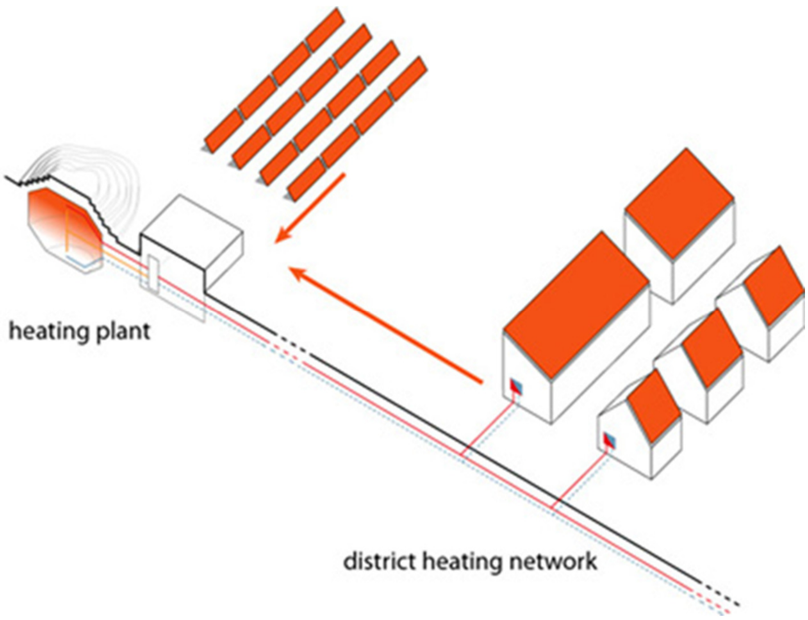

Feasibility for solar district heat in region Västra Götaland

Master's Thesis in the Master's Programme Sustainable Energy Systems

Louise Thrysøe Ekström

Department of Civil and Environmental Engineering
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Master's Thesis BOMX02-16-150
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Cover: A sketch of centralized solar heat by solar district heating.

Department of Civil and Environmental Engineering, Gothenburg, Sweden, 2016

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ABSTRACT

The interest in large-scale solar heating has increased all around Europe from 140 MW in 2007 to 750 MW in end 2015. It can play an important role in the heating sector as it can increase the share of renewables and together with district heating system can increase the overall efficiency. The major advantage of solar heat is the non-limitation and availability all over.

Sweden was one of the first countries to develop large-scale solar heat, but due to a very positive development for biomass fuel and changed rules for energy performance for building in Europe the development of large-scale solar heating decreased in Sweden. The positive development in biomass has led to a transition from fossil fuel used in heating plants to solid wood fuel which today creates opportunities to complement with solar heat. This since many heating plants often consists of a wood fuel fired boiler that runs all year around and an oil fuel fired boiler running during peak demand. During the summer month when the heat demand is low, the wood fuel fired boiler will be running on low power with low efficiency. Solar district heating systems connected to existing wood fired boilers with a central water tank as heat storage will make it possible to run the wood boiler on higher efficiency which will decrease emissions and operation costs. However, there is a major lack of awareness and knowledge about the potential with district heating and large-scale solar heat. This together with the low price for wood fuels has led to poor incentives to invest in solar system.

The region Västra Götaland consists of 49 municipalities. The region is associated with the EC project SDHp2m about solar district heating that has a focus on technologies for large-scale solar district heating plants and their implementation into the district heating network. The aim of the study is to identify and select feasible heating plants within the region that have the opportunities of complementing solar heat to existing district heating systems. At least four existing boilers have been identified. The aim for further work is that at least one of these plants will move on to be used as a demonstration plant during 2017-2018 for other interested actors in the future. The thought is that through a demonstration plant, the gap between the actual status of existing technologies and knowledge about these technologies can hopefully be reduced and thereby increase the incentives.

Key words: District heating, Solar heating, Heating plants, Västra Götaland

Contents

Preface

In this master's thesis a survey of all the heating plants located within region of Västra Götaland has been done. Existing solid wood fired heating plants that could be complemented with solar heat has been identified. The thesis is conducted in cooperation with the EU-project SDHp2m.

I would like to express my gratitude to my supervisor and examiner Jan-Olof Dalendäck at Chalmers University of Technology for his support during this work and always dedicating time to answer my questions as well as taking me to the Conference of Solar District Heating in Denmark.

Borås, October 2016

Louise Thrysøe Ekström

Notations

Formula

CO_2	Carbon dioxide
SO_2	Sulphur dioxide
HCl	Hydrochloric acid
NO	Nitrogen Oxide

Abbreviations

CHP	Combined heat and power
DH	District heating
SDH	Solar district heating
DBDH	Danish Board of District heating
GHG	Greenhouse gas
ETC	Evacuated tubular collectors
FPC	Flat plate collectors
VGR	Region of Västra Götaland
BFB	Bubbling fluidized bed
CFB	Circulating fluidized bed

1 Introduction

Combustion of fossil fuels continues to dominate the global energy market. Currently, fossil fuels provide almost 80% of world energy supply. (Metz et al, 2007) This global dependence on fossil fuel has led to the release of greenhouse gas emissions including carbon dioxide, methane and some traces of nitrous oxide, which has contributed to concentrations in the atmosphere that is no longer environmentally sustainable. This, since it has the potential to cause climate change including air pollution, acid precipitation and stratospheric ozone depletion. Reduction of the greenhouse gas emissions will require a transition to zero- and low carbon technologies (Metz et al, 2007) For these reasons, including energy security, many countries around the world pursue an energy policy focussing on energy efficiency and increasing the share of renewable energy sources. (Lund et al, 2010)

The ability to heat and supply hot water to buildings is essential. Today, it is intensively being discussed how to do so in the best way where the combustion of fossil fuel should be reduced or completely avoided (Lund et al, 2010). District heating systems is a network of piping that distributes heated water to multiple housing, which then returns to the main heating plant to be reheated. These systems have a significant effect of reducing the greenhouse gas emissions and increasing the overall energy efficiency in urban areas. Solar heat is generated by array collectors that absorb solar radiation from the sun and transfer this heat to a fluid that passes through them. The heat is then sent to the district heating network where it contributes to supply heat. Here, the idea is that solar heat is used to supply heat during the summer month when the total load demand is low. In Sweden the energy use for heating and hot water in households and non-residential buildings accounts for more than half of the total energy use within the sector. (Swedish Energy Agency, 2015) The building sector can thus play an important role in mitigating climate change, where solar heat can increase the share of renewables in the heat supply in the district heating network. Since solar energy is practically unlimited, available everywhere and does not emit any emissions.

Sweden were among the first countries to demonstrate the possibilities to use solar heat in the district heating systems. Sweden built a series of solar heating plants during the period 1982 to 1992 that all were larger than other countries had ever built. However, the need to replace fossil fuels in district heating systems and large availability of bioenergy has led to a positive development for biomass fuels as primary energy in the district heating systems. This development together with changed rules for energy building performance has decreased the interest in large-scale solar heating plants. In contrast to Sweden, Denmark has continued their interest in large-scale solar heating plants and have developed 20 new solar heating plants during the last 5 years. All these solar heating plants together have an area larger than 200000 m^2. The interest in solar heat in Denmark is due to decreased possibilities to use combined heat and power plants, since Denmark have a high tax on natural gas and a low price for electricity due to the high use of wind power. This leads to more feasibility to operate boilers to supply heat to the district heating system and solar heat makes the operation of the boilers more cost efficient. (Dalenbäck et al, 2013)

Large-scale solar heating plants are less attractive in Västra Götaland due to the existence of industrial waste heat and heating plants that is supplied by biomass. The Swedish district heating network is to a large extent supplied by heating plants that uses solid wood as fuel often wood chips that runs all year around. During the summer when the heat demand is low, the boiler will run on low load with low efficiency. A combination of heat storage and solar collectors will make it possible to run the wood boiler on high efficiency which will decrease emissions. At the same time the reduced amount of wood fuel needed will led to decreased operation costs and less transportation, since the heat demand is produced by solar heat. However, low price for wood fuels and the lack of knowledge about the combination have led to small incentives for investments in solar heat in Sweden, even though the costs for solar collectors has decreased the last couple of years due to the positive development in Denmark. (Dalenbäck, 2013)

1.1 Framework for the project

Västra Götaland is a region located on the west part of Sweden and is associated to the EU-project SDHp2m, where the EU-project SDHp2m stands for "solar district heating – policy to market". The project has a focus on technologies for large-scale solar district heating plants and their implementation into the district heating network. The project is developed around the three regions Thuringen in Germany, Styria in Austria and Rhone Alpine in France where all are planning to develop solar heat into their district heating systems. The Swedish partner in the project is CIT Energy management which are looking for potential Swedish demonstrations project to implement solar heating in the region of Västra Götaland. (Dalenbäck, 2016a)

1.2 Purpose

The region of Västra Götaland have 1.6 million inhabitants on 24000 km^2 and has 49 municipalities which have one or more block and/or district heating plants using solid wood fuels. Block heating supply heat for a neighbourhood and is a part of the district heating network. This work will investigate all heating plants located within that region and investigate the interest and possibilities to complement solar heat to an existing heating plants based on solid biofuels that have the right opportunities. Considering possible expansion of future developments involving solar heat, those heating plants that are interested are also considered. The investigation is based on how their surroundings and operation status looks like today together with future investments.

The aim of the work is to identify a number of heating plants that have the right possibilities and interest of complementing solar heating in existing blocks and district heating systems based on solid wood fuel boilers within the region of Västra Götaland. Among the identified plants one will hopefully lead to a demonstration plant in 2017-2018. A demonstration plant for a large-scale solar district heating plant. Through this demonstration plants, the gap between the actual status of existing technologies and knowledge about these technologies can hopefully be reduced as well as to show the economic feasibility for large-scale solar district heating plants in Sweden.

1.3 Delimitation

Due to time constrains, the thesis does not include the selection of specific demonstration plants. Only the identified heating plants with the right opportunities to be a demonstration plant are presented within the thesis.

2 Background

The first part of this chapter includes a description of district heating network, firstly in generally terms where after in more specific terms in Sweden. The second part of this chapter will describe solar district heating in terms of technologies, typology and economics.

2.1 Introduction of District heating system

District heating systems have been used in Europe since the 14th century (Kensby, 2015) and involves heating multiple houses where heat is distributed by circulating either hot water or low-pressure steam through underground systems of piping. The heat is generated by heat plants or cogeneration plants, and other sources like geothermal resources, solar heat, electric boilers and large heat pumps. Cogeneration plants convert fuel into electricity and useful heat simultaneously, where the heat is either supplied for industrial applications or used to supply heat to the district heating network. Heat from thermal plants is transferred to the consumers through the undergrounded system of piping using hot water to industrial, commercial and residential users. (Rezaie & Rosen, 2012) Consumers are connected to the district heating system by a district heating substation, which includes two heat exchanger, one for hot water and one for heating. After the hot water has gone through the substations it returns to the heating plants for reheating and redistribution. The heat losses are greater when using steam as heat carrier, and can be minimised by keeping the temperature of the forward water from the heating plants as low as possible. This since, heat losses depend on temperature difference between the district heating water and the surrounding temperature of the district heating pipes. Heat load in district heating systems is the aggregated heat load from the consumers connected to the district heating network and the distribution losses. Due to large variation in the outdoor temperature between summer and winter large heat load variations are created over the year. (Gadd & Werner, 2013) By changing the flow temperature of the forward water, these variations can be met, which requires the central heating plants to operate on both low as well as high load levels. In Sweden the forward water has a temperature between 70 and 120 degrees depending on the heat load demand, whereas the temperature of return water varies between 40-65 degrees. (Erikson, 2009)

One of the advantage of district heating is economies of scale, meaning higher efficiencies in the conversion process and lower fuel costs for the whole system. (Erikson, 2009) This since heat generated in large boilers is more efficient than individual home-owners firing their own boilers. The other advantage is the flexibility to distribute heat from different energy sources like fossil fuels, natural gas, wood, waste municipal, solid waste or mixed systems combining two or more energy sources. However, due to high investment costs and grid losses in the district heating network the distribution of heat over long distances have a limited range. This implies that it is economic feasible to build district heating system in areas where the heat demand is sufficiently high. (Werner & Frederiksen, 1993)

2.2 District heating in Sweden

Northern European countries are the main users of district heating systems. Sweden has notable carbon dioxide taxes on fuel oil, natural gas and electricity which makes district heating more attractive financially, due to high efficiency. (Rezaie & Rosen, 2012) In 2013 Sweden had installed district heating that supplies 58 TWh or 50% of the heating capacity, the rest is electric heating, heat pumps, and biofuel boilers. (Agency, 2015). The fuel supply to the district heating systems in Sweden is shown in Figure 2.1 including waste incineration and waste heat which is excess heat from industrial facilities. Since 1980 the country has decreased its dependency on fossil fuels and thereby decreased carbon dioxide from 340 g/kWh to 65 g/kWh. During the same period, there has been an increase on biofuels like wood products.

However, still 3 TWh comes from fossil fuels used as primary energy as back-up during peak demand. These fossil fuels are often used in the block heating networks which consist of wood fuel fired boilers and an oil fuel fired boiler. Here the wood fuel fired boiler runs all year around and the oil fuel fired boiler runs during peak demand or when the wood boiler needs to be cleaned.

The combustion of fossil fuels and wood fuels emits greenhouse gases, mainly carbon dioxide, CO_2. However, if harvested biofuels are replaced with new vegetation it results in zero net emissions of CO_2. Since biomass consumes the same amount of CO_2 from the atmosphere during growth as it releases during combustion. Waste incineration also emits CO_2 and other pollutants, however leaving it on landfill would result in emissions of methane. (Werner & Frederiksen, 1993)

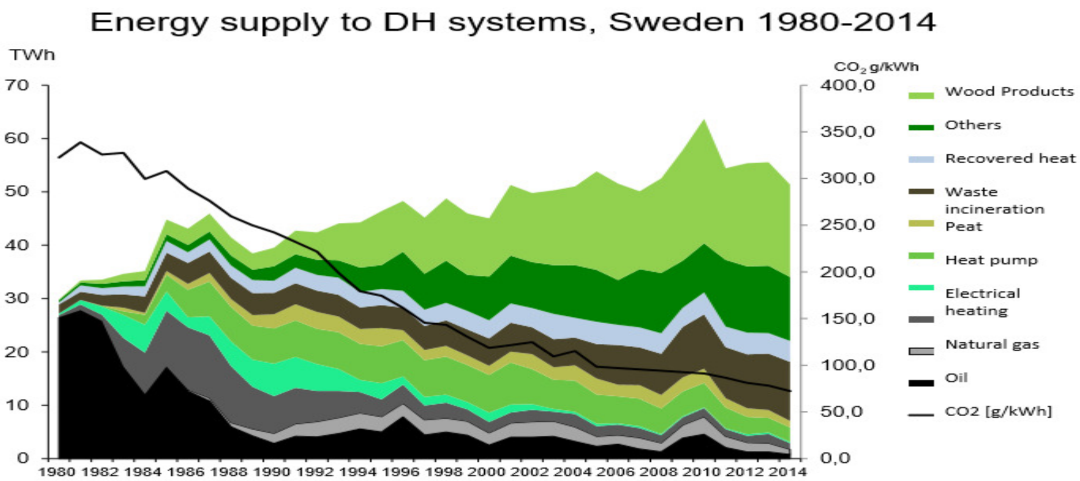

Figure 2.1: Fuel supply to district heating in Sweden. (Source: Kensby, 2015)

The positive development for biofuels in Sweden has led to an increased use of bioenergy due to its low price, and is generally seen as a key factor to replacing fossil fuel consumption in the district heating systems. This replacement has decreased the greenhouse gas emissions and at the same time improved energy security in Sweden. However, solid biomass fuels are associated with low energy density and somewhat difficult to storage and is a material that is geographically scattered. Thanks to good logistic management among biomass suppliers in the country, the biomass is not a scattered material in Sweden. (Olsson et al, 2016)

2.3 Solar district heating

Solar heating plants consists of large collector fields integrated into the district heating network where they absorb solar radiation from the sun for supplying heat to residential and industrial areas. The heat transferring liquid is usually water which is pumped through the collector fields delivered to the central heating plant. Most plants have pressurised collector systems with an anti-freeze mixture, usually glycol is added to the water (Dalenbäck, 2010) due to risk of freezing the heat transferring liquid in the pipes during winter times. In order to store the produced heat variation an energy storage is added. The storage will be charge with heat during hours with surplus produced heat and be discharged during peak demand hours. A measure to effectively even out the demand for heat and make the system more cost efficient. (Schmidt, 2004)

The solar collectors can be installed in two different ways into the system, centralized or distributed installation, and see Figure 2.2. Centralized systems consist of ground mounted solar collectors next to the central heating plant and is used in Scandinavia. Here the solar thermal field feeds in at a central node of the district heating network. (Schmidt, 2004) Distributed solar systems consist of solar collectors installed on roof and is often used in central Europe due to high land cost at new building sites. Here the heat is transferred to the heating plant through a collecting grid. Afterword the heat obtained from both systems is distributed to the district heating system. The most common types of collectors used are flat plate collectors (FPC), but evacuated tube collectors (ETC) are also used. (Buoro et al, 2014)

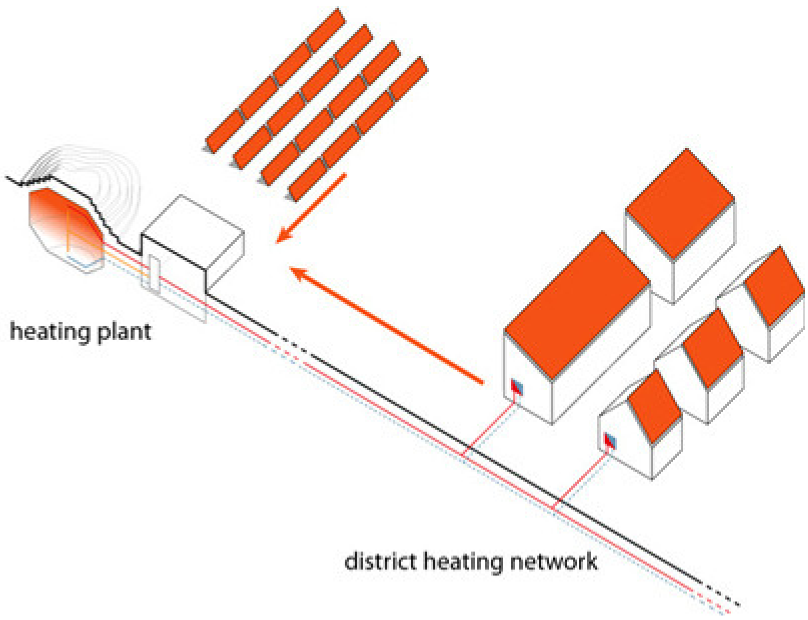

Figure 2.2: Centralized solar heat (Source: Solar district heating)

The average solar radiation in Sweden is around 1000 kWh/m^2 per year with its maximum during day and summer time. The heat is however mainly needed nights and during winter, which is why some kind of heat storage is necessary. And typically, the annual heat generated from solar collectors is 400 KWh/m^2 (Schmidt, 2004) Solar assisted district heating systems can be subdivided into two major system types with short-term heat storage and systems with seasonal heat storage. Systems with short-term heat storage are using diurnal water storage to cover 10-20% of the total yearly heat demand with solar energy whereas systems with seasonal heat storage are designed to cover 50% or more of the total heat demand by solar energy. Most of the plants with diurnal water storage are designed to supply 80-100% of summer heat load during July and August where they often are used to supply heat to large multi-family dwellings, hospitals and district heating systems of large housing estates. (Schmidt, 2004) This also means that a short-term heat storage has a high charge/discharge power but a lower energy storage capacity. Whereas, the plants equipped with seasonal storage contains water in insulated tanks to cover the yearly heat demand for large housing estate. These seasonal storages have a large energy storage capacity with relatively low energy losses. The energy storage can be up to an entire year. The seasonal time shift of heat demand is compensated between solar irradiation and the seasonal heat storage. Where surplus heat that is produced in summer period is charged into the seasonal heat storage to be used for heat supply in autumn and winter. (Dalenbäck, 2013)

There are mainly four types of seasonal heat store developed: hot-water heat store, duct heat store, gravel-water heat store and aquifer heat store. The decision to use a certain type depends on local conditions and the geological and hydrogeological situation in the ground below the respective construction site (Schmidt, 2004). Depending on what type of seasonal heat storage, the system has a start-up time of three to five years to reach normal operational condition. This since the underground around the heat storage needs to be heated up to minimum useful temperature before heat can be extracted, leading to higher heat losses during the start-up time. Therefore, the system efficiency is lower during that period. The return temperature gives the lowest temperature level in the system and decides the minimum discharged temperature for the seasonal heat storage. Meaning a high return temperature lower the heat capacity of the heat store (Schmidt, 2004). Therefore, the return temperature is an important design and construction parameter for the heat distribution systems, since a high return temperature also reduce the efficiency of the boiler and solar collectors. In some plants a heat pump is used to lower the temperature further in the bottom of water storages.

2.4 System typology

There are two main applications of solar heat in Swedish district heating systems. Either by combining a solar collector array with a bioenergy boiler plant or by applying solar collectors on buildings connected to a district heating system and thereby improving the energy performance of the building (as defined in the present building code).

2.4.1 Bioenergy and solar district heating

The first opportunities to introduce solar thermal energy appears in small existing block heating or new district heating systems where they use biomass fuel boilers to combine with the solar collectors. These existing block heating or district heating systems often have two boilers, one biomass fired boiler that runs all year around, typically without a buffer storage tank, and an oil fired boiler to cover peak demand. During summer time when the heat demand is low the boiler will be running on minimal load levels with low efficiency. Due to difficulties to regulate some of the combustion technologies and to keep up a high efficiency at varying load level.

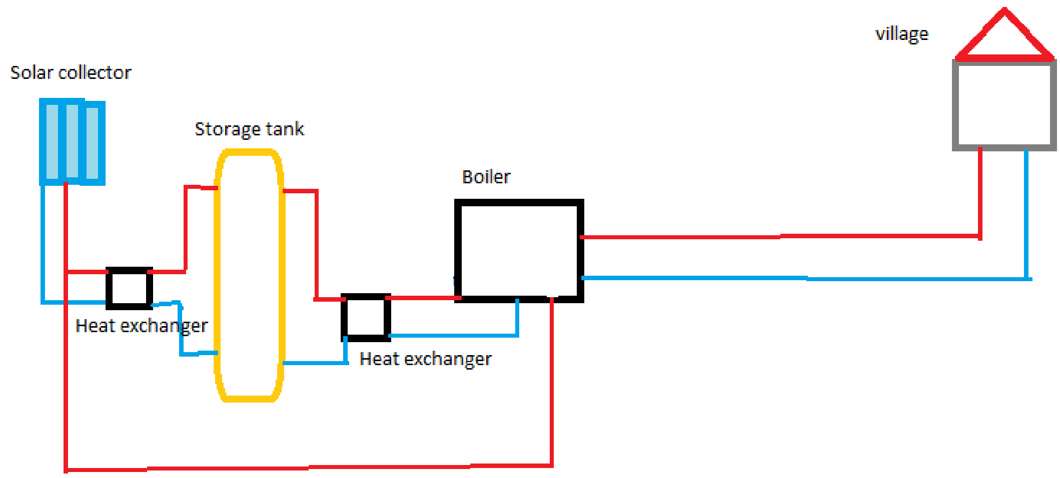

Figure 2.2: Bio-fired boiler connected to heat storage and solar collector.

The system, se Figure 2.2, consist of a heat storage and solar collectors combined with a wood fuel fired boiler. The solar collectors transfer heat from the sun to the fluid passing through them, so when the temperature is high enough in the collectors a pump will transfer the fluid through a heat exchanger, to either the water filled storage tank or delivered directly into the district heating network during the summer time. Minimizing the need for the boiler to heat up the returning temperature to desired temperature, before leaving the plant.

When the heat demand increases the boiler will be used more and more frequently to heat up the returning temperature. The storage tank is used as a buffer to cover load demand, when the heat demand is less than minimum operation load of the boiler. When heat is needed from the storage tank, the heat is transferred through a heat exchanger and used the heat up the returning temperature. To increase the efficiency of the boiler, it can charge the tank, when it's not fully loaded with heat from the solar collectors and be used to discharge during high-demand hours. Meaning that the storage tank makes it possible to store heat when the solar collector produces more heat than used during summer times as well as when the boiler produces more heat than load demand during rest of the year. Making the whole system both more environmental and cost efficient and minimizing the need for the boiler to meet the varying demand. The heat supply is pumped in and out of the storage tank at the top of the tank whereas the cold return water is injected at the floor. (Halpin, 2011) Here it is important to have a control that secures to keep hot water in the top of the tank. (Atkin, 2010)

Even when the wood fired boiler needs to be cleaned during summer months, the heat will be produced by the solar collectors instead of as today by the oil boiler. Therefore, the introduction of solar collectors and storage tank will increase the investment of the heating plant, improve the efficiency of the wood fuel fired boiler and reducing both emissions and the operation costs by reduce the amount of wood fuel needed. This implementation can be used both for municipal or private district heating operator but also for private housing owner. (Dalenbäck, 2015)

2.4.2 Energy performance and local solar heating systems

In Sweden the energy performance of a building is defined as bought energy per kWh, which indicates that the owner of the building can account for better energy performance if the amount of bought energy decreases. This makes solar technologies attractive, because the amount of district heating to the buildings will decrease even though the solar collectors are connected to on the building primary or secondary system (more about this below). Therefore, installation of solar collectors on buildings can be a substitute to additional insulation. (Dalenbäck et al, 2013) The owner of the building is only charged for the net use of the district heat, since the solar heat is fed into the district heating system achieved by a feed-in tariff. (Dalenbäck, 2015)

This is where the second opportunity to introduce solar energy into the district heating systems appears. Initially used by local housing companies, to preheat hot water in their buildings. Achieved by installing decentralized solar collectors to improve the energy performance of the buildings. (Dalenbäck, 2015) In Sweden the first were installed on the secondary side during 1985. Here the solar collectors are connected through a heat exchanger to a storage tank which again is connected through a heat exchanger to the district heating systems, see Figure 2.4. Here the first heat exchanger is used to warm up the water in the storage tank that is used to preheat the hot water inside the building. The need for extra heat especially during the winter month comes from the district heating systems that through the second heat exchanger deliver the extra heat needed to heat the hot water. This system is designed according to the need for hot water inside the building where it covers 30-40% of the yearly need for hot water. Here the yearly heat yield can be around 400 kWh/m^2. (Dalenbäck et al, 2013) These type of plants is normally owned and operated by the local housing owner. (Dalenbäck, 2010)

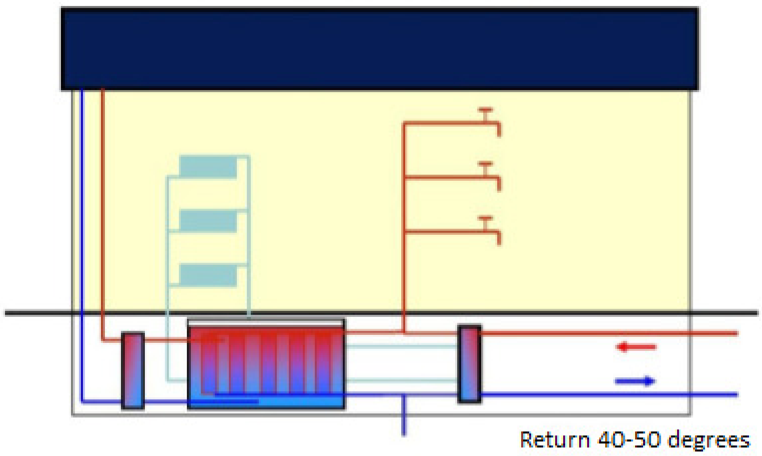

Figure 2.4: Connecting through secondary side (Source: Dalenbäck et al, 2013).

During the 2000's the installation of solar collectors has been on the primary side, where they through a heat exchanger is connected directly to the district heating system. A second heat exchanger connects the district heating system to the buildings in order to preheat hot water, see figure 2.5. Here the system is designed according to the available roof area and the dimension of the district heating network to the building.

The solar energy is first delivered to the district heating system and the district heating system delivers the hot water to the building. As a result of the direct connection to the district heating system it's used as a heat storage, and there is therefore no need for a storage tank in this installation. However, this kind of installation need more management and regulation between solar energy delivered to the district heating system and bought district heat to the building. (Dalenbäck et al, 2013) There are three options for ownerships, the housing facility owner, a specific plant owner or the utility. (Dalenbäck, 2010)

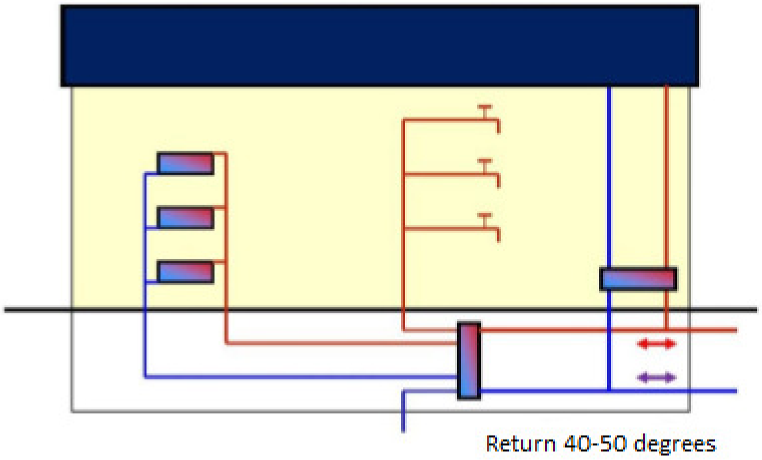

Figure 2.5: Connection through primary side (Source: Dalenbäck et al, 2013)

The energy efficiency of the solar collector is depending on the average temperature inside the collector, which is why it is important to keep the temperature inside the district heating network as low as possible. Today the flow temperature during winter time is around 90-100 degrees and 75-80 degrees during summer time. In order to increase the energy efficiency of the solar collectors the return flow has to be kept as low as possible, (Erikson, 2009) which is why regardless if the installation is on the secondary or primary side, the return temperature should be around 40-50 degrees in order to keep a good yearly yield.

2.5 Solar heat in district heating

The combination of district heating and solar district heating can increase the overall energy efficiency in the urban areas, reduce emissions and at the same time increase the share of renewables energies in the heat supply. This will lead to a more sustainable development, since it does not emit any greenhouse gas emissions and the solar energy is unlimited and available everywhere. Furthermore, energy density for solar heat is much higher than biomass fuels considering generated heat per area unit. However, the technological weakness for solar heat is the requirement for space, as with any renewable energy sources. The assumed potential of solar district heating may contribute with 20 to 58 TWh per year, or 4 to 10 % of the total use of district heating. Based on the assumption that district heating will hold its market share. (Dalenbäck, 2013) According to Lindenberger et al. the relative primary energy savings increased for district heating systems when large-scale solar heat was combined with the district heating systems. Furthermore, the CO_2 equivalent emissions decreased with solar heat combined with district heating systems. Also Buoro et al. found that distributed solar energy system allows to reduce both the primary energy consumption and energy supply annual cost. All of this shows the strengthens of combing district heating with solar heat

2.6 Taxes and economy

The overall renewable energy target for Sweden is that at least 50% of the energy should come from renewable source in gross final energy consumption and 62% of the heat consumption should be met by renewable sources by 2020. This is among others done through taxes on CO2 and energy, but also economic support for solar heating installations. (IEA, 2016)

Large solar heating systems have the advantage of scale and often have low specific investment costs compared to small applications. This is especially the case in Denmark, where there is a strong market growth for large systems, and the solar heat cost is about 40 Euro/MWh. A substantial part of the investment cost of solar heating plants with seasonal heat storage is caused by the heat storage (Lindenberger, 2000). However even though the costs have gone down it is not yet considered to be low enough to be used by thermal utilities and facility managers. There is a major lack of awareness and knowledge about the potential with district, block heating and large-scale solar heating. Due to the low price for wood fuels together with lack of awareness about solar collectors, investment in solar system have received small incentives. (Dalenbäck, 2013)

3 Development of solar district heat

The chapter will describe the history behind solar district heating from present until today. Here after a brief description of the application today divided into block and district heating where a description of two solar district heating plants in Sweden are presented: Ellös and Kungälv.

3.1 History

The integration of solar thermal systems into district heating networks are becoming more and more used around Europe. The introduction of solar heat into the district heating network began after the oil crisis in the late 1970's by the interest in large-scale solar heating systems with seasonal storage, where Sweden, Denmark and Netherlands had a leading role. Sweden started to develop these large-scale solar heating plants in order to replace oil in the district heating system. Due to the very positive development for wood fuels, which can be seen in Figure 2.1, together with EU directives on energy performance on buildings, the interest in large-scale solar systems decreased. Leading to that Sweden replaced oil with biofuels in the district heating systems. (Dalenbäck, 2013)

The development of large-scale solar heating - solar heating plants with >500 m^2 solar collectors or 350 kW_{th} nominal thermal power - has been documented since late 90's and started to take off in 2007. Large-scale solar heating increased from about 130 plants with altogether 140 MW_{th} nominal thermal power in 2007 to 195 plants with 382 MW_{th} in operation in 20 EU-countries in 2013 (Dalenbäck, 2013) The development can be seen in Table 3.1 where Denmark have had a very progressive development of large-scale solar heating systems. There are around 200 plants in operation in 20 EU-countries where Denmark have 43 solar plants in operation whereas 32 of them are built in the period in between 2008-2013. Sweden, which have the second largest development, have 22 solar plants in operation but only 4 of them are built in the same period. Two thirds of all large-scale heating plants in Table 3.1 are connected to existing buildings, especially in Sweden, Denmark and Austria. Furthermore, the majority in Sweden and Austria are built in connection to wood fuel fired heating plants. (Dalenbäck, 2013) The development has been further increased since 2013. At the end of 2015 there were more than 250 plants with altogether a nominal thermal power of 745 MW_{th} in operation in Europe. The largest plant in operation located in Vojens has 70 000 m^2 of solar collectors (49 MW_{th}) and a new plant with 150 000 m^2 of solar collectors (105 MW_{th}) is under construction in Denmark. (Dalenbäck, 2016b) See Appendix A for current information about the solar heating plants in Europe.

Table 3.1: Number and nominal power of large-scale solar plants in different EU27-counties; 1 MW(th) = 1,430 m^2 (Source: Dalenbäck, 2013)

	No. of plants built 2008 – 2013	Total no. of plants in operation	No. of plants closed	Total no. of plants built	Nominal power in operation in MW(th)
Denmark	32	43	–	43	236
Sweden	4	22	12	34	22
Austria	9	23	2	25	24
Germany	3	22	1	23	28
Spain	–	16	–	16	9
Greece	–	14	–	14	11
France	4	12	–	12	9
Netherlands	1	8	1	9	11
Switzerland	2	9	–	9	6
Poland	4	8	–	8	6
Italy	2	7	–	7	4
Others	4	11	2	13	15
	65	**195**	**18**	**213**	**382**

The development of solar plants in Denmark is partly due to the political desire to significantly increase renewable energy and partly to phase out fossil fuels. After the oil crisis during the 1970 Denmark replaced oil with natural gas found in the North Sea, leading to increased use of natural gas. In order to decrease the fuel demand of natural gas, a tax have been added leading to a high price for natural gas at the same time as a high share of wind power resulting in varying electricity prices influences the use of combined heat and power. This leads to more feasibility to operate boilers to supply heat to the district heating system. Heat generated from natural gas becoming too expensive creating incentives for solar heat. (Dalenbäck, 2016b) Leading to competition among the suppliers for solar collector arrays which have led to low prices and economy of scale. (Kristensen, 2011)

Another notable thing is that district heating systems in Denmark have somewhat lower distribution temperature levels compared to Sweden. This heightens the efficiency of the solar collectors, and there are two explanations for these low temperature levels. Most district heating systems in Denmark are direct-coupled systems, which means there are no heat exchangers, and thereby no temperature degradation between the district heating network and the customer secondary systems. Even the use of large-scale solar heating plants in the district heating in Denmark have created incentives for low distribution temperatures in the district heating systems. (Gadd & Werner, 2014)

Another difference between the two countries are that in Sweden the heating plants are mostly owned by the municipalities whereas in Denmark they are owned by cooperations. Meaning that the sole decision making and financial aspect in Sweden lies at the heating plants, and people being supplied with district heating having small influence on the decisions. Whereas in Denmark people supplied with district heating from the heating plants have a voice regarding decision making around future sources. Typically, the cost for the district heat is lower with cooperative, since the customers are financiers.

All of these above explanations have benefited the development of solar heat in Denmark which have led to a point where investors are willing to invest in large-scale solar systems are coming up and are completely in line with the development in the wind sectors (Kristensen, 2011) something that can be utilized in other countries.

3.2 Applications in Sweden

The integration of large-scale solar heating plants can be divided into block and district heating systems.

3.2.1 District heating

For solar district heating systems both decentralized and centralized mounted collectors can be used. The majority of the first solar district heating plants was developed by different energy companies in order to supply heat in their own district and block heating systems. Sweden started these type of plants during the 70's and all of these plants were phased out during the 90's. During the late 90's Kungälv developed a solar district heating plant, Munkegärdeverket see Figure 3.1, which is the largest in Sweden, with 10000 m^2 centralized collector array connected to an existing wood fuel fired boiler plant with a 1000 m^3 buffer storage tank. These 10000 m^2 solar collectors corresponds to 7 MW. (Dalenbäck, 2016c)

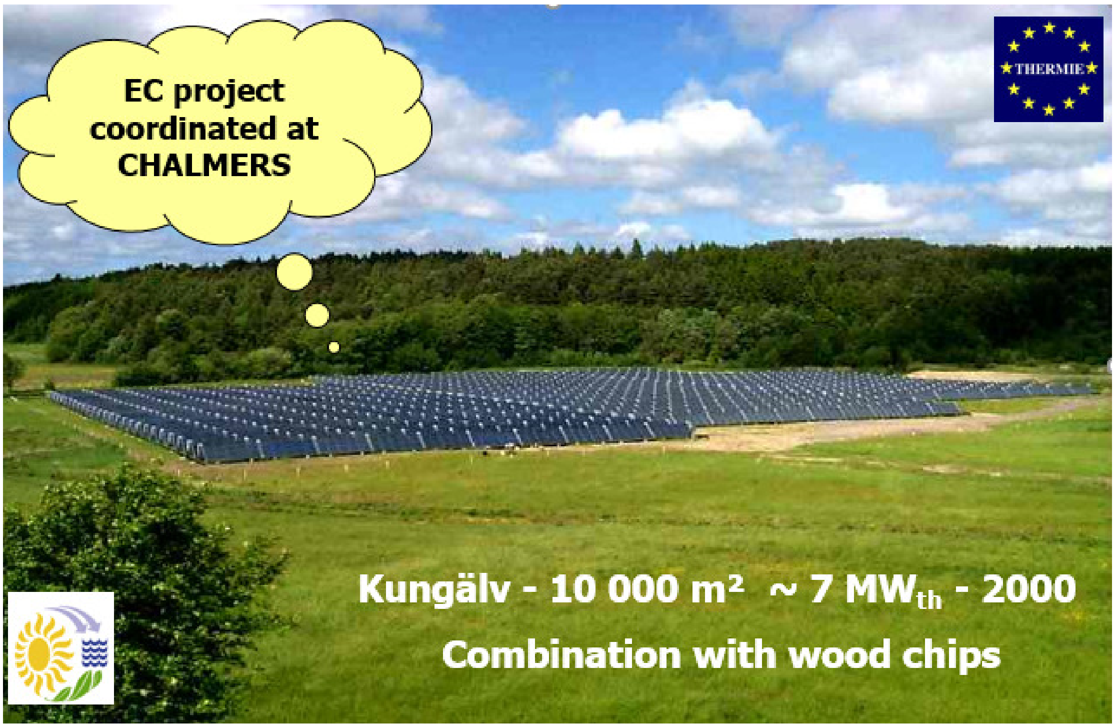

Figure 3.1: Munkegärdeverket in Kungälv (Source: Dalenbäck, 2016d)

3.2.2 Block heating

Block solar heating systems are smaller than 5 GWh/year and the majority have roof-mounted collectors. Already in the 80's the Swedish housing company EKSTA bostads AB, see Figure 3.2, initiated this type of plants with about 7000 m^2 decentralized collectors. (Dalenbäck, 2010) In 2010, Orust municipal built a new block heating system, Ellös see Figure 3.3, where a chips fired boiler is connected to 1000 m^2

decentralized solar collectors corresponding to 0,7 MW as well as a stort-term storage tank. It typically supplies 4-5 GWh per year. The original design of Ellös consists of a system with 2000 m^2 ground mounted solar collectors, but only 1000 m^2 was installed. The experience from this plant the first years, was that the connected heat load was less than predicted and thereby the installed boiler was too large, which resulted in poor operation. In 2015 the boiler was rebuilt to what it is today, 4 MW. (Dalenbäck, 2015)

Figure 3.2: EKSTA bostad in Kullavik.(Source: Dalenbäck, 2016d)

Figure 3.3: Ellös in Orust (Source: Dalenbäck, 2016d)

4 Method

The chapter will include a description of the method used to identify all heating plants within the region of Västra Götaland as well as a qualification of the data collected. Last the chapter will present a short description of the seminar held during the thesis.

4.1 Collection of data

Information about all heating plants located within the region of Västra Götaland were collected through two steps. First, a survey was developed and distributed to all municipalities during April and May 2016 asking about basic operation information for the different heating plants. This survey was also used to identify the interest among the heating plants if they would consider complementing solar heat into their systems. Second, the organisation for the Swedish district heating network was used, together with the homepage from different municipalities to gather information.

To correct all the information gathered, some tables with all the information collected above was returned to the heating plants by e-mail, in order to identify possible errors.

All of the collected information were used to identify the feasibility for complementing solar heat in the region and to identify some feasible heating plants to complement solar heat with. Each potential heating plant was looked at through different maps on internet and was based on previous knowledge from my supervisor. Those heating plants that were of interest was contacted, as well as those that had showed interest for implementing solar collectors.

As a reference for the new large-scale solar district heating plant, the existing block heating plant in the village of Ellös at Orust Island in Västra Götaland will be used. It has a wood chips boiler with 4 MW design power, 1000 m^2 of solar collectors corresponding to 0.7 MW and 200 m^3 storage tank. This plant was built in 2010 and received grant support within a national municipal support scheme. The new solar district heating plant that are to be used as a demonstration plant needs to be larger and to show economic feasibility with a reasonable grant support.

4.2 Quality of data

The data found through homepages were uneven, since some municipalities have a lot of information regarding their heating plants and others have no information. The same problem is valid for contact information where to send the survey. Help was received through - Hållbar Utveckling Väst - the region energy office to contact all energy advisors in all municipalities. The quality of data received varied since the contact person's knowledge about the local situation varied. Some municipalities were difficult to get information from, since they did not respond to the survey nor did they have information about their heating plants on their homepages. In order to reach these municipalities, e-mail was sent specific to their district heating provider, but again not all answered. The collected data was further compared with data in the report "Energibalanser för Västra Götalands län och kommuner år 2013" (Andersson, 2013) in order to check and complement data. See Appendix B, for sources of information.

4.3 Seminar

A seminar was held during September 2016 were representatives from all identified heating plants were able to meet and receive information about the EU-project SDHp2m as well as the results. The main idea was to increase interest among the representatives for the project and possibly to identify some heating plants that could consider complement solar heat.

5 Theory

The chapter will describe the theory which have been used to evaluate the feasibility of solar heat in the region. The chapter will start with describing the thermodynamic laws used together with different types of biomass. The last part of the chapter will describe the different combustion units used for heat production.

5.1 Thermal power and energy

Energy is movement or the potential to induce movement and according to first law of thermodynamic and conservation of energy it can neither be destroyed nor created. It can only be transformed through conversion from one energy form to another. The energy flow starts with primary energy which is the form of energy found in nature such as fossil fuel, sunlight, wind, hydropower and biomass. The flows proceed from these primary sources through energy carriers obtained by conversion of primary energy through thermal technology to provide services for end-users. (Atkin, 2010)

Thermal energy that is bound to biomass fuel is transformed inside a heating plant to heat energy where it is transformed to mechanic energy, electricity or utilized as heat for a district heating system. When these transformations happen there will always be losses, since in a natural thermodynamic process the sum of the entropies of the interacting thermodynamic systems will increase according to second law of thermodynamics. (Atkins, 2010) Meaning that the increasing disorder which occurs naturally in process will result in lost work. This means that since thermal energy is a less ordered form of energy than work, one joule of thermal energy cannot fully be converted into one unit of work. This can be measured by exergy which is a measure of the maximum amount of work that can be extracted from a system when it reaches equilibrium with its surroundings. Work is power multiplied with time, where work is in joules, power is watt and time is in seconds, see Equation 4.1. Heating plants effect is usually specified as energy per year which has the unit watthours (Wh). (Elliott, 2009)

$$\text{Work} = \text{Power}^{*}\ \text{Time} \tag{4.1}$$

Biomass can be divided into what part that is being used in a heating plant. The positive development in bioenergy has led to the use of mainly tree types of solid biomass fuels in Sweden; wood chips, pellets and briquettes. Wood chips are small pieces of wood that have been cut to between 5mm and 50mm and can be obtained from several sources locally and is relatively bulky. Pellets and briquettes are made from sawdust or fine shavings of wood extruded under pressure so that the wood resin binds the material into cylindrical shapes if pellets and physically larger with different shapes if briquettes. (Rural energy, 2015) The properties of the biomass fuel are varying depending on origin, treatment and its compositions. The combination of low moisture content and highly compressed material gives pellets and briquettes a high volume energy density, typically three to four times that of wood chips. This then requires less storage space than wood chips making them attractive in urban applications. (Biomass energy centre, 2011) Briquettes are often used as alternative to firewood logs (Wood pellets and briquettes, 2011)

For each type of fuel, a heating value (H_0) can be specified which a measure is of released chemical energy. The quality of each fuel are depending on the heating value and if often measured by a calorimeter. The calorimetric heating value specifies the heat that is released during complete combustion with oxygen and the products of the process are cooled down to 25 □C. Whereas the effective heating value, Hi, is the heat that can be released when the water that is produced during the combustion process are evaporated. The heating value is always higher than its effective heating value. (Wimmerstedt et al, 2012)

Table 4.1: Different effective heating value for different types of fuel (Bjurström et al, 2003)

Type of fuel	Moisture content [%]	Effective heating value dry [MWh/t]	Effective heating value, moist [MWh/t]	Effective heating value [MWh/m^3]
Wood chips	50	5,4	2,4	0,7
Pellets	10	5,4	4,8	2,6
Oil		11,4		10
Briquette	10			

From Table 4.1, it can be seen that pellets have a much lower moisture content and the heating value is generally higher than chips, allowing them to burn with high combustion efficiency. Oil have a much higher heating value compared to the other bioenergy. In general, the drier the fuel, the more expansive it is, as it provides more heat per unit volume than wet fuel. (Bjurström et al, 2003)

5.2 Combustion technologies

The type of biomass and the capacity of the boiler decides the combustion technology, see Table 4.2 where 10 KW corresponds to the output from a household boiler whereas 10 MW corresponds to the output from a district heating network to heat 2000 apartments. For heat production in large scale from burning of biomass usually three types of boilers are used: fluidized bed, grate and powder boilers, whereas for heat production in small scale is usually done in different specialized burners. (Tekniska lösningar for produktion av värme, 2009) All boilers have the same structure which consists of furnace, evaporator, superheater and reheater - but have different feeding and combustion of the fuel. The furnace is where the combustion of biomass takes place, and the heat transfer are used for the evaporative, superheating and reheating duty. The evaporative duty is performed by the wall of the combustor, which consists of bundles of pipes transferring water into the steam drum. Here the steam or hot water is separated from the water. The steam is send to the superheater and reheater whereas the water is going back to the evaporators. The hot flue gas that exits the combustion enters the convective pass section where heat is transferred into the superheater/reheater and economiser to respectively raise, the steam and feed water temperature. When the gas leaves the convective section, the heat in the flue gas is generally used for pre-heating of primary and secondary air. In the superheater the steam is expanded in a high-pressure steam turbine whereafter the steam is used for district heating. (Koornneef et al, 2006)

The type of solid biomass, technology and capacity affects the start-up time for the boiler to reach rated power, which is the time it takes to warm up a boiler before it reaches a state where it can deliver heat to the district heating system. The start-up time also depends on the time during which the unit has been inactive. (Göranson & Lundberg, 2014)

Table 4.2: Typically, technologies for different capacity. (Source: Tekniska lösningar for produktion av värme, 2009)

Capacity	**10 kW**	**100 kW**	**10 MW**	**100 MW**
Technology	Pelletsburner	Pelletsburner or pellets in rust boiler	Wood chips or briquettes in rust boiler	Wood chips in fluidized bed

5.2.1 Grate boilers

Grate firing boilers is one of the main technologies used in biomass combustion for heat and power production. The grate has the function of lengthwise transport of the fuel where it dries, gasifies and burns on the grate, se Figure 5.1. The feeding of the fuel needs to be uniform in order to obtain a good combustion with low emissions. This technique is mostly used for bark, sawdust, wood chips and briquettes, where the quality of the biomass decides how fast the fuel can be transported into the furnace in order to obtain a complete combustion. As a results the speed of the ignition front at the grate determines the stability of combustion as it is here the releases of volatiles are. The primary air enters from beneath the grate and is distributed together with the movement of the grate, which affects the mixing and biomass conversion in the fuel bed. Here after secondary air is supplied for complete burnout and lower emissions by forming local recirculation zones and forming different local combustion environments. At last the grate is either air-cooled or water-cooled. The air-staging is done in order avoid the formation of nitrogen oxides, since it reduce the availability of oxygen in the flame and also lower the temperature peaks of the flames. (Yin et al, 2008)

The characterization of a grate boiler it that it will rather run at minimum load level than completely stop, due to high monitoring of transported fuel on the grate and into the furnace (Bjurström et al, 2003).

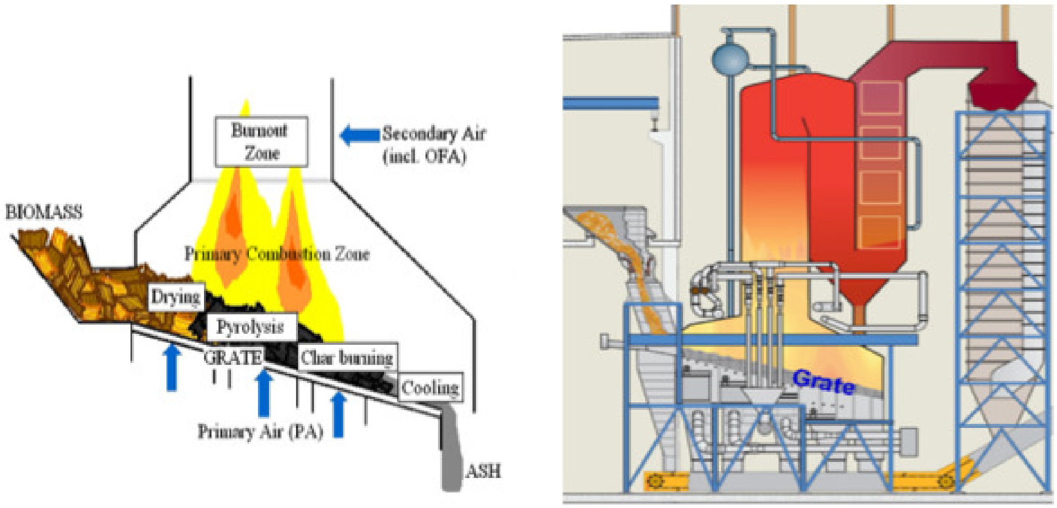

Figure 5.1: Grate boilers. Right: Grate-fired boilers burning biomass. Left: the lengthwise transport of fuel on a grate (Source: Yin et al, 2008)

5.2.2 Fluidized bed

The fluidized bed was introduced in 1970 and is another combustion technique. Here the fuel together with inert material, commonly sand, is fluidised with help of combustion air that is blown from below through the bed. This upward flow of combustion air makes bubbles occur that gives fluid-likes properties between the gas/solid mixtures. The combustion is taking place in the fluidized bed of fuel and inert material, where the fuel is fed under, into or onto the bed. (Leckner & Lyngfelt, 2012) The combustion can be staged in different parts of the furnace. The fuel reacts in the bed with oxygen in the upward airflow. The lower combustion zone contains a high amount of the fuel mix, sorbent and ash. Secondary air is fed above the combustion zone where the density of solid particles is low, in order to improve the fuel to oxygen ratio and thus the combustion efficiency. The bed acts as a heat buffer enabling high heat transfer between the particles. Due to this the fluidized bed has the ability to burn low-grade fuels with low heating value, high ash content and high moisture content and is very suitable for biomass and waste. (Koornneef et al, 2006) In order to absorb sulphur dioxide (SO_2) and/or hydrochloric acid (HCl) different additives can be added for example limestone. The characterization of this technique is that the combustion temperature is low, around 800-900 □C, which limit the formation of NOx. Also here is the need for uniform fuel feeding to obtain good combustion and once the fluidized bed is stopped, it takes a long time to reach rated power, almost 48 hours. (Bjurström et al, 2003). The collection of ash, bed materials and non-combustible solids is done under the bed. (Leckner & Lyngfelt, 2012)

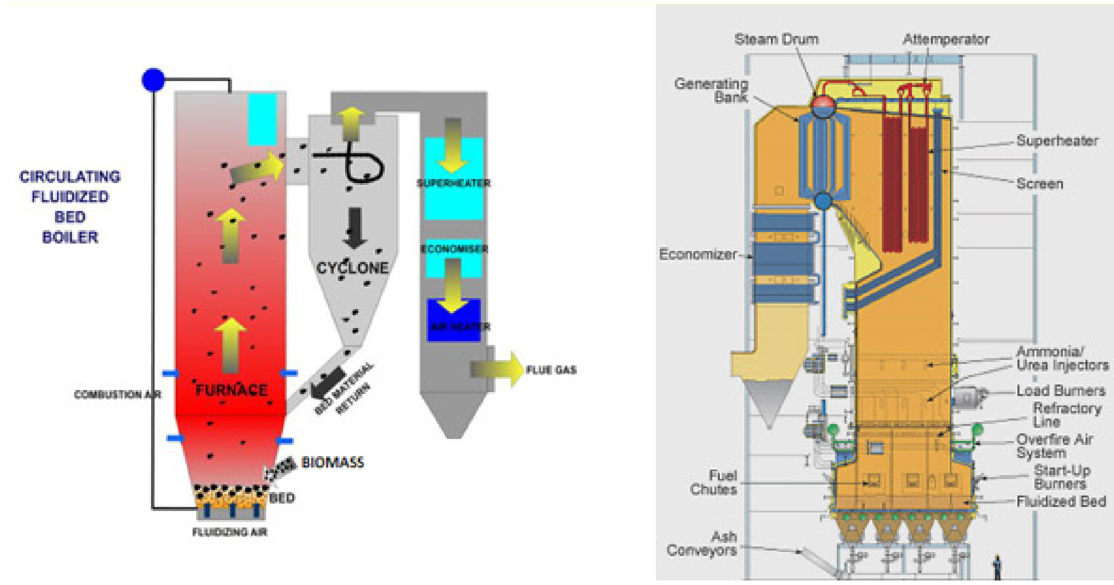

Figure 5.2: Right: Bubbling fluidized bed. Left: Circulating fluidized bed. (Source: Koornneef et al, 2006)

As the technology evolved, two variants of this technology were developed. The bubbling fluidized bed (BFB) which was the first version. The other version is the circulating fluidized bed (CFB), see Figure 5.2, and was derived from the BFB technology and exceeds its prototype in terms of sulphur removal, efficiency and scale. The basic difference between BFB and its CFB is the fluidisation velocity, which is higher for CFB compared to BFB. This does that the solids are more equally vigorously mixed along the combustion height in CFB. This results in a more homogenic temperature distribution in a CFB compared to a BFB combustor. Due to the high velocity of CFB a cyclone is necessary in order to collect solids entrained with the flue gas before it enters the convective passes. (Koornneef et al, 2006)

5.2.3 Powder boilers

Initially powder boilers used to be fuelled with oil or coal, but most of them in Sweden have been converted into being fuelled with bio powder (Bjurström et al, 2003). The biomass used must have a relatively low moisture content and be finely pulverized, which means that these boilers require more fuel handling and preparation equipment. This also means that it is mostly suited for pellets and briquettes. The boilers are therefore equipped with a furnace where the biomass is dried and undergoes pyrolysis before gases is led into the burner. Here the air supply is integrated inside the burner and is done stepwise in order to obtain a low combustion temperature and thereby decrease the formation of NOx. The pulverized biomass is fed into the furnace by a tangentially swirl above the pyrolysis fuel, which a popular system using four burners corner to corner to create a fire ball at the centre of the furnace, se Figure 5.3. The ashes fall to the bottom of the furnace. (Leckner & lyngfelt, 2012) The powder boilers can go up and down in load levels and still keep a high efficiency. (Bjurström et al, 2003).

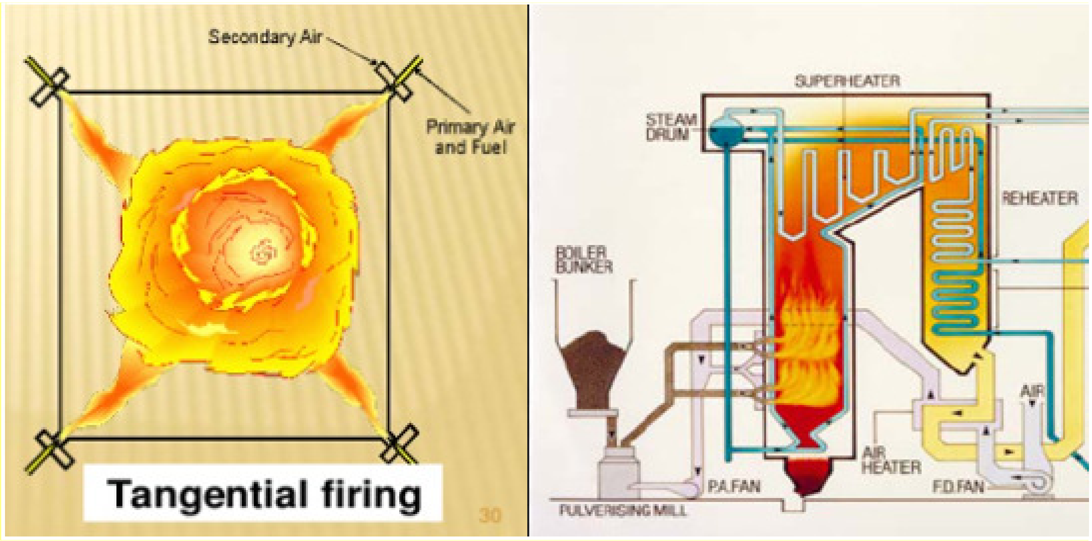

Figure 5.3: Left: Four burners corner to corner. Right: Powder boilers. (Source: Bjurström et al, 2003)

6 Evaluation of feasibility

This chapter will present the results of the evaluation of the feasibility of Västra Götaland to complement solar heat into existing district heating systems. The chapter will start with a presentation of the district heating network of the region, thereafter a more specific information of each heating plant within the region. The chapter will end with an evaluation and discussion of the results.

6.1 Block and district heating in Västra Götaland

Table 6.1 shows all 116 identified heating plants located within each municipality in Västra Götaland, if and where they receive waste heat recovery. It also shows the total amount of delivered heat and the total use of energy within each municipality. The total use of heat is the sum of all district heat used for the industry, residential and working places within each municipality. The heat production is larger than heat used due to distribution losses. For more information about the different numbers and the different heating plants, see Appendix C.

Table 6.1: All 116 identified heating plants inside region of Västra Götaland

Municipalities	Number of heating plants	Heat recovery	Total heat production in 2013 [GWh/year]	Total use of heat in 2013 [GWh/year]
Ale	0	Part of Göteborg DH	40	64
Alingsås	7		146	124
Bengtsfors	5	Munksjö Paper AB	25	23
Bollebygden	1		7	6
Borås	1		733	685
Dals-ed	1		9	7,5
Essjunga	1		8	7
Falköping	5		147	128
Färgelanda	1		4,5	4
Grästorp	1		27	24
Gullspång	1		7,7	7
Göteborg	6		4051	3458
Götene	4		43	37
Herrljunga	2		28,5	22
Hjo	1		41	32
Härryda	3		71	61
Karlsborg	2		19	16
Kungälv	4	Connected to Göteborg DH	106	127
Lerum	4		57	53
Lidköping	4		393	294
Lilla Edet	1	SCA and Vargön alloys in vänersborg	14	12

Lysekil	2	Preemraffs refinery	53	43
Mariestad	2		236	213
Mark	5		116	111
Mellerud	1		16,5	15,5
Munkedal	1		8,3	6,8
Mölndal	1	Connected to Göteborg DH	476	290
Orust	1		9	8
Partille	0	Connected to Göteborg DH	0	164
Skara	7		93	85
Skövde	7		406	361
Sotenäs	0		0	0
Stenungsund	1	Borealis polyeten and Perstorp oxo	94	76
Strömstad	1		0	0
Svenljunga	1		42	40
Tanum	2		10	9
Tibro	1		59	50
Tidaholm	1		64	58
Tjörn	3		0	0
Tranemo	1	Ardaglas AB and Hållandersenergi AB	47	38
Trollhättan	4		392	360
Töreboda	1		26	23
Uddevalla	4		302	270
Ulricehamn	3		60	51
Vara	3	Heat recovery	52	47
Vänersborg	1	Vargön alloys	160	145
Vårgårda	5		39	36
Åmål	2		48	43
Öckerö	0		0	
	116		8786,5	7734,8

Table 6.1 shows that there are more heating plants then there are district heating systems which corresponds to the definition of district heating systems. Since one district heating network can utilise multiple heating plants in order to supply heat, some of the municipalities distribute heat to other municipalities like Göteborgs energy supply heat to Ale and Partille, and they do not have any heating plants of their own. Göteborg – the largest city in the region - both produce and have the highest heat demand of all municipalities. In addition, Göteborg also can deliver (waste) heat to Kungälv and Mölndal district heating network. Other municipalities utilise waste heat from the industries located within their municipalities like Stenungsund which gets their waste heat from Borrealis and Perstorp Oxo. There are only two municipalities that lack district heating: Sotenäs and Öckerö.

Out of the 116 thermal power plants, 5 of those already have installed solar collectors on their heating plants. These 5 solar district heating networks are located within 4 municipalities, which is Kungälv, Götene, Skara and Orust, see Table 5.2

Table 6.2: Heating plants with solar heat

Municipalities	Name of heating plant	Type of boiler	Capacity [MW]	Area of solar collector [m²]	Accumulator tank [m³]
Kungälv	Munkegärdeverket	Wood chips	23	10000	1000
Kungälv	Stället (stålkullen)	Pellets	0,5	600	No
Götene	Lundsbrunn	Pellets	0,2	Yes	No
Skara	Ardala	Pellets	0,4	Yes	No
Skara	Varnhem	Pellets	0,2	planned	No
Orust	Ellös	Wood chips	4	1000	200

It can be seen that the solar collectors array is connected to solid wood fired boilers. Those that are connected to wood chips boilers are also connected to an accumulation tank and those that are connected to pellets are not. Through mail conversation with Kungälv energy is was mentioned that the operation today of solar collector array for the Munkegärdeverket, is reduced to 4000 m^2 (2,3 MW) after a leakage in a distribution pipe that blocked the safety valves and led to damage of parts of the collector array. The possibility to buy cheap waste heat from Göteborg DH the summer time has had a negative influence on the economic feasibility to reinvest in the lost solar collector array. (Thorson, 2016)

6.2 Where to implement solar heat

All the heating plants have been arranged according to their type of solid wood fuels. Table 6.3 shows all heating plants fired with wood chips, Table 6.4 shows all heating plants fired with pellets and last Table 6.5 shows all heating plants fired with briquettes. Table 6.3-6.5 displays the name of all heating plants within each municipality, their capacity together with the heating plants surroundings and ownership.

Table 6.3: Wood chips boilers

Municipalities	Name of heating plant	Capacity [MW]	Surroundings	Ownership
Alingsås	Sävelund	35	industrial area	Municipal
Bollebygden	Bollebygdens PC	3	Planned area	Municipal
Borås	Ryaverket	130	Planned area	Municipal
Dals-ed	Lantmännen agrovärme dals-ed	1.7	Detailplanned area	Lantmännen agrovärme,
Essunga	Nossebro PC	6		Municipal
Falköping	Marjarp	25	Detailplanned area	Municipal
Färgelanda	Panncentral			Privat

Grästorp	Grästrops fjärrvärme AB	3.5	Detailplanned area	Lantmännen agrovärme
Göteborg	Sävenäs HP3	100	industrial area	Municipal
Götene	Västerbyverket	25		Municipal
Herrljunga	Herrljunga el AB	6	Planned area	Municipal
Herrljunga	Annelund	0.8	Planned area	Municipal
Hjo	Hjo PC	11.5	Industrial area	Municipal
Härryda		5		solörbioenergi
Härryda		12		solörbioenergi
Härryda				solörbioenergi
Karlsborg	Karlsborg PC	3	industrial area	Municipal
Karlsborg	Statens fastighetsverk	8	industrial area	Government
Kungälv	Munkegärdeverket	23		Municipal
Lerum	Aspedalen	19.3		Municipal
Lerum	Floda	5.8		Municipal
Lidköping	Östra havnen	30	Industrial area	Municipal
Mark	Assbergsverket	26.8		Municipal
Mark	Horred	2	Detailplanned area	Municipal
Mariestad	Katrinefors	70		Municipal
Orust	Ellös	4		Municipal
Skara	Harven	10		Municipal
Skara	Uddetorp	8		Municipal
Skövde	Lövsängverket, 1970	40		Municipal
Svenljunga				solörbioenergi
Tibro	Tibro PC	19	Industrial area	Neova
Trollhättan	Stallbacken	44		Municipal
Trollhättan	Kronogården	8		Municipal
Trollhättan	Lextorp	17		Municipal
Töreboda	Töreboda PC	20	Industrial area	Municipal
Uddevalla	Hovhultsverket	50		Municipal
Vara	Vara PC	10	Planned area	Municipal
Vårgårda	vårgårda ångfabrik	7	Industrial area	Rindi energi
Vårgårda	VH biogas	0.5	industrial area	Rindi energi
Åmål	Statkraft fjärrvärmeverk	12		Municipal

Table 6.4: Pellets boilers

Municipalities	Name of heating plant	Capacity [MW]	Surroundings	Ownership
Alingsås	hemsjö	0.2	Rural	Municipal
Alingsås	sollebrunn	0.8	Centrally	Municipal
Alingsås	regions tvätteri	5.5	industrial area	Municipal
Bengtsfors	Bengtsgården	3		Municipal

Bengtsfors	Industrigatan, bengtfors	2		Municipal
Bengtsfors	Bäckefors	1		Municipal
Bengtsfors	Dals långed	3		Municipal
Falköping	Stenstorp	1.5	Detailplanned area	Municipal
Falköping	Jättene	1.5	Detailplanned area	Municipal
Gullspång	Gullspång PC	1		Municipal
Göteborg	RYA	100	industrial area	Municipal
Göteborg	Skarvik	3	industrial area	Municipal
Göteborg	Skepplanda	1	Detailplanned area	Municipal
Götene	Hällekis	0.8		Municipal
Götene	Lundsbrunn	0.2	Detailplanned area	Municipal
Götene	Källby	0.2	Detailplanned area	Municipal
Kungälv	Stället (stålkullen)	0.5		Municipal
Kungälv	Kärna			Municipal
Kungälv	kode			Municipal
Lerum	Stenkullen	1		Municipal
Skara	Ardala	0.4	Detailplanned area	Municipal
Skara	varnhemskolan	0.2	Detailplanned area	Municipal
Skara	Axvall		Detalplanered area	Municipal
Skövde	Stöpen			Municipal
Skövde	Tidan			Municipal
Skövde	Timmersdala	1.8		Municipal
Strömstad	Tångens PC	1		Municipal
Tjörn	Tourane AB	0.4	Detailplanned area	Pemco
Tjörn	Kållekärr	1.2	Detailplanned area	Municipal
Tjörn	Skärhamn PC	0.6		Municipal
Ulricehamn	Timmele	0.6	School area	Municipal
Ulricehamn	Gällstad	0.7	Rural	Municipal
Ulricehamn	HVC simhallen	2.5	Detailplanned area	Municipal
Vara	Lantmännen agrovärme, kvänum	3	Detailplanned area	Lantmännen agrovärme
Vårgårda	Lena skola	0.1	School area	Rindi energi
Vårgårda	Hols skola	0.1	School area	Rindi energi
Vårgårda	Nårunga skola	0.1	School area	Rindi energi
Åmål	Svetsaren, Nordverk	0.4		Municipal

Table 6.5: Briquettes boilers

Municipalities	**Name of heating plant**	**Capacitet [MW]**	**Surroundings**	**Ownership**
Bengtsfors	Billingsfors	1.2		Municipal
Falköping	Dotorp	9	Detailplanned area	Municipal
Falköping	Floby	4.5	Detailplanned area	Municipal
Falköping	Jättene	3.5	Detailplanned area	Municipal
Lerum	Gråbo	6		Municipal

Mariestad	Lyrestad PC	1.4		Municipal
Munkedal	Långedalsverket	3		Municipal
Skövde	Skultorp			Municipal
Uddevalla	Arödsverket	1.5		Municipal

From Table 6.3 it can be seen that wood chips vary from a 0,5 MW up to 130 MW, whereas briquettes from Table 6.5 vary between 1-10 MW. Pellets from Table 6.4 vary from 100 kW up to 5 MW yet one of the pellets boiler have a capacity of 100 MW. The Tables also shows that most of the plants are owned by the municipalities, however out of the 44 identified wood chips boilers 12 are owned by ESCO. ESCO are other types of ownerships besides municipalities.

6.2.1 Ownership

The fact that the heating plants are owned by the municipalities can be beneficial, since they have larger responsibility and sometimes have other incentive besides the economic aspect – here some municipalities have a vision about a fossil free town – this could benefit the investment in more renewables. That the heating plants are owned by ESCO can facilitate the decision making, but could make the economic aspect problematic, since often it is ESCO that are responsible for the operation of the heating plant and the municipality that are responsible for the distribution of heat. Therefore, ESCO might be focusing on making profit.

6.2.2 Technology and type of solid wood

Wood chips are difficult to burn efficiently in a conventional furnace due to its lower heating value, high moisture content, and its low fixed carbon. Therefore, fluidized bed is mostly used to burn wood chips. Fluidized beds have a long start-up time creating a high operation cost during part load levels due to low efficiency. The controllability is also a problem. This makes wood chips very attractive for complementing with solar heat.

Pellets and briquettes have a high heating value and low moisture content that allows them to burn with high efficiency. Pellets is a clean fuel both for handling and combustion. The high energy density for pellets makes them easy to transport and allows for small storage volumes. These properties make pellets used in small scale and medium scale heating in rust boiler or powder boilers, where they can utilise higher efficiency at varying load levels. This makes complementation of solar heat in existing plants less attractive, from an efficiency improvement point of view. The combination of solar heat and pellet boilers is otherwise a good combination.

Briquettes are similar to pellets but are larger and offer alternative to firewood logs with higher energy density. Therefore, briquettes are often used in medium to large scale heating rust boilers, these boilers will rather go down in minimum load level than stop due to bad controllability. This makes them interesting for solar heat.

6.2.3 Plant size.

The capacity of the boiler cannot be too big since it is not likely that a huge demonstration plant will be built nor can it be too small since it would not be economic feasible for the plant owner to invest in solar heat. Taking the reference plant in Ellös into consideration which has a designed wood chips boiler with 4 MW, 1000 m^2 of solar collectors and 200 m^3 storage tank. A boiler in between 4 – 30 MW would be feasible. Below 4 MW, the demonstration plant would not be classified as a large-scale solar district heating plant, since Ellös is a block solar heating plant. No larger than 30 MW since the connected heat load to the boiler will be too huge for the solar collectors to cover summer time and then the boiler needs to be more in operation. However, this is not a problem, since it can charge it against the storage tank and still keep a high efficiency, but the solar collector field will be huge for it to be noticed in the operation of the plant. A huge solar plant is as mentioned before not likely, since the investment costs as well as combined heat and power plants based on waste starts to complicate the systems.

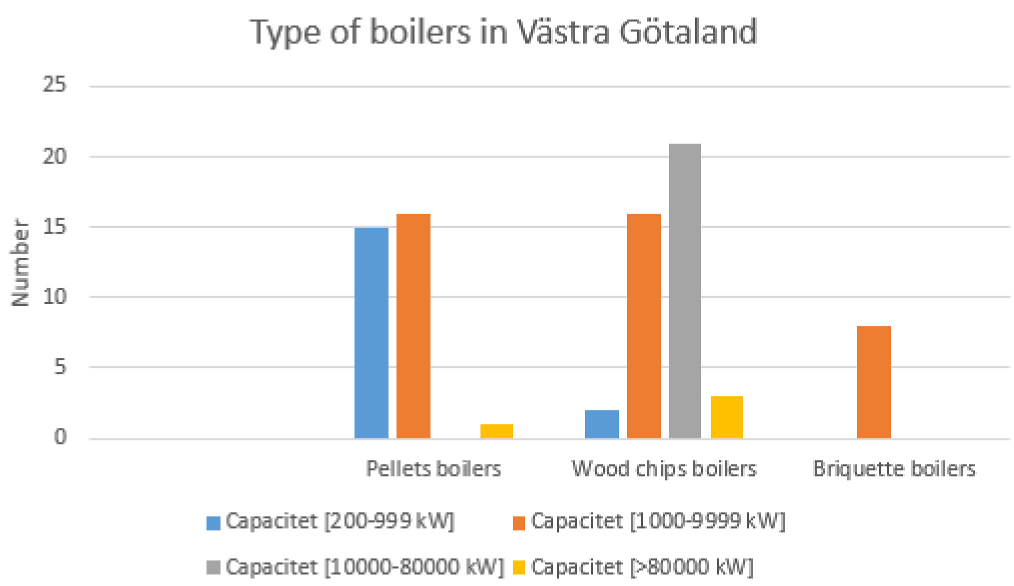

Figure 6.1: Number of solid wood boilers in Västra Götaland regarding capacity and type of solid wood

Figure 6.1 is based on table 6.3-6.5 and shows that pellets boilers are mostly represented in the capacity in between 200-9999 kW, while wood chips boilers are mostly represented in the capacity in between 10000-80000 kW. This corresponds with Table 4.2, which indicates that pellets are mostly used as fuel in powder and rust boilers, whereas wood chips are used in large rust or fluidized beds. Briquette boilers are only represented in the capacity in between 1000-9999 kW, which means that this fuel is used in medium units also corresponding to Table 4.2

6.2.4 Space requirement

Another factor regarding feasibility for implementing solar heat is space requirement, since there is need for space for the solar collector array and possibly a storage tank. Taking the reference plant in Ellös into account with 1000 m^2 area of solar collector corresponding to 0.7 MW the heating plant needs space around 1000–30000m^2 when the heating plants are around 4-30MW. This indicates that the heating plant cannot be centrally located but industrial or maybe planned areas would be good. Assuming that the demonstration plant should cover 20% of the total annual heat load, the demonstration plant would need 1000-9000m^2.

To really know if there are space enough, different maps needs to be looked into and site visits needs to be performed, since many heating plants have no information about what type of areas it is placed in or around. This have not been done at this early stage.

6.3 Feasibility for solar heat in Västra Götaland

The initial scanning of the 116 heating plants located within Västra Götaland aims to get the first impression about the feasibility for complement solar heat to existing heating plants. As mentioned previously in order to implement solar heating into an already existing block, the wood fuel boiler needs to be of a certain size. The start-up time matter, in order for the solar collectors to be economic feasible and attractive, which is why the properties of the biofuels, technologies and capacity matter. Wood chips are very interesting due to its bad part load efficiency. Briquettes are of interest but most of them are quite small units whereas pellets are not that interesting from an efficiency improvement point of view.

Now looking specifically into wood chips boilers. Figure 6.2 shows all wood chips boilers within the region where 30 MW is marked. All boilers above 30 MW are not feasible to complement with solar heat but all others are, except those below 4 MW. This indicates how many boilers that could be used to complement with solar heat.

Considering that the solar heat should cover 20% of the heat load would lead to the need of 1000-9000 m^2 area of solar collector fields. Taking this into consideration has led to the initial interest in Herrlunga (6 MW), Vara (10 MW), Tibro (19 MW) and Töreboda (20 MW) to carry out the initial feasibility studies. For the four municipalities to supply 20% of their heat supply with solar heat Herrljunga needs 1716 m^2, Vara needs 2860 m^2, Tibro needs 5434 m^2 and Töreboda needs 5720 m^2 collector fields. All of them are owned by the municipalities besides Tibro which are owned by Neova. All of them are located on planned or industrial areas and all of them have showed great interest in complementing solar heat during different contact. The heating plant in Hjo (11.5 MW) also had the right opportunities to complement their heating plant with solar heat, due to their surroundings, size of capacity and ownership. However, they showed no interest at all.

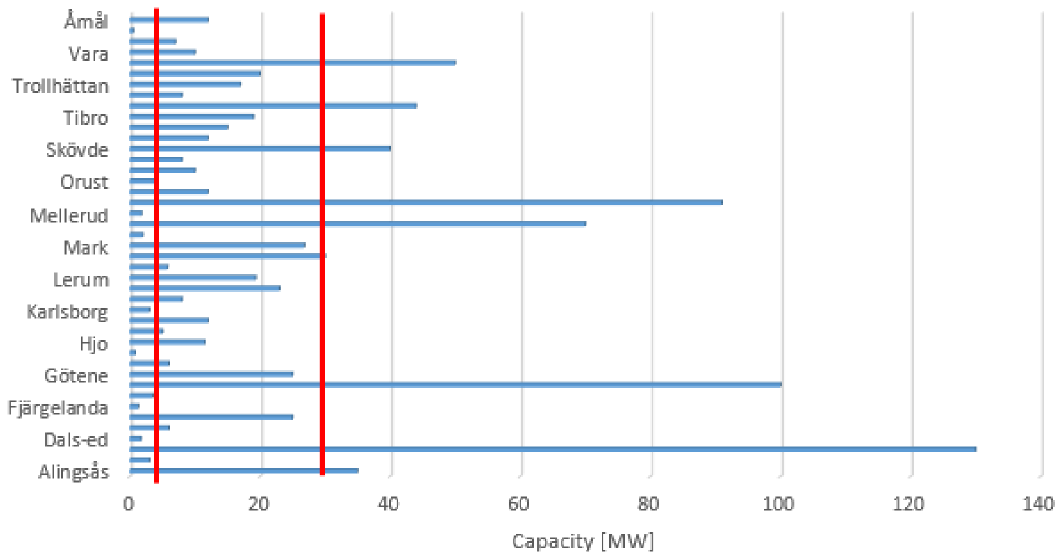

Figure 6.2: All wood chips boiler inside Västra Götaland where 4 and 30 MW is marked.

During the seminar, some plant owners expressed their interest in complementing solar heat even though they did not belong to preffered group, since they have small pellets boilers. Therefore, could more feasibility studies be carried out.

6.4 Discussion

Almost all information about available space for the solar collectors and storage tank is gathered through different maps, actual information is needed in order to evaluate the actual possibility. This could lead to further feasible heating plants. Also local conditions and interest for solar heating expressed by the plant owners at the seminar might change the situation about only looking into wood chips fired boilers.

The advantage of Västra Götaland is that district heating is already installed, which means that the feasibilities can focus on the potential possibilities to complement existing heating plants with solar heat and maybe a storage tank. Other countries could customize the Swedish guidelines by introduce taxation of fossil fuels to promote their district heating in the future.

Almost all plants within the region provide renewable heat by using solid wood fuel. Therefore, the main idea is not to replace fossil oil, since it has already been done in Sweden, see figure 2.1, but to increase efficiency and reduce emissions in existing boilers. Thereby save more wood fuels than the amount replaced by the solar heat. However, the operation costs for using wood fuels are low, creating a challenge to provide strong incentives for implementing solar heat. Another challenge is to convince that the improved design with solar heat will improve the operation costs for the plant owner as well as the plants efficiency.

During summer time, a lot of cities in Västra Götaland can utilise the industrial waste heat to cover the district heating load. Industrial waste heat is more economic feasible than solar heat something that could be seen in Kungälv where they instead of reinvest in lost solar collector array buy waste heat from Göteborg. However, combined solar-biomass heating plant would be a good system to build if there is no available industrial waste heat and biomass heating plant is used to supply the district heating. Combined solar-biomass heating plant can improve the efficiency of biomass heating plant and reduce the unnecessary heat losses. Västra Götaland are using many wood chips fired boilers that have huge opportunities to complement with solar heat. In the coming future, if the transportation cost and the price of biomass itself become too high, the solar energy will make more contribution to the district heating in the coming future.

7 Further work

Västra Götaland is associated with the IEE-project solar district heating that has a focus on technologies for large-scale solar district heating plants and their implementation into the district heating network. The interesting heating plants that have been identified to have the right possibilities to complement solar heat into their system which will hopefully lead to at least one heating plant that could move on to be used as a demonstration plant during 2017-2018. In order to do this, the identified heating plant in this report needs to be ranked from a feasibility point of view.

The feasibility studies that needs to be done, will include possibilities to lower the return temperature, the placement of the solar collectors and a storage tank. Furthermore, placement for planned boilers and extensions of the district heating networks is also included into the feasibility studies. This need more precise information regarding space available and how their district heating network looks like for each heating plant as well as investment cost for the solar heat.

The possibilities to lower the return temperature could be done by looking into each heat consumer in the district heating network, if some of the consumers have a high demand for heat especially if the network includes an old oil boiler, by disconnecting that or replace it, the return temperature would be lowered.

8 Bibliography

Agency, Swedish energy. *Energy in Sweden 2015*. Eskilstuna: Swedish Energy Agency, 2015.

Andersson, Thomas. *Energibalancer för Västra Götalands län och kommuner år 2013*. Eskilstuna: Klimatskyddsbyrån, 2013.

Atkins, Peter & Jones, Loretta. *Chemical principles - The quest for insight* . New York, United states of America: Clancy Marshall, 2010.

B. Metz, O. R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer. "Energy supply." Adegbululgbe, A., Fenhann, J., Konstantinaviciute, I., Moomaw, W., Nimir, H., Schlamadinger, B., Torres-Martinez, J., Turner, C., Uchiyarna, Y., Vuoöri, S., Wamukonya, N., Zhang, X. *Climate change 2007: mitigation*. Cambridge university press: Cambridge, United Kingdom and New York, USA, 2007. 251-322.

"Biomass energy centre." 2011. *information sheet 1 - biomass pellets and briquettes.* <http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,18519&_dad=portal&_schema=PORTAL [viewed 2016-07-27]>.

Bjurström, H., Ilskog, E., Berg, M. *Askor från biobränslen och blandbränslen - mängder och kvalitet*. Eskilstuna: Statens energimyndighet, 2003.

Buoro, D., Pinamonti, P., Reini, M. "Optimization of a distributed cogeneration system with solar district heating." *Applied energy* 2014: 298-308.

Dalenbäck, Jan-Olof. "Fjärrvärmesystem." 2016. *Solvärme i fjärrvärmesystem SDH.* <http://solar-district-heating.se/sdh-sweden/fjarrvarmesystem/ [viewed 2016-09-01]>.

—. "Solar district heating and cooling." *Euroheat&power* (2013).

—. "Solar district heating in Europe." 2015.

—. *Success factors in solar district heating*. Gothenburg: CIT Energy management AB, 2010.

Dalenbäck, J-O., Lennermo, G., Andersson-Jessen, P-E., Kovacs, P. *Solvärme i fjärrvärmesystem - utvärdering av primärkopplade system*. Stocholm: Svensk fjärrvärme AB, 2013.

Dälenbäck, Jan-Olof. "SDH 2016 - Billind, Danmark." den 21 09 2016. *Svensk solenergi.* <http://www.svensksolenergi.se/nyheter/kalendarium/sdh-2016--billund-danmark [viewed 2016-09-07}>.

Elliott, J. Richard & Lira Carl T. *Introductory - chemical enginaaring thermodynamics*. New York, Castleton: Prentice Hall, inc, 2009.

Erikson, Karin. *Introduction and development of the Swedish district heating systems*. Lund: Lund university, 2009.

Gadd, H. & Werner, S. "Daily heat load variations in Swedish district heating systems." *Applied Energy* 2013: 47-55.

Göranson, Lisa & Lundberg, Liv. "Intermittent renewables, Thermal power and hydropower complements or competitors." Sandén, Björn. *Systems perspektives on renewable power*. Göteborg: Chalmers University of technology, 2014. 119-127.

IEA. "International energy agency - solar heating and cooling programe." 2016. *status of solar heating/cooling and solar buildings.* <http://www.iea-shc.org/country-report-sweden [viewed: 2016-06-08]>.

Kensby, Johan. "Energy supply." *buildning service engineering*. Guthenburg: Chalmers, 09 12 2015.

Leckner, Bo & Lyngfelt, A. ”Ångpanneteknik.” technology, Chalmers university of. *Energiteknik och miljö*. Guthenburg: Institutionen för energi och miljö, Chalmers university of technology, 2012. 68-96.

Lindenberger, D., Bruckner, T., Groscurth, H-M., Kümmel, R. “Optimization of solar district heating systems: seasonal storage, heat pumps and cogeneration.” *Energy* (2000): 591-608.

Lund, H., Möller, B., Mathiesen, B. V., Dyrelund, A. “The role of district heating in future renewable energy systems.” *Energy* (2010): 1381-1390.

Olsson, O., Eriksson, A., Sjöström, J., Anerud, E. “Keep that fire burning: fuel supply risk management strategies of swedish districh heating plants and implications for energy security.” *biomass and bioenergy* (2016): 70-77.

Rezaie, Behnaz & Rosen, Marc. “District heating and cooling: review of technology and potential enhancements.” *Applied energy* 2012: 2-10.

“Rural energy.” 03 05 2015. *Wood chip vs. wood pellets - the benefits of different types of biomass wood fuel.* <http://www.ruralenergy.co.uk/insight/wood-chip-vs-wood-pellets-benefits-different-types-biomass-wood-fuel [viewed 2016-07-27]>.

Schmidt, T., Mangold, D., Mûller-Steinhagen, H. “Central solar heating plants with seasonal storage in Germany.” *Solar energy* (2004): 165-174.

“Solar district heating.” n.d. *SDH - Solar district heating.* <http://solar-district-heating.eu/SDH.aspx [viewed 2016-09-28]>.

“Tekniske lösninger for produktion av värme.” 16 02 2009. *bioenergiportalen.* <http://www.bioenergiportalen.se/?p=2052&m=1599&page=pannlosningar [viewed: 2016-08-13]>.

Thorson, Ola. *Mail konversation* Louise Thrysöe Ekström. den 09 09 2016.

Werner, S & Frederiksen, S. *Fjärrvärme - teori, teknik och funktion.* Lund, Sweden: Studentlitteratur, 1993.

Wimmerstedt, R., Persson, L., Elmeroth, L. “Teknisk förbränningslära.” Chalmers. *Energiteknik och miljö*. Guthenburg: Institutionen för energi och miljö, Chalmers university of technology, 2012. 47-68.

“Wood pellets and briquettes.” 2011. *Biomass energy centre.* <http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,18519&_dad=portal&_schema=PORTAL [viewed 2016-08-20]>.

Appendix A: Current information about solar heating plants in Europe

Figure A.1 shows all solar heating plants where the solar collector fields are larger than 500 square meter (350 kW) and located within Europe. This illustrates Denmark development. Table A.1 shows all large-scale heating plants in Sweden and Denmark.

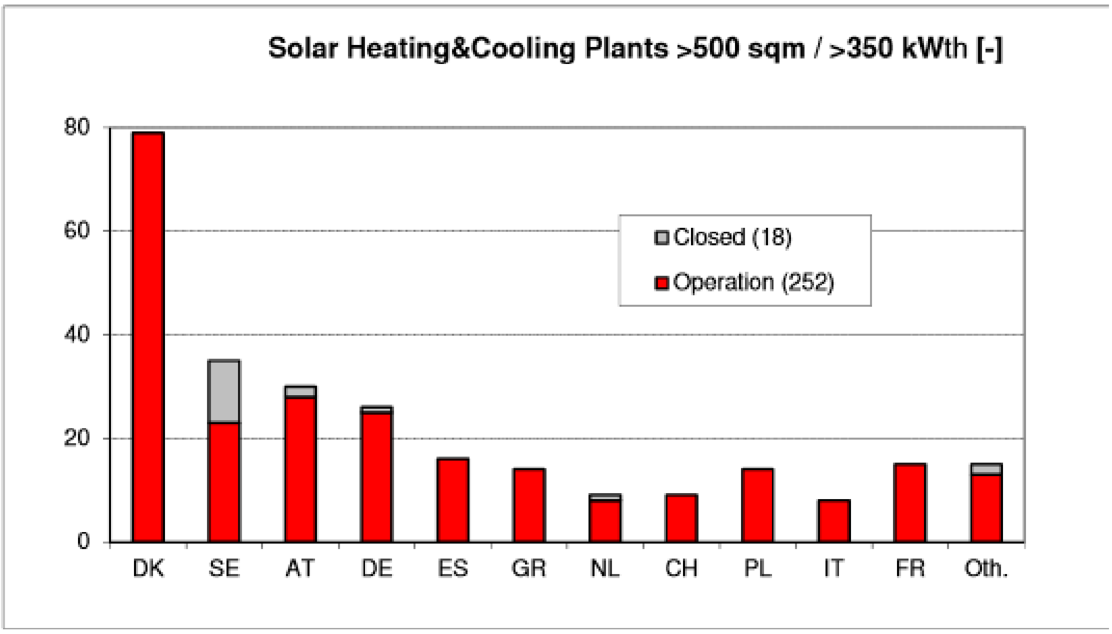

Figure A.1: Solar heating&cooling plants by countries. (Source: Dalenbäck, 2016d)

Table A.1: All large-scale heating plants in operation in Sweden and Denmark. (Source: Dalenbäck, 2016d)

No	In operation Plant, Year in operation	Owner, Country	Area(m^2)	MWth
1	Kungälv, 2000- **Reconstr.**	Kungälv Energi AB, SE	10 000	7,0
	Anneberg, 2002-	HSB Brf Anneberg, SE	2 400	1,7
	Fränsta, 1999-	Vattenfall Energimarknad, SE	1 650	1,2
	Gårdsten, 2000-	Bostads AB Gårdsten, SE	1 410	1,0
	Bo01, 2001	Sydkraft Värme Syd AB, SE	1 400	1,0
	Säter, 1992-	Hedemora Energi AB, SE	1 250	
	Kullavik 4, 1987-	EKSTA Bostads AB, SE	1 185	
	Heleneholm, 2006-	Malmö Stad, SE	1 100	
	Kockum Fritid, 2002-	Sydkraft Värme Syd AB, SE	1 100	
10	Fjärås Vetevägen, 1991-	EKSTA Bostads AB, SE	1 095	
	Åsa, 1985-	EKSTA Bostads AB, SE	1 030	
	Odensbacken, 1991-	Örebro Energi (Sydkraft), SE	1 000	
	Ellös, 2010-	Orust kommun, SE	1 000	
	Hågaby, 1998-	Uppsalahem AB, SE	930	
	Hammarkullen, 1985-	Gbg Bostads AB, SE	850	
	Lerum, 2015-	Lerums kommun, SE	850	
	Ekerö, 1997-	AB Ekeröbostäder, SE	800	
	Särö, 1989-	EKSTA Bostads AB, SE	740	
	Vallda, 2013-	EKSTA Bostads AB, SE	680	
20	Älta, 1998-	HSB Brf Stensö, SE	600	
	Kungälv, 2001-	Kungälv Energi AB, SE	600	
	Malmö Airport, 2008-	Luftfartsverket, SE	502	
	Molkom, 2011-	Karlstad Energi, SE	501	
23	**Sweden**	**Total**	**32 673**	22,9
1	Vojens, 2012-	Vojens Fjernvarme, DK	69 991	49,0
	Gram, 2009-	Gram Fjernvarme, DK	44 836	31,4
	Dronninglund, 2014-	Dronninglund Fjernvarme, DK	37 500	26,3
	Marstal, 1996-	Marstal Fjernvarme, DK	33 300	23,3
	Ringkøbing, 2010-	Ringkøbing Fjernvarmevaerk, DK	30 000	21,0
	Hjallerup, 2015-	Hjallerup Fjerrnvarme, DK	21 546	15,1
	Vildbjerg, 2014-	Vildbjerg Tekniske Værker, DK	21 240	14,9
	Hadsund, 2015-	Hadsunds Bys fjernvarmevaerk, DK	20 513	14,4
	Nykøbing Sjælland, 2014-	Nykøbing Sj. Varmevaerk, DK	20 084	14,1
10	Helsinge, 2012-	Helsinge Fjernvarme, DK	19 555	13,7
	Gråsten, 2012-	Gråsten Fjernvarme, DK	19 017	13,3
	Braedstrup, 2007-	Braedstrup Varmevaerk, DK	18 612	13,0
	Tarm, 2013-	Tarm Varmeværk, DK	18 585	13,0
	Aulum, 2015-	Aulum Fjernvarme a.m.b.a., DK	16 015	11,2
	Løgstør, 2014-	Løgstør Fjernvarmevaerk, DK	15 208	10,6
	Jetsmark, 2015-	Jetsmark Energivaerk, DK	15 183	10,6
	Oksbøl, 2010-	Oksbøl Varmeværk, DK	14 745	10,3
	Hundested, 2015-	Hundested Varmevaerk, DK	14 465	10,1
	Östervang, Varpelev, 2015-	Östervang Sjaelland, DK	14 112	9,9
20	Jægerspris, 2010-	Jægerspris Fjernvarme, DK	13 405	9,4
	Vrå, 2015-	Vrå Varmeværk A.m.b.a., DK	13 100	9,2
	Sydlangeland 1, 2013	Sydlangeland Fjernvarme, DK	12 512	8,8
	Grenaa, 2014-	Grenaa Varmeværk, DK	12 096	8,5
	Veggerløse, 2011-	Sydfalster Fjernvarme, DK	12 075	8,5
	Hvidebaek, 2013-	Hvidebaek Varmeværk, DK	12 038	8,4
	Sæby, 2011-	Sæby Fjernvarme, DK	11 921	8,3
	Toftlund, 2013-	Toftlund Fjernvarme, DK	11 000	7,7
	Svebølle-Viskinge, 2011-	Svebølle-Viskinge Fjernvarme, DK	10 024	7,0
	Taars, 2015-	Taars Varmeværk A.m.b.a., DK	10 011	7,0
30	Broager, 2009-	Broager Fjernvarme, DK	9 988	7,0
	Løgumkloster 1, 2015-	Løgumkloster Fjernvarme, DK	9 700	6,8

	Hvide Sande, 2014-	Hvide Sande Fjernvarme A.m.b.A., DK	9 576	6,7
	Christiansfeld, 2013-	Christianfeld Varmeværk, DK	9 545	6,7
	Langå, 2015-	Langå Varrmevaerk, DK	8 505	6,0
	Frederiks, 2013-	Frederiks Varmeværk, DK	8 438	5,9
	Strandby, 2008-	Strandby Varmevaerk, DK	8 012	5,6
	Karup, 2013-	Karup Varmeværk, DK	8 000	5,6
	Vejby-Tisvilde, 2012-	Vejby-Tisvilde Fjernvarme, DK	8 000	5,6
	Soenderborg/Vollerup, 2008-	Soenderborg Fjernvarme, DK	7 681	5,4
40	Gørding, 2012-	Gørding Varmevaerk, DK	7 472	5,2
	Skørping, 2012	Skørping Fjernvarme, DK	7 300	5,1
	Tørring, 2009-	Törring Kraftvarmevaerk, DK	7 284	5,1
	Ærøskøping, 1998-	Ærøskøping Fjernvarme, DK	7 093	5,0
	Snedsted (THY), 2015-	Snedsted Varmevaerk, DK	6 502	4,6
	Ejstrupholm, 2011-	Ejstrupholm Fjernvarme, DK	6 243	4,4
	Kværndrup, 2015-	Kvaerndrup Fjernvarme, DK	6 242	4,4
	Hejnsvig, 2010-	Hejnsvig Varmeværk, DK	5 763	4,0
	Aasa, 2014-	Asaa Fjernvarme A.m.b.a., DK	5 650	4,0
	Tistrup, 2010-	Tistrup Varmeværk, DK	5 400	3,8
50	Ulsted, 2006-	Ulsted Varmevaerk, DK	5 012	3,5
	Ørnhøj-Grønbjerg, 2012	Ørnhøj-Grønbjerg Kraftvarmevaerk, DK	5 000	3,5
	Mou, 2013-	Mou Kraftvarme, DK	4 775	3,3
	Jerslev, 2015-	Jerslev Kraftvarmevaerk, DK	4 612	3,2
	Tim, 2013-	Ringkøbing Fjernvarmevaerk, DK	4 235	3,0
	Haderup, 2015-	Haderup Kraftvarmeværk, DK	4 234	3,0
	Tversted, 2013-	Tversted Kraftvarmeværk, DK	4 000	2,8
	Feldborg, 2012-	Felborg Kraftvarme, DK	4 000	2,8
	Sandved-Tornemark, 2012-	Sandved-Tornemark Kraftvarmeværk, D	3 918	2,7
	Rise, 2001-	Rise Fjernvarme, DK	3 750	2,6
60	Skuldelev, 2015-	Skuldelev Energiselskab a.m.b.a., DK	3 742	2,6
	Gjerlev, 2014-	Gjerlev Varmeværk A.m.b.a., DK	3 500	2,5
	Sig, 2013-	Sig Fjernvarme, DK	3 479	2,4
	Öster Hurup, 2015-	Öster Hurup varmevaerk, DK	3 226	2,3
	Ry, 1988-	Ry Fjernvarme A/S, DK	3 040	2,1
	Hilleroed/Ulleroed, 2007-	Hilleroed Kommunale Fjernvarmevaerk	3 007	2,1
	Høje Taastrup, 2015-	Høje Taastrup Fjernvarme, DK	3 000	2,1
	Insenvad, 2014-	Ikast El- og Varmeværk A.m.b.a, DK	3 000	2,1
	Flauenskjold, 2014-	Flauenskjold Fjernvarme, DK	3 000	2,1
	Skovlund, 2012-	Skovlund Varmevaerk, DK	2 970	2,1
70	Nordby, 2002-	Samsø Energiselskab, DK	2 500	1,8
	Gl Rye, 2014-	Rye Kraftvarmeværk A.m.b.a., DK	2 495	1,7
	Dianalund, 2011-	Filadelfia, DK	2 000	1,4
	Hørsholm, 2012-	Velux, DK	1 275	
	Tubberupvænge, 1991-1997	Herlev kom. Boligselskab, DK	1 030	
	Saltum, 1988-	Saltum Fjarnvarme A/S, DK	1 005	
	Thisted, 2012-	Thisted Varmeforsyning	830	
	Elmegården, 2010-	Hilleroed Forsyning, DK	800	
	Avedøre, 2009-	Store Hus Boligselskab, DK	755	
	Ottrupgaard, 1995-	Ottrupgaards bofaellessk., DK	565	
79	**Denmark**	**Total**	**823 838**	576,7

Appendix B: Gathering information

Gathering the different information was mostly based on survey and information from the different homepages. Table A.1 shows where the different information where gathered besides the report used and Table A.2 shows specific information gathered through the different homepages

Table A.1: Information from the different municipalities

Municipalities	Information	Contact
Ale		
Alingsås	Homepage and survey	Jonas Dahl
Bengtsfors	Homepage and survey	Örjan Stranberg
Bollebygden	Homepage	Thomas Bengtsson
Borås	Homepage	
Dals-ed	Homepage	Lars Blom
Essjunga	Mail conversation	Peter Johansson
Falköping	Homepage	
Fjärgelanda	Homepage	
Grästrop	Survey	Tomas Andersson and Lars Blom
Gullspång	Mail conversation	Lars Johansson
Göteborg	Homepage and survey	Thomas Johanson
Götene	Homepage and survey	Fredrik Hedman
Herrljunga	Survey	Thomas Bengtsson
Hjo	Survey	Kenneth Eriksson
Härryda	Homepage	
Karlsborg	Survey	Patrik Larsson and Stefan Lagerkvist
Kungälv	Mail conversation and Homepage	Ola Thorson
Lerum	Homepage	
Lidköping	Homepage and survey	Lars Blom
Lilla Edet	Homepage	
Lysekil	Homepage and survey	Stefan Jolback
Mark	Mail conversation and Homepage	Tobias Jansson and Lars Blom
Mariestad	Homepage and mail conversation	Kjell åke wallström
Mellerud	Homepage	
Munkedal	Homepage	
Mölndal	Homepage	
Orust	Homepage	
Partille		
Skara	Homepage and survey	Fredrik hedman
Skövde	Homepage	
Sotenäs	Homepage	
Strömstad	Mail conversation	Jan Simonsson
Svenljunga	Homepage	

Stenungsund	Homepage	
Tanum	Survey	Gustav Englund
Tibro	Survey	Per Kroon and Mikael Jonsson
Tidaholm	Homepage	
Tjörn	Survey	Jan Jansson and Janne Gregoriusson
Tranemo	Homepage	
Trollhättan	Homepage	
Töreboda	Mail conversation	Kjell åke vallström
Uddevalla	Homepage	
Ulricehamn	Survey	Henrik Säwe
Vara	Homepage and survey	Lars Blom
Vänersborg	Homepage	
Vårgårda	Survey	Thomas Bengtsson
Åmål	Homepage and survey	Rolf Gustafsson
Öckerö		

Table B.2: Homepages information

Homepage and information
Alingsås
http://www.alingsasenergi.se/fjarrvarme/projekt-savelundsverket-pannlinje-c
Bengsfors
http://www.bengtsfors.se/boendeochmiljo/energiochuppvarmning/fjarrvarme/fjarrvarmeanlaggningar/billingsfors
http://www.bengtsfors.se/boendeochmiljo/energiochuppvarmning/fjarrvarme/fjarrvarmeanlaggningar/backefors
http://www.bengtsfors.se/boendeochmiljo/energiochuppvarmning/fjarrvarme/fjarrvarmeanlaggningar/dalslanged
http://www.bengtsfors.se/boendeochmiljo/energiochuppvarmning/fjarrvarme/fjarrvarmeanlaggningar/bengtsfors
Borås
http://www.borasem.se/vanstermeny/omforetaget/varaanlaggningar/ryaverket.4.7243a9a4125d5ad4db1800015547.html
Fjärgelanda
http://www.rorvarme.se/fjarrvarme
Göteborg
http://www.goteborgenergi.se/Om_oss/Var_verksamhet/Produktionsanlaggningar/Rosenlundsverket
http://www.goteborgenergi.se/Files/dok/produkter/Reko%20verksamhetsgenomlysning%202014%20G%c3%b6teborg%20Energi%20AB.pdf
Götene
http://www.gotenevatten.se/sv/fjarrvarme.aspx
Kungälv
http://www.kungalv.se/Bygga--bo--miljo/energi-uppvarmning/
Härryda
http://solorbioenergi.com/
Lerum
http://www.lerumfjarrvarme.se/Fjarrvarmenatet/Vara_anlaggningar/Varmecentraler
Lidköping

http://www.lidkopingsvarmeverk.se/Varme-och-elproduktion.aspx
Lilla Edet
http://www.borasem.se/vanstermeny/omforetaget/varaanlaggningar/ryaverket.4.7243a9a4125d5ad4db1800015547.html
Lysekil
http://www.levailysekil.se/fjarrvarme/var-fjarrvarme.html
Mariestad
http://katrineforskraft.se/fakta-kring-kraftvarmeverket/
Mellerud
http://www.mellerud.se/media/114147/pmbh111130.pdf
Uddevalla
http://www.uddevallaenergi.se/omoss/varverksamhet/varaproduktionsanlaggningar/varme/langedalsverket
Härryda
http://fjarrvarme.solorbioenergi.se/project/molnlycke/
Orust
http://www.orust.se/amnesomrade/byggaboochmiljo/energiochuppvarmning/fjarrvarme.4.32c676ab13fc39bc3232dfa.html
Skara
http://www.skaraenergi.se/sv/fjarrvarme-fakta.aspx
Skövde
http://www.varmeverk.skovde.se/Produktionsanlaggningar/skultorp/
http://www.varmeverk.skovde.se/Produktionsanlaggningar/Timmersdala/
http://www.varmeverk.skovde.se/varmekallan_ny/Block-4---nytt-/Block-4---fragor-och-svar/
http://www.varmeverk.skovde.se/Lovangsverket/
Stenungsund
http://www.stenungsund.se/webbsidor/huvudmeny/byggabomiljo/energiochuppvarmning/fjarrvarme/hurfungerarfjarrvarme/vanligafragor
Tidaholm
http://www.tidaholmsenergi.se/
Tranemo
https://www.tranemo.se/bygga-bo-och-miljo/
Trollhättan
https://www.trollhattanenergi.se/privat/fjarrvarme/
Töreboda
http://www.vanerenergi.se/toppmeny/fjarrvarme/harproducerasdinfjarrvarme.4.3b465a25148214b0566889.html
Uddevalla
http://www.uddevallaenergi.se/omoss/varverksamhet/varaproduktionsanlaggningar/varme/hovhultsverket
http://www.uddevallaenergi.se/omoss/varverksamhet/varaproduktionsanlaggningar/varme/brattasverket
http://www.uddevallaenergi.se/omoss/varverksamhet/varaproduktionsanlaggningar/varme/lillesjoverket
http://www.uddevallaenergi.se/omoss/varverksamhet/varaproduktionsanlaggningar/varme/arodsverket
Vara
http://www.varaenergi.se/vara-fjarrvarme/
Vänersborg
https://www.vattenfall.se/globalassets/fjarrvarme/orter-foretag/miljoredovisning-vanersborg-2014.pdf
https://www.vattenfall.se/fjarrvarme/orter/vanersborg/
Åmål
http://statkraft.se/energikallor/kraftverk/sverige/Amal/

Appendix C: All identified heating plants

Table C.1 shows all identified heating plants with name, heat supply and who owns the heating plants. Table C.2 shows the exact information gathered about the composition of all heating plants fired with wood chips. Table C.3 shows the exact information gathered about the composition of all heating plants fired with briquette and pellets. Table C.4 shows the exact information gathered about the composition of all heating plants fired with only fossil fuel and Table C.5 shows all heating plants which lack data. Table C.6 shows the heat production and use for 2013 identified through the report Klimatskyddsbyrån, 2013, but also the identified heat production through this report.

Table C.1: Basic information regarding all identified heating plants located inside the region

Municipalities	Name of heating plant	Heat supply	Name of owner	ownership
ale			Göteborgs energi	Municipal
Alingsås	Sävelund fjärrvärmeverk	Urban	alingsås energi	Municipal
	PC Gjutaren	reserve urban	alingsås energi	Municipal
	PC Noltorp	reserve urban	alingsås energi	Municipal
	PC hemsjö	Small town	alingsås energi	Municipal
	Sollebrunn närvärme	Block	alingsås energi	Municipal
	alingsås sjukhuset	Block	alingsås energi	Municipal
	Regionservice tvätteri		alingsås energi	Municipal
Bengtfors	Bengtsgården	Urban	Bengtfors energi	Municipal
	Industrigatan, bengtfors	Small town	Bengtfors energi	Municipal
	Billingsfors	Small town	Bengtfors energi	Municipal
	Bäckefors	Small town	Bengtfors energi	Municipal
	Dals Långed	Urban	Bengtfors energi	Municipal
bollebygden	Bollebygd fjärrvärme AB	Urban	bollebygds fjärrvärme	Municipal
Borås	Ryaverket, 1965	Urban	Borås energi och miljö	Municipal
Dals ed	Lantmännen agrovärme Dals ed, 1996	Urban	Farmaenergi i ED	40% privatpersons in ED municipal and 60% lantmännen agrovärme,
Essjunga	Nossebro PC	Urban	Nossebro energi	Municipal
Falköping	Marjarp, 2001,2013		falbygdens energi	Municipal
	Dotorp, 1985		falbygdens energi	Municipal

	Floby, 1992		falbygdens energi	Municipal
	Stenstorp, 2008		falbygdens energi	Municipal
	Jättene		falbygdens energi	Municipal
Fjärgelanda	panncentral	Small town	Rör och värme AB	Privat
Grästrop	Grästorps PC, 2002	Urban	lantmännen agrovärme	fjärrvärmebolag
Gullspång	Gullspång PC	Urban	Gullspång energi	Municipal
Göteborg	RYA	Urban	Göteborgs energi	Municipal
	rosenlund	Urban	Göteborgs energi	Municipal
	Angered panncentral	Urban	Göteborgs energi	Municipal
	Sävenäs HP3	Urban	Göteborgs energi	Municipal
	Skarvik, 2008	Block	Göteborgs energi	Municipal
	Skepplanda, 2004	Small town	Göteborgs energi	Municipal
Götene	Hällekis	Urban	Götene vatten och värme	Municipal
	Västerbyverket	Urban	Götene vatten och värme	Municipal
	Lundsbrunn	Block	Götene vatten och värme	Municipal
	Källby	Block	Götene vatten och värme	Municipal
Herrljunga	Herrljunga El AB	Urban	Herrljunga elektriska	Municipal
	Annelund	Urban	Herrljunga elektriska	Municipal
Hjo	Hjo PC, 1999	Urban	Hjo energi	Municipal
Härryda			solörbioenergi	ESCO
Karlsborg	Karlsborg värme AB Fjärrvärmecentral, 1999	Urban	karlsborgs värme	Municipal
	Statens fastighetsverk, fjärrvärmecentral, 1973, 2005, 2011	Block	statens fastighetsbolag	ESCO
Kungälv	Munkegärdeverket	Urban	Kungälv energi	Municipal
	Waste heat from Göteborgs energi			
	Stället (stålkullen)	Small town	Kungälv energi	Municipal
	Kärna	Small town	Kungälv energi	Municipal
	Kode	Small town	Kungälv energi	Municipal
Landvetter			solörbioenergi	ESCO

Lerum	Aspedalens		Lerum fjärrvärmenergi	Muncipalities: 51%lerums energi and 49% göteborgs energi
	Gråbo		Lerum fjärrvärmenergi	Municipal
	Stenkullen		Lerum fjärrvärmenergi	Municipal
	floda		Panncentralen i Lerum AB	privat
Lidköping	Hovedanlägning PC filen, östra havnen	tötort	lidköpings värmeverk	Municipal
	PC släggan, västra havnen		lidköpings värmeverk	Municipal
	Såtenergi AB, 1996	Small town	lantmännen agrovärme	ESCO
	PC ulriksdal		lidköpings värmeverk	Municipal
Lilla Edet	Waste heat from SCA	värmer alle större industroer samt tätorten		
	Waste heat from vargön alloys			
Lysekil	Får spillvärme från Preemraffs raffinaderi			
	P1 badhusberget	reserv, småstad	leva i lysekil	Municipal
	P2 sjukhuset	reserv, småstad	leva i lysekil	Municipal
Mark	Assbergsverket i Skene		mark fjärrvärme	Municipal
	Fritsla Panncentral		mark fjärrvärme	Municipal
	Hyssna Panncentra		mark fjärrvärme	Municipal
	Snickarens PC		mark fjärrvärme	Municipal
	PCT horred, 1999		lantmännen agrovärme	ESCO
Mariestad	katrineford,	Urban	vänerenergi	Municipalties: 88%mariestad, 12%töreboda
	Lyrestad PC	Urban	vänerenergi	Municipalities: 88%mariestad, 12%töreboda
Mellerud				
Munkedal	Långedalsverket, 2007	Small town	Uddevalla Energi	Municipal
Mölndal	Riskulla		Göteborgs energi	Municipal
Mölnlycka			solörbioenergi	ESCO
orust	ellös	Small town		
Partille			Göteborgs energi	Municipal
Skara	Harven		skara energi	Municipal

	Uddetorp		skara energi	Municipal
	Diakonen (reservverk)		skara energi	Municipal
	Tjuren (reservverk)		skara energi	Municipal
	Ardala	Small town	skara energi	Municipal
	Varnhemskolan	Block	skara energi	Municipal
	Axvall	Block	skara energi	Municipal
Skövde	Skultorp		skövde värmeverk	Municipal
	Stöpen	Small town	skövde värmeverk	Municipal
	Timboholm		skövde värmeverk	Municipal
	Tidan	Urban	skövde värmeverk	Municipal
	Timmersdala	Urban	skövde värmeverk	Municipal
	Blok 4	Built in 2016	skövde värmeverk	Municipal
	Lövsängverket, 1970		skövde värmeverk	Municipal
Sotenäs				
Strömstad	Tångens PC	Urban	Strömstad energi	Municipal
Svenljunga			solörbioenergi	ESCO
Stenungsund	Spillvärme från Borealis Polyeten och Perstorp Oxo		stenungsund energi och miljö	Municipal
Tanum	Östanvind	Small town	Neova AB	ESCO
	Kalkåsliden	Block	Neova AB	ESCO
Tibro	Neova, fjärrvärmecentral	Urban	Neova AB	ESCO
Tidaholm				
Tjörn	Tourane AB,	Small town	Tourane AB	ESCO
	PC kållekärr	Small town	Törns bostadAB	Municipal
	PC Skärhamn	Small town	Tjörns bostad	Municipal
Tranemo			E.ON	ESCO
			Ardagh AB	
			Hållanders energi	privat
Trollhättan	kraftvärmeverket Lextorp		Trollhättan energi	Municipal
	Stallbacka värmeverk		Trollhättan energi	Municipal
	Kronogårdens värmeverk		Trollhättan energi	Municipal
	Sjuntorps värmecentral		Trollhättan energi	Municipal

Töreboda	Töreborda PC	Urban	vänerenergi	Municipalities: 88%mariestad, 12%töreboda
Uddevalla	Lillesjöverket	Urban	Uddevalla Energi	Municipal
	Hovhultsverket	Urban	Uddevalla Energi	Municipal
	Brattåsverket	reserv, small town	Uddevalla Energi	Municipal
	Arödsverket	Urban	Uddevalla Energi	Municipal
Ulricehamn	PC timmele	Block	ulricehamn energi	Municipal
	PC Gällstad	Small town	ulricehamn energi	Municipal
	HVC simhallen	reserv, Block	ulricehamn energi	Municipal
Vara	Vara PC	Urban	Vara energi	Municipal
	Vedum PC Spillvärme from kök	Urban	Vara energi	Municipal
	Lantmännen agrovärme kvänum	Urban	lantmännen agrovärme	ESCO
Vänersborg	Spillvärne från vargön alloys			
	Önaforsverket	Urban	vattenfall	ESCO
Vårgårda	Vårgårda ångfabrik AB	Urban	rindi energi	ESCO
	VH biogas AB	Block	rindi energi	ESCO
	Lena skola	Block	rindi energi	ESCO
	Hols skole	Block	rindi energi	ESCO
	Nårunga skola	Block	rindi energi	ESCO
Åmål	214, Svetsaren 2 Nordverk	Small town		
	Statskaft fjärrvärmeverk	Urban	Statkraft	ESCO
Öckerö				

Table C.2: Composition of wood chips boilers

Municipalities	Name of heating plant	wood chips boiler [kW]	Biooil Boiler [kW]	Oil Boiler [kW]	Natural gas [kW]	Waste incineration [kW]	El-boiler [kW]	Flue gas condens [kW]
Alingsås	Sävelund fjärrvärmeverk	35000		12000	500			3000
Bollebygden	Bollebygd fjärrvärme AB	3000						
Borås	Ryaverket	130000				40000		
Dals ed	Lantmännen agrovärme	1700		3000				
Essjunga	Nossebro PC	6000						
Falköping	Marjarp	25000	12000				2300	5000
Fjärgelanda	panncentral	1300						

Grästrop	Grästorps PC	3500		3500				
Göteborg	Sävenäs HP3	100000						
Götene	Västerbyverket	25000		16000				2500
Herrljunga	Herrljunga El AB	6000						
Herrljunga	Annelund	800						
Hjo	Hjo PC	11500		14000				3000
Härryda	Landvetter	5000						
Härryda	Mölnlycka	12000						
Karlsborg	Karlsborg värme AB Fjärrvärmecentral	3000		4500				2000
Karlsborg	Statens fastighetsverk, fjärrvärmecentral	8000		9400				
Kungälv	Munkegärdeverket	23000		26000				3000
Lerum	Aspedalens	19300						
Lerum	floda	5800						
Lidköping	Hovedanlägning PC filen, östra havnen	30000	40000	8000		40000		
Mark	Assbergsverket i Skene	26800						7000
Mark	PCT horre	2000		4000				
Mariestad	katrineford,	70000		30000				16800
Mellerud	Klacken	1800		1000				
Mölndal	Riskulla	91000						
Mölnlycka		12000						
orust	ellös	4000		4500				ja
Skara	Harven	10000			2000			3000
Skara	Uddetorp	8000						2000
Skövde	Lövsängverket	40000						12000
Svenljunga		12000						
Tibro	Neova, fjärrvärmecentral	19000		7500				1000
Tidaholm	Eldaren	15000						
Trollhättan	kraftvärmeverket Lextorp	17000		40000			3700	
Trollhättan	Stallbacka värmeverk	44000	50000				25000	
Trollhättan	Kronogårdens värmeverk	8000		16000				
Töreboda	Töreborda PC	20000						
Uddevalla	Hovhultsverket	50000						10000
Vara	Vara PC	10000						
Vårgårda	Vårgårda ångfabrik AB	7000		8000				
Vårgårda	VH biogas AB	500						
Åmål	Statskaft fjärrvärmeverk	12000		19000				2000

Table C.3: Composition of pellets and briquette boilers

Municipalities	Name of heating plant	Pellets boiler [kW]	Briquette boiler [kW]	Biooil boiler [kW]	Oil boiler [kW]	Elboiler [kW]
Alingsås	PC hemsjö	200			50	
Alingsås	Sollebrunn närvärme	800			1000	450
Alingsås	Regionservice tvätteri	5500				10000
Bengtfors	Bengtsgården	3000			3160	
Bengtfors	Industrigatan, bengtfors	2000			2900	
Bengtfors	Billingsfors		1160		2000	
Bengtfors	Bäckefors	1000			1000	
Bengtfors	Dals Långed	3000			1720	
Falköping	Dotorp, 1985		9000	10000		
Falköping	Floby, 1992		4500		4000	
Falköping	Stenstorp, 2008	1500				1800
Falköping	Jättene	1500	3500		3500	
Gullspång	Gullspång PC	1000				
Göteborg	RYA	100000				
Göteborg	Skarvik, 2008	3000				
Göteborg	Skepplanda, 2004	1000				
Götene	Hällekis	800			1950	
Götene	Lundsbrunn	200			200	
Götene	Källby	200			200	
Kungälv	Stället (stålkullen)	500			730	
Kungälv	Kärna					
Kungälv	kode					
Lerum	Gråbo		6000			
Lerum	Stenkullen	1000				
Mariestad	Lyrestad PC		1400			
Munkedal	Långedalsverket, 2007		3000	4000		
Skara	Ardala	400			400	
Skara	Axvall					
Skara	Varnhemskolan	200			200	
Skövde	Timmersdala	1800			2000	
Skövde	Skultorp					
Skövde	Stöpen					
Skövde	Tidan					
Strömstad	Tångens PC	1000			1500	
Tjörn	Tourane AB, 2000	400			500	
Tjörn	PC kållekärr, 2008	1200			1700	
Tjörn	PC Skärhamn, 1977	600			1400	
Uddevalla	Arödsverket, 2008		1500	2000		
Ulricehamn	PC timmele, 2007	620				350

Ulricehamn	PC Gällstad	700			700	
Ulricehamn	HVC simhallen	2500			7000	
Vara	Lantmännen agrovärme kvänum	3000			3000	
Vårgårda	Lena skola	120				
Vårgårda	Hols skole	100				
Vårgårda	Nårunga skola	100				
Åmål	214, Svetsaren 2 Nordverk	400				

Table C.4: Heating plants which only uses fossil fuels

Municipalities	Name of heating plant	Biooil Boiler [kW]	Oil Boiler [kW]	Natural gas [KW]	Elboiler [kW]	Straw boiler [kW]
Alingsås	PC Gjutaren		16000			
Alingsås	PC Noltorp		18000			
Göteborg	Angered panncentral	75000				
Göteborg	Rosenlund			669000		
Lidköping	PC släggan		75000			
Lidköping	Såtenergi AB,		3000			4000
Lidköping	PC ulriksdal		6000			
Lysekil	P1 badhusberget		9800			
Lysekil	P2 sjukhuset		9600			
Mark	Snickarens PC					110
Skara	Diakonen (reservverk)		8800			
Skara	Tjuren (reservverk)		9860			
Uddevalla	Brattåsverket	160000			10000	
Vänersborg	Önaforsverket	60000				

Table C.5: All heating plants with no information

Municipalities	Name of heating plant
Alingsås	alingsås sjukhuset
Härryda	
Mark	Fritsla Panncentral
Mark	Hyssna Panncentra
Skövde	Timboholm
Skövde	Blok 4
Tanum	Östanvind
Tanum	Kalkåsliden
Trollhättan	Sjuntorps värmecentral
Uddevalla	Lillesjöverket

Table B.6: Heat production and use in 2013 and 2016

Municipalities	Total heat production in 2013 [GWh/year]	Total identified heat production 2016 [GWh/year]	
Ale	40	0	
Alingsås	146	157,6	Down since 2013
Bengtsfors	25		-
Bollebygden	7	8	Producing same heat
Borås	733	600	Down since 2013
Dals-ed	9	7	Producing same heat
Essjunga	8	7	Producing same heat
Falköping	147	135	Down since 2013
Fjärgelanda	4,5	0	-
Grästrop	27	10,5	Missing identified heat
Gullspång	7,7	3,5	Missing identified heat
Göteborg	4051	3997,4	Down since 2013
Götene	43	41,9	Down since 2013
Herrljunga	28,5	23	Down since 2013
Hjo	41	0	-
Härryda	71		-
Karlsborg	19	0	-
Kungälv	106	127	Up since 2013
Lerum	57	0	-
Lidköping	393	16	Missing identified heat
Lilla Edet	14	12	Producing same heat
Lysekil	53	43,058	Down since 2013
Mariestad	236	137,8	Missing identified heat
Mark	116	120	Up since 2013
Mellerud	16,5	0	-
Munkedal	8,3	7,5	Producing same heat
Mölndal	476	0	-
Orust	9		-
Partille	0		-
Skara	93	12,5	Missing identified heat
Skövde	406	0	-
Sotenäs	0	0	-
Stenungsund	94	18	Missing identified heat
Strömstad	0	2,4	Received district heat since 2013

Svenljunga	42		-
Tanum	10	0	-
Tibro	59	0	-
Tidaholm	64	60	Down since 2013
Tjörn	0	5,3	Received district heat since 2013
Tranemo	47	0	-
Trollhättan	392	400	Up since 2013
Töreboda	26	28	Producing same heat
Uddevalla	302	293,5	Producing same heat
Ulricehamn	60	48	Producing same heat
Vara	52	50,1	Producing same heat
Vänersborg	160	130	Down since 2013
Vårgårda	39	23,6	Missing identified heat
Åmål	48	39,6	Down since 2013
Öckerö	0		-
	8786,5	6565,258	