia, Norway and Poland. (Fortum 2018a; Fortum 2018b.) Fortum's global production in the year 2017 was 29 TWh of district heating. In Finland Fortum has a heat capacity of 2 GW. (Fortum 2018h.)

Fortum sees that the existing district heating and cooling systems can support the battle against climate change with multiple different solutions. Efficient district heating and cooling system utilises all surplus heat available to the district heating production and the district heating network is used not to only distribute, but also to store the heat energy. Sustainable district heating inputs are for example renewable fuels and waste heat from industries and data centres. Energy is used optimally and less energy is wasted. These solutions are presented in figure 10. (Fortum media bank)

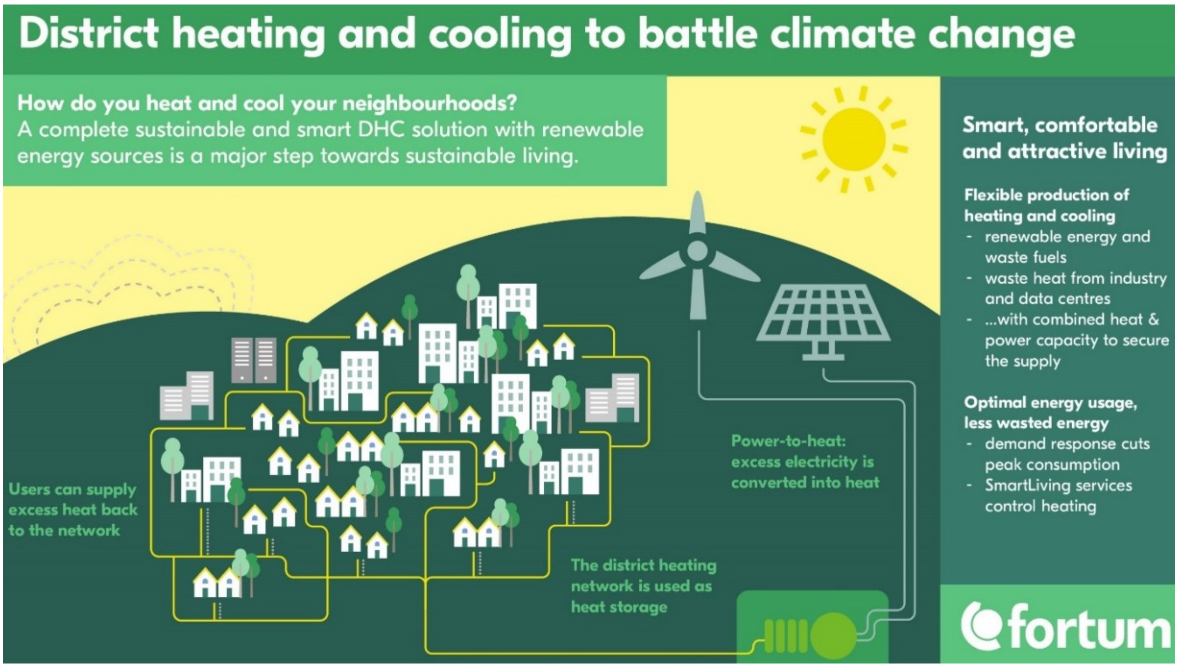

Figure 10. A smart and sustainable district heating and cooling solution (Fortum media bank).

Because of the energy sector transition the pressure to develop more sustainable solutions for energy production in district heating and cooling systems are high in Fortum. In addition to the traditional sources, such as combusting of fossil and biomass fuels, Fortum has a wide selection of newer solutions in use. Some solutions which are implemented to the district heating production in Fortum are presented in figure 11. There are two heat pumps utilising heat from waste water, two HOBs utilising biogas from a closed landfill as a fuel and waste heat utilisation from datacenters used in the existing district heating systems. Fortum uses horse manure as a fuel in its own boiler and also has a horse manure service for staples and energy producers. Fortum produces pyrolysis oil in the Joensuu area and uses it as a fuel in both the Joensuu and Espoo areas. An open district heating concept was implemented during spring 2018. The open district heating refers to system to which small-scale producers can sell their excess heat energy. Fortum has made a commitment that district heating is carbon-free in Espoo by 2030 and committed to produce 80 % of district heating in Joensuu with renewable fuels by the year 2025.

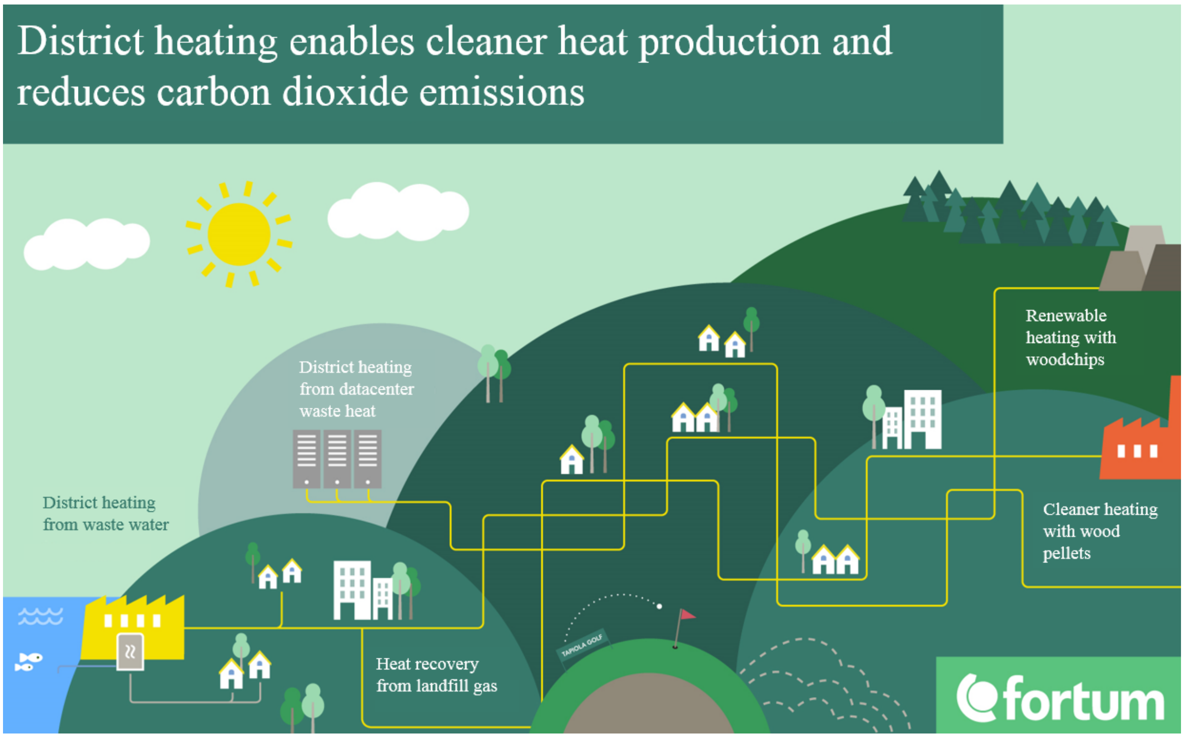

Figure 11. Sustainable sources used in the Fortum's existing systems (Fortum internal material).

2.8 Future of district heating and cooling

The existing district heating system is often referred as the 3rd generation district heating system. In the 1st generation district heating system the main heat sources were coal and waste. The efficiency in the 1st generation system was quite poor and supply steam temperature was as high as 200 °C. Transformation from the 1st generation to the 2nd generation happened according to Lund et al. (2014) in the 1930's. In this transform CHP-units were included to the district heating production methods, energy efficiency increased and the supply temperature decreased. The current situation, the 3rd generation district heating, includes insulated distribution pipes, renewable fuels and surplus heat in addition to the sources used already in the 1st and 2nd generation systems. The energy efficiency is better and supply temperature is lower than in the 2nd generation system. (Koskelainen & Saarela 2006, 32; Lund et al. 2014.)

In the future the 4th generation district heating system is expected to utilise multiple energy sources and to use lower temperatures in the distribution network. Also one key element in the 4th district heating system is intelligence and the fact that the customers will be producers in the same tame. Sometimes consumer being simultaneously a producer is referred as the "prosumer". The 4^{th} generation district heating system requires smart ways to operate the whole system to gain the most optimal outcome. Multiple solutions, such as seasonal thermal storages, two-way district heating and large-scale utilisation of renewables, are included to the 4^{th} generation district heating systems. (Lund et al. 2014.) There is a growing interest for decentralisation in Finland and it will alter the existing situation in the district heating and cooling systems. All of these future aspects are discussed in the following sub-chapters.

The energy sector itself is extremely complex and there is not only one solution to achieve the targets, but many different technologies and solutions which can coexist and which will disrupt the existing energy systems. Also it is not simple nor easy to say what kind of consequences does an action have in the complex energy system. The existing systems can appear as barriers to the new solutions since the mind-set often is to use the existing equipment and establishments until the end of their life cycle.

2.8.1 Decentralisation

The traditional district heating system is a centralised system with one or multiple large energy production units. The decentralised energy production usually refer to locally produced and consumed energy; electricity, heating or cooling, which is produced with local renewable sources. Often the prosumers introduced in previous chapter are associated with decentralisation: in the future energy system the customer buildings are not only potential energy users, but also energy storages and energy producers. Some examples of the technologies used in the decentralised heat production are small boilers utilising local biogas and wood residue, different heat pump solutions or solar panels. Strict alingnment between centralised and decentralised production is difficult to specify, but key factors are small-scale production and locality of the heat source. (Pesola et al. 2010, 6.) Decentralised heat energy can be delivered in a totally isolated system or in an area heating system. In an isolated system all of the produced heat energy is consumed at the production site. The area heating refers to a system in which the heat energy produced is distributed to a few customers near-by. The larger district heating networks with centralised units usually cover big and dense inhabitated areas in the cities. (Vihanninjoki 2015, 1–6.)

The non-fossil energy sources are one argument explaining the growing interest in a decentralised systems during few last years. Furthermore, energy self-sufficiency is a tempting factor. Decentralisation has been happening already and its role might grow to be even more significant in the future. One notable example of the growing interest to decentralisation in Finland is the increased amount of sold heat pumps which has been growing rapidly during last decade. The most popular heat pumps are air-to-air heat pumps. Also ground source heat pumps have gained more popularity. One advantade of a heat pumps is that they can also be used to produce cooling. The cumulative heat pump sales presented as sold heat pumps in Finland is presented in figure 12. AAHP refers to air-to-air heat pumps, AWHP refers to air-to-water heat pumps, ExHP refers to exhaust air heat pumps and GSHP refers to ground source heat pumps. Especially the amount of air-to-air heat pumps and ground source heat pumps have been growing, as seen from the figure. (Sulpu 2017.)

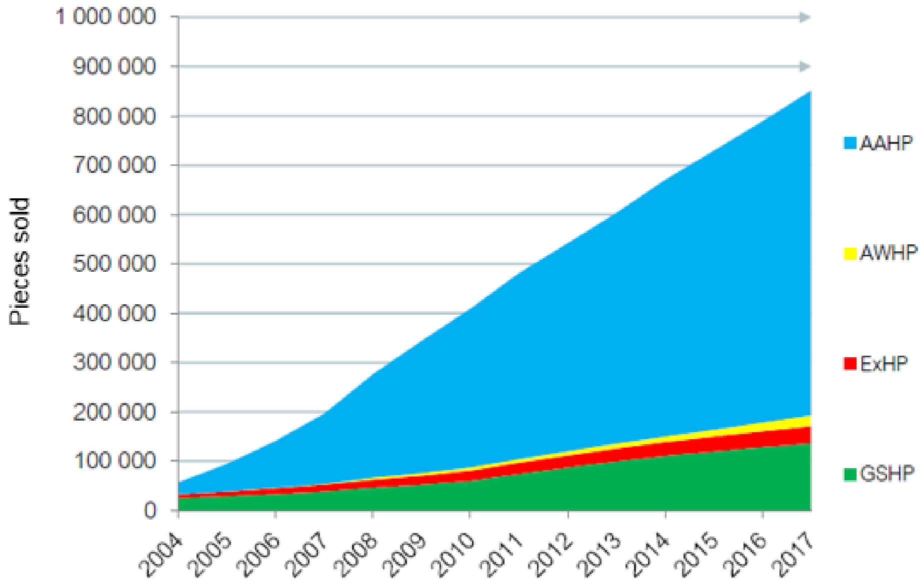

Figure 12. Cumulative heat pump sales in Finland (Sulpu 2017).

In some cases it is possible to utilise the surplus heat from the decentralised heat production to the existing district heating systems. In this case the production location should be close to the existing district heating network for the utilisation to be feasible. Feasibility depends on the amount, the location and the temperature of the surplus heat. And depending on the temperature, surplus heat is transferred either to the supply or to the return line. At the moment Fortum has a few customers utilising their surplus heat to the district heating network. (Fortum 2018d.) In the future low-temperature district heating systems could make the utilisation of surplus heat more easier, because then less heat pump capacity is needed to make a temperature increase to the low-temperature surplus heat before it can be utilised in the district heating system. At the moment in the district heating distribution systems the supply water temperature can even exceed 100 °C, which might be a problem for the surplus heat utilisation. In the low-temperature networks the supply temperature can be as low as 40 °C. Lund et al. (2014) predicts that the low-temperature networks will play a major role in 2020–2050 in the 4th generation district heating systems. (Lund et al. 2014, 3–9.)

2.8.2 Seasonal thermal energy storages

A seasonal thermal energy storage in the district heating and cooling system refers to a storage which can store the thermal energy up to several months. In addition to heating, thermal energy storages can be used as cold storages. Currently the thermal energy storages used in the district heating systems are large tanks of water in which the excess heat is stored for future use short-termly. These are often referred as heat accumulators. The seasonal storages are being developed, but are not widely used yet. For example the Arlanda airport has the world's biggest water storage which is storing and providing heat energy during winter and providing cooling during summer to the airport. (Retermia 2018.)

The key challenge in the seasonal thermal storages based on water is the thermal losses. As stated in the basic thermodynamics, the temperature difference between two systems tends to form a thermal equilibirium. So the heat energy from the thermal storage tends to transfer to the colder outdoor substance if possible. An underground thermal energy storage provides one solution to decrease the thermal losses: below a depth of 10–15 meters the temperature remains stable and doesn't change according to the seasons. (Lee 2013, 15.) Temperature in this depth equals to annual ground surface temperature. In Finland it is estimated that in in the southern Finland the temperature below 15 meters remains 6–8 °C all year round and in the northern Finland the temperature below 15 meters remains 1–2 °C all year round. (Geological Survey of Finland 2018.)

The seasonal thermal energy storage underground can be constructed to an aquifer, to a borehole or to a cavern. In an aquifer thermal energy storage groundwater is extracted using a water well and water is conveyed to a heat exchanger. Water is then discharged to a surface water body or injected back to the aquifer. For heat storing the storage efficiency is 50–80 % (Lee 2013, 63, 59.) If no groundwater areas are available, borehole thermal energy storages can be used. Borehole thermal energy storages require either horizontal or vertical loops for thermal energy storing. Vertical loops are more expensive than horizontal, but require less pipelines. Borehole thermal energy storages include different applications: one- or multiple boreholes in different designs. (Lee 2013, 95, 101.) Large borehole thermal energy storages have an annual thermal loss of approximately 10–15 % (Lee 2013, 117). Cavern thermal energy storages require underground cavities, which can be e.g. abandoned mines or tunnels or rock caverns. Artificial caverns are possible to be made, but require massive investments. In the beginning of cavern thermal energy storage energy losses are high, but during one or two years when the situation is stable the thermal losses should be less than 10 %. (Lee 2013, 125.)

The mass of the building can act as a thermal storage also. The building materials, such as concrete or bricks, can store heat energy and balance the fluctuation in the inside temperatures during one day. For example the house structures can store solar heat so that the inside temperatures can be warm enough during nights without any additional heating. This is called a passive utilisation of solar energy. (Motiva 2016.) Also demand-side management utilises buildings' heat-storing properties. Furthermore, the existing district heating distribution network is basically a one big tank of water and it could be utilised also as a thermal storage, not only as a heat distributer.

2.8.3 Demand-side management

The term demand-side management (DSM) refers to energy consumption modification aiming to balance the energy load profile. Valor Partners Oy (2015) defines district heating DSM as "shifting of the district heating consumption in time and thus adjust the timing of heat power needs comparing to the usual consumption without endangering the quality of service". The term DSM have been used widespreadly, but it shouldn't be used to refer to actions aiming to increase the energy efficiency or to any district heating consumption restrictions. (Valor Partners Oy 2015, 5.) Traditionally the basic operating principle of the district heating system has been to fulfil the fluctuating customer needs by starting up or shutting down available energy production units. Now the spotlight has moved also to the customer side. (Johansson 2014, 32.) The leading target of DSM in the district heating systems is to balance the production, not so much to decrease the absolute amount of the heat energy consumed and produced. The reduction of the total amount of the consumed heat energy requires e.g. permanent indoor temperature reductions.

In the electricity side DSM has been in use longer than in district heating. There are similar analogies but also differences between electricity DSM and district heating DSM. The basic principle behind methods used to balance the energy loads are similar, but bcause district heating system operates with a longer time constant, the outcomes are different. In the electricity side the effects of electricity cut-offs are instantly visible. If the supply of district heating is reduced, consequences can be notable only after few hours in space heating and might not be notable even then. If all heating is cut off, domestic hot water is not available. This is why the domestic hot water production is excluded from district heating DSM. Long time constant creates possibilities for district heating DSM: the heat supply decreasing to even zero percent affects to the indoor temperatures moderately slow and it takes multiple hours to be notable. If the supply is reduced to only some ten or twenty percentage comparing to normal situations the reduction in indoor temperature is small and slow. (Valor Partners Oy 2015, 5.)

In figure 13 is presented an example of the time it takes for a building indoor temperature to drop 3 °C at different levels of heat supply. From the figure it can be seen that if the energy supply is reduced to 0 %, it still takes up to 4 hours to the indoor temperature to drop 3 °C. (Johansson 2014, 38.)

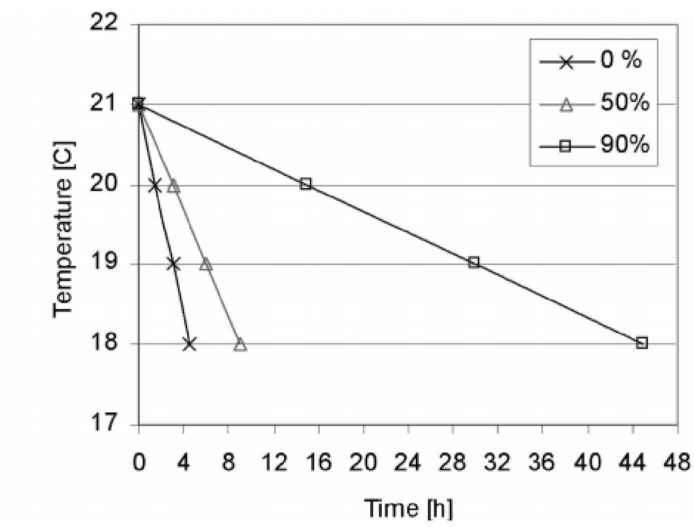

Figure 13. An example of the time constant at different levels of energy supply (Johansson 2014, 38).

DSM operations to balance the energy load profile are peak clipping, valley filling and load shifting (Johansson 2014, 33–34). In peak clipping the energy consumption is reduced during the peak hours and in valley filling the consumption of energy is increased during the lower demands. In load shifting the time of the consumption is shifted from the peak hours to hours with lower demands. Load shifting includes characteristics from both valley filling and peak clipping. In figure 14 is presented a simplified examples of peak clipping, valley filling and load shifting. In the figure the blue curve represents the energy demand without the DSM. (Wang et al. 2014, 667.)

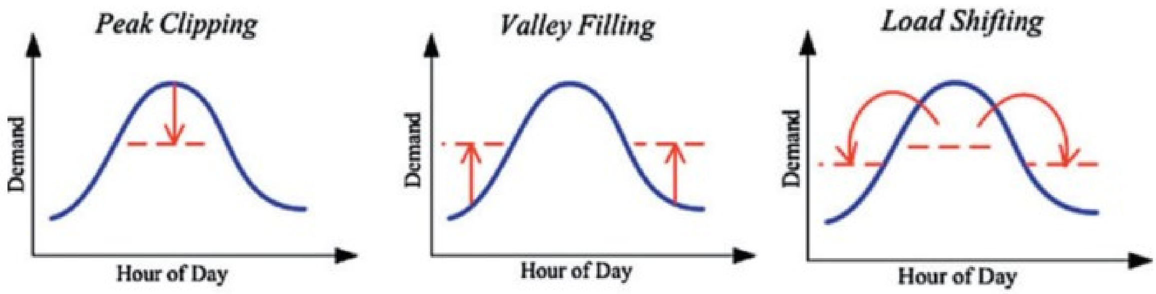

Figure 14. Examples of DSM operations to balance the energy load profile (Wang et al. 2014, 667).

Load shifting is not always occuring during the peak hours: sometimes it could be feasible or beneficial for the producer to shift heating loads outside of the peak hours. In the load shifting the valley filling action can start before the excpected peak hours and thus load the heat energy into the buildings in advance. In this way the peak clipping can be executed unnoticeably to the consumers.

The benefits from district heating DSM origin from decreased usage of peak load units and smoother operation of the whole system. In multiple district heating systems production in base load units is more cost-effective comparing to peak load units, which is why the load is wanted to shift. Fewer start-ups and decreased usage of the peak load units reduce the energy production costs and the usage of start-up fuels. In the long-term investment to a new peak load unit could be postponed or even avoided due DSM implementation. It is important to remember that all district heating systems differ from each other and not all and equal benefits are gained in the different systems. There are characteristics recognised which can increase or decrease the benefit potential of DSM. The factors increasing the benefit potential of DSM are poor possibility to heat storing, significant differences between production costs in different units, scarce-sized production units, availability of volatile surplus heat and non-optimal district heating network. (Valor Partners Oy 2015, 5, 14; Johansson 2014, 33.)

The district heating companies esimate that with existing solutions the implementation of DSM could bring 1–3 % reduction in the yearly costs. With simulations the theoretical long-term savings can be up to 5–25 % from the total costs. (Valor Partners Oy 2015, 25, 28.) A study was executed conserning utilisation of district heating DSM to Jyväskylä area, where there is a district heating network with approximately 300 MW peak capacity. In this case study DSM was used in the mornings between 6–9 am in approximately 160 customer buildings, one customer building has a heated area of 20 000 m^3 or more (connection capacity >500 MW). In the case study if there was a HOB using heavy fuel oil as a fuel, which could be shut down or its start-up could be avoided, cost savings were gained. As a result there was 131 possible shut downs or avoided start-ups of the energy production units found due the implementation of DSM. The total cost savings were 13 000 €/a with a maximum momentary peak cut of 20 MW of the total heat supply in the system. The cost savings in this case originated from lower the fuel costs, the net profit of back-pressure CHP electricity sales and the avoided fuel usage during start-ups and shut-downs. Also in this study the possibility to avoid investment in a new HOB was compared to DSM implementation. If the district heating company saves an investment to a 20 MW HOB, which equals to approximately 1,8 M€, because of DSM the annual additional savings would be 144 000 €/a (with an interest rate of 5 % and divided to 20 years). (Kärkkäinen et al. 2003, 68–73.)

The theoretical potential of DSM in Helsinki district heating system was studied by Kontu (2014). The aim was to study if residential buildings could act as short-term heat storages without having more than 1 °C drop in the indoor temperatures. In Helsinki district heating system the share of residential block buildings is 54 % from all of the district heating customers' measured space area. The DSM potential is calculated based on the realised consumption during year 2012. Building stock connected to the district heating system in Helsinki was divided based on the age of the buildings, since characterises of the building affect how the building responses to heat reduction. In this study simulations heat was cut off for one hour on every weekday morning at 7 am. The results from this study are presented in figure 15. In the figure the grey line represent the total district heating consumption without DSM in every day at 7 a.m. in the system and the bars represent the simulated maximum decrease in heat demand by DSM at 7 am in residential buildings of different ages. Simulation was conducted so, that DSM is not implemented if it is estimated that during heat cut-off the indoor temperature reduces more than 1 °C. The theoretical potential for DSM in this study was estimated to be 1 percent of the total district heating supply. Momentary effect was much larger, up to 80 percent. (Kontu 2014, 70.)

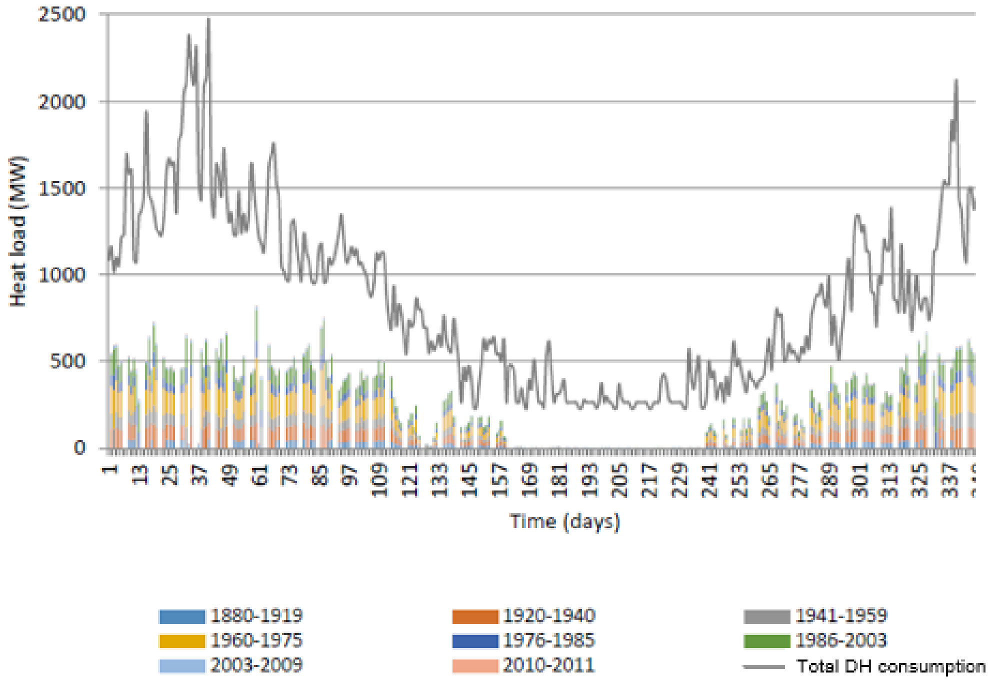

Figure 15. Maximum daily potential of DSM in buildings in Helsinki district heating system during year 2012. (Kontu 2014, 70).

In district heating DSM there has to be a significant amount of individual buildings connected to the system to gain benefits. The customer needs to have an interest to participate in DSM, which can be created by environmental or economic incentives. It is not certain whether the customer would participate on DSM without any economic compensation or not, but from electricity DSM it has been noticed that customers generally require some kind of compensation in order to participate in DSM. On the other hand there is reports showing that the customers are ready "to save the planet" without any compensation. (Johansson 2014, 33–34, 46.) Utilisation of DSM can be executed e.g. by a dynamic pricing, in which the purchase price of district heating follows the production costs. Dynamic pricing would work on market terms, but for it to function properly the customer must be interested about the prices. If the price gap between high and low consumption hours is too low the effect to the customer behaviour is minimal. Another option is to have a mass control signal alarming the buildings' own heat distribution center about the high prices and the distribution center autimatically reduces the heat supply. Mass control signal requires willing from the customer to participate and intelligence from the system to work properly. (Valor Partners Oy 2015, 25, 28.)

Some potential negative sides of DSM are identified in the Valor Partners study. The first challenge is related to the execution of DSM: if the system is executed poorly, the consumption peak will shift in time, but can be even higher than without DSM. This happens if all of the customer equipment are operated simultaneously with similar cost signals. The other challenges are uncertainties in the consumption predictions, the possible losses for district heating companies from fixed incentives, too big investments comparing to benefits and too strong controlling by the service provider. If DSM is controlled too strongly, in extreme cases the customer could suffer from too cold indoor temperatures. The district heating distribution pipes can suffer from the major temperature changes, so the temperature changes must be as slow as possible. Accepted temperature change is approximately 1 °C during a five minute time period. (Valor Partners 2015, 15–16.)

It should also be noted that the benefits from DSM can be gained with usage of heat accumulators and heat-storing properties of the distribution networks. With heat accumulators start-up of the peak load unit can be avoided and stored heat can be used instead. Weaknesses of heat accumulators comparing to DSM are big investments, the heat losses and finding a location in which the heat accumulator serves the whole district heating distribution network. (Valor Partners 2015, 15–16, 20.) Kärkkäinen et al. (2003) presents that the best feasibility of DSM would be gained when using DSM in spring and autumn seasons. This is to avoid the stress to the heat exchangers, piping and radiators because of heat and ventilation load peaks during the DSM execution. (Kärkkäinen et al. 2003, 69.)

2.8.4 Smart future district heating and cooling systems

The term smart district heating and cooling system refers to a system in which the different production technologies are fitted to be a part of the system so, that the production technologies support each other in the overall system and the whole system is optimised. This enables the possibility of heat accumulators and seasonal thermal storages to be utilised to balance the district heating production on hourly, daily and yearly basis. (Sitra 2015.) Digitalisation is an important enabler of the future smart district heating and cooling systems

(Känkänen et al. 2018, 23) because accurate monitoring and intelligence is needed to the optimisation. Digitalisation can be defined as applying digital technologies and infrastructures to business, economy and society (Autio 2017, 1). To the customer a smart energy system can appear as a smart home where all home appliances (e.g. electric cars and their charging, smart heating and cooling, ventilation and washing machines) are synchronised, automatised and optimised. In a smart home all services regarding living and inhabitation are integrated to one aggregate aiming to produce pleasant surroundings with as low energy consumption as possible. (Deloitte 2016.)

Accurate monitoring and related services as well as intelligence are needed in the smart district heating and cooling systems to navigate the consumption and optimise the production in the best way possible. (Sitra 2015.) The utilisation of the information and communication technology (ICT)-systems is the most commonly mentioned factor when discussing about smart energy systems. The utilisation of ICT-system requires remote and real-time data. The measurement data should be collected from the energy production units, from the customers and from different parts of the networks constantly. (Kontu 2014, 34–36.) Increasing usage of e.g. different measurement data management systems, energy management data systems and forecasting of energy demands makes the optimisation of district heating and cooling systems more effortless. (Känkänen et al. 2018, 24–25)

Lund et al. (2010) presented two different views for the future of district heating and cooling. One view is that in the future different low-, zero- or even plus-energy buildings will decrease the needs of external heating. In Finland heat energy production and/or thermal storages are needed even with even plus-energy houses, because the needs for heating during the cold winter season doesn't disappear. Other view is that waste heat, waste incineration and the existing energy production units will be operated together with geothermal heat, solar thermal energy and large heat pumps to apply the surplus heat for house heating. In this case the district heating network would play an important role. (Lund et al. 2010, 1381.) Part of the presented future view have been realised since 2010: waste heat is utilised and large heat pumps are in use in many district heating systems. In the year 2014 Lund et al. (2014) proposed that the future energy system is "a smart energy system" which will combine smart electricity, heating, cooling and gas grids. These networks will be coordinated to find synergies and to have an optimal solution for each one of the networks as well as for the whole combined system. (Lund et al. 2014, 1–2.)

Peura et al. (2017) see two points for the future energy sector: the existing centralised energy production will take care of the energy-intensive industries and energy management of bigger population centres. New, decentralised part will take care of all of the other energy needs and will produce energy to the population centers and to individual consumers. In the future energy systems the existing energy production units can still be in use: hybrid power plants can utlise existing gas-firing boilers and combine sources like wooden fuels, solar and geothermal energy and thermal storages or heat accumulators in the same area. (Peura et al. 2017, 7–8, 66–69.)

As a summary, multiple studies emphasise the role of the existing assets but also propose utilisation of new methods to be used in parallel with the existing infrastructure. Co-operation is needed between all energy sectors. The importance of accurate monitoring and intelligence in the energy system is emphasised since optimisation and controlling of it is difficult without. Intelligence is needed to the system: the data itself doesn't make the system smart but enables e.g. modifying of the state of the network. Decentralisation, seasonal thermal storages, heat accumulators and DSM all require intelligence and automatized controlling.

A smart city energy-project report published in summer 2018 defined central notes and recommendations for the future development of energy sectors. The first one is that dialogue and interaction between the customer and the energy company enables more intelligent and customer-centric energy system. In the future the district heating and cooling company might have increased role in controlling the production of customer's own energy and the usage of the energy. Other interesting note is, that the equipment controlling customer's energy consumption and production should allow remote access and control. Also joint ways of acting should be created. Digital service platforms are recommended to pilot in district heating and cooling. (Känkänen et al. 2018, 58.)

3 ENVIRONMENTAL IMPACTS AND REQUIREMENTS FOR MCP-UNITS

3.1 Air pollutants from combustion

Combustion of fuel produces gaseous emissions to the atmosphere. This chapter presents an introduction to the formation and control of gaseous emissions regulated by the MCP-decree, which are dust, nitrogen oxides and sulphur oxides. This chapter as well as the whole thesis concentrates on the gaseous emissions from the combustion process. Combustion of fuels is only one step in the process. The whole supply chain of a fuel produces different environmental impacts.

Air pollutants can be defined as species in the air which can cause negative impacts to the human health and to the environment. Air pollutants can be divided to primary and secondary air pollutants. The term primary pollutant refers to the substances which have been released but not (yet) undergone any reactions which would alter them. In other words, they are emitted directly from the sources. The term secondary air pollutant refers to substances produced by reactions with normal atmospheric fractions or by different chemical reactions of two or more primary air pollutants. Primary air pollutants from combustion processes are e.g. dust, volatile organic compounds (VOC) or carbon monoxide (CO). Secondary air pollutants can be e.g. ground level ozone or acid mist. (Tan 2014, 1–2.)

Greenhouse gases are gases which can trap the heat into the atmosphere and accelerate the greenhouse effect. Greenhouse gases have been produced from natural sources for a long time. Comparing to that, only recently the extra anthropogenic greenhouse gases have caused negative effects to the atmosphere. (Tan 2014, 1–2.) In common definition greenhouse gases include fluorinated gases (F-gases), nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) (Edenhofer et al. 2014, 7). The fate of air emissions from the combustion process is presented in figure 16.

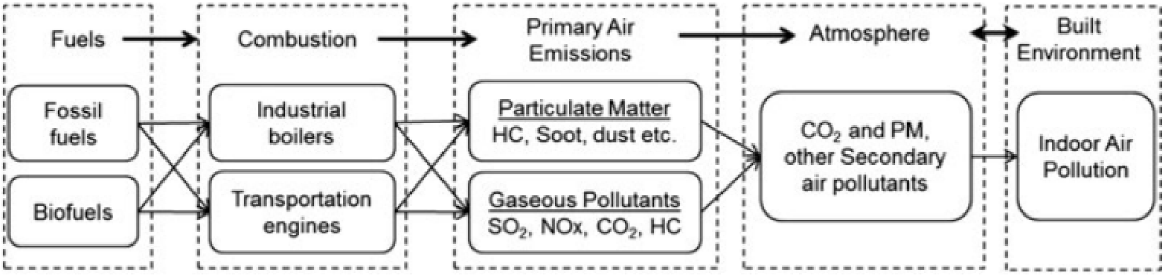

Figure 16. The fate of air emissions from combustion (Tan 2014, 18).

3.1.1 Dust

Dust (or particulate matter) refers to a mixture of solid particulates and liquid drops suspended into the air. Dust consists of primary air pollutants and/or secondary air pollutants. Dust varies in size, commonly dust is divided based on the diameter of a particulate; to particles smaller than 2,5 µm ($PM_{2,5}$) and to particles smaller than 10 µm (PM_{10}). (Tan 2014, 2–6.) The fine particles (the diameter approximately 0,1–1 µm) are formed in the combustion process from the ash-forming elements that are volatilized in the furnace. Larger particles are formed from the mineral impurities in the fuels. In addition to these elements, combustion in fluidized bed boilers forms dust, which consist of the fragmented bed material. The final phase of ash-forming materials is different based on the fuel, the combustion process and the conditions. The primary dust emissions from the combustion processes consist mainly of unburned fuel (hydrocarbons), elemental carbon (soot), sulphates and mineral salts. (Ohlström et al. 2006, 5.)

The prime negative impact of dust is its impacts to the human health: it desposites into the human respiratory system and is settled in the alveoli for weeks or even years. The chemicals and toxins which are absorbed by the particulates are dissolved in the alveoli and then transported to the circulation system of the body. The potential health effects of dust are e.g. lung cancer, asthma and other respitarory infections. The fine particles drift deeper to the respiratory system and therefore cause more serious health problems. (Tan 2014, 2–6.)

Dust can be reduced from flue gases with cyclones, electrostatic precipitators, bag filters and wet scrubbers or combination of these. If using a cyclone the flue gas is conveyed through the cyclone and gas stream circulates spirally towards bottom, causing the particles to be thrown to the walls of the cyclone. Cyclone can be single- or multi-cyclone separator.

Cyclones are simple and moderately inexpensive solutions for dust the removing. The investment cost to a multi-cyclone separator for medium energy production unit is approximately 1500–2000 €/MW depending on the size of the energy production unit and the fuels used. The operation and maintenance costs are moderately low, 0,1 €/MWh, without the disposal of ashes. Cyclones are reliable and operation and maintenance is simple. The separation capacity of a cyclone is 60–90 %. (Jalovaara et al. 2003, 64–65; Finnish energy & Finnish ministry of Environment 2012, 6–7.)

Electrostatic precipitators use electrostatic forces to clean dust from the flue gases. Dust particles are charged in the electric field which causes them to be attracted to the collecting electrodes. Dust is collected or washed off from the collecting electrodes. Electrostatic precipitators are commonly used in larger units. The separation capacity of electrostatic precipitator can be over 99 % with solid fuels. Because of the low electricity consumption and small pressure loss, the operation and maintenance costs are low, 0,1 €/MWh, without the disposal of ashes. Electrostatic precipitators are reliable and have long operating times. The investment cost of the electrostatic precipitator is high, 15 000–20 000 €/MW, which can be a problem in medium energy production units. When pursuing high separation capacities, 99,5 % and over, the price escalates quickly. (Jalovaara et al. 2003, 60–61.)

Fabric filter (or bag filter) separators and wet scrubbers are used commonly only in larger units. Fabric filters use filtration to separate dust from the gas stream and their separation efficiency is up to 99,9 %. The investment cost is approximately 15 000–20 000 €/MW. The filters need to be changed in 2–4-year intervals which makes the operation costs high. It is estimated that in the medium energy production units the operation and maintenance costs are approximately 0,3 €/MWh without the disposal of ashes. In wet scrubbers dust is washed from the gas stream by using water. Water absorbs also other impurities from the flue gas stream, such as sulphur compounds and other acidic gas components.

Wet scrubbers enable the heat from the flue gas to be recovered, which improves the operational economy and can raise the total efficiency of the energy production unit to over 100 %. The separating capacity of a wet scrubber is typically 90–95 % with solid fuels and lower with oil fuels. The disadvantage of a wet scrubber is the waste water emerged in the process. The investment cost of a wet scrubber is typically between 30 000–40 000 €/MW with heat recovery and 20 000–30 000 €/MW without heat recovery. It is estimated that in medium energy production units the operation and maintenance costs are approximately 0,3–0,5 €/MWh, without the disposal of ashes. (Jalovaara et al. 2003, 62–65.)

3.1.2 Nitrogen oxides

Nitrogen oxides are gaseous compounds consisting of nitrogen and oxygen. In flue gases these compounds are commonly nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). The main sources of nitrogen oxides from combustion process are nitrogen from fuel and nitrogen in combustion air. Nitrogen oxides can be formed in different ways in the combustion process, and the end products from different reactions are referred as thermal NO, fuel NO and prompt NO. Thermal NO and prompt NO origin from the nitrogen in combustion air. Fuel NO is according to its name originated from the fuel. (Wielgosiński 2012, 306.)

The formation of fuel NO takes time and the process consist of multiple reactions. The amount of nitrogen in the fuel is relatively small, but it is more reactive than nitrogen in the combustion air. Thermal NO is formed in the combustion process when molecular nitrogen (N_2) reacts with molecular oxygen (O_2) and forms nitric oxide. Thermal NO formation requires high temperature, approximately more than 1400 °C. Prompt NO refers to nitrogen oxides formed in the early stage of flame from the nitrogen and oxygen when hydrocarbon radicals are present. (Tan 2014, 210–211, 215; Wielgosiński 2012, 208, 307–308.)

Generally the main source of nitrogen oxide in the combustion process is fuel NO. The formation of nitrogen oxides from different reactions as a temperature function is presented in figure 17. From the figure it can be seen that the formation of fuel NO starts in low temperatures, but when the temperatures rises, the amount of thermal NO increases. (Tan 2014, 215.)

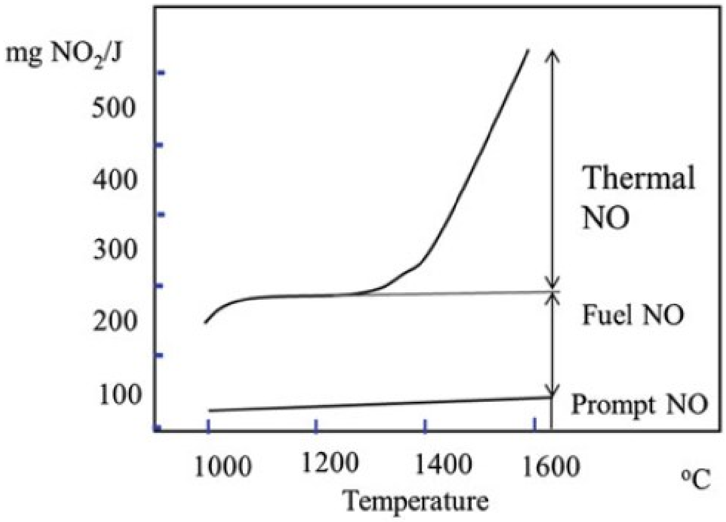

Figure 17. The formation of thermal, fuel and prompt NO as a temperature function (Tan 2014, 215).

Nitrogen oxides accelerate the climate change, cause acid rain and worsen visibility. For humans high concentrations of nitrogen oxides can cause respiratory diseases, such as asthma.

Nitrogen oxides can be reduced with primary or secondary methods. Primary methods aim to prevent the NO_X formation. Primary methods can include for example choosing less pollutive fuel or different combustion adjustments. Fuel or air feeding in the combustion process can be staged, which leads to reduced combustion temperature. Lower combustion temperature reduces the production of thermal NO. Other solutions to reduce the temperature of the combustion and in that way the formation of thermal NO are low amount of excess air and reduced air preheating. Flue gas recirculation reduces NO_X by mixing the flue gases in the air in the combustion chamber. Mixing of flue gases and air reduces the oxygen availability and the flame temperature, leads to deferred conversion of nitrogen into nitrogen oxides and the formation of the thermal NO, but still maintains high efficiency. Burners aiming to reduce the NO_X-levels are commonly called low-NO_X-burners. A low-NO_X-burner can utilise flue gas recirculation or air or fuel staging. They are designed so, that they delay and improve the combustion and increase the heat transfer in the boiler. (Lecomte et al. 2017, 80.)

In addition to the primary methods, NO_X can be reduced with different secondary methods. These methods are selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR). In the SNCR method nitrogen oxides react with ammonia or urea at high temperatures without a catalyst and form nitrogen. In the SCR method nitrogen oxides react to nitrogen with ammonia in a catalytic bed. Both SCR and SNCR methods are used only in special cases in the medium energy production units. The operational cost of SNCR has been identified to be 1500–2000 €/removed ton of NO_X and the operational cost of SCR has been identified to be 3000–4000 €/removed ton of NO_X. (Jalovaara et al. 2003, 68; European Union 2016.)

3.1.3 Sulphur oxides

Sulphur oxides include sulphur dioxide (SO_2) and sulphur trioxide (SO_3). Sulphur oxides formed in the combustion process are mainly originated from the sulphur content of the fuel. Sulphur oxides are formed when the sulphur elements in the fuel are oxidized. It is assumed that 90–95 % of the sulphur in the fuel reacts to SO_2. Furthermore, SO_2 can be oxidized to SO_3. In typical engineering practices it is assumed that approximately 3 % of SO_2 is converted to SO_3. (Tan 2014, 208–210; Wielgosiński 2012, 305.)

The amount of sulphur in selected fuels is presented in table 1. The content of sulphur fluctuates depending on the characteristics, such as quality of the fuel. Generally the sulphur content of a gas oil is between 0,1 m-%, and it can be reduced in refineries to be less than 0,05 %. The sulphur content in heavy oils used in Finland is between 0,8–0,95, but there is heavy oil qualities availabe with as low as 0,1 m-% sulphur content. (Alakangas et al 2016, 206; Tan 2014, 208.)

Table 1. The sulphur content of selected fuels (adapted from Alakangas et al 2016, 206).

Fuel	Sulphur content (m-%, dry)
Gas oil	0,1
Heavy fuel oil, low-sulphur quality	0,8–0,95
Heavy fuel oil, with sulphur	2,3
Peat	0,05–0,3
Wood	0,05

Sulphur oxides can harm the respiratory system and make breathing difficult. Sulphur oxides can drift with particulate matter to deep in the lungs and cause problems to human health. In the environment sulphur dioxide can cause acid rain and worsen visibility.

SO_2 can be reduced by changing the fuel quality or from flue gases by adding a calcium compound which reacts with SO_2. In the scope of the medium energy production units this method is applied only in special cases (Jalovaara et al. 2003, 66). Alternatives for sulphur emission reduction with calcium compounds are to inject it in the furnace or to the flue gases. Limestone or other lime compound can be injected into the furnace, which reacts with sulphur dioxide and form calcium sulphate. Calcium sulphate can be then removed from flue gases along with fly ashes in the dust separator systems. In the duct sorbent injection (DSI) the sorbent (for example sodium carbonate or hydrated lime) is injected in the flue gas stream. The sorbent reacts with acidic gases and forms a solid compound which is removed with dust abatement techniques. (Jalovaara et al. 2003, 66–67, 83; Lecomte et al. 2017, 106, 112.)

Sulphur reduction methods can be divided to dry, semi-dry and to wet methods. In dry method the injected compound is dry. In semi-dry method a calcium based component is mixed to water and injected to flue gases. In wet method the flue gases are washed with water and different solutions reacting with water. From these methods only wet methods produce waste waters. The separating capacity of a dry method is 50–80 % and operating costs are 400–600 € for each removed ton of sulphur, including investment, usage and maintenance costs. Dry method is simple, affordable and doesn't consume much electricity. With semi-dry method it is possible to reach a separating capacity of 90 %. Typical costs of semi-dry methods in Finland and with solid fuels are 700–900 € for each ton removed. (Jalovaara et al. 2003, 66–67, 83; Lecomte et al. 2017, 106, 112.)

3.1.4 Biomass combustion

From the biomass combustion the majority of dust is originated from the ash-content of the fuel. Biomass can be combusted in a fluidized bed, in a grate (mixed or mechanical) firing or in a gasification boiler. Fluidized beds can be fixed, bubbling, turbulent or circulating beds. When using fluidized bed boilers the majority of the dust originates from ash, which exits as fine particles in fly ash. High amount of fly ash leads to needs for efficient dust separation equipment, such as electrostatical precipitators or bag filters. Also part of the bed material exits as fly ash. Grate firing boilers remove the majority of ash via grate as bottom ash, which is easier to collect than fly ash. (Finnish energy & Finnish ministry of Environment 2012, 6–7; Jalovaara et al. 2003, 29–41.) Achievable emission levels for solid biofuels with different techniques are summarised in table 2.

Table 2. Emission levels with different technologies for particulate matter from biomass combustion (Pirhonen 2014, 11).

Technology	**Achievable emission level of dust [mg/m^{3}n]**	**Separating capacity [%]**
Multicyclone	Approximately 200	60–90
Electrostatic precipitator	<30	99–99,9
Fabric filter	<20	99,9
Cyclone/multicyclone and scrubber	Approximately 45	90–95

Combustion adjustments are usually sufficient for biomass NO_X reduction. In special cases SCR or SNCR methods are needed. (Jalovaara et al. 2003, 83.) The emission levels of sulphur oxides from combustion are determined by the sulphur content of the fuel. The most cost-effective primary way to reduce the amount of sulphur is to choose a fuel with a low sulphur content. From solid fuels wooden fuels have the lowest sulphur-content. When using e.g. peat as a fuel SO_2 reduction methods are needed.

3.1.5 Liquid fuel combustion

Liquid fuels commonly used in heat-only boilers are gas oil and heavy fuel oil. In addition to these, the case company produces and uses pyrolysis oil. Pyrolysis oil is produced from biomasses via fast-pyrolysis in a pyrolysator. In the pyrolysis oil production process the biomass is gasified in oxygen-free circumstances and condensed to a liquid phase. The selected properties of different oil fuels are presented in table 3 (Alakangas et al. 2016, 181, 184).

Table 3. Properties of different oil fuels (adapted from Alakangas et al. 2016, 181, 184, 206).

	Water content [m-%]	**Viscosity (40 °C), [mm²/s]**	**Net calorific value [MJ/kg]**	**Ash content [m-%]**	**Sulphur content [m-%]**
Heavy fuel oil	~0	1690	40,3	max 0,08	2,3
Heavy fuel oil, low sulphur	~0	20–420	max 40,6	0,05	0,8–0,95
Gas oil	~0	2–4,5	42,6	<0,001	<0,1
Pyrolysis oil	20–30	15–35	13–18	0,01–0,1	<0,05

The amount of dust from the liquid fuel combustion can be reduced by reducing the size of the atomized fuel drops, by changing the fuel oil to a lighter quality or by increasing the amount of excess air or delay the time in the combustion process. Dust occurs only a minimal decree in the gas oil combustion. (Wielgosiński 2012, 310). Heavy fuel oils produce dust due to the higher ash-content of the fuel. Cyclones or multicyclones are used commonly in small energy production units to reduce the amount of dust from the flue gas stream. NO_X can be reduced with low-NO_X-burners, by circulating the flue gases or by staging the combustion air. For gas oil combustion the MCP-decree regulates emission limit values only for NO_X. (Jalovaara et al. 2003, 42–49.)

The emissions from the diesel engines depend on the fuel. Sulphur-free gas oil doesn't produce sulphur emissions. Nitrogen emissions can be reduced by e.g. diluting the fuel mixture or adding water to combustion chamber. The reduction of sulphur content, ash content and aromatic content reduces also the dust emissions. (Jalovaara et al. 2003, 56.)

3.1.6 Gaseous fuel combustion

Gaseous fuels used in the medium energy production units in Fortum are natural gas and landfill gas. Natural gas has low dust, sulphur and nitrogen emissions. Natural gas doesn't contain nitrogen itself and NO_X emissions originate from nitrogen in the combustion air. The most efficient ways to reduce NO_X from the natural gas combustion are low-NO_X-burners, combustion air phasing and flue gas recirculation. (Jalovaara et al. 2003, 51–53.) For natural gas combustion the MCP-decree regulates only NO_X-emissions.

Emissions from landfill gas combustion depend on the landfill characteristics which are e.g. the waste component distribution and the age of the landfill. Landfill gas consist of approximately 45–55 % methane and 30–40 % carbon dioxide and small amounts of multiple organic and inorganic substances. (Rasi 2009, 10.) Methane from old landfills is combusted to CO_2 because methane has a higher global warming potential than CO_2. If the energy potential from the landfill gas cannot be utilised, it is combusted in gas flares to reduce the global warming impacts. The fate of landfill gases is presented in figure 18. (Lee et al. 2017, 336.)

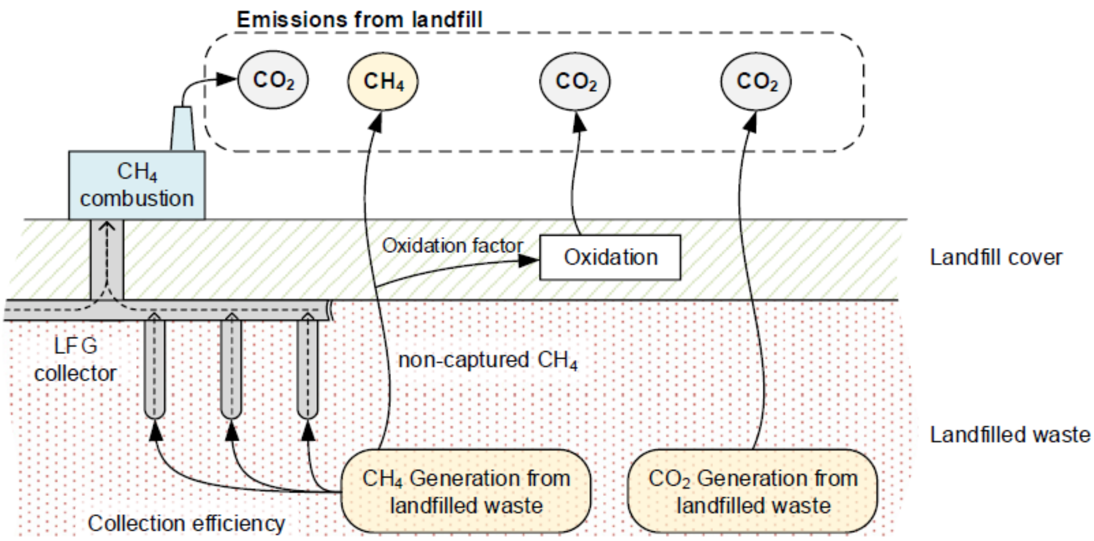

Figure 18. Fate of landfill gas emissions generated from landfilled organic waste (Lee et al. 2017, 336).

3.2 Legislation regulating operation of medium energy production units in Finland

In Finland all operations which cause or can cause environmental pollution or contamination are regulated by the environmental protection act (527/2014). All operations which require an environmental permit or registration to authorities' data systems are mentioned in the environmental protection act. Before year 2010 all new energy production units, generally bigger than 5 MW, needed an environmental permit. There were reference emission limit values for medium energy production units and the environmental act required applying the best available technology. The reference document used is called "Best available techniques

(BAT) for 5–50 MW energy production units in Finland" and it provides references for authorities to help to decide the emission limit values in the environmental permits. (Jalovaara et al. 2003, 3.)

The environmental protection act was revised in 2010 (253/2010). After the revision instead of applying for an environmental permit it was possible to register all energy produduction units smaller in size than 50 MW with some exceptions. Along with the environmental protection act revision a new decree called the "Government Decree on the environmental protection requirements of energy production units with a rated thermal input below 50 megawatts" (or "PiNo-decree") (445/2010) was published. The aim of the publication was to specify the demands for operation of medium energy production units and information needed for the registration process. (Salo-Asikainen 2010, 1.) The PiNo-decree was mainly applied to all 5–<50 MW units, but not to:

- Units covered by the Government Decree on Waste Incineration
- Units that use combustion products for direct heating, drying or other treatment of objects or materials, such as reheating furnaces and furnaces for heat treatment
- Post-combustion units designed to purify waste gases by combustion and which are not operated as independent combustion units
- Incineration of whole animal carcasses

The PiNo-decree was revised in 2013 and the new version was called the PiPo-decree (750/2013). The official name of the decree was the same as before: "Government Decree on the environmental protection requirements of energy production units with a rated thermal input below 50 megawatts". The revision from the PiNo-decree to the PiPo-degree was executed to e.g. specify some emission limit values for peak and reserve units and to make some smaller changes based on hands-on experiences from the operations of existing energy production units.

The MCP-directive was published by the EU in the Official Journal of European Union on 25th of November 2015. Its requirements were adopted to the Finnish legislation on 28.12.2017. The MCP-directive sets requirements only for gaseous emissions limit values and monitoring of gaseous emissions. Because there were the existing PiPo-decree effective in Finland, the MCP-directive and PiPo-decree were combined to be a new decree called

"Government decree on the environmental protection requirements of medium energy production units", shortly "MCP-decree" in this thesis. The most significant change compared to the PiPo-decree was the scope: in the PiPo-decree the scope was 5–<50 MW energy production units and in the MCP-decree the scope is 1–<50 MW units. After the MCP-decree publication the 1–<5 MW energy production units are required to fulfil emission limit values which were applied before only in special cases. Emission limit values of the energy production units which were in the scope before 2018 were also changed. Because of the PiPo-decree and MCP-directive requirements combining in Finland the requirements by the PiPo-decree are now applied also to the 1–<5 MW energy production units.

The environmental protection act (527/2014) was also revised due the publication of the MCP-directive. Due the revision all energy production units in the scope of the MCP-decree are to be registered. Basically all energy production units in the PiPo-decree scope were registered before the MCP-decree implementation. In addition to registration obligation the environmental protection act requires publishing of some information about medium energy production units in the open information network.

3.3 Air pollution requirements by MCP-decree

The MCP-directive provided possibility for long transition periods and these were applied to the MCP-decree in Finland. These long transition periods are set especially because of the changes in the scope. Transition periods are defined for 1–<5 MW existing units until the beginning of 2030 and for 5–<50 MW existing units until the beginning of 2025. ≥5 MW units producing 50 % or more of the useful heat content to the public district heating network have transition period until the beginning of 2030. This exemption is applied to all ≥5 MW units in the scope of this study. Some exemptions for these transition periods are defined for units with low operating hours, units producing district heating, units using solid biomass as a fuel and operate in areas with good air quality and units used in gas compression stations. Exemptions in transition periods are described more exactly in table 4.

Table 4. Exemptions in MCP-decree (1065/2017) transition periods.

Unit description	**Exemption**
Existing units which have a rated thermal input more than 5 MW and at least 50 % of the useful heat production of the unit is utilised to the public district heating network	Transition period is until the beginning of 2030, however so, that the emission limit value for dust is not more than 150 mg/m^{3}n and the emission limit value for SO_2 is not more than 1100 mg/m^{3}n
Solid biomass units located in areas where emission limit values for dust set by the Council of State's decree of air quality (79/2017) have not exceeded in a way described in the decree's 4 § in three years after the environmental permit or registration	Transition period is until the beginning of 2030. However, so that the emission limit value for dust does not exceed 150 mg/m^{3}n

There is also exemptions for the existing energy production units operating less than 500 or 1000 hours during one year as a 5-year rolling average (table 5).

Table 5. Exemptions in MCP-decree (1065/2017) for existing energy production units' emission limit values.

Role of energy production unit	**Exemption**
Units operating less than 500 hours during one year (5-year rolling average)	No emission limit values, except for units using solid biomass the emission limit value for dust is 200 mg/m^{3}n
Units operating more than 500 hours but less than 1000 hours during one year as 5-year rolling average and which are used to produce heat during exceptionally cold weather conditions.	Emission limit values are the same as emission limit values for backup- and emergency units during the transition period, except for the units using solid biomass the emission limit value for dust is 200 mg/m^{3}n

In general in Finland all energy production units are intended to be used during wintertime, so all energy production units in Finland are defined to be units used in exceptionally cold weather conditions (Rinne 2017, 18).

3.3.1 Emission limit values for existing units

The MCP-decree defines energy production units which started operation before 20.12.2018 as existing units. Energy production units which started operation after 20.12.2018 are defined as new units. In the earlier definition by the PiPo-decree the energy production units which started operations before June 2010 were defined as existing units. Units that started operations later than in 1st of June 2010 were defined as new units. Emission limit values are presented in multiple different situations in the MCP-decree Annexes (table 6). Tables refer to the emission limit value tables in the MCP-decree appendix 1. 1 A refers to the first part of annex 1, the emission limit values for existing and new units and 1 B refers to emission limit values for transition times.

Table 6. Emission limit values for different situations presented in MCP-decree.

<table>
<tr><th>Start of the operation and thermal input</th><th>Emission limit values 2018–2025/2030</th><th>Emission limit values 2025/2030 →</th></tr>
<tr><td>After 20.12.2018, 1–<5 MW</td><td colspan="2" rowspan="2">1065/2017 Annex 1 A, PART 2: Emission limit values for new units, table 4</td></tr>
<tr><td>After 20.12.2018, 5–<50 MW</td></tr>
<tr><td>1.6.2010-20.12.2018, 1–<5 MW*</td><td rowspan="2">1065/2017 Annex 1 B: Emission limit values for transition periods, table 2</td><td>1065/2017 Annex 1 A, PART 1: Emission limit values for existing units, table 1 (2030 →)</td></tr>
<tr><td>1.6.2010-20.12.2018, 5–<50 MW</td><td>1065/2017 Annex 1 A, PART 1: Emission limit values for existing units, table 2 (2025 →)</td></tr>
<tr><td>Before 1.6.2010, 1–<5 MW*</td><td rowspan="2">1065/2017 Annex 1 B:Emission limit values for transition periods, table 1</td><td>1065/2017 Annex 1 A, PART 1: Emission limit values for existing units, table 1 (2030 →)</td></tr>
<tr><td>Before 1.6.2010, 5–<50 MW</td><td>1065/2017 Annex 1 A, 1 PART 1: Emission limit values for existing units, table 2 (2025 →)</td></tr>
</table>

* If unit is part of operations requiring environmental permit. Otherwise no limit values before 2030.

Emission limit values are based on the starting time of energy production unit operations and the thermal input of the unit. For example a 1–<5 MW energy production units in which operations started between 1.6.2010–20.12.2018 have emission limit values during years 2018–2030 as presented in the MCP-decree's Annex 1 B table, only if they are part of operations requiring an environmental permit. If not, there is no emission limit values applied for these unit before the year 2030. After 2030 the emission limit values for 1–<5 MW units are presented in the MCP-decree's Annex 1 A part 1 in table 1.

Compared to the PiPo-decree requirements the MCP-decree tightened especially emission limit values for dust from solid biofuels combustion and from other liquid fuels than gas oil. NO_X emission limit values from gaseous fuels and other liquid fuels combustion and SO_2 limit values from other liquid fuels and other gaseous fuels combustion were tightened.

Emission limit values set by the PiPo- and by the MCP-decrees for existing energy production units with selected fuels are presented in table 7. Tightened values are highlighted with red. Because multiple units operate as peak and reserve units the peak load emission limit values are also presented in the table. The PiPo-decree limit values for peak and reserve units (units operating less than 1500 hours during one year as a 5-year rolling average) are presented in parentheses. The MCP-decree limits for units operating over 500 hours but less than 1000 hours during one year as a 5-year rolling average and which are operated during exceptionally cold weather conditions are also presented in parentheses. If an existing energy production unit operates less than 500 hours during one year (as a 5-year rolling average) there is no emission limit values applied, except for those units firing solid biomass the limit value for dust is 200 mg/m^3n.

All values presented in the table are defined at a temperature of 273,15 K, at a pressure of 101,3 kPa, after correction for the water vapour content of the waste gases and at a standardised O_2 content (solid fuels O_2 = 6 %, gaseous and liquid fuels O_2 = 3 % in combustion gaseous and liquid fuels O_2 = 15 % in gas turbines and engines).

Table 7. A comparison between PiPo- and MCP-decree emission limit values.

Existing units		**Dust [mg/m³n]**		**NOx [mg/m³n]**		**SO_2 [mg/m³n]**	
		PiPo	MCP	PiPo	MCP	PiPo	MCP
Wood and other solid biomasses	1≤P≤5 MW	300 (375)	50 (200)	450 (500)	450 (500)	200	200
	5<P≤10 MW	150 (250)	50 (200)	450 (500)	450 (500)	200	200
	10<P≤20 MW	50 (125)	50 (140)	450 (500)	450 (500)	200	200
	P>20 MW	50 (125)	30 (140)	450 (500)	450 (500)	200	200
Peat	1≤P≤5 MW	300 (375)	50 (200)	600 (625)	600 (625)	500	500
	5<P≤10 MW	150 (250)	50 (200)	600 (625)	600 (625)	500	500
	10<P≤20 MW	50 (125)	50 (125)	600 (625)	600 (625)	500	500
	P>20 MW	50 (125)	30 (125)	600 (625)	600 (625)	500	400
Gas oil	1≤P≤15 MW	50	-	900	200	1700	-
	15<P<50 MW	50	-	600	200	1700	-
Other liquid fuels	1≤P≤5 MW	140 (200)	50 (200)	900	650	1700	350 (850)
	5<P≤15 MW	140 (200)	30 (140)	900	650	1700	350 (850)
	15<P<50 MW	50 (140)	30 (140)	600	650	1700	350 (850)
Natural gas	1≤P≤15 MW	-	-	400	250	-	-
	15<P<50 MW	-	-	300	200	-	-
Other gaseous fuels	1≤P≤15 MW	-	-	400	250	-	200
	15<P<50 MW	-	-	300	250	-	35 (biogas 170)

Emission limit values set by the MCP-decree for existing combustion engines and gas turbines are presented in table 8. PiPo-requirements are presented in table 9. Units operating less than 500 hours have emission limit values only for dust (200 mg/m^{3}n). Emission limit values vary in PiPo- and MCP-decrees, but especially the NO_X-levels are tightening significantly because of the revision, from 2300 mg/m^{3}n to 190 mg/m^{3}n.

Table 8. MCP-decree emission limit values (mg/m^{3}n) for existing combustion engines and gas turbines.

	Dust [mg/m³n]	**NO_X (as NO_2) [mg/m³n]**		**SO_2 [mg/m³n]**
	Motors and gas turbines	Motors	Gas turbines	Motors and gas turbines
Gas oil	-	190	200	-
Other liquid fuels (1≤P≤20 MW) (P>20 MW)	 20 10	 190 190	 200 200	 120 120
Natural gas	-	190	150	-
Other gaseous fuels	-	190	200	15 60 (biogas)

Table 9. Emission limit values set by PiPo-decree for existing combustion engines and gas turbines.

	Dust [mg/m³n]	**NO_X (as NO_2) [mg/m³n]**	**SO_2 [mg/m³n]**
Oil diesel motor	60	1850	600
Gas diesel motor	-	1850	-
Spark-ignition motor	-	190 (250)	-
Dual fuel motor Gas Oil	 - -	 380 2300	 - -
Gas turbine	-	150 (250)	-

3.3.2 Transition period emission limit values

Emission limit values for transition periods are defined separately for units which were in use at first of January 2010 or whose environmental permit was announced before that day and for units started after the first of June 2010. This classification is because the first decree regulating these energy production units was applied from the first of June 2010 (445/2010). Emission limit values for transition periods for units in use before 1st of June 2010 are presented in table 10. Emission limit values for backup- and emergency units are in parentheses. During the transition time backup- and emergency units refer to units operating less than 1500 hours during one year (as a 5-year rolling average).

Table 10. Emission limit values for transition periods for energy production units which were in use before first of January 2010.

Rated thermal input	Dust [mg/m^3n]	NO_X (as NO_2) [mg/m^3n]	SO_2 [mg/m^3n]
Liquid fuels [1]			
$1 \leq P \leq 15$ MW	140 (200) [2]	900	350 (850) [2]
$15 < P < 50$ MW	50 (140) [2]	600	350 (850) [2]
Gaseous fuels			
$1 \leq P \leq 15$ MW	-	400	-
$15 < P < 50$ MW	-	300	-
Wood and other solid biofuels			
$1 \leq P \leq 5$ MW	300 (375)	450 (500)	200
$5 < P \leq 10$ MW	150 (250)	450 (500)	200
$10 < P < 50$ MW	50 (125)	450 (500)	200
Peat			
$1 \leq P \leq 5$ MW	300 (375)	600 (625)	500
$5 < P \leq 10$ MW	150 (250)	600 (625)	500
$10 < P < 50$ MW	50 (125)	600 (625)	500

[1] Other liquid fuels than gas oil and heavy oil these emission limit values are applied from the first of January 2020
[2] Not applied to gas oil

Emission limit values for the transition periods for units which started operations after 1st of June 2010 are presented in table 11.

Table 11. Transition period emission limit values for units which started operations after first of January 2010.

Rated thermal input	Dust [mg/m³n]	NO_X (as NO_2) [mg/m³n]	SO_2 [mg/m³n]
Liquid fuels [1]			
$1 \leq P \leq 15$ MW	50 [2]	800	350 [2]
$15 < P < 50$ MW	50 [2]	500	350 [2]
Gaseous fuels			
$1 \leq P \leq 15$ MW	-	340	-
$15 < P < 50$ MW	-	200	-
Wood and other solid biofuels			
$1 \leq P \leq 5$ MW	200	375	200
$5 < P \leq 10$ MW	50	375	200
$10 < P < 50$ MW	40	375	200
Peat			
$1 \leq P \leq 5$ MW	200	500	500
$5 < P \leq 10$ MW	50	500	500
$10 < P < 50$ MW	40	500	500

[1] Other liquid fuels than gas oil and heavy oil these emission limit values are applied from the first of January 2020
[2] Not applied to gas oil

Emission limit values for combustion engines for transition periods and gas turbines are defined separately for:

- Units which started operations earlier than 1st of June 2010 or whose environmental permit was announced before that day.
- Units which started operations after 1st of June 2010.
- Emergency units with operating time less than 500 hours during one year (as a 5-year rolling average).

All combustion engines and gas turbines studied in this thesis are emergency units (used less than 500 hours during one year). Emission limit values for emergency units are presented in table 12.

Table 12. Emission limit values for emergency use combustion engines and gas turbines for transition periods.

	Dust [mg/m³n] O_2 = 15 %	**NO_X (as NO_2) [mg/m³n]** O_2 = 15 %	**SO_2 [mg/m³n]** O_2 = 15 %
Oil diesel motor (GI)	70 [1]	2000	300 [1]
Gas diesel motor (GD), gas	-	1900	-
Spark ignition engine (SG)	-	200	-
Dual fuel motor (DF), gas	-	400	-
Dual fuel motor (DF), oil	70 [1]	2300	300 [1]
Gas turbine	-	150	-

[1] Not applied to gas oil

3.3.3 Monitoring requirements

The MCP-decree shortens the frequency of gaseous emission measurements. Measurements are required for air pollutants which limit values are set in the MCP-decree. Only carbon monoxide are to be measured even though there is no limit value regulated for it. Sulphur dioxide emissions can be defined instead of measuring with some other methods verified and approved by authorities. The first measurements of a new unit should be executed during the first four months after the operation is started, granted permit or registered, whichever is the latest. Following measurements should be executed based on the requirements or always when executing any major changes. Monitoring requirements for new units and existing units after the transition periods are presented in table 13.

Table 13. Monitoring requirements for new and existing energy production units after the transition periods.

Pollutant	Rated thermal input[3] 1–20 MW	Rated thermal input[3] > 20 MW
Dust, NO_X, SO_2 and CO [1,2]	At least once in three years with following exceptions: - Units operating not more than 500 hours in a year: the measurements shall be done at least 1500 operating hours intervals, but at least once in five years - Units operating not more than 1000 hours in a year: the measurements shall be done at least 3000 operating hours intervals, but at least once in five years	At least once a year, with following exceptions: - Units operating not more than 500 hours in a year: measurements shall be done at least 1500 operating hours intervals, but at least once in five years - Units operating not more than 1000 hours in a year: measurements shall be done at least 3000 operating hours intervals, but at least once in five years

[1] Dust, nitrogen oxides and sulphur dioxides should be measured only if emission limit value have been set
[2] If carbon monoxide is measured continuously, periodic measurements for carbon monoxide are not needed
[3] If two or more new energy production unit's flue gases are conveyed to the same stack (or could be conveyed to the same stack by authority's estimation), the measurement period is defined by combined power of units

Periodic measurement requirements during transition periods for units with a thermal rated input of 5–50 MW are presented in table 14. There are few exemptions to these requirements: Units with yearly operation time not more than 1500 hours (as a 5 year rolling average), measurements should be executed not more than 7000 hours intervals but at least once in 7 years and requirements are not applied to emergency units with operating time not more than 500 hours in one year (as a 5 year rolling average).

Table 14. Measurement requirements for transition periods for units with a rated thermal input more than 5 megawatts and less than 50 MW.

Pollutant	Gas and gas oil	Heavy fuel oil	Solid fuels
Dust	-	Once in three years	Once in three years
NO_X	Once in five years	Once in three years	Once in three years

3.4 MCP-decree's estimated effects on Finland

The leading argument for the MCP-directive publication was to increase the air quality in cities across the EU. In Finland the concentrations of air pollutants in the air have remained the same or reduced since year 1990 and the quality of air is good in general. Especially the amounts of SO_2, CO and total reduced sulphur compounds (TRS) emissions have been reducing notably in Finland. Also the concentration of NO_X in the air has been reducing. Even though the concentrations of different air pollutants had been reducing over the past decades in Finland, at the same time the air pollution levels are still high and problematic in many cities in Europe. Consequently, limit values set for the air quality are often exceeded in the EU. (Suoheimo et al. 2015, 8–10.) Because of the good air quality level to begin with, effects from the MCP-decree to Finnish air quality might remain minimal.

Total costs to the emission reduction equipment because of the MCP-decree are approximated to be at least 21 M€ in Finland. This is mainly because increasing amount of emission reduction equipment is needed. Also additional costs from monitoring are expected to rise. The biggest impacts from the MCP-decree are to existing units with a thermal input of 1–5 MW since they were not in the scope earlier. Additional emission requirement equipment is needed in these units. There are approximately 1400 HOBs in this size operating in Finland and one third of these uses solid biomasses as a fuel. (Suoheimo et al. 2015, 23, 55.)

4 SITUATION OF MCP-UNITS AT THE CASE COMPANY

4.1 Overview of the study

All of the units studied in this thesis with their basic information are presented in the appendix 1. The basic information includes names and locations of the units, amount of boilers located in the same area with their starting years, rated thermal inputs, heat capacities and main and reserve fuels used. Information concerning gaseous emissions includes the current measured emission levels, the emission limit values at the moment and after the transition periods and monitoring requirements now and after the transition periods. Emission limit values are not applied for units operating less than 500 hours during one year (as 5-year rolling average). There is multiple units operating less than 500 hours during one year in the lst, but limit values for these units are still presented in the appendix 1 since the operating hours might change in the future. These limit values are highlighted as red and are not be concerned as the implemented emission limit values at the moment.

Energy production units and their roles in the district heating systems are studied one district heating network at a time in the following sub-chapters. Fortum's district heating systems in Finland are located in Espoo-Kirkkonummi, Järvenpää-Tuusula and Joensuu areas.

4.2 Espoo and Kirkkonummi network

There are three CHP-units, one heat-only boiler, a heat pump plant with two heat pumps and an auxiliary boiler located in Suomenoja area and nine heating plants located over the Espoo district heating network. Fortum's district heating network in Espoo-Kirkkonummi area including existing units, their locations and thermal power inputs is presented in figure 19. All of the units in the DH system are presented in the figure. The units in Suomenoja, Kaupunginkallio, Kivenlahti, Otaniemi, Vermo and Tapiola are larger in size than 50 MW and are not in this study's scope. The base load of this network is produced in the CHP-units located in the Suomenoja area.

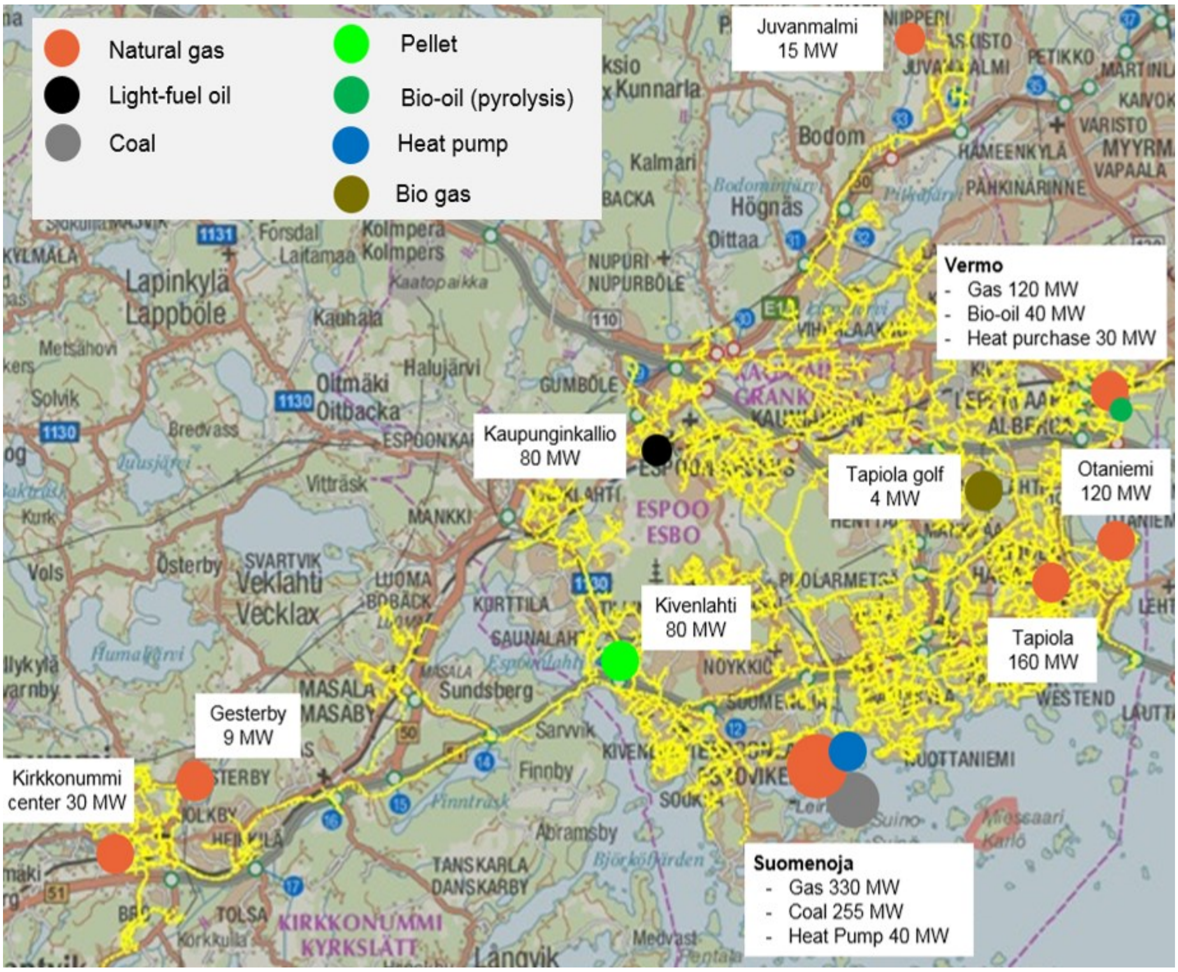

Figure 19. The Espoo-Kirkkonummi district heating network.

Units located in Juvanmalmi, Kirkkonummi, Gesterby and Tapiola Golf areas and Suomenoja auxiliary boiler are included in this study's scope. Natural gas is the main fuel of all of these units excluding Tapiola Golf unit and gas oil is used as a reserve fuel. Bio gas from closed landfill is used as a main fuel in Tapiola Golf unit. Suomenoja auxiliary boiler, Juvanmalmi units and Tapiola Golf units are used 500 hours yearly. Units located in the Espoo-Kirkkonummi network studied in this thesis, their main and reserve fuels, thermal inputs and operating hours during years 2016 and 2017 are presented in table 15. In addition to the boilers producing heat, there are two reserve engines in Kivenlahti securing cooling production in case of emergency. During 2016 and 2017 these units were started up only in order to test the equipment.

Table 15. MCP-scope units in the Espoo-Kirkkonummi district heating network.

Unit	**Boiler**	**Main fuel**	**Reserve/ start-up fuel**	**Input power [MW]**	**Operating hours**	
					2016	**2017**
Juvanmalmi, Espoo	K1	Natural gas	Gas oil	18	4021	1994
Suomenoja, Espoo	SO7	Natural gas	-	17	3838	3567
Tapiola Golf, Espoo	K1 K2	Biogas Biogas	Liquid gas Liquid gas	2,2 2,2	6480 6480	6480 6480
Kirkko-nummi centre	K1 K2 K3 K4	Natural gas Natural gas Natural gas Natural gas	Gas oil Gas oil Gas oil Gas oil	5,6 11,1 11,1 6,7	76 2251 1108 0	225 226 309 0
Gesterby, Kirkko-nummi	K1 K2 K3	Natural gas Natural gas Natural gas	Gas oil Gas oil Gas oil	2 3 4	5 0 3	0 2 0
Kivenlahti cooling unit, Espoo	DG1 DG2 DG3	Sulphur free gas oil		2,5 2,5 2,5	<1 <1 <1	<1 <1 <1
Tapiola cooling unit, Espoo	DG1 DG2 DG3 CPS1 CPS2 CPS3	Sulphur free gas oil		2,5 2,5 2,5 4 4 4	<1 <1 <1 <1 <1 <1	<1 <1 <1 <1 <1 <1

Information concerning emission limit values, emission levels and measurement requirements is presented in appendix 1. Gaseous emissions from Juvanmalmi unit, Suomenoja auxiliary boiler and Gesterby unit have been measured during last years. In these units all emission levels (NO_X, SO_2 and dust) were lower than limit values set in the MCP-decree. Kirkkonummi centre unit have not been measured yet, but it can be assumed that emission levels are lower than the MCP-limits since the fuels used and the role of the unit is similar to those ones already measured. Emissions from Kirkkonummi unit are to be measured during the year 2018.

Tapiola Golf unit is located on a closed landfill and uses bio gas from the closed landfill as a fuel and liquid gas as an ignition fuel. There are two boilers which both have thermal input of 2 MW. These boilers were first taken in to use in 2007 but were moved to this location in 2014. Tapiola Golf boilers are defined as new units by the PiPo-decree definition because of the location change. In normal situations these boilers are operating over 6000 hours during one year. Emission levels have not yet been measured and the requirement by the MCP-decree is to measure them latest during the year 2030. It's almost impossible to estimate the amount of the air emissions from landfill gas combustion without measurements, since they can vary significantly based on the waste quality and the age of the landfill. Also it is uncertain how long the landfill produces biogas worth utilisation. The purpose is to utilise biogas as long as it's produced from the closed landfill.

There were no identified investment needs in the Espoo-Kirkkonummi district heating network due the MCP-decree, which is because natural gas is used as main fuels in majority of the units. Emissions from Tapiola Golf unit must be measured and the unit should be registered not later than in 2030 if it is still operating. Emissions from Kirkkonummi unit should be measured during 2018.

4.3 Järvenpää and Tuusula network

The whole Järvenpää-Tuusula district heating network with existing units and their thermal inputs is presented in figure 20. Järvenpää CHP-unit is not in this study's scope but is included to the figure to clarify the whole system. There are three natural gas HOBs and one reserve engine located at the same area (Ristinummi) with the CHP-unit. In addition to the CHP-area, there are six heat-only boilers located in the network. Kaskitie unit presented in the figure is still in place, but is not operated anymore.

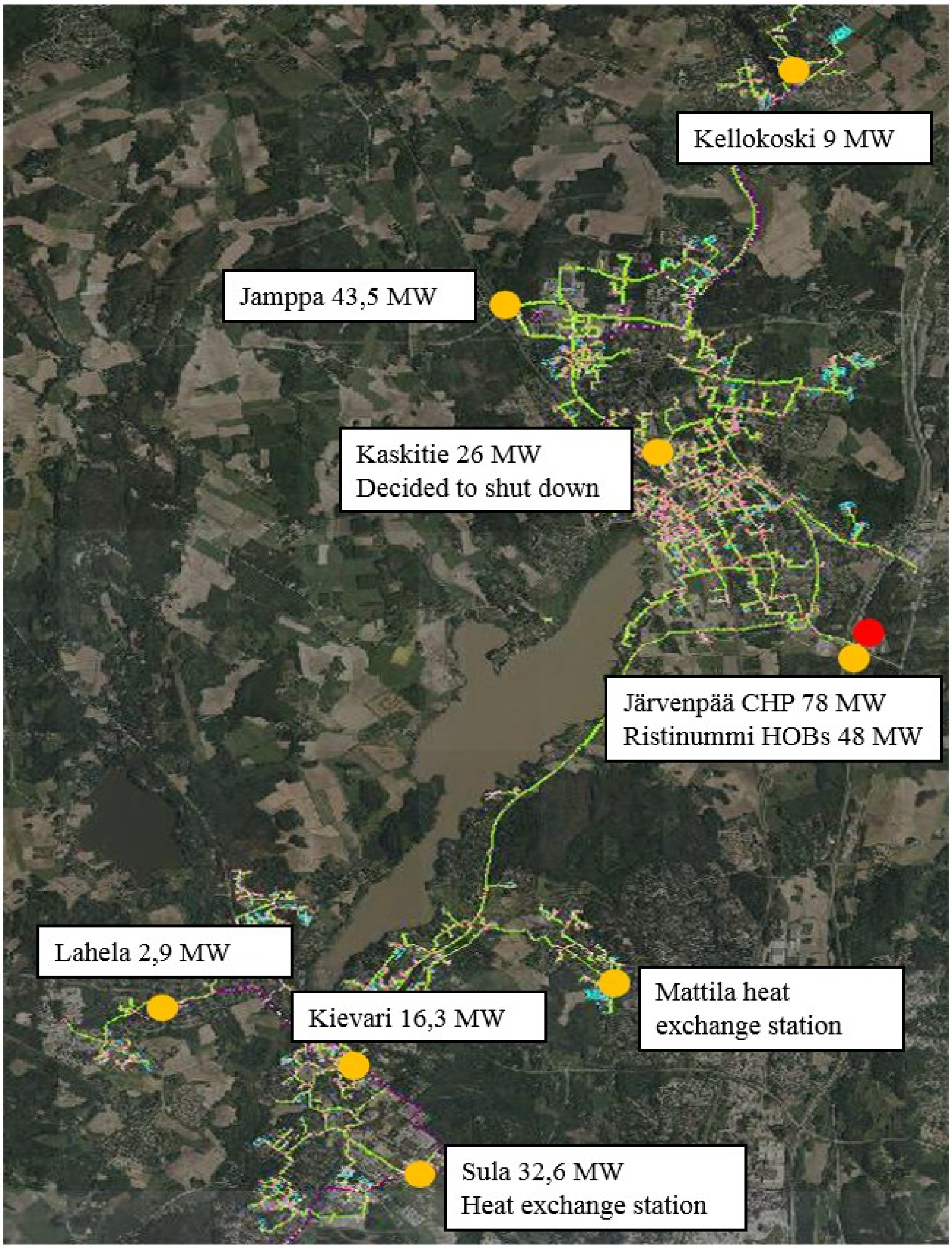

Figure 20. The Järvenpää-Tuusula district heating network.

Information of the units in the scope located in the Järvenpää and Tuusula district heating network is presented in table 16. All units excluding Lahela unit use natural gas as a main fuel and gas oil as a reserve fuel. Almost all of these units are operating as peak load units. Only the operating times of Ristinummi HOBs and Jamppa unit exceed 1000 hours yearly. Current emission levels and limit values are found in appendix 1.

Table 16. MCP-scope units in the Järvenpää-Tuusula district heating network.

Unit	Boiler	Main fuel	Reserve fuel	Thermal input [MW]	Operating hours	
					2016	2017
Ristinummi HOBs	K1	Natural gas	Gas oil	16	1633	610
	K2	Natural gas	Gas oil	16	1188	1468
	K3	Natural gas	Gas oil	16	1146	1739
Jamppa, Järvenpää	K1	Natural gas	Gas oil	16,3	2400	0
	K2	Natural gas	Gas oil	16,3	2400	405
	K3	Natural gas	Gas oil	10,9	1200	500
Kievari, Tuusula	K1	Natural gas	Gas oil	16,3	16	20
Sula, Tuusula	K1	Natural gas	Gas oil	16,3	169	100
	K2	Natural gas	Gas oil	16,3	169	50
Kellokoski, Tuusula	K2	Natural gas	Gas oil	5,4	614	20
	K4	Natural gas	Gas oil	4	614	700
Lahela	K1	Gas oil	-	1,4	0	0
	K2	Gas oil	-	1,4	0	0
Ristinummi reserve engine		Sulphur free gas oil	-	1	<1	<1

Gaseous emissions from Ristinummi HOBs and Jamppa, Sula and Kellokoski units have been measured and their emissions levels were all below the MCP-decree's limit values (presented in appendix 1).

There were no investment needs in the Järvenpää and Tuusula district heating network area due to the MCP-decree publication, which is mainly because of natural gas is used as a fuel. In Lahela unit emission measurements needs to be done and the unit must be registered no later than in the year 2030.

4.4 Joensuu network

The Joensuu district heating network covers Joensuu city area in the Eastern Finland. There is one CHP-unit and multiple HOBs located in the district heating network. The overall system with all of the energy production units and the whole district heating distribution network is presented in figure 21.

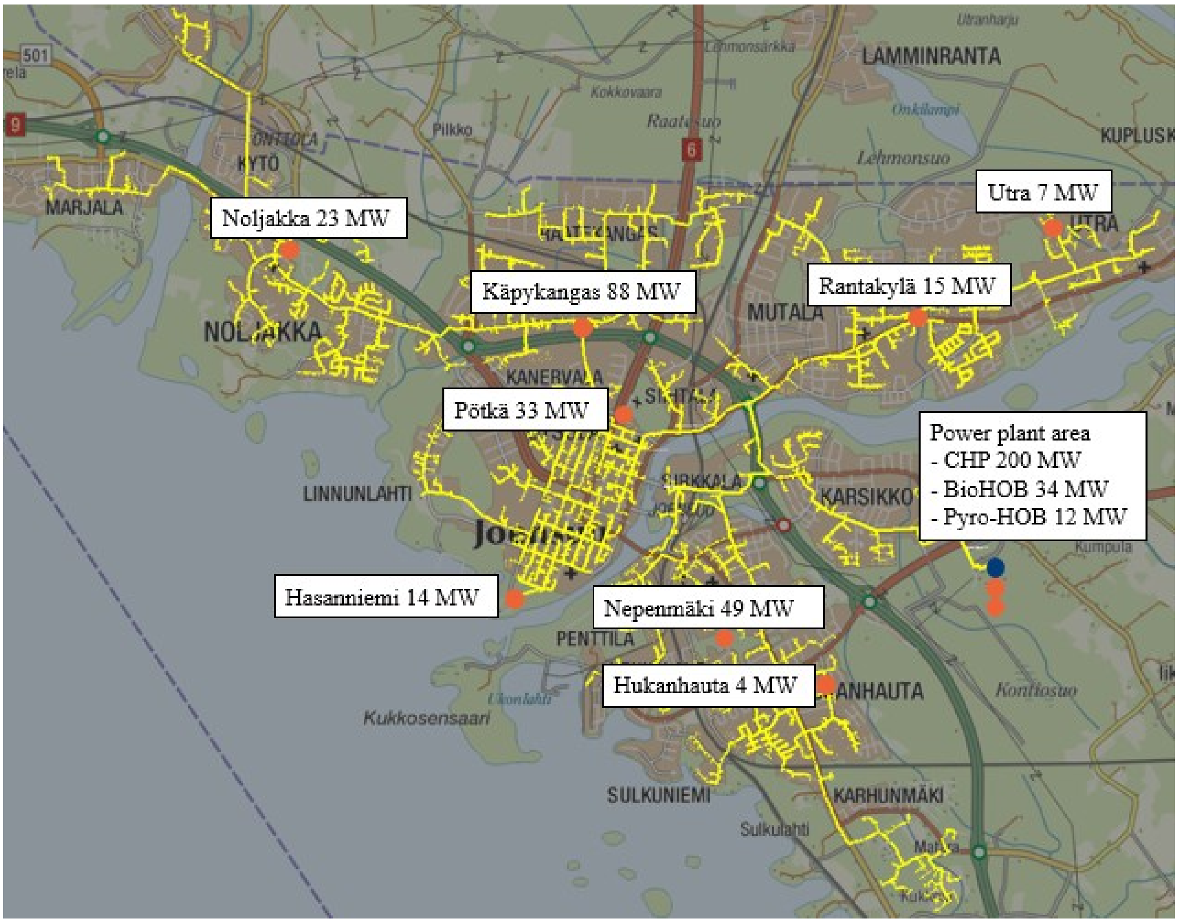

Figure 21. The Joensuu district heating network.

All existing energy production units in the scope and their fuels, thermal inputs and operating hours during years 2016 and 2017 are presented in table 17. All energy production units in the Joensuu area, excluding biomass HOB and pyrolysis oil HOB located in the power plant area, use gas oil as a fuel and are operated approximately 500 hours or less yearly. Rantakylä unit was changed to a smaller one in 2017 and because of this the operating hours in earlier years are not relevant and are not presented in the table.

Table 17. MCP-scope units in the Joensuu district heating network.

Unit	Boiler	Main fuel	Reserve fuel	Thermal input [MW]	Operating hours	
					2016	2017
Hasanniemi	K1	Gas oil	-	13,8	514	150
Hukanhauta	K1	Gas oil	-	4,4	15	29
Kontiosuo	K2 K3	Biomass Pyrolysis oil	Gas oil -	34 12	3555 300	2972 1000
Nepenmäki	K1	Gas oil	-	48,9	114	43
Noljakka	K1	Gas oil	-	22,7	563	548
Pötkä	K1 K2 K3	Gas oil Gas oil Gas oil	- - -	11,1 11,1 11,1	61 53 11	22 42 16
Rantakylä	K1	Gas oil	-	14,5	Not applicable	
Utra	K1	Gas oil	-	7	327	244

Gaseous emissions from all energy production units located in the Joensuu area have been measured. All emission levels were lower than limit values set by the MCP-decree in current operating situations. Boilers located in Noljakka and Rantakylä were changed to use gas oil as a fuel and haven't been measured yet with gas oil. Both of these will be measured during 2018.

In the current operating situation no investments are needed to the existing units in the Joensuu district heating network. Capacity in the Joensuu district heating system has been reorganized during 2017–2018 and one possibility is that the operating hours of Utra unit are needed to be increased in the future comparing to years 2016 and 2017. If the operating hours of Utra unit exceed 500 hours during one year the emission limit values by the MCP-directive are applied. Emission levels and limit values, and the possibilities to fulfil the requirements in changed operating situation is studied in the following sub-chapter.

4.4.1 Case: Utra

Utra energy production unit is located in the eastern part of Joensuu. There is one boiler with 7 MW fuel input in Utra. Operation of Utra unit started in 1994 and heavy fuel oil was used as a fuel during 1994–2017. Utra unit was changed to use gas oil as a fuel in 2017 due the PiPo-decree's tightened emission limits. Unit is equipped with multicyclone. Emission levels with gas oil as a fuel were measured in 2017. During the last 5 years Utra unit has been operating less than 500 hours during one year and in this situation no emission limit values are applied. Measured emission levels are presented in table 18 with emission limit values in parentheses for a unit operating more than 500 hours during one year.

Table 18. Emission levels and limit values for the Utra unit if used more than 500 hours during one year.

Pollutant and fuel		**Emission level (2017) [mg/m^{3}n]**	**Emission limits for transition period (2018-2030) [mg/m^{3}n]**	**MCP final emission limits (2030→) [mg/m^{3}n]**
NOx	Gas oil	215–228	(600)	(200)
SO_2	Gas oil	9	-	-

The uncertainty of the conducted NO_X-measurements was defined to be ± 24 mg/m^{3}n and thus emission levels are not far from limit values after the transition period. Gaseous emissions as tonnes from the Utra unit during year 2017 are presented in table 19. These values are based on the amount of gas oil used during year 2017 and on the emission measurements. It can be seen that the total emissions are marginal from the Utra unit comparing to total amount of pollutants from whole Joensuu system: CO_2: 336 thousand tonnes, from which 208 thousand tonnes $CO_{2,bio}$ and 128 thousand tonnes $CO_{2,fossil}$, dust: 18 tonnes, NO_X: 609 tonnes and SO_2: 38 tonnes.

Table 19. Air emissions from Utra unit during 2017.

	Dust	**NO_X**	**SO_2**	**CO_2 (fossil)**
Amount of pollutant [t/a]	0,1	0,2	0,9	255

Three different scenarios are studied to fulfil the limit value for NO_X but also to increase the share of renewables used in production or to decrease combustion altogether with demand-side management. The scenarios are stated as following:

1. Primary method: adjust or change the burner
2. Transform the boiler to be able to use pyrolysis oil as a fuel
3. Cover peak load needs with demand-side management

Scenario 1

Since the measured NO_X emission level is not far from the defined emission limit value, the adjustment of burner could be the only action needed to reach the NO_X limit value if operation hours are increased. The optimal combustion circumstances can reduce the amount of NO_X emissions originating from the combustion process. For example reduced combustion temperatures reduce the formation of NO_X. The adjustment of burner can be done during normal maintenance of the unit and in this case no big investment might not be neeed. Because of these reasons the adjusting is an obvious first step.

After the adjustment the emission levels are to be measured again. If the adjustment doesn't produce enough reduction in the NO_X-levels, the second option is to purchase new burner to the boiler. Transition time is until 2030 and there is multiple years to adjust burner and test if limit values are fulfilled. Long transition time also leaves time for purchasing new burner and test it if the adjustment is not enough. Utra unit has still many years of operating time left so new burner is a reasonable investment.

Scenario 2

In the scenario 2 the possibility to use pyrolysis oil as a fuel instead of gas oil in the case unit, Utra, is studied. Pyrolysis oil was chosen to be studied in this case because it is a renewable fuel produced by Fortum. Pyrolysis oil is produced in a pyrolysator located in the Joensuu power plant area. This scenario includes a study of the total costs in existing situation and total costs in a simulated situation in which the fuel of Utra unit is pyrolysis oil. The aim of the calculation is to examine the amount of the difference between the total cost of gas oil usage comparing to pyrolysis oil usage. Cost savings in this situation are gained from fuel procurement, from fossil fuel taxes and from CO_2-costs. Costs are estimated to be significant enough to change the merit order of city HOBs in Joensuu district heating system. The basic principle of the current merit order based on the production costs is presented in figure 22. This figure is not in scale, just for demonstration purposes.

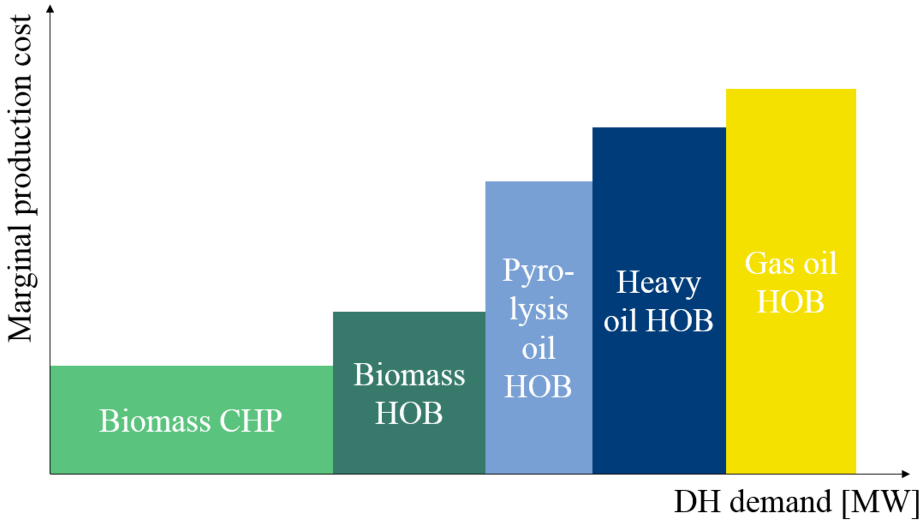

Figure 22. Basic merit order of different units in Joensuu.

In the Joensuu district heating system the energy production in CHP-unit has the lowest production costs due benefits from the combined heating and electricity production. Rest of the merit order is based on the fuel costs: solid biomass has lower purchase costs than liquid oil fuels and gas oil is more expensive than heavy oil. Also fossil fuel taxes and CO_2-costs are affecting to merit order. If pyrolysis oil HOB is taken into this comparison the production costs are between biomass HOB and heavy oil HOB.

Pyrolysis oil can't be used in a gas oil boiler without modifications, because properties of pyrolysis oil differ from gas oil. Pyrolysis oil is an acidic liquid (pH 2,5) and it has high viscosity. Oil feeding chain must be replaced since steel material which can resist the acidity of the pyrolysis oil is needed. The cost of the modifications needed is approximately 100–120 €/kW based on earlier experiences. In this case it is assumed that similar heat output is reached with pyrolysis oil than with gas oil. Emission limit value for NO_X from pyrolysis oil combustion is higher comparing to gas oil and the NO_X limit value is easier to reach with pyrolysis oil. Pyrolysis oil is produced from biomasses and contains ash originating from the biomasses. Dust emissions from pyrolysis oil combustion origin from the ash from the fuel. In pyrolysis oil combustion investments are needed for dust removal; combustion of pyrolysis oil requires electrostatic precipitator or bag filter to keep dust emission levels below the limit values.

Feasibility of the modification and fuel switching is studied through a case study. Case study was executed using an internal modelling tool and with temperatures in 2017. The production of district heating in year 2017 is presented in figure 23. The figure demonstrates the potential of gas oil and heavy oil based production which could be replaced. From the figure it can be seen that the CHP-unit dominates the production of district heating most of the time, only during summer revision the production is based on HOBs. Bio-HOB and existing pyro-HOB are started up after the CHP-unit and the operating time of gas oil HOBs is minimised.

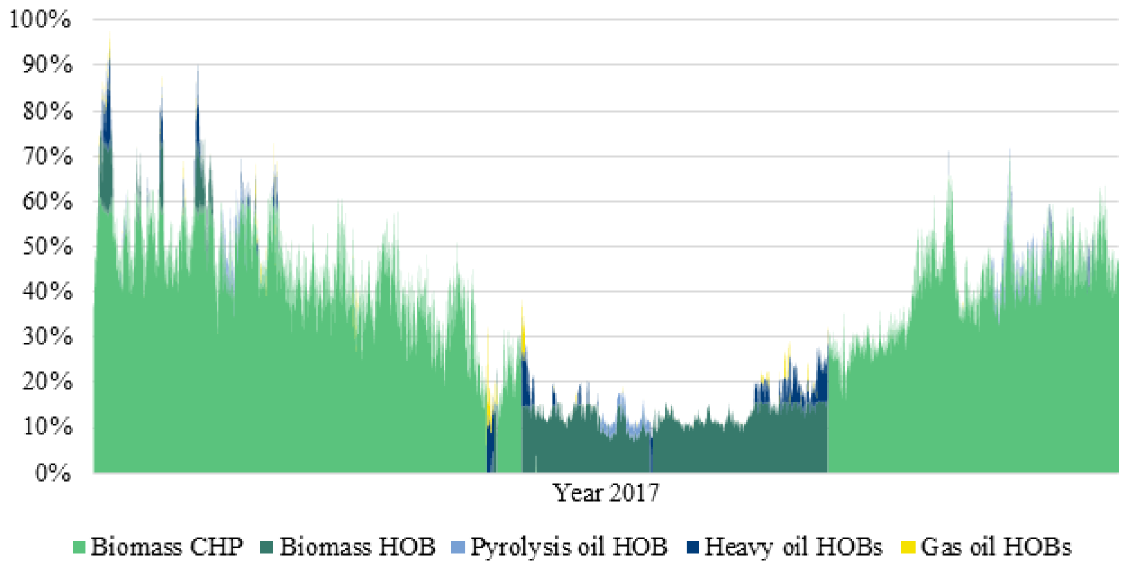

Figure 23. Production in Joensuu district heating system during year 2017.

In this scenario the total energy production costs during year 2017 were calculated in the current fuel situation and were compared to the case in which gas oil is replaced with pyrolysis oil in Utra. Tool calculates the production costs based on fuel costs and taxes, CO_2-costs and electricity price. Tool studies only normal situations, no disturbances are taken into account. Operation and maintenance costs are also excluded from the calculation. Realised fuel costs, electricity price and taxes were based on the real costs during 2017 and 2018. The difference between overall district heating system costs in current and in simulated situation represents the yearly savings due the fuel change.

Based on the calculation tool the amount of the total replaceable district heating production in 2017 was approximately 2000 MWh. The potential replaceable production is moderately small, mainly due the big capacity of biomass-based production in the Joensuu district heating system. There is a lot of uncertainties in the calculation which should be noted. Temperatures and prices used were only an example from a few years. Multiple different prices are affecting the result of calculation: basic fuel prices of every fuel used in the calculation, electricity prices, fossil fuel taxes and CO_2 emission trading costs. There is variation and uncertainties concerning all of these prices, but especially fuel procurement and electricity prices are fluctuating constantly. Operation and maintenance costs and disturbances are not taken into account can have significant effects on the total costs in real situations. This scenario was not calculated any further because of the small amount of replaceable production in the case unit.

Scenario 3

In this scenario it is studied whether there is sufficient capacity in Joensuu area to utilise demand-side management instead of starting up the Utra unit to cover momentary peak demands. This scenario also assesses the potential benefits of DSM utilisation. Utilisation of DSM is based on management of a big mass of buildings and if the connected capacity is enough, there is a possibility to use the DSM. It is identified by the case company that it is possible to gain 15 % decrease in momentary district heating consumption from buildings peak capacity with DSM without any noticeable effects on indoor conditions. Speed of changes in indoor temperatures depend on the type of the building, whether the ventilation is used or not and the outdoor temperature.

If the aim is to shift 5 MW of production with DSM, needed customer mass connected to the DSM is 33 MW if achieved temporarily decrease in heat supply is 15 %. In DSM the size of customer matters: in smaller buildings the investment to DSM equipment would be too high comparing to potential benefits. This is because the cost of the equipment needed for DSM is equal to all sizes of buildings, but benefit is bigger from larger buildings. In this study the potential customers in Joensuu district heating system were examined from the current customer mass so, that only middle-sized and bigger customers were taken into account. The threshold value used was 150 kW of connected capacity of one building. Healthcare buildings were taken out from this scenario study because there are critical needs for example in hospitals. Excluding healthcare buildings there are approximately 650 customers in the Joensuu district heating network with a connection capacity of 150 kW or more. The total connected capacity of these customers is 253 MW and the total estimated peak capacity is 161 MW. Since the requirement of covering the Utra unit (5 MW) was 33 MW of connected capacity, the customer potential is reached with middle-sized and bigger customers in Joensuu area.

Equipment with investment cost of 1200 € and 1500 € to connect one customer are used in this scenario calculations. If all customers in Joensuu with connection capacity of 150 kW or more are connected to DSM, there would be 650 customers with total of 161 MW estimated peak load demand. If it is assumed that all of these customers are willing to join DSM, the investment costs are total 780 000 € with 1200 € customer equipment and total 975 000 € with 1500 € customer equipment. To cover only the heat output of Utra unit, not all of these customers are needed to connect to DSM. If assumed that 35 MW of connected capacity is enough to cover 5 MW peaks, then the needed amount of customers is 233 customers with a 150 kW of connected capacity. Investment costs of different situations are shown on table 20.

Table 20. Investment costs of selected scenarios.

	35 MW of estimated peak capacity connected (á 150 kW)	**161 MW of estimated peak capacity connected (á >150 kW)**
á 1200 €	280 000 €	780 000 €
á 1500 €	350 000 €	975 000 €

The total investment cost to cover only the 5 MW demand peaks currently is thus between 280 000–350 000 €, but in this situation the demand peak could only last a few hours. If wanted to compare the investment to the operational savings potential found by Kärkkäinen et al (2003), the needed DSM potential would be 80 MW with a total momentary reduction of maximum 20 MW (25 %). Economic benefits of DSM in Jyväskylä district heating system found in the study by Kärkkäinen et al. (2003) were approximately 13 000 €/a. If assumed that Jyväskylä system studied by Kärkkäinen et al. (2003) is similar enough to be compared to Joensuu system, the payback time of the investment would equal to the case study in

Jyväskylä (15–20 years) (Kärkkäinen et al. 2003, 73). Because different district heating systems have different properties, further study to examine the potential reduction in operational costs is needed for more detailed information. For example peak load unit fuels differ in the study by Kärkkäinen (heavy oil) and in Joensuu system (gas oil), but this simplification defines the magnitude of the potential savings in operational costs. Similar economic benefit potential was found by Johansson (2014): estimated cost savings were 7800 – 23 500 €/a.

If DSM is implemented in the Joensuu system the heat supply needed in post heating period would be produced after the highest consumption peaks in the biomass-based production units (CHP and bio-HOB) instead of gas oil-based city HOBs. The price gap between biomass-based production and gas oil-based production is significant, but the duration of the peaks is not long, which keeps the savings in operational costs quite low. Also as seen in scenario 2, the gas oil-based production possible replaced with 5 MW is maximum of 2000 MWh yearly, because of the structure of the district heating system Because DSM is suitable only for momentary heat reduction, only a part of the 2000 MWh potential is possible to shift in time.

In the long term a new investment could be avoided because of DSM. The investment to DSM can be compared an investment to a new 5 MW oil-HOB, which roughly equals to an investment cost of 1,25 M€. If the 35 MW of connected capacity is wanted, the investment to DSM would be 280 000 € with 1200 € equipment or 350 000 with 1500 € equipment. In addition to investment cost there would be annual savings from operational costs.

4.4.2 Case: HorsePower in Kontiosuo

Since the mind-set in energy system transition is to utilise more waste sources and less primary fuels to the district heating system, in this case is studied whether an exemption concerning animal by-product combustion in medium energy production units could be exploited in a case unit. In the year 2017 European Commission amended regulation of health rules regarding animal by-products and derived products not intended for human consumption (EU 142/2011). This included an exemption enabling combustion of the manure of farmed animals as a fuel in medium energy production units without a waste incineration permit (European Commission 2017). The exemption conserns only medium energy production units, in larger energy production units a waste incineration permit for horse manure combustion is needed. Changes easing the combustion of manure are impelemented to Finnish legislation by changing the environmental protection act and law of animal-derived by-products (882/2018). There is environmental benefits for manure combustion found in a study by Natural Resources Institute Finland: a study shows that combustion of horse manure produces smallest loads to the environment comparing to composting or utilisation in landscaping. In the study the whole life-cycle of manure was studied as a life-cycle assessment. (Manninen et al. 2016, 9–10.)

Fortum offers a service called Fortum HorsePower which is an all-inclusive service for staples and energy producers in which the bedding is provided to staples and the horse manure and bedding mix is delivered to energy production units to be utilised as a fuel. Fortum already uses horse manure as a fuel at it's own CHP-unit in Järvenpää. (Fortum 2018e.) There is one unit in the scope of this study in Joensuu which uses only solid biomasses as a fuel. In this case study it is calculated how the exemption would affect on the emission limit values if horse manure is included into the case units fuel-mix. Also other requirements for horse manure combustion are studied.

Because of the exemption, emission limit values can be calculated with multiple fuel unit emission limit value equation instead of applying waste incineration emission requirements. Emission limit value equation for multiple fuels is presented in equation 1 (1065/2017).

$$Value = \frac{value_{fuelA} * A + value_{fuelB} * B + value_{fuelC} * C}{A + B + C} \quad (1)$$

A	Net calorific value of fuel A [MJ/kg] x amount of fuel [kg/h] or [t/a]
B	Net calorific value of fuel B [MJ/kg] x amount of fuel [kg/h] or [t/a]
C	Net calorific value of fuel C [MJ/kg] x amount of fuel [kg/h] or [t/a]

Emission limit values were calculated with equation 1 by using three different mixing ratios: 5 %, 10 % and 15 % horse manure and remaining amount wooden biomasses. Mixing ratios are settled to these ones based on boiler-technical reasons, availability of the horse manure and calorific values of fuels. The results of calculations are presented in table 21. To clarify the situation the emission limit values for 100 % wooden biomasses combustion are presented in the first line. Emission limit values used in calculations for horse manure combustion are the following: dust 15 mg/m^{3}n, NO_X 300 mg/m^{3}n and SO_2 75 mg/m^{3}n. Used net calorific value of horse manure was 1,5 MWh/t and wooden biomass 2,5 MWh/t. Calorific value of biomass is an average from different wooden biomass fuels from statistics Finland (Statistics Finland 2018). Calorific value of horse manure is based on information from Fortum's horsepower webpages (Fortum 2018e).

Table 21. The emission limit values for horse manure and biomass mixture with different mixing ratios.

Mixing ratio [%]	**NO_X [mg/m^{3}n]**	**SO_2 [mg/m^{3}n]**	**Dust [mg/m^{3}n]**
0	450	200	30
5	445	196	30
10	441	192	29
15	436	188	29

There are also other requirements set for animal by-product firing in MCP-scope units which can require significant investments. Flue gas temperature shall be equal to or more than 850 °C at least during two seconds, boiler must include an additional burner to ensure adequate temperature also during start-ups or shut-downs and the results from the temperature measurements shall be saved so, that authorities are able to ensure that combustion temperatures have been sufficient. Dust and NO_X emission levels shall be measured yearly and SO_2 levels yearly or emission are reported based on calculations.

Temperatures in existing case unit, which is a fluidized bed boiler, rarely exceed 850 °C and because of that modifications are needed to ensure reaching required combustion temperature. Possible modifications to fulfil the temperature requirements can be e.g. to adjust the air distribution, decrease heat transfer with new refractory lining in the boiler or to use primary air preheating. Also an additional burner is needed. The existing burner in the case unit is designed for start-ups and doesn't currently reach needed temperatures, so an additional burner or separate fuel feeding is needed. Residence time requirement is at least 2 seconds in 850 °C or more, which does not fulfil in the current situation. If the temperature in the bed is increased with modifications to be at least 850 °C, the residence time requirement can be fulfilled. In this case the theoretical residence time was calculated in three different situations and with real measured values. All process values used in calculations are presented in table 22.

Table 22. The values used to calculate residence time in 850 °C or more. In the calculations it was assumed that temperature requirement is fulfilled with boiler modifications.

	29.8.2017	**30.7.2017**	**10.2.2017**
Thermal power [MW]	36,6	24,8	13,3
Oxygen in fuel gases [%]	4,31	4,24	5,84
Temperature in bed [°C]	850	850	850
Temperature in upper part of the furnace [°C]	767	720	584
Circulating gas [kg/s]	0,68	1,7	0,87
Overall air [kg/s]	21,33	14,23	8,41
Primary air [kg/s]	9,60	6,40	4,63
Secondary air [kg/s]	7,47	4,98	2,94
Tertiary air [kg/s]	4,27	2,85	0,84

In the calculations the boiler was divided to three sectors: first sector between primary and secondary air inlet, second one between secondary and tertiary air inlet and third between tertiary air inlet and top of the furnace. Real dimensions of the boiler were used. Residence time in 850 °C or more was calculated separetely in all sectors with three different thermal inputs in which. It was assumed that the temperature in the fluidized bed is at least 850 °C. Flue gas temperatures after first and second section were calculated based on heat transfer estimation and calculated flue gas flows. The temperature after the third section, on top of the boiler was the real measured temperature. It was assumed that temperature changes linearly in each section. Flue gas residence time at temperature of 850 °C or more was calculated for each section. Total residence time at temperature of 850 °C or more is sum of the residence times in all of the three sections. Results are presented in table 23.

Table 23. Calculated residence times in different situations.

	29.8.2017	**30.7.2017**	**10.2.2017**
Thermal power [MW]	36,6	24,8	13,3
Residence time in ≥ 850 °C [s]	2,93	3,74	5,71

If the modifications are enough to reach 850 °C temperature in the fluidized bed also the residence time requirement is fulfilled in all loads. Residence time calculated is based on some assumptions and simplifications, but it is obvious that required 2 seconds in 850 °C can be reached. The quality of fuel affects to the bed temperatures. If the fuel quality is better, the combustion temperature is higher. Residence time is the shortest when the load is the biggest and vice versa. This is because a bigger amount of flue gases are produced when load is biggest. If the amount of flue gases increases also the speed of flue gases in the boiler increases.

Costs of boiler modifications needed to reach the required 850 °C temperature in the fluidized bed were not calculated in this study and require further investigations. In addition to the boiler modifications, the investments to fuel handling are needed if new fuel type is wanted to be included into the existing system. Based on an internal study the cost for afterwards modifications to fuel handling in existing system are approximatedly 40–60 €/kW. Horse manure and MCP-decree requires emission measurements for dust, NO_X and SO_2 to be done once during one year, when current requirement is to measure them in every other year. Instead of measurements SO_2 can be defined calculatory based on fuel properties.

5 RESULTS

5.1 Effects of the MCP-decree on the case company's energy production units

Results from the comparison between the current gaseous emission levels and the MCP-decree's limit values were good for the case company: in current operating situation in all units the measured gaseous emission levels were lower than up-coming emission limit values set by MCP-decree. If operating hours of the existing units remain the same, no investments to flue gas cleaning are needed. Monitoring requirements will tighten in almost all units because of the MCP-decree. After the transition periods the periodic emission measurements are to be executed more frequently than before. Requirements before and after MCP-decree implementation are presented in appendix 1. Among the Fortum's existing medium energy production units in Finland there were five units in which gaseous emissions were not measured before or during this thesis, but shall be measured in future. In larger than 5 MW units measurements should be conducted during 2018 based on MCP-decree and in smaller than 5 MW units not later than 2030.

Most of the existing medium energy production units in Espoo-Kirkkonummi and Keski-Uusimaa areas have natural gas as a main fuel. Natural gas produces low amounts of gaseous emissions regulated by the MCP-decree. The amount of gaseous emissions in the flue gases from natural gas boilers reaches the limit values without additional investments to flue gas cleaning equipment. Future of Tapiola Golf unit remained unknown because the air emissions have not been measured and are impossible to estimate because the age and waste fraction distribution in the landfill is unknown. The propose concerning this unit is to continue the operations as they are as long as there is landfill gas available to be utilised. If the unit is still in operation in 2029 when MCP-decree requirements are applied, latest then the emission levels must be measured. If measured emission levels exceed the emission limit values by the MCP-decree, in this case the most realistic outcome is to shut down the operations, since the total size of the unit is less than 5 MW and investment to flue gas cleaning equipment might be too big comparing to the size of the unit.

Because of the PiPo-decree a majority of the units in Joensuu were modified to be able to use gas oil instead of heavy oil during year 2017. PiPo-decree tightened emission limit values so, that continuing of heavy oil combustion required massive investments for emission reduction. Because of this, switching from heavy oil to gas oil was more attractive solution even though gas oil is more expensive fuel than heavy oil. MCP-decree emission limit values are much easier to reach with gas oil combustion because it produces lower levels of gaseous emissions comparing to heavy oil combustion. Multiple case company's energy production units in the Joensuu area use gas oil as a fuel. Natural gas is not available in Joensuu area. From these units Hasanniemi, Pötkä and Utra units would exceed the NO_X-emissions limit value for gas oil combustion after transition periods if there is needs to operate these units more than 500 hours during one year. Dust and SO_2-levels would remain below the emission limit values if MCP-decree emission limit values are applied.

Utra unit was chosen to be studied as a case because of its location in the end of the existing district heating network. In the future it might need to be operated more to ensure delivery reliability for all customers in the end of the network. Three different scenarios studied are presented in table 24.

Table 24. Solutions for Utra NO_X-reduction

	Cost	**Pros**	**Cons**
Adjusting the burner	Part of maintenance: no identified separate cost	- No investment cost	- Fossil fuel remains as a fuel - NO_X-reduction not certain
Utilise demand-side management	240–925 k€	- Avoided gas oil usage - No CO_2-costs or fossil fuel taxes - Smoother operation	- Investment cost to customer equipment - Controlling of DSM - Real cost savings unknown
Change the unit to use pyrolysis oil	700–840 k€	- Renewable fuel - Fortum fuel - No CO_2-costs or fossil fuel taxes	- Investment cost to boiler modifications - Operational costs - Lack of replaceable production in the system

The most realistic first step for Utra unit is to adjust the burner to gain optimal combustion circumstances, if the operating hours of the unit are increased. With long transition time the burner can be adjusted and then measured again. If adjusting doesn't produce emission reduction, then the second step is to replace existing burner with new one. New burner might become topical also because of age of existing burner.

Switching to a pyrolysis oil fuel is a scenario in which the fuel is switched from fossil fuel to renewable fuel. In the case of operating hours increasing to exceed 500 hours during one year emission limit values are applied and flue-gas cleaning is needed. In the pyrolysis oil scenario the current gas oil-based production which could be replaced was identified to be approximately 2000 MWh yearly. Because of the moderately small amount of replaceale production, the profitability is quite weak and case 1 remained as the most realistic option. Due to this the calculations were not taken any further. Key factor to this result is the small potential of replaceable gas oil and heavy oil-based production, which is due the dominant capacity of biomass-based production available in the district heating system. In Joensuu area the production capacity of biomass-based production is enough even to -15 °C outdoor temperatures in normal operating situations. In some other production structure similar investment could be highly profitable. If CO_2-costs and fossil fuel taxes keep on increasing, investment to increase the share of pyrolysis oil based production might turn out to be more profitable in the selected scenario. Also if the burner adjusting is not enough, this case could be considered. Because the transition period is until 2030, the development of the situation should be followed.

Utilisation of DSM was studied to replace part or all of the operating hours of Utra unit. It has both economic and environmental benefits. The savings in operational costs are estimated to be quite low in reference studies, even though the difference in production costs per MWh produced can be high between peak load units and base load units. In the studied Joensuu system the difference is the cost between gas oil-based production and biomass-based production. Also some operational cost savings are gained from avoided start-ups. The short duration of one demand peak possibly shifted with DSM keeps the yearly benefit potential quite low, because not all morning peaks are possible to be shifted. The possibility of the shifting depends on the mass of the buildings in DSM and the outdoor temperatures.

If there would be an investment need to a flue gas cleaning equipment in Utra unit because of increasing operational hours, the investment to DSM would turn out to be more feasible comparing to flue gas investment. The savings in operational costs will be higher in the future if CO_2-costs and taxes will continue increasing, also as in the pyrolysis oil case. The investment to DSM depends on the amount of customers connected to DSM. Smaller investment (total of 280 000 €) is enough to cover the demand peaks equal to the thermal power of Utra unit, but then there is smaller amount of momentary reduction available. If the demand peak exceeds than 5 MW, some gas oil based production unit is to be started.

During cold winter in Joensuu the duration of the higher demand peak can be too long to be shifted with DSM. Because the outdoor temperatures in Joensuu are low during winter, the district heating system has to be sized so, that there is enough capacity to cover longer freezing winter days. Thus the avoidant of an investment to a new HOB is not as straightforward as presented in the case study.

5.2 How peak load can be produced more sustainably in the case company?

In the Utra case in research question 1 the switching to pyrolysis oil or the demand-side management utilisation would gain environmental benefits from renewable fuel usage instead of fossil fuels. In both situations 255 tonnes of fossil-CO_2 is avoided during one year. In demand-side management it could be assumed that some percentage from the overall yearly production can be reduced, but as presented earlier, in Helsinki district heating system this reduction is only one percent from the total production of district heating.

Using DSM to shift the consumption, the fossil fuel-based production can be avoided and fewer start-ups of peak load units are needed. Because of this the utilisation of DSM could be from environmental perspective the best option for peak load consumption covering. It was identified that the customer potential is more than adequate in Joensuu district heating system at the moment to utilise DSM and to replace part of the operating hours of Utra unit. Long transition period until the end of 2029 enables studying and testing of different solutions. During the transition period potential mass for DSM utilisation could be gained and connected and in 2030 there could be enough connected capacity in DSM.

The second case study examined a possibility to use horse manure as a fuel in a case unit, which is an existing boiler currently using solid biomass as a main fuel. It was found that significant modifications are needed to ensure that all requirements for horse manure combustion in medium energy production unit are fulfilled. The furnace temperature is needed to be increased with boiler modifications and the fuel receiving system needs updating to be adequate to receive and transfer horse manure. If the boiler is modified to achieve required temperature in the furnace, also the residence time requirement for flue gases (2 seconds in 850 °C temperature) is fulfilled. Probably no additional flue gas cleaning systems are needed in this case, since emission limit values wouldn't tighten significantly. From this case study it can be assumed that drivers for animal by products usage as a fuel arise from other aspects than the exemption for MCP-scope units. These drivers can be e.g. profitable purchase prices of animal by products or location of energy production unit close to where animal by products are produced. Use of horse manure as a fuel is reasonable particularly in areas with a lot of horses and not enough fields in which to use the manure as fertilizer.

6 CONCLUSIONS AND DISCUSSION

6.1 Review of MCP-directive and its impacts to case company, Finland and Europe

The effects by the MCP-decree on Fortum's existing energy production units in Finland in the scope were minimal. Impacts of the MCP-decree were initially estimated to be more significant, but because of the nature of Fortum's existing district heating systems and medium energy production units the impacts of MCP-decree remained small. Because of this a review of possible solutions which could increase the sustainability of peak load production and MCP-units as a whole was included to the study. Consequently, the whole scope of the thesis was widen and district heating systems were studied more comprehensively.

Even though the impacts on case company's units remained small, during the study it was clear that in other heat production systems the requirements might be impossible to reach without significant investments. Smallest (1–5 MW) boilers in the scope which use biomasses as a fuel will face the biggest challenges due the MCP-decree in Finland. This is because of the tight emission limit value for dust for these units. Small biomass-firing units can operate outside of cities and utilise local biomasses e.g. wood residues as a fuel, and maybe form a small area district heating network with a few customers. After the transition periods, if emission reduction methods needed are too expensive, it is possible that these units are forced to be shut down. Possible substitute for biomass boilers could be e.g. heat pumps or electric heating if an existing district heating network is too far. Other possible substitutes could be geothermal heat or natural gas or gas oil fired boilers, but geothermal heat is not possible to use in e.g. groundwater areas. Gas oil combustion and especially natural gas combustion can reach the defined emission limit values without any flue gas cleaning equipment, which makes them an attractive substitutes for biomass boilers.

As described above, there is a possibility that existing biomass boilers might be replaced with some other solutions possibly utilising fossil fuels if new emission limit values are too tight for existing units. If biomasses are switched to e.g. natural gas, the gaseous emissions regulated by the MCP-decree might reduce, but the fossil-CO_2 would increase. If at the moment the fuels used in small biomass HOB are e.g. local residues, the transform from this situation to e.g. usage of gas oil is a step to a wrong way concerning the renewable energy targets. If existing solid biomass boilers are switched to e.g. ground source heat pumps, environmental benefits from decreased emissions and fuel usage are achieved, but peak loads might be problematic to cover with ground source heat pumps alone. As stated earlier, the long transition periods in MCP-decree enable implementing of new solutions to heating and cooling purposes. As in all of the units in the scope of this study the transition period is until 2030, the solutions replacing these in future might not be even in commercial use yet. Also the leading target in energy system transition is to end combustion-based energy production altogether.

The target of MCP-directive publication in the European Union was to reduce the total amount of pollutive emissions across the Europe and to improve the air quality especially in the cities. The air quality in some cities in Europe will improve notably because of it. After the requirements are implemented, the air quality situation overall in EU could be more even and stable. In Finland the effect of MCP-decree to air quality might not be noticeable, since the air quality is really good already. Centralised district heating systems are one factor affecting to the good air quality in cities.

6.2 Sustainable heat production

District heating and cooling forms a complex system with multiple different combustion units, alternative energy inputs and ways of working. The existing infrastructure is heavy and the investments are massive and often made to be used for many decades. Consequently the changes in the systems are happening slowly. Energy sector transformation highlights the importance of co-operation between electricity, heat and transportation sectors, which could reduce needs for peak load production of district heating. On the other hand e.g. decentralisation and the rising of prosumers can increase the needs for peak load production in district heating. Peak load production is highly bounded to whole heating sector and its development, which is why it is challenging to predict the best peak load solutions for the future district heating systems.

The district heating companies will face big challenges in future years, as will all energy systems worldwide. The tightening legislative requirements and ambitious emission targets must be fulfilled and in the same time companies financial situations have to be maintained properly. When simultaneously fuel prices fluctuate, taxes increase and multiple energy companies pursue local, renewable fuels in their production, the future fuel prices and supply potential is almost impossible to predict. What is certain is that changes are ahead: sustainably produced biofuels can't cover all district heating currently produced with fossil fuels. When the whole district heating and cooling system is in transition phase and tightening requirements concern also the base load, smaller parts of the whole system, like MCP-scale peak load units, might not be the first one to be developed beyond minimum requirements. There is still potential in these units to be more sustainable.

Environmental impacts from the district heating process origin from the usage of fuels: the production, supply chain and combustion of fuels all have environmental impacts. Pumping of oil and natural gas, excavation of coal, harvesting of forest to wooden biomasses and peat extraction require massive equipment and logistics infrastructure, including pipelines, trucks, trains and barges. The supply chain of fuels was not studied more detailed in this thesis, but it is good to keep in mind that fuel procurement requires a lot of energy and has environmental impacts too. The gaseous emissions from the combustion process itself are only one part of the environmental impacts from the district heating and cooling system based on combustion.

In this study demand-side management was identified to be environmentally and economically feasible solution to cover part of the current fossil fuel-based peak load production in the studied system. At the moment DSM for district heating is being studied and piloted by multiple companies. It is not widely used yet, but is identified to be more common in future. Potential of district heating DSM has been identified to be significant, but in the current operating model utilisation of DSM requires willingness from customers to participate. It is also possible that in future DSM is an integral part of district heating system, not an additional "block" in system optimisation. Utilisation of DSM will reduce the needs for peak load units in normal production situations, but during extremely cold weather situations or longer disturbances DSM is not enough and offers only short-time solution. In these situations the existence of fast medium energy production units is crucial if there is no seasonal thermal storages or other solutions available. In some cases, e.g. in capital area of Finland, there is multiple district heating systems side by side and during disturbance situations in one district heating system the aid could also come from another district heating system located near.

One environmental target in Finland is to use a bigger share of renewable and/or local fuels in energy production. In the MCP-scale units natural gas or liquid fuels are often used because they are easy to handle and boilers are fast to start-up when needed. And even though if fuel is switched from fossil fuel to renewable fuel, the total amount of emissions produced in the combustion process doesn't automatically decrease and investments to flue gas cleaning equipment might be needed.

One key factor in public discussions regarding to energy sector transformation is the sufficiency of fossil fuel-related costs and tightening emission limit values. It has been questioned that are taxes and limit values really high or tight enough to transform the market-terms working energy sector? If they were, there would be increased pressures to develop new solutions. Also what remains unknown is the current situation of the world: is the European Union's efforts enough if there is big polluters going on the other way?

6.3 Future research

Load management remains as one of the biggest subject of studies in northern district heating systems. How it is possible to answer to the fluctuating needs sustainably? Usage of fossil fuels is wanted to reduce, there will be increasing competition from renewable fuels, and also as DSM isn't the ultimate solution to cover all of the fluctuating demands, new solutions are needed. Synergies between heat and electricity markets could be exploited, but electricity systems have their own fluctuations and challenges in efficient storage technologies too. All in all, the different energy networks should be studied as a whole and synergies are needed to gain the most optimal and the least polluting way of operating.

In normal operating situations solutions like DSM or heat accumulators can replace the usage of peak load units already in short-term, but during disturbances other solutions like seasonal thermal storages or co-operation between heating producers is needed. Seasonal thermal storages and DSM together are a solution with economic and environmental benefits, and their utilisation to district heating systems concerning peak load production would be interesting to study. If the estimated cost savings due DSM are estimated to be between 1–25 %, the cost savings from the total production costs, from optimal usage of DSM with seasonal thermal storages and co-operation between sectors could bring even bigger benefits. Biggest questions about DSM implementing are the controlling of DSM, the willingness of customers to participate, possible incentives required and also the pricing model. Implementing of DSM requires real-time measuring data, intelligence in the network and automatized systems. It should be ensured that consumers doesn't receive any unpleasantness.

7 SUMMARY

The MCP-directive was published by the European Union in 2015 and was implemented to the Finnish legislation in the end of 2017. The scope units of the MCP-directive are energy production units with a thermal power of 1 MW or more but less than 50 MW. The main objective of this thesis was to study whether Fortum's units in the scope in Finland are in line with the MCP-decree. And if not, what action paths there is to fulfil the requirements. Basic information, emission levels, emission limit values and monitoring requirements of the units in the scope were examined and part of the scope units were registered to the environmental authorities' data systems.

In the existing situation majority of the units studied in this thesis fulfilled the requirements set by the MCP-decree. Because of the reorganised production structure in the Joensuu district heating system it was studied what kind of action paths there is if the role of a case unit is changed and the MCP-decree's emission limit values are applied. Scenarios chosen to be studied were primary methods to decrease emissions in the case of operating hours increasing, switching the fuel to bio oil and utilising demand-side management to replace all or part of the operating hours of the case unit and thus avoid the applying of MCP emission limit values.

Also the utilisation of the exemption concerning horse manure combustion in medium energy production units unit was studied in a case unit. It was identified that requirements are possible to reach, but the incentive to add horse manure to the fuel mix is needed in addition to the exemption itself.

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APPENDIX 1

City	Energy production unit	Boiler	Starting Year	Electricity power [MWel]	Heat power [MWth]	Fuel power [MWf]	Usage 2016 [h]	Usage 2017 [h]	Operation time category [h]	Main fuel	Reserve fuel	Emission levels NOx mg/m3n	Emission levels SO2 mg/m3n	Emission levels Dust mg/m3n	Transition time limits NOx mg/m3n	Transition time limits SO2 mg/m3n	Transition time limits Dust mg/m3n	MCP-limits NOx mg/m3n	MCP-limits SO2 mg/m3n	MCP-limits Dust mg/m3n	Monitoring requirement during transition period	MCP monitoring requirements (based on current operating hours)	Monitoring requirements applied	Emission limit values applied	Latest emission measurements
Espoo	Juvanmalmi LK377	k1	2000		16	18	4021	1994	>1000	Natural gas	Gas oil	130 / 178	-	- / 39	300 / 600	-	-	200 / 200	- / -	- / -	Once in 5 years	Once in 3 years	2025	2030	21.5.2015
	Kivenlahti LK375	DG1	2010	1		2,5	20	20	<500	Gas oil		1630	-	12	-	-	-	-	-	-	Not required if used <500 h/a	Once in 1500 hours or at least once in 5 years if used <500 h/a	2030	2030	Approximated based on Tapiola LK317
		DG2	2010	1		2,5	20	20	<500	Gas oil		1630		12	-	-	-	-	-	-					
		DG3	2012	1		2,5	20	20	<500	Gas oil		1630		12	-	-	-	-	-	-					
	Suomenoja	So7	1977		15	17	3838	3567	>1000	Natural gas		186	-	-	300	-	-	200	-	-	Once in 5 years	Once in 3 years	2025	2030	14.1.2015
	Tapiola LK371	DG1	2011	1		2,5	20	20	<500	Gas oil		1630	55	12	-	-	-	-	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2030	2030	23.5. & 13.8.2013
		DG2	2011	1		2,5	20	20	<500	Gas oil		1630	55	12	-	-	-	-	-	-					
		DG3	2011	1		2,5	20	20	<500	Gas oil		1630	55	12	-	-	-	-	-	-					
		CPS1	2011	1,6		4	20	20	<500	Gas oil		890	55	6	-	-	-	-	-	-					
		CPS2	2011	1,6		4	20	20	<500	Gas oil		890	55	6	-	-	-	-	-	-					
		CPS3	2011	1,6		4	20	20	<500	Gas oil		890	55	6	-	-	-	-	-	-					
	Mankkaa (Tapiola Golf) LK383	k1	2007		2	2,2	6480	6480	>1000	Landifll gas		Not monitored yet			-	-	-	250	200	-	Not required if used <500 h/a	Once in 3 years	2030	2030	-
		k2	2007		2	2,2	6480	6480	>1000	Landifll gas		Not monitored yet			-	-	-	250	200	-					
Kirkko-nummi	Kirkkonummi center LK379	k1	1990		5	5,6	76	250	<1000	Natural gas		Not monitored yet			400	-	-	200	-	-	Once in 7000 hours or 7 years	Once in 3000 hours or 5 years if used 500-1000 h/a	2025	2030	-
		k2	1990		10	11,1	2251	226	>1000	Natural gas		Not monitored yet			400	-	-	200	-	-	Once in 5 years	Once in 3 years			
		k3	1990		10	11,1	1108	309	>1000	Natural gas		Not monitored yet			400	-	-	200	-	-					
		k4	2003		6	6,7	0	0	<500	Natural gas		Not monitored yet			(400)	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a			
	Gesterby LK384	k1	1999		1,8	2	5	0	<500	Natural gas	Gas oil	78 / -			-	-	-	(250 / 200)	- / -	- / -	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2030	2030	20.-21.12.2016
		k2	1998		2,7	3	0	2	<500	Natural gas	Gas oil	120 / -			-	-	-	(250 / 200)	- / -	- / -					
		k3	1990		3,6	4	3	0	<500	Natural gas		133 / -			-	-	-	(250)	-	-					
Joensuu	Hasanniemi LK387	k1	2005		12,8	13,8	514	150	<500	Gas oil		240	23	6	(900)	-	-	(200)	-	-	Once in 7000 hours or 7 years	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	27.2.2017
	Hukanhauta LK395	k1			4	4,4	15	29	<500	Gas oil		218	-	1	-	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2030	2030	16-30.1.2013
	Kontiosuo power plant	k2	2009		30	34	-	2972	>1000	Biomass		161	<1	2	450	200	50	450	200*	30	Once in 2 years	Once in 3 years	2025	2030	15.12.2016
		k3	1998		9	12	300	1000	>1000	Pyrolysis oil		205	4	<1	900 until end of 2019, 800 from 2020	120	50	650	350	30	Once in 3 years				14.-15.2016, NOTE: includes flue-gases from k2
	Nepenmäki LK396	k1	2015		45	48,9	114	43	<500	Gas oil		201	3	3	(500)	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	21.1.2016
	Noljakka LK389	k1	2002		20	22,7	563	548	<1000	Gas oil		Not monitored with gas oil			600	-	-	200	-	-	Once in 7000 hours or 7 years	Once in 3000 hours or 5 years if used 500-1000 h/a	2025	2030	-
	Pötkä LK393	k1	1993		10	11,1	61	22	<500	Gas oil		218	-	1	(900)	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	3.-4.4.2017
		k2	1993		10	11,1	53	42	<500	Gas oil		240	6	2	(900)	-	-	(200)	-	-					
		k3	1993		10	11,1	11	16	<500	Gas oil		230	-	2	(900)	-	-	(200)	-	-					
	Rantakylä LK387 (Moved to this location in 2017)	k1	2017		12,8	14,5	430	230	<500	Gas oil		Not monitored with gas oil			800	-	-	200	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	-
	Utra LK392	k1	1994		6	6,8	327	244	<500	Gas oil		227	9	-	(900)	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	28.2.2017
Järvenpää	Järvenpää power plant area, LK288	k2	2010		15	16	1633	610	>1000	Natural gas	Gas oil	156 / -	-	-	200 / 500	-	-	200 / 200	-	-	Once in 5 years	Once in 3 years	2025	2030	7-8.12.2016
		k3	2010		15	16	1188	1468	>1000	Natural gas	Gas oil	145 / -	-	-	200 / 500	-	-	200 / 200	-	-					
		k4	2010		15	16	1146	1739	>1000	Natural gas	Gas oil	169 / -	-	-	200 / 500	-	-	200 / 200	-	-					
	Jamppa LK253	k3	2007		10	10,9	2400	10	>1000	Natural gas	Gas oil	119 / -	-	-	400 / 600	-	-	200 / 200	-	-	Once in 5 years	Once in 3 years	2025	2030	14.12.2016
		k1	2007		15	16,3	2400	405	>1000	Natural gas	Gas oil	108 / -	-	-	300 / 900	-	-	200 / 200	-	-					
		k2	2008		15	16,3	1400	500	>1000	Natural gas	Gas oil	90 / -	-	-	300 / 900	-	-	200 / 200	-	-					

APPENDIX 1

Basic information												Emission levels			Transition time limits			MCP-limits			Monitoring during transition times	MCP monitoring requirements (based on current operating hours)	Monitoring requirements applied	Emission limit values applied	Latest emission measurements
City	Energy production unit	Boiler	Starting Year	Electricity power [MWel]	Heat power [MWth]	Thermal power [MWth]	Usage 2016 [h]	Usage 2017 [h]	Operation time category [h]	Main fuel	Reserve fuel	NOx	SO2	Dust	NOx	SO2	Dust	NOx	SO2	Dust					
												mg/m3n			mg/m3n			mg/m3n							
Tuusula	Kievari LK238	k1	1991		15	16,3	16	20	<500	Natural gas		124 / -	-	-	300	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2025	2030	5.2.2018
	Sula LK251	k1	2003		15	16,3	169	100	<1000	Natural gas	Gas oil	111 / -	-	-	300 / 600	-	-	200 / 200	-	-	Once in 7000 hours or 7 years	Once in 3000 hours or 5 years if used 500-1000 h/a	2025	2030	5.2.2018
		k2	2007		15	16,3	169	50	<1000	Natural gas	Gas oil	147 / -	-	-	300 / 600	-	-	200 / 200	-	-					
	Kellokoski LK293	k2	2008		3,5	4	614	20	>1000	Natural gas	Gas oil	-	-	-	400 / 900	-	-	250 / 200	-	-	Once in 7000 hours or 7 years	Once in 3 years	2030	2030	-
		k4	2008		4,5	5,4	614	700	>1000	Natural gas	Gas oil	100 / -	-	-	400 / 900	-	-	200 / 200	-	-	Once in 5 years		2025		5.2.2018
	Lahela LK271	k1	2006		1,3	1,4	0	0	<500	Gas oil		Not monitored yet			-	-	-	(200)	-	-	Not required if used <500 h/a	Once in 1500 hours or 5 years if used <500 h/a	2030	2030	-
		k2	2006		1,3	1,4	0	0	<500	Gas oil		Not monitored yet			-	-	-	(200)	-	-					

Note: emission limit values highlighed and in parentheses with red are applied only if operating time exceeds 500 hours during one year

*MCP: no limit value for SO2 if only wooden biomasses