TOOLBOX FOR PROSUMTION IN DISTRICT HEATING

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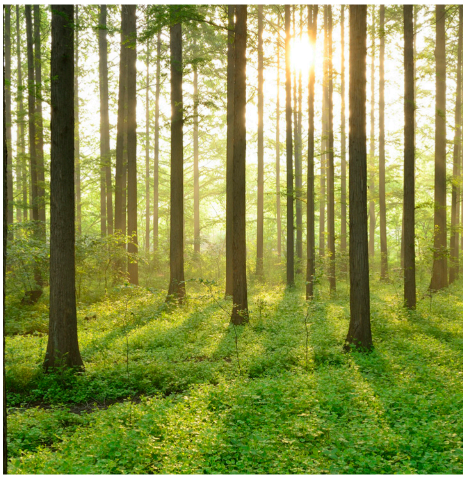

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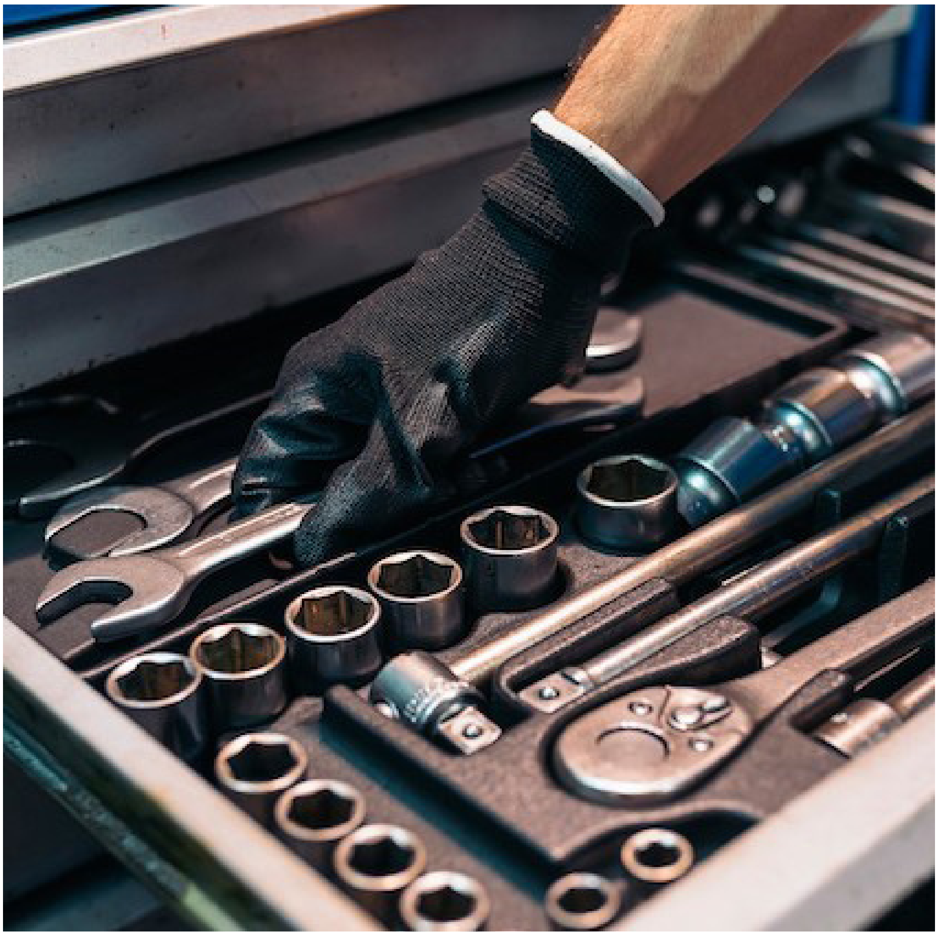

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Toolbox for prosumtion in district heating

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Foreword

The project Toolbox for prosumtion in district heating aims to provide district heating companies with tools for designing standardized offers to prosumers and small-scale heat suppliers. The report presents existing standardized offers and the economic potential for two types of prosumers in different district heating systems.

The project was led and conducted by Johan Kensby, Utilifeed, together with Jonas Ottosson and Nathalie Fransson from IVL Swedish Environmental Research Institute and the colleagues Melissa Eklund and Linnea Johansson at Utilifeed.

A reference group consisting of Holger Feurstein, Kraftringen (chair); Agneta Filén, Halmstads Energi & Miljö; Christina Hedegaard-Friis, E.ON Värme Sverige; Karolina Falk, Tekniska Verken i Linköping; Magnus Swedblom, Norrenergi; Petter Hansson, Göteborg Energi och Sofia Petersson Svanfeldt, Vattenfall has followed the project and assured the quality and the usability of the results.

The project is part of the FutureHeat program, whose long-term goal is to contribute to the vision of a sustainable heating system with successful companies that utilize new technological opportunities and where the investments made in district heating and cooling are utilized to the best of their ability. This project is part of the second phase of the program. The FutureHeat program is led by a steering committee consisting of Jonas Cognell, Göteborg Energi (chair); Anders Moritz, Tekniska verken i Linköping; Anna Hinderson, Vattenfall AB; Charlotte Tengborg, E.ON Värme Sverige; Fabian Levihn, Stockholm Exergi; Holger Feurstein, Kraftringen; Joacim Cederwall, Jönköping Energi; Johan Brossberg, Borlänge Energi; Leif Bodinson, Söderenergi; Lena Olsson Ingvarson, Mölndal Energi; Magnus Ohlsson, Öresundskraft; Niklas Lindmark, Gävle Energi; Per Örvind, Eskilstuna Strängnäs Energi & Miljö; Petra Nilsson, Växjö Energi; Staffan Stymne, Norrenergi; Stefan Hjärtstam, Borås Energi och Miljö; Svante Carlsson, Skellefteå Kraft; Ulf Lindquist, Jämtkraft and Julia Kuylenstierna (co-opt), Energiforsk. Deputies have consisted of Ann Britt Larssson, Tekniska verken i Linköping; Lars Larsson, Borlänge Energi och Peter Rosenkvist, Gävle Energi.

Julia Kuylenstierna, program manager FutureHeat

The results and conclusions in this report are presented from a project within a research program run by Energiforsk. The authors are responsible for the content.

Summary

Utilizing excess heat that would otherwise have been excessd is one of the most important aspects of district heating systems. In many district heating systems, there are examples of collaborations between the heating company and industrial partners that provide excess heat. Often, such collaborations handle large-scale deliveries of heat to the district heating grid, and each heat supply collaboration is managed with individual agreements and long negotiations. Many large heat suppliers are already connected to district heating grids, but there are also several types of potential smaller heat suppliers that could also be utilized. In order to make the transition towards a renewable energy system, all forms of energy must be utilized efficiently. In order to be able to utilize excess heat from a variety of smaller suppliers and prosumers, the processes to connect to hearing grids must be simplified and standardized. This report intends to provide district heating companies with tools for designing standardized offers for small-scale heat suppliers and prosumers.

In the report, existing standardized offers for small-scale heat supply to Swedish district heating grids are described. The economic potential for two different types of small-scale heat suppliers, a data centre and a grocery store, in six different types of Swedish district heating grids are calculated through simulations.

A data center utilizing compressor chillers for cooling can deliver the excess heat to district heating grids at a cost that is 880 – 1,710 kSEK/year less than it would have cost the district heating company to generate the corresponding amount of heat. The greatest cost savings are achieved in heat grids with relatively high marginal generation costs and least potential is in archetype grids with an already high proportion of excess heat in the production mix. For a studied grocery store, the corresponding economic potential for exporting heat is 110 – 300 kSEK/year, depending on how the production mix is composed in the receiving heating grid.

An important part of an offer to potential small-scale heat suppliers is the economic compensation for the delivered heat. The compensation should reflect the benefits that the delivery entails for the district heating company and compensation per energy unit can be set at a constant level, as a function of outdoor temperature or based on ongoing production planning. Models for calculating economic compensation for the heat delivery that better reflect the actual alternative generation cost result in greater system benefits from the heat delivery. However, such models are more complex, and, in many cases, a simpler model may be fully sufficient and even necessary to conclude agreements with suppliers.

The added demand for data communication between district heating companies and small-scale heat suppliers is in many cases only a few new signals and

interfaces. The information that may need to be shared in continuous data streams are energy prices, weather forecasts, required supply temperature and heat supply forecasts.

Content

1 Introduction

Being able to utilize excess heat that would otherwise have been excess is one of the most important aspects of district heating systems (Frederiksen & Werner, 2013) and it is not uncommon to utilize excess heat in Swedish district heating systems. There are many examples of larger industries supplying large amounts of excess heat during all seasons of the year and this heat accounts for an important part of the heat supply in some district heating systems. But how is the situation for smaller actors who want to supply excess heat to district heating systems? For large suppliers of heat, the supply and the transaction often involve a unique tailored contract preceded by extensive negotiations. If smaller heat deliveries are to be cost-effective for district heating companies to handle, standardized technical solutions, business models and contracts are required. The aim of this project is to provide energy companies with the tools they require in order to be able to cost-effectively launch standardized offerings for selling heat to their district heating systems.

The project as a whole has two phases and this report covers to the first phase, Phase 1, which focuses on the development of business concepts, methods and tools that through simulations are used to describe the conditions and potential of small-scale excess heat deliveries and prosumtion in different types of district heating grids. The plan for a second phase, Phase 2, is to further develop the results from Phase 1 into an IT-solution that can be cost-effectively rolled out in many district heating companies and handle the functions required to have a standardized offer for small-scale heat delivery. Phase 2 has not begun at the time of writing and the goal is to together with a group of energy companies to seek funding for the second phase. Phase 2 also combines the results of Phase 1 with development Utilifeed conducts in the projects Smart Fjärrvärmeanalys (Smart District Heating Analyses) and Flexi-Sync. With the synergies from those projects, there is a very good opportunity to develop a service that, among other things, provides for the possibility of developing a service that, among other things, automates the generation of price lists for selling heat to the heat grid and continuously calculates the compensation each supplier will receive based on automatically validated measurement data. Such a service can facilitate the process of opening up heating grids for small-scale heat suppliers.

The objectives of Phase 1 (the part covered in this report) are to:

- Perform an analysis of existing knowledge and solutions for small-scale excess heat and prosumtion in district heating systems.
- Evaluate the potential for small-scale excess heat and prosumtion in different types of district heating systems.
- Describe business model concepts and models for remuneration.
- Apply and simulate the economic potential and business logic on at least one concrete case study. The study shall include at least one case where a heat pump is required to increase the temperature of the excess heat and take into account related costs for doing so.

- Describe what data needs t be communicated between energy companies and property owners in order for the developed concepts to work.

Keywords

Prosumtion, Prosumer, District Heating, Excess Heat, System Perspective, Business Model

2 Prosumers and small-scale excess heat suppliers in Sweden – an overview of existing solutions

In many district heating systems, supply of excess heat from major industries is a part of the production mix. Although such deliveries are fairly common in Sweden, the degree of standardization is quite low and most deliveries are managed on a case-by-case basis, with special agreements written between the heat supplier and the district heating company. This project is focused on heat deliveries from small-scale heat sources and prosumers where price negotiations and contract writing are as standardized as possible in order to effectively integrate different types of potential prosumers and suppliers of excess heat. A prosumer is customer in a district heating grid that also generates heat and when the generation is greater than the prosumers demand for heat, excess heat is exported to the heat grid. Almost all results and aspects in this study apply to both prosumers and small-scale heat suppliers (that never buys heat only export when they have excess) and the two terms are used interchangeably in the report unless it's explicitly stressed otherwise.

The analysis of existing knowledge compiles known solutions for supply of heat from small-scale heat sources and prosumers to Swedish district heating systems and describes four cases in more detail regarding technology, ownership, contracts and business models.

A literature search has been carried out to identify examples of solutions where small-scale prosumers and suppliers of excess heat through standardized concepts and offers are given the opportunity to deliver heat to district heating grids. In addition to a literature search in scientific databases and reviews of Energiforsk report database, the reference group has also contributed material.

Historically, many small-scale solutions have been individual projects or pilots. An overall review of prosumers in Swedish and non-Swedish district heating systems was carried out in 2016 by Lennermo et al., which is also proposed detailed technical designs of facilities for delivery to district heating grids (Lennermo, Lauenburg. & Brange, 2016). In this project, some additional Swedish examples are also described that have emerged since the 2016 report by Lennermo et al. Since 2016, there has been a development in the industry towards creating standardized solutions for prosumers and Stockholm Exergi, Tekniska verken, Vattenfall Värme and Norrenergi have developed concepts for prosumers and small-scale heat suppliers that are commercially mature or close to commercialization. The following chapter first provides a review of solutions for prosumers and small-scale heat suppliers. It briefly covers some more unique case-by-case solutions and dives deeper in the more standardized solutions.

2.1 KRAFTRINGEN

Kraftringen in Lund does not have a standardized offer for prosumers and small-scale heat suppliers, but their district heating system incorporated heat deliveries from several of large-scale collaborations with customers and heat suppliers that have been negotiated and designed on an case-by-case basis.

Examples of collaborations with prosumers and small-scale excess heat suppliers

Brunnshög is a new district under construction in northeastern Lund. In Brunnshög Kraftringen develops concepts for energy, mobility, and lighting in collaboration with Lund Municipality, Science Village Scandinavia, the research facilities ESS and MAX IV as well as property developers in the region. Brunnshög is developing the world's largest low-temperature district heating grid (35-65°C) as a demonstration within the COOL DH project, an EU-funded project under the Horizon 2020 program (Kraftringen, 2019b).

The motivation for the low-temperature district hearing grid is to be able to take advantage of the excess heat produced on MAX IV and in the future also on the ESS. Today, the heat from MAX IV is recycled from three different flows at the site. The warmest flow can be connected directly to Lund's district heating grid, while the other two flows use heat pumps that raise the temperature to 75-80°C before exporting the heat to the heat grid. MAX IV can deliver a maximum heat output of 4.5 MW (Kraftringen, 2019b). When the low-temperature grid is completed, most of the heat will instead be delivered to that grid. The low-temperature district heating grid is designed for a supply pipe temperature of 65°C and a return temperature of 35°C. The first delivery took place in 2019 (Kraftringen, 2019c). A long-term agreement of 20 years was already signed in 2013 between ESS and Kraftringen regarding both the supply of excess heat from ESS to Kraftringen's district heating grid and district heating delivery to ESS during the construction phase and, if necessary, also during operation (Kraftringen, 2019b). ESS is expected to start operations in 2023 and be fully operational a few years later (ESS, E.ON & Lunds Energi, 2013).

Data Center, Lund

Kraftringen owns a newly built (2018) co-location server hall in Lund, called Turbnen, which today does not generate any excess heat. However, a future expansion is planned, that will increase the heat generation enough to provide excess heat that will be exported to the district heating grid in Lund (Kraftringen, 2019).

2.2 E.ON

In E.ON's Swedish district heating systems, there are several examples of collaborations with prosumers and small-scale heat suppliers, which are briefly described in this section. However, these examples are larger projects and special cases where the agreements and solutions can be difficult to apply as standardized concepts.

Ectogrid, Lund

Ectogrid is an energy system concept patented by E.ON to circulate, reuse and distribute energy between buildings in an area and thus optimize energy use. The ectogrid heat-sharing concept Ectogrid will be tested for the first time in Medicon Village in Lund, a life science park, where excess energy will be able to be harnessed und utilized to balance in the system. A low temperature, 5-40°C, heating and cooling systems will be built and unlike conventional district heating, no large production facilities will be present in the system. The low water temperature requires each building to install a heat pump that can raise the temperature. To better balance the system, an hot water storage tank is used for thermal energy storage. Construction of the EctoGrid-area began in 2017 with the goal of 15 commercial buildings and residential buildings to be connected by 2020. Today Medicon Village uses 10 GWh of heat and 4 GWh of cooling annually and E.ON estimates that with the construction of Ectogrid, only 3 GWh of energy supply to the system will be needed (E.ON, 2019b).

Low-temperature district heating grid, Hyllie

In the Hyllie district of Malmö, the goal is to have an energy supply consisting of 100% of renewable and recycled energy by 2020. The newly built houses in Hyllie are therefore built with solutions to be able to produce their own energy and have, for example, photovoltaics or solar collectors on the roofs. In 2015, the solution was not yet in operation and E.ON was working on developing a business model (Samsyn Hyllie, 2015).

A case study was conducted in 2015 that examined the heat potential of prosumers in Hyllie and concluded that the potential heat supply from prosumers was between 50-120% of the heat demand in the district on an annual basis. The interval depends on whether Hyllie was allowed to export heat to the city-wide district heat grid or whether all heat had to be used locally. One limitation was that a large part of the excess heat was available in the summer, when the heating demand is at its lowest. The greatest potential for exporting heat came from a few customers who had a fairly even cooling demand throughout the year, shopping centers, a sport arena and grocery stores. All cooling demands in the district were assumed to be met with compressor chiller machines and the excess heat from these chillers was assumed to be 65°C. The area would then be designed so that this supply temperature of 65°C would be sufficient (Brange, Englund, & Lauenburg, 2016).

Solar thermal, Malmö, Timrå

E.ON has several examples of installations where solar collectors supply excess heat to district heating grids. The grid with most such installations is in Malmö, Sweden. In the Bo01 district and at Kockum Fritid, E.ON has installed solar collectors on properties and is also responsible for their operation and maintenance. An agreement with the property owners gave E.ON the right to install the facility and be responsible for it for 25 years, after which the installation is taken over by the property owner. The installations in Bo01 total an installed area of 1 291 m^2 distributed over 9 buildings and the installation in Kockum is 1 050 m^2. Other facilities in Malmö owned and operated by the City of Malmö are in Augustenborg (2005, 426 m^2), Helenholm (2007, 1128 m^2), Stensjön (2008, 46m^2) and Segepark (2008, 230 m^2). For these installations, there is an agreement between the property owner and the district heating supplier regarding the export of solar heat in connection with the property owner's purchase of district heating. This also applies to the solar collector installation in Timrå (2009, 262 m^2) (Dalenbäck, Lennermo,Andersson-Jessen,& Kovacs, 2013).

Data center, Vallentuna

In 2019, Binero Group's data center in Vallentuna started supplying excess heat to E.ON Värme. Fully developed, the excess heat is estimated to cover one third of Vallentuna's district heating needs total heat demand. The server hall is cooled by heat pumps that have their warm side exporting heat to the district heating grid (E.ON, 2019b).

2.3 GÖTEBORG ENERGI

A collaboration between Göteborg Energi and Gårdstensbostäder has resulted in prosumers that supply solar heating to the district heating grid in the district of Gårdsten. The collaboration was developed to demonstrate direct connection of solar collectors to the district heating grid. The 150m^2 plant is owned by Gårdstensbostäder, which then has an agreement with Göteborg Energi for the export of solar heat to the district heating grid (Dalenbäck,Dalenbäck Lennermo,Andersson-Jessen,& Kovacs, 2013). Göteborg Energi's district heating system also includes large excess heat deliveries from industries in the surrounding area, but these are large-scale collaborations that are difficult to generalize.

2.4 FOUR CONCEPTS IN DETAIL: ÖPPEN FJÄRRVÄRME, DELAD ENERGI, SAMENERGI, AND VÄRME TILLSAMMANS

The project has been able to identify dozens of different concepts or solutions that in some way allow prosumers or small-scale suppliers of excess heat to supply heat to a district heating grid and in some way get compensation for this. Among these concepts, four are judged to be more mature and fit better with the description as standardized offerings regarding technology, ownership, contracts and business models. The concepts that are not described in more detail are more of the type individual projects where contracts and compensation are determined individually on a case-by-case basis. In the case of COOL DH at Kraftringen, the delivery of excess heat is part of a larger project at a research facility, which can be difficult to generalize for other district heating grids in Sweden. A relatively large number of installations where solar heating supplies heat to district heating grids have been identified, mainly through the previous Remote Vision Report Solar Thermal in District Heating Systems - Evaluation of Primary *Coupled Systems* (Dalenbäck, Lennermo,Andersson-Jessen,& Kovacs, 2013), but the treatment of delivery from these installations has varied a lot between district heating grids and involves relatively marginal heat deliveries.

The four concepts described in more detail are characterized by the fact that they are more mature solutions. Three of the four solutions, (Öppen Fjärrvärme, Delad Energi and SamEnergi) are publicly launched while Värme Tillsammans is in a pilot stage.

2.5 ÖPPEN FJÄRRVÄRME

Stockholm Exergis' offer for prosumers and small-scale excess heat suppliers is called Öppen Fjärrvärme (Open District Heating). Over 20 reference cases are in operation within the concept. Öppen Fjärrväme was estimated in 2018 to produce enough heat to supply the equivalent of 31,000 apartments with heating (113 GWh). The offer is primarily aimed at data centers, grocery stores and other industrial activities that generate excess heat. Data centers account for the largest single heat source of the delivered excess heat to the district heating system (75 GWh) (Stockholm Exergi, 2019).

Stockholm Exergi states on its website several motivators for why they initiated the concept Öppen Fjärrvärme and thus opened up the district heating market for prosumers and small-scale excess heat suppliers. On the one hand, it is part of the continuous work to improve energy efficiency and to have a more efficient fuel use. In particular, Stockholm Exergi sees future competition in the market for raw materials and fuels. Stockholm Exergi also sees that this type of solutions can be an option to get rid of the last share of fossil fuels remaining in the generation mix and achieve the set target of 100% renewable and recovered energy. Furthermore, it can contribute to a smarter use of the district heating grid in order to avoid investments and expansions. Stockholm Exergi also sees a future risk of uncertainty and fluctuations in the energy market as the share of renewable fuels increases and sees third-party access as a flexibility to stabilize the market (Stockholm Exergi, 2019).

Öppen Fjärrvärme still represents a small share (113 GWh 2018) of the total heat generated in Stockholm Exergis district heating system (8 216 GWh 2017) (Energimarknadsinspektionen, 2019). Stockholm Exergi states that they are internally satisfied with opening up for third-party access to the district heating grid. Feedback has been positive and interest internationally, especially regarding heat recovery from data centers, has increased in recent years (Sivengård, 2019).

During the start-up of Öppen Fjärrvärme, some feasibility studies were carried out and a rough assessment of the potential for excess heat delivery within Stockholm Exergis grid area. It was estimated that 50% of the excess heat from existing data centers in the Stockholm area is economically profitable to export to the heat grid and for new data centers the corresponding figure was estimated to 80%. It was also estimated that 15-20% of the excess heat potential from grocery stores could be recovered and utilized in the district heating grid. The forecast for establishment of new grocery stores in the area has been assessed as small. The larger industries in Stockholm, few in number, are already exporting excess heat and for smaller industries the potential has not been evaluated (Sivengård, 2019).

Stockholm Exergis' offer for exporting excess heat deliveries in the concept Öppen Fjärrvärme has the most suppliers connected to the grid among all the studied standardized concepts. The main success factors for this identified by Stockholm Exergi are that suppliers have been able to easily evaluate the solution both economically and technically and that Stockholm Exergi has marketed the concept strenuously. The standardised contractual arrangements and price models make it easier for suppliers to assess their benefits. A profitability calculation is made early in the project by Stockholm Exergi in consultation with the supplier and in several cases the calculation has been decisive for decisions. The overall technical solutions are available as templates for achieving good performance in a heat pump solution and to technically evaluate the solution. The interest for becoming excess heat suppliers was initially low and it required both perseverance in discussions with potential suppliers and active marketing both nationally and internationally, mainly directed at the data center industry (Sivengård, 2019).

Technical aspects: technical solutions, connection principles

The local conditions for the district heating grid at the geographical position where a potential excess heat supplier is located are directly determining if the excess heat can be accepted and what contractual forms that are applicable. Power limitations and supply temperature are the two conditions that are primarily affected based on local conditions. The district heating company needs to have detailed models of the distribution grid in order to understand the conditions at different positions in their grid (Sivengård, 2019). Normally, Stockholm Exergi estimates that it takes 6-9 months to fully investigate the technical conditions of a supplier (Stockholm Exergi, 2019).

Different connection principles are applied based on the conditions at the individual possible heat suppliers. The most common connection is Return/Supply when water is taken from the district heating grid's return pipe, heat exchanged and returned to the supply pipe. Where a heat pump is used, the heat pump itself is the heat exchanger. For deliveries from processes that already maintain a high enough temperature, only one heat exchanger (Sivengård, 2019) is installed.

The design of the connection to the heat grid also varies depending on local conditions (Sivengård, 2019). Stockholm Exergi has several collaborations with data centers providing heat and has therefore developed a standardized solution for utilizing excess heat from such facilities. Normally, without excess heat recovery, data centers are provided with cooling from chillers that vent the excess heat in a cooling towers, but by the data center instead invests in heat pumps to cover the cooling demand, the heat can be absorbed into the district heating grid (Rylander, 2015). Especially at cold temperatures, it is important to be able to properly model the district heating system in order for the mix of distributed local heat pumps and the central generation units to result in the correct supply temperature at the customer (Sivengård, 2019).

The supply profile from the connected excess heat suppliers is in principle constant over the year. The majority of providers are data centers and the load vary only by a few percent on an annual and hourly basis. Other industrial customers in pharmaceutical and food sectors also have a stable heat supply profile with a certain daily variation depending on the processes present at each supplier. The delivery to the district heating grid therefore is relatively constant over the year, but due to the fact that the compensation for sold heat can be very low or non-existent in summertime, most suppliers interrupt their delivery then (Sivengård, 2019).

Business model: Remuneration, agreements and responsibilities

The remuneration model for *Öppen Fjärrvärme* is divided into four different types of contracts depending on the characteristics of the heat delivery (Stockholm Exergi, 2019). The grid is also divided in two geographical regions, northern and southern Stockholm, with different compensation level. The reason why compensation levels differ between northern and southern Stockholm is that the two grids are not interconnected, and the generation costs differ between the grids (Sivengård, 2019). The four different types of contracts are described below:

- **Öppen Avropsvärme (Open On Demand Heating):** A contract form suitable for operations with a heat excess that is evenly distributed over the year, e.g. data centers. The agreement is based on an agreed fixed heating power supply that can be demanded by Stockholm Exergi for the next days when outdoor temperature is below 12°C. The required supply temperature is normally 68°C but may be higher. The remuneration is divided into two parts, a fixed monthly compensation for having the heating power available to be supplied on demand and a variable compensation based on the amount of heat supplied. If the availability of the supply does not meet the agreed level, the compensation is reduced, an adjustment that occurs on an annual basis.

- **Öppen Spotvärme (Open Spot Heating):** Suitable for activities with varying heat excesses when no minimum supply or on demand heating can be guaranteed by the supplier. The compensation for supplied heat is calculated solely on the amount of heat supplied. Öppen Spotvärme is further divided into three types of contracts with different requirements for supply temperature and compensation levels, these are described in the list below and in principle in Figure 1.
    - *Öppen Spotvärme Prima (Open Spot Heating Prime)*: Heat is supply to the supply pipe in the district heating grid and the required temperature is based on the temperature that Stockholm Exergi guarantees its customers, which varies with the outdoor temperature in the span of 68-103°C.
    - *Öppen Spotvärme Inblandning (Open Spot Heating Mixing)*: Heat is supply to the supply pipe in the district heating grid and the temperature requirement is constant throughout the year at 68°C.
    - *Öppen Spotvärme Retur (Open Spot Heating Return):* Heat is supply to the return pipe in the district heating grid and the supplied water flow should be at least 3°C higher than the incoming water flow from the return pipe.

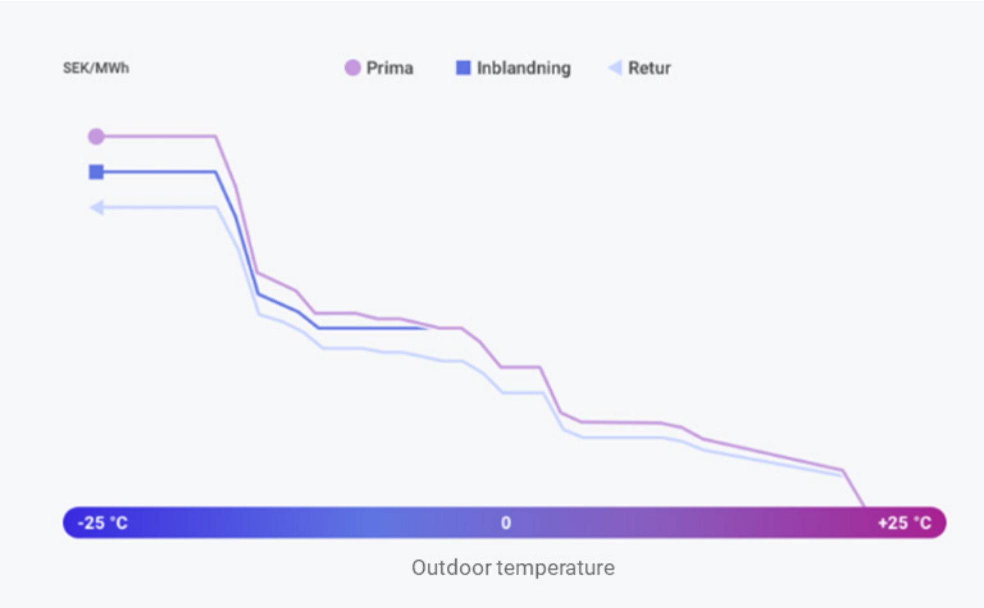

Figure 1 Compensation level for Öppen Spotvärme, based on forecast outdoor temperature and type of contract (Stockholm Exergi, 2019).

In addition to the compensation described above, which is paid from Stockholm Exergi to the heat supplier monthly (Stockholm Exergi, 2019), Stockholm Exergi charges a fee for Öppen Fjärrvärme customers to cover the investment on their part with a certain repayment period (Sivengård, 2019). The breakdown of the investment cost consists of Stockholm Exergi investing in and owning the energy meter, communication equipment for meter data and the pipes up to and through the meter location. All other necessary equipment is invested in and owned by the heat supplier. The heat supplier is responsible for the functionality of the substation, ensuring it and can transfer heat to the grid. The contract regulates how quickly the customer needs to act if Stockholm Exergi notices a discrepancy that negatively affects their end customers (Stockholm Exergi, 2019), (Sivengård, 2019).

The compensation per supplied unit of heat energy and the required supply temperature for all four contract types and both geographical areas is published on the public website of Öppen Fjärrvärme no later than 16:00 one day ahead. (Stockholm Exergi, 2019). The compensation for heat energy is set on an hourly basis based on the forecasted alternative cost for Stockholm Exergy to generating the same heat and a profit margin. The alternative cost for heat generation is calculated in an Excel-based program, with e.g. long-term forecasts for weather, heat demand, fuel prices and planned changes in generation units and grids as input. The forecast for the alternative cost of heat generation is given as a function of the outdoor temperature and the compensation levels for the next day is calculated using the current weather forecast for the area, either from SMHI's weather station in Bromma or Observatorielunden in Stockholm depending on the geographical position of the excess heat supplier. The difference in compensation between different temperatures is strongly correlated with the value for Stockholm Exergi of avoiding heat generation in their own plants. The contract form *Öppen Spotvärme Inblandning (Open Spot Heating Mixing)* is used when the supply temperature from the supplier is not high enough for direct delivery to the end customer and requires to me mixed with higher supply temperatures from other heat sources. The avoided cost of generating the additional heat for mixing that occurs when the supplied excess heat has a higher temperature is the cause of the varying amount of extra compensation a supplier get from supplying *Öppen Spotvärme Prima (Open Spot Heating Prime)* compared to *Öppen Spotvärme Inblandning (Open Spot Heating Mixing)*. Heat supply to the return pipe can negatively impact the efficiency of other heat sources in the district heating system and 1 MWh of heat delivered to the return pipe is therefore valued less than the corresponding amount of heat supplied to the supply pipe and this is reflected in a static reduction of the compensation level. Another option to calculate the compensation would have been to dynamically calculate the compensation based on current operating mode of plants in the system. However, this option was opted out because it was considered to make it too difficult to carry out a profitability assessment for the potential excess heat suppliers (Sivengård, 2019).

Before a project is initiated, the estimated payback time is calculated, and the projects need to be profitable for the process to proceed. For the data center industry, the payback period usually needs to be around 5-7 years for the project to be realized. The challenge in the assessment of the profitability is often to get realistic data on the cost for alternative cooling solutions (not exporting excess heat), both for new and for existing facilities (Sivengård, 2019).

The contracts written between the district heating company and the excess heat supplier are long-term. The contracts for *Öppen Avropsvärme (Open On Demand Heating)* are signed for 10 years with a the right for the excess heat supplier to extend the deal for five years, the economical compensation levels in the contract are indexed annually. The contracts for *Öppen Spotvärme (Open Spot Heating)* are open-ended contracts with three months' notice for the excess heat supplier and a one-year notice period for Stockholm Exergi (Sivengård, 2019).

In cases where the excess heat supplier also purchases heat from the district heating company, i.e. is a prosumer, two separate agreements are signed. A standard contract for the purchase of heat from the district heating grid and one of the contract types for supply heat to the grid according to the Öppen Fjärrvärme concept. Separate energy meters are installed to measure the flow of heat in each direction flow. During the pilot phase for Öppen Fjärrvärme, variants for combined contracts where tested, but this is no longer offered. The measurement is carried out with a conventional energy meter for district heating. The reading interval for delivery to the district heating grid is shorter than for the delivery from the grid, in order to be able to monitor the supply temperature in greater detail (Sivengård, 2019).

Examples of existing suppliers in Öppen Fjärrvärme

Öppen Fjärrvärme have about 20 suppliers of excess heat in the form of data centers, grocery stores and other businesses. In most cases, the supplier acts only as a supplier of excess heat (not also buying heat), the number of prosumers in Öppen Fjärrvärme is in the minority. In order to reduce the number of contract variants, heat recovery from industrial processes are also included in Öppen Fjärrvärme (Sivengård, 2019).

Data centers

Stockholm Exergi has several collaborations up and running with data centers around Stockholm and in number, data centers make up the majority of suppliers in Öppen Fjärrvärme.

Bahnhof Pionen was one of the pilot projects for Öppen Fjärrvärme and now has the contract form *Öppen Spotvärme Inblandning (Open Spot Heating Mixing)*. In normal operation, 600 kW of heat is supplied at a temperature of 68°C. Bahnhof's facility consists of two serial connected chillers/heat pumps that cool down the data center and excess energy from the cooling process is supplied to the district heating grid. Stockholm Exergi has invested in the pipe from the data center to the district heating grid (SEK 1.3 million). Bahnhof's share of the investment consisted of the new cooling system, e.g. heat pumps and pipe installation (SEK 3.4 million). Bahnhof has also kept the old chillers as a backup cooling system. All of Bahnhof's three data centers in the inner city of Stockholm are connected to Stockholm Exergis district heating grid (Stockholm Exergi, 2019). One of the data centers also sells cooling, which is generated with local heat pumps, to the district cooling grid when there is excess capacity from cooling to the data center (Sivengård, 2019).

Interxion's data center is connected to the cooling grid and buys process cooling at 14°C from Stockholm Exergi. Process cooling 14°C is a special offer for data centers where cooling and heat recovery are packaged with alarm monitoring and up time guarantee. At Interxion, the district cooling is used to cool the data center and the excess heat from the process results in heated water (approximately 24°C) returned to Stockholm Exergi. Stockholm Exergi has heat pumps centrally that raise the temperature further for supplying the heat to the district heating grid. Stockholm Exergi has invested SEK 1.1 million in pipes, control and monitoring equipment and measuring equipment, while Interxion has invested SEK 1.5 million in a district cooling substation. The old cooling system with chillers and cooling towers has been retained for redundancy (Stockholm Exergi, 2019).

H&M's data center in Stockholm is another example where Stockholm Exergi can utilize the excess heat on days when the outdoor temperature is below 7°C. The collaboration has been ongoing since 2013 and was one of the first pilot projects for Öppen Fjärrvärme.

Every year, 1.7 GWh of heat is supplied to the district heating grid (Stockholm Exergi, 2019).

Grocery stores

Coop Rådhuset on Kungsholmen was the first grocery store to be connected through Öppen Fjärrvärme to Stockholm Exergis district heating grid. Only minor changes to the existing cooling system had to be made to be able to deliver heat directly to the district heating grid, as well as a connection between the secondary side and the district cooling grid. One advantage of the increasingly common carbon dioxide-based refrigeration solutions in grocery stores is that the temperature of the excess heat from these is high enough to be connected directly to the district heating grid without the need to further raise the temperature. The grocery store supplies both excess heat to the supply pipe on the district heating grid (about 30kW with the contract form *Öppen Spotvärme Prima (Open Spot Heating Prime)*) and to the return pipe in the district cooling grid (about 30kW). Stockholm Exergi invested SEK 100,000 to connect the store to the district heating grid, which included pipes, valves and metering equipment. KF Fastigheter invested SEK 405,000 for retrofitting equipment in the store, which included replacing heat exchangers and pumps (Stockholm Exergi, 2019).

Crematorium

Since 2015, Råcksta crematorium supplies excess heat to Stockholm Exergis district heating grid. The heat supply corresponds to the heating demand of approximately 400 apartments and the chosen contract form is *Öppen Spotvärme (Open Spot Heating)* (Stockholm Exergi, 2019).

2.6 DELAD ENERGI

Since 2015, Tekniska Verken have been offering customers in their district heating and cooling grids the opportunity to supply excess energy to the grids. The concept is called Delad Energi (Shared Energy) and is a standardized offering that provides a systematic way to receive deliveries of excess heat to the grids. The offer includes a remuneration model, examples of technical connection solutions and contract templates. Examples of potential prosumers for Delad Energi are grocery stores utilizing carbon dioxide as refrigerant for refrigeration, freeze houses and data centers.

In 2020, one contract with a heat supplier was signed within Delad Energi (Falk, 2020).

Technical aspects: technical solutions, connection principles

Delad Energi is offered to customers who are able to deliver heating or cooling to the grids in any form. The delivery can be made to either the supply or return pipe and for each potential prosumer the technical connection is designed based on the conditions of that particular prosumer. Factors that come into play include the possible supply temperature, amount of heat that can be exported and the location of the prosumer in the grid. Requirements are set for minimum and maximum supply temperature and other factors. These requirements do not vary over the year (Falk, 2020).

Figure 2 shows an illustration of what Delad Energi can in principle look like for a prosumer or supplier when the temperature of the excess heat is high enough to be delivered directly to the supply pipe of the district heating grid (Tekniska Verken, 2019b). The connection principle is in this case Return/Supply, water flows from the district heating grid's return pipe, through heat exchangers where it is heated by the prosumer's excess heat and is then supplied to the supply pipe in the district heating grid (Lennermo, Lauenburg, & Brange, 2016).

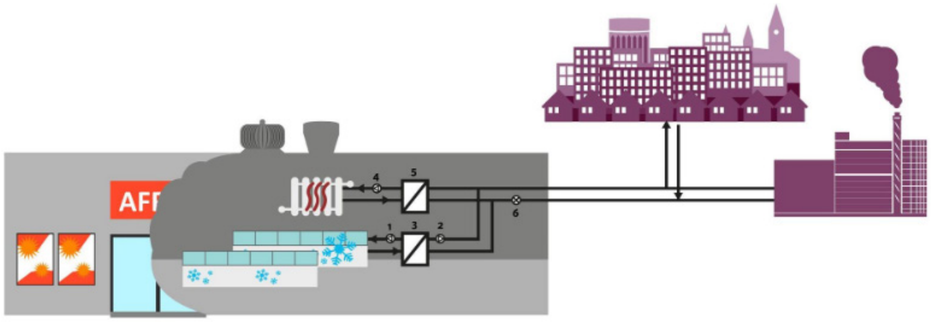

Figure 2 Illustration of installation of Delad Energi for supplier that can supply heat to the supply pipe in the district heating grid (Tekniska Verken, 2019b)

Tekniska Verken has produced several examples of what the connection of a prosumer could look like and how the operation works. Three possible cases include: internal heat demand; excess heat and external heating demand.

In the first case, internal heat demand, there is a demand for heat within the property and the excess heat will then primarily supply that demand and be recovered within the property. The excess heat is transferred to the secondary side via a heat exchanger without passing the energy meter. An alternative connection is that the excess heat is supplied directly to the secondary side.

Case number two, excess heat, occurs when the excess heat exceeds the property's demand for heat and the excess heat is then fed on to the district heating grid via the energy meter. It is the measured energy in the meter that is the prosumer receives economical compensation for within the concept Delad Energi and the energy meter can measure and integrate flow in both directions, for the supply or delivery of heating or cooling.

Case three, external heat demand, occurs when the property has a demand for heat and the installation functions then as a traditional district heating substation. A non-return valve prevents flow through the heat exchanger (Tekniska Verken, 2019b).

If the available excess heat delivered from the prosumer does not maintain a sufficiently high temperature, the return/return connection principle is used instead, where the feed-in system takes water from the district heating grid's return pipe, heats it and returns it to the return pipe.

For an existing district heating or cooling customer, it is usually necessary to install an additional heat exchanger with associated pipe installation and pumps in order to supply heating or cooling to the grid. In addition, a new energy meter is required by Tekniska Verken to measure both the supplied and used energy of the prosumer. The energy meter is equipped with two separate integrators and four temperature sensors to measure energy and volume flow in both directions (Tekniska Verken, 2019b).

In terms of monitoring and communication, no additional installations are made beyond what is done at a regular district heating customer (Falk, 2019).

Business model: Remuneration

A district heating customer who joins Delad Energi receives an additional contract in addition to his/her usual district heating consumer contract. For the energy supplied by the customer to the grid, the customer is compensated economically for each kWh and the compensation is paid once a month (Falk, 2019). The compensation per kWh is calculated by Tekniska Verken and is based on the system benefit from the heat supply (Tekniska Verken- Delat Energi, 2018). Compensation is paid only for supplied energy and not for any on demand heating power.

The compensation per kWh is agreed upon in a contract in order to be able to make an assessment of his investment. The compensation level is higher for the supply of heat on the supply pipe in the district heating grid than for deliveries to the return pipe. The compensation level can be adjusted yearly by Tekniska Verken to reflect any changes in district heating system (Falk, 2019).

The level of the economical compensation is based on the alternative cost for heat generation and differs between the different grids that Tekniska Verken operates. In the Linköping grid, for example, the compensation varies between three defined parts of the year just like the price for district heat in that grid. This is to reflect the value of the heat since it varies with the current fuel mix in. In some of Tekniska Verken's smaller grids, the level of compensation is constant throughout the whole year since the cost of heat generation in those grids varies little over the year (Falk, 2019).

Business model: Contracts and responsibilities

In the Delad Energi concept, the prosumer is responsible for the investment costs and for the installation of the equipment needed in addition to the district heating substation to enable the export of excess heat. This is analogous to the division of responsibilities of a traditional district heating customer who consumes heat only. If the prosumer is already a district heating or cooling customer of Tekniska Verken, the same pipes can normally be utilized for the export. Otherwise, Tekniska Verken are responsible for the connection to the district heating grid and the delivery point is defined to the shut-off valve between Tekniska Verken's system and the prosumers equipment.

Since the prosumer owns all equipment inside the shut-off valve, the prosumer is also responsible for the operation and maintenance of theat equpment (Tekniska Verken, 2019b).

Tekniska Verken have developed a process for how cooperation with a prosumer can move from discussions to deployment according to the following steps:

- **Contract**
  An initial dialogue between the potential prosumer and Tekniska Verken deals with the structure of the contract. Economic factors regarding the remuneration model and compensation level and the requirements of the technical specifications regarding temperature, pressure, power, and connection principle.
- **Connection to the grid**
  Tekniska Verken are then responsible for connection to the district heating grid if the building is not already connected.
- **Installation**
  The prosumer pays for and is responsible for the design and installation of additional necessary equipment. The solution must be designed in accordance with the technical regulations of Energiföretagen Sverige (organization for Swedish energy companies) for district heating substations and the local regulations of Tekniska Verken.
- **Commissioning**
  Before commissioning, the installation must be tested by the customer's pipe contractor. In connection with this, Tekniska Verken are contacted for inspection. Tekniska Verken will then also install the new energy meter required to calculate consumed and delivered thermal energy (Tekniska Verken, 2019b).

2.7 SAMENERGI

Vattenfall Värme launched in November 2019 SamEnergi. SamEnergi is a standardized offering designed to take advantage of excess heat from companies that can supply heat to Vattenfall's district heating grid. The target group for the offer is data centers, grocery stores, sports facilities, coffee roasting industry and food warehouses with refrigerator and freezer storage. One driving force for developing the concept SamEnergi has been to be able to utilize energy resources and reduce emissions from heat generation (Vattenfall AB, 2019c). Another driving force for developing SamEnergi is to be ready for managing any regulated access to district heating grids the comes with Fjärrvärmelagen (The District Heating Act) (see also Chapter 2.9).

Up until the year 2019 the concept was implemented at two pilot suppliers of excess heat, Lindvalls Kafferosteri (a coffee roastery) in Uppsala and Dagab's frozen and refrigerated storage in Jordbro. Lindvall's Kafferostri is a prosumer, since they both consume district heat and supply excess heat to the grid. The estimated supply of excess heat from the roastery is 500 MWh per year, at the same time the roastery is estimated to buy 250 MWh of district heating per year to cover internal heating requirements when the roasting boiler is not in operation (Vattenfall, 2018).

Dagab's warehouse only sells excess heat to the district heating grid and is estimated to be able to deliver 7,500 MWh of heat annually (Bionergitidningen, 2017). During 2019, a third supplier has also been linked to SamEnergi, bageri- and pastry wholesaler Kobia in Tyresö. Kobia is scheduled to start delivering 400 MWh of heat annually to the Vattenfall district heating grid starting in May 2020 (Vattenfall, 2020)..

Technical aspects: Technical solutions, connection principles

Suppliers of excess heat can supply heat to Vattenfall's grid on the supply pipe. For each potential heat supplier, Vattenfall conducts an investigation of which connection principle is best suited and requires input pressure and supply temperature. In particular, the availability of excess heat and the supply temperature determine the type of offer that is relevant for the supplier (Andersson, 2019).

Business model: Remuneration

Through SamEnergi, Vattenfall Värme offers companies to supply excess heat to the district heating grid according to three standardized contracts, or products. These are referred to as *SpotVärme (Spot Heat)*, *MicroVärme (Micro Heat)* and *Årsvärme (Annual Heat)*. Common to all three contracts is that Vattenfall Värme pays a compensation to the supplier per kWh heat (Vattenfall AB, 2019b). The level of compensation to the supplier is set per hour and reflects the cost savings that Vattenfall achieves in its district heating generation by not having to generate the heat in its own plants. The products are offered in all geographical areas, where Vattenfall owns and operates district heating grids (Vattenfall AB, 2019c).

In *SpotVärme (Spot Heat)*, the compensation for heat delivered heat varies per hour and is published one day ahead on SamEnergi's website, or through a direct link to the supplier's control system. With *SpotVärme (Spot Heat)* there are no requirements on the amount of energy to be supplied or at what time. The supplier decides when he deliver heat. The supplier's decision to deliver or not deliver heat may depend on his available excess heat and the compensation that Vattenfall offers for the heat that given hour (Vattenfall AB, 2019b). For each district heating grid, Vattenfall Värme performs a daily production planning for the next 24 hours. Based on this production plan, the marginal generation cost of heat per hour is calculated, which is used to set the compensation for the heat received through *SpotVärme (Spot Heat)* (Andersson, 2019).

The product *SpotVärme (Spot Heat)* is also used as a basis for the other two products. *MicroVärme (Micro Heat)* is aimed at suppliers with low-grade heat that is not suitable for direct input on the supply pipe in the district heating grid. The supplier feeds heat into the grid on the same basis as for *SpotVärme (Spot Heat)*, but the compensation amounts to a proportion of the compensation that would have been received in the event of a supply of high temperature heat. The proportion of this share depends on the district heating grid to which the delivery takes place. (Andersson, 2019). The supplier has no requirements for quantity or timing for heat deliveries, but delivers according to its own conditions (Vattenfall AB, 2019b). All delivery through *MicroVärme (Micro Heat)* are connected so the heat from the return pipe is heated and then delivered to the supply pipe in the district heating grid (Return/Supply) (Andersson, 2019).

The third product is called *Årsvärme (Annual Heat)* and is aimed at suppliers who can predict their deliveries for longer periods of time. With *Årsvärme (Annual Heat)*, the supplier also receives a fixed compensation for the heating power they can supply, in addition to the variable compensation for supplied energy. For *Årsvärme (Annual Heat)*, Vattenfall and the supplier need to jointly agree on a long-term plan for how the delivery works and is economically compensated. The guaranteed heating power from a supplier of *Årsvärme (Annual Heat)* means that Vattenfall can avoid, postpone, or reduce investments in generation and/or distribution capacity. It is this avoided cost of this is the basis of the extra compensation for a supplier of *Årsvärme (Annual Heat)* (Andersson, 2019).

For all three products, there is also an annual fee for the supplier that Vattenfall Värme charges to cover its costs for measuring, invoicing, and connection to the district heating grid (Vattenfall AB, 2019b).

If the supplier also uses district heating to cover its own heating needs, this is not included in the SamEnergi transaction, but a separate, conventional, contract for district heating use is signed (Andersson, 2019).

Business model: Contracts and responsibilities

As with other concepts described, the heat supplier in SamEnergi is responsible for adapting its facilities to be able to deliver according to the requirements for the product for which the contract has been signed. Vattenfall can initially estimate the supplier's annual revenue from heat deliveries, as well as advise on technical design. Based on this, it is up to the supplier to assess the profitability of starting to supply heat. Some suppliers need to make larger investments than others to enable the export, for example if heat pumps need to be installed to increase the supply temperature (Vattenfall AB, 2019b).

Vattenfall owns and is responsible for the operation and maintenance of equipment for measuring supplied energy and the piping required to connect the supplier to the district heating grid (Andersson, 2019).

2.8 VÄRME TILLSAMMANS

In 2019 Norrenergi developed its concept Värme Tillsammans, which is a solution offered with the purpose to take advantage of excess heat from prosumers and small-scale suppliers by supplying the heat to Norrenergi's district heating grid. The solution is in a pilot phase and when it is launched it will target all Norrenergi's customers and include a standardized remuneration model, technical solutions, and a billing solution. Norrenergi has identified properties containing data centers as the customer segment with the highest potential since they often have an excess heat during periods when Norrenergi needs heat (Swedblom, 2019).

Technical aspects: Technical solutions, connection principles

In an ongoing pilot project, a standardized feed-in substation is planned to be used. The concept for it has been developed in a project financed by the Swedish Energy Agency where Norrenergi, Skara Energi and Mälarenergi have participated. If the solution works well in the pilot project, it is planned to be used for future connections. Since there is not yet a ready connection, there are some uncertainties in what the technical solution should look like and who will own the substation utilized for exporting the heat. It is therefore also unclear at the time of writing how operational and functional responsibility should be distributed between the heat supplier and Norrenergi (Swedblom, 2019).

The technical solution can be described as a substation for the input of excess heat to the supply pipe of district heating according to the Return/Supply principle. Figure 3 shows a principled connection when a property in which a data center supplies excess heat from chillers to the district heating grid. The supply substation is located after a "heat recovery exchanger" and takes in district heating water from the district heating return and feeds the heated water onto the supply pipe. The substation also ensures that the water has a sufficiently high temperature before it is fed back into the district heating grid. Since most of the heat from the chillers goes to covering the building's internal heat demand, the building heating system is directly connected to the hot side of the chiller without an extra heat exchanger in between. Therefore, an additional heat exchange is required between this hot water circuit and the district heating circuit.

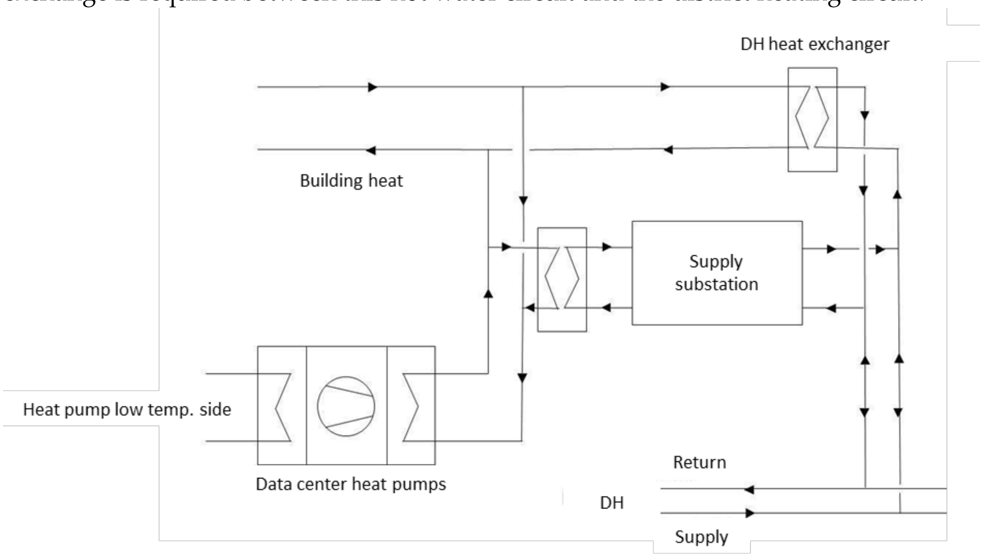

Figure 3 Schematic sketch of the heat recovery principle in Värme Tillsammans. The figure shows an example of how a data center can deliver heat to the district heating system (Swedblom, 2019).

The purpose of the substation is to feed heat to the supply pipe of the district heating grid at the right pressure and temperature when there is more heat available in the building than the internal heating demand. The idea is that the substation will deliver a stable supply temperature regardless of the return temperature of district heating that enters it. The substation consists of a circulation pump, feed in pump, flow meter, pressure gauge, filter, manometer, pressure protection, several valves and temperature gauges and control systems.

The system is controlled according to the following load cases:

Load case 1: All heat is needed for the building's internal heat demand; the substation controls the flow so that no heat is transferred to the district heating grid.
Load case 2: Part of the heat is used to cover the building's internal heat demand; the set point for the heating circuit is set to >74°C. The water is recirculated until it reaches a temperature of 74°C when a control valve in the substation opens and the heat transfer to the district heating grid begins. In order to lower the temperature of the flow that that is used for heating the building, a shut is used that mixed the flow to the heating system with its return flow.
Load case 3: No heating demand in the building; all heat is exported to Norrenergi's district heating grid.

All measurements for calculating remuneration to the supplier are made with a flow sensor that can measure the flow both when Norrenergi delivers district heating to the customer and when the customer delivers heat to Norrenergi's district heating grid. This flow sensor if connected to two integrators that integrates the flow in each direction together with readings from two temperature sensors.

With the help of the same sensors, Norrenergi also monitors that the supply temperature delivered to the heating grid is not too low since there is a risk that it would cause supply problems for other customers in the grid. The monitoring takes place in Norrenergi's generation facility, where Norrenergi can manually turn off the supply of heat if the temperature of it deviates from the requirements set. In order to supply heat, the supplier is also required to maintain the correct pressure conditions so as not to cause interference in Norrenergi's grid (Swedblom, 2019).

Business model: Remuneration

Prosumers and other heat suppliers in Värme Tillsammans are only compensated for the amount of energy they have supplied to the district heating grid each month. No compensation is paid for the guaranteed power they could possibly provide, but this is planned to be developed after the closure of the pilot projects. The compensation for energy is determined by a compensation per unit of energy that is fixed per season. The tree defined season are summer, winter and spring/autumn. The compensation level is calculated based on Norrenergi's average marginal generation cost for the season, with a certain margin for variations in Norrenergi's fuel costs.

The delivery must meet certain requirements in order for compensation to be paid. In addition to the requirement that the heat must be supply at the correct differential pressure, the most important requirement is set for supply temperature. The requirement for supply temperature varies with outdoor temperature, as described in the diagram in Figure 4 .

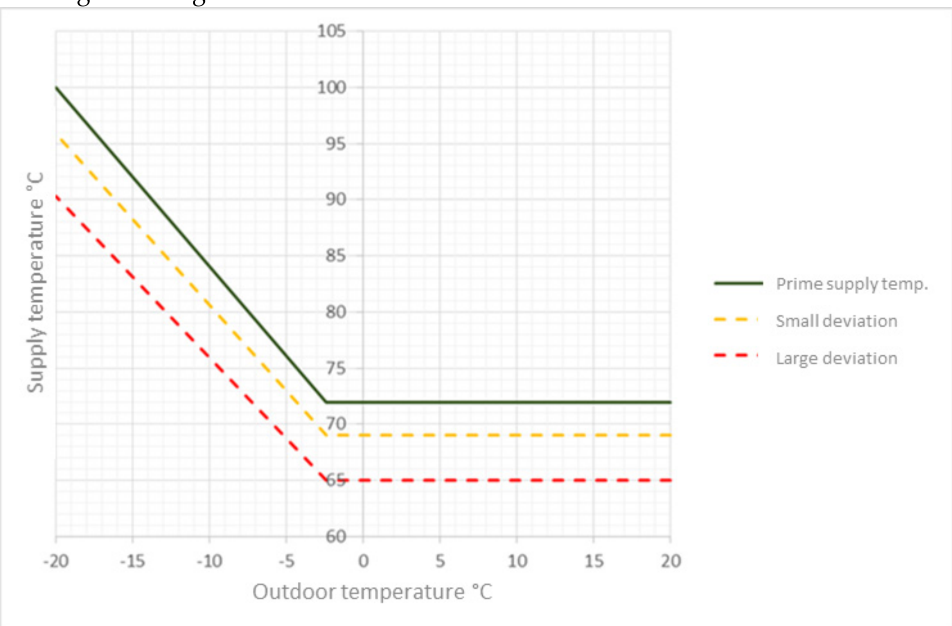

Figure 4 Temperature requirements for the delivery of prime supply temperature and what is considered to be a smaller deviation and a major deviation (Swedblom, 2019).

The customer is guaranteed receipt at full compensation for temperatures above prime supply temperature, i.e. regular conduction temperature at the respective supplier. If the temperature is below the defined prime supply temperature, a lower compensation is paid to the heat supplier and Norrenergi has the right to request a cancelation of the heat supply.

For smaller deviations in the supply temperature, the supplier's compensation level is reduced to 50% of the level at the prime supply temperature and for major deviations the customer receives no compensation.

The compensation is calculated monthly in retrospect and is based on measured hourly values for the delivered amount of energy described earlier and at is reduced for hours where the supply temperature is below the prime supply temperature according to the principles described above. (Swedblom, 2019)

Business model: Contract and responsibilities

At the time of writing, Norrenergi has not yet determined what ownership structures and responsibility for operation and maintenance in Värme Together will look like (Swedblom, 2019).

2.9 THE SWEDISH LAW REGARDING ACCESS FOR THIRD PARTIES AND PROSUMERS

In 2008, *fjärrvärmelagen*[1] *(the district heating act)* became law and for the first time regulated the district heating business in law. One of the intentions of the district heating act was to strengthen customers' position in their relation with district heating companies, including by partly regulating the pricing of district heat and making demands on how information about pricing should be communicated (Eriksson, Tedebrand, & Werther Öhling, 2013). One aspect that has been discussed for a long time in the district heating market is so-called *third-party access.* The debate has revolved around the competitive situation at the generation end in district heating, where energy companies have been considered to be in a monopolistic position. In order to increase competition regarding the generation of district heat, the government's study *Fjärrvärme i konkurrens*[2] *(District heating in competition)* suggested that the generation and distribution of district heating should be separated and that generators of heat should be given free access to supply heat to the district heating grids (Abrahamsson & Nilsson, 2015). The investigation led to the possibility for external heat suppliers to supply heat and the regulation of this supply in 2014.

The *section Access to pipelines* in the District Heating Act states that "If a district heating company receives a request for supplying heat the heat grid from an entity who wishes to sell heat to the district heating company or use the distribution grid for the distribution of heat, the district heating company shall negotiate access with the requesting entity. The obligation to negotiate means that the district heating

[1] Fjärrvärmelagen (2008:263) http://rkrattsbaser.gov.se/sfst?bet=2008:263

[2] SOU 2011:44

company shall seek to agree on terms for access with the entity making the request."

District heating companies are therefore obliged by law to at least investigate whether a potential supplier of heat should be allowed to supply the heat. In addition, the obligation applies only to the supply of prime heat to the supply pipe. The standardized concepts described in this report thus offer more than the law requires, as they also allow the delivery of heat that has lower temperature to the supply pipe, as well as to the return pipe.

The law also states that the person who has requested access to the pipelines must pay the investment cost of the connection. All the concepts described are designed accordingly, the supplier of heat accounts for all its own investment costs. On the other hand, it should be noted that all district heating companies offering standardized solutions bear the investment cost of new metering equipment and any pipelines on the primary side. However, the district heating companies charge a fee to cover these costs in Öppen Fjärrvärme and SamEnergi.

The law also states that regulated access agreement should be valid for 10 years. Among the concepts described in this report, it has only been stated that Öppen Fjärrvärme's contract periods run over 10 years for on demand heating, whereas for spot heat there are contractual periods of up to one year.

Finally, the law states that district heating companies must pay compensation for the heat that the supplier feeds to the grid. The paragraph for this concludes "The compensation shall correspond to the benefit for the district heating company". This last formulation has shaped the concepts described, in which district heating companies have faced the challenge of making the estimate themselves of the benefits of the heat supplied in their heat grids. In all cases, this has involved some form of estimation of the alternative of heat generation per time period or as a function of outdoor temperature.

3 Method

3.1 SIMULATION OF THE POTENTIAL FOR TWO TYPES OF PROSUMERS

The system benefit from using heat from two prosumers in six different archetype heat grids has been studied, resulting in a total of twelve studied cases. The analysis is based on a simulation over three years where it is calculated for each hour whether it is economically viable from a system perspective to export heat. The calculation of whether it is economically viable is based on a comparison of the additional electricity cost for the prosumer to increase the temperature of the excess heat so that it can be used in the district heating grid (compared to if the excess heat had been cooled away to the environment) and the marginal cost of heat generation in the district heating grid. If the additional electricity cost is lower than the marginal cost of heat generation, a heat export takes place and created economical value from the export is set as the difference between the two factors.

To enable analysis for different conditions such as weather and electricity prices, three different years have been simulated, 2015, 2016 and 2017. Outdoor temperature for this time period has been taken from SMHI's MESAN-model. The cost of electricity consists of Nordpool day-ahead spot prices (hourly values), electricity certificates (monthly values), energy tax and electricity grid fee.

3.2 ARCHETYPE HEAT GRIDS

Six archetype heat grids representing different types of district heating grids to which the prosumers could be connected have been used in the analysis. The archetype grids are divided into three different fuel mixes, Extra combined heat and power, Extra heat pump and Extra excess heat. Each fuel mix is then divided into one variant with and one without hot water storage tank, giving a total of six combinations. Annual average heat generation for all archetype grids is 500 GWh and the hot water storage tanks have a storage capacity of 500 MWh. The archetype grids are described in more detail in the report for a previous FutureHeat-project: The value of flexible heat demand (Kensby, et al., 2019). The first change that has been made to the archetype grids in this study from the previous study is that the oil and gas used for peak load boilers (a total of 2% of the heat generation) has been replaced by biooil and biogas. The change has been made to reflect the ambitions of the heating industry, where the goal for the industry is to become fossil fuel-free by 2030 (Fossilfritt Sverige, 2019). Table 1 presents an overview of the archetype heat grids and profiles for heat generation are shown for three of the archetype grids in Figure 5, Figure 6 and Figure 7. It has been assumed that the replacement of fuel in the peak load boilers does not entail changes in the variable generation costs of the archetype grids. The marginal cost of heat generation for all archetype grids is reported in Annex A: Marginal generation costs in archetype grids.

Table 1 Overview of archetype grids used for simulations

Fuel mix	Installed heat output	Share of annual heat generation without storage tank	Share of annual heat generation with storage tank
Extra combined heat and power	**Combined heat and power** At maximum electricity generation: 62.5 MW heat 21 MW electricity In bypass operation (no electricity): 83.5 MW heat **Hot water boilers** 95 MW	**Combined heat and power** 88.9% **Hot water boilers** 11.1%	**Combined heat and power** 89,7% **Hot water boilers** 10.3%
Extra heat pump	**Combined heat and power** At maximum electricity generation: 33.6 MW heat 11.3 MW electricity In bypass operation: 44.9 MW heat **Heat pumps** 40 MW **Hot water boilers** 95 MW	**Combined heat and power** 55.7% **Heat pumps** 30.7% **Hot water boilers** 13.6%	**Combined heat and power** 56.1% **Heat pumps** 30.7% **Hot water boilers** 13.2%
Excess heat	**Combined heat and power** At maximum electricity generation: 33.6 MW heat 11.3 MW electricity In bypass operation: 44.9 MW heat **Excess heat** 40 MW **Hot water boilers** 95 MW	**Combined heat and power** 32.0% **Excess heat** 59.1% **Hot water boilers** 8.9%	**Combined heat and power** 32.0% **Excess heat** 59.8% **Hot water boilers** 8.2%

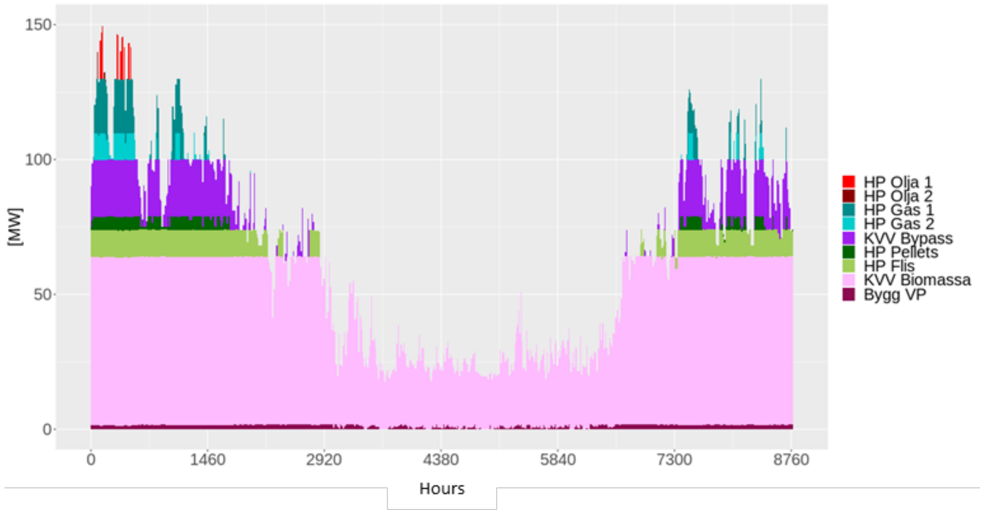

Figure 5 Heat generation 2016 in archetype grid: Extra combined heat and power without hot water storage tank

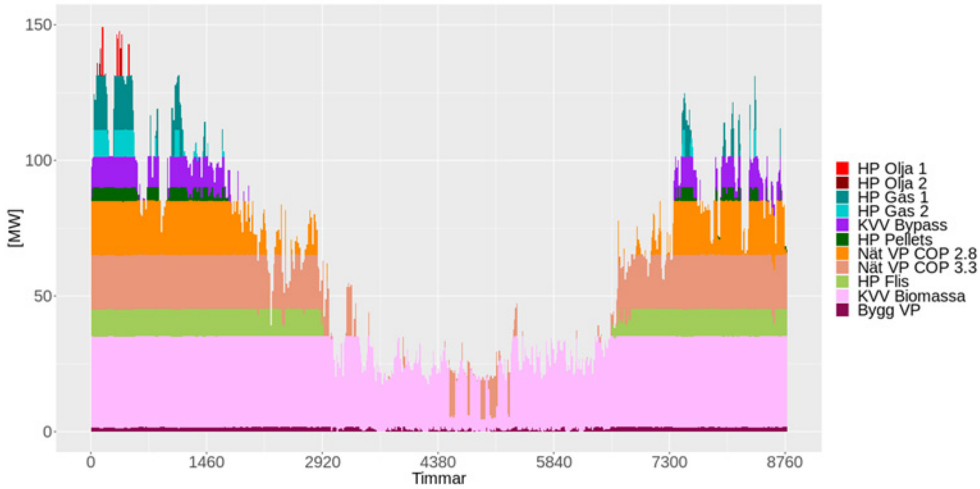

Figure 6 Heat generation 2016 in archetype grid: Extra heat pump without hot water storage tank

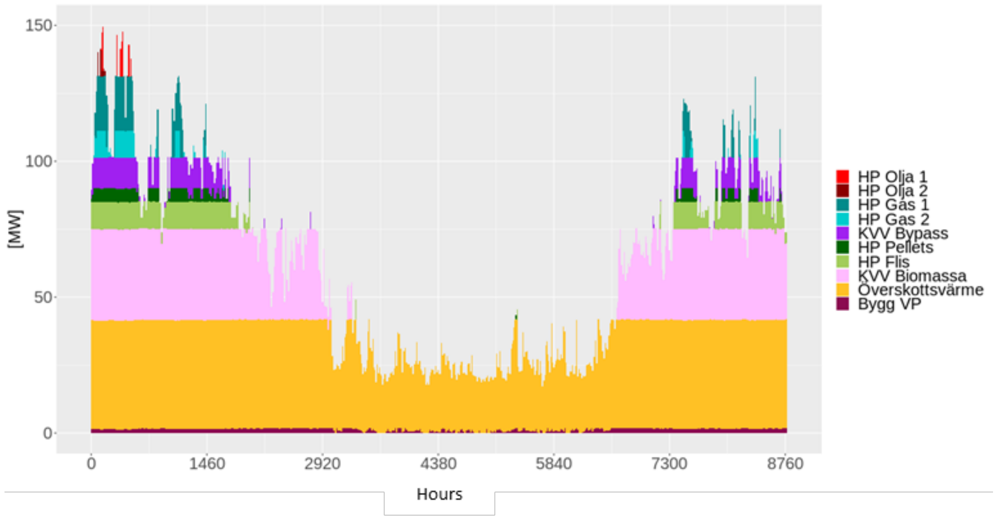

Figure 7 Heat generation 2016 in archetype grid: Excess heat without hot water storage tank

3.3 THE VALUE OF POWER

If the prosumer can guarantee a delivery at times when the district heating grid is close to its design heat demand, the district heating system can provide the same security of supply with a lower generation capacity in other parts of the system. Connecting prosumers can then lead to the energy company being able to avoid alternative investments or decommission an existing peak load boiler. Information on the economic value of power has been collected by the reference group having indicated their investment costs in new generation and fixed operation and maintenance costs per MW of generation capacity. The analysis in this report is based on an average of the data collected from the reference group. Investment costs are recalculated at a capital cost per year and when the energy company has not made this conversion itself, an internal interest rate of return of 8% has been assumed. The calculated values are shown in section 4.2.2.

3.4 TWO TYPES OF PROSUMERS

In this project, a data center and a grocery store have been selected to be used in the analysis of the system benefits for the export of excess heat to the different archetype grids.

3.4.1 Data Center

Simulations for the data center are based on existing data from the data center Bahnhof Thule in Stockholm, which since 2014 has supplied district heating and cooling to Stockholm Exergis grid through Öppen Fjärrvärme. The plant uses three serial connacted heat pumps with a nominal heat output of approximately 1.5 MW and 1 MW of cooling power. The cooling demand in the data center is 0.5 MW and it is almost constant throughout the year and the plant is thus designed to cover a cooling demand that is twice as large as the local cooling demand. All of the excess cooling and heating is delivered to Stockholm Exergis grid. The heat pumps evaporators cool the return pipe on the district cooling grid and refrigerant used in the data center cooling system at the same time. The heat pumps condensers deliver heat to the district heating grid through a Return/Supply connection.

Since this study focuses on prosumtion in district heating, the case study is adapted to represent a data center that can only supply heat to a district heating grid and not district cooling. Therefore, only the part of the heat supply from the data center that is a result of the internal cooling demand of about 0.5 MW is taken into account. It has been assumed that the heat generation in the heat pump is scaled linearly with cooling generation, which results in 0.75 MW of heat that can be supplied to the district heating grid from the data center. An overview of the data center is provided in Table 2:

Table 2 Overview of parameters for the data center case study

		Notes
Installed cooling power	1 MW	For internal cooling demand and supply to the cooling grid
Internal cooling requirement	0.5 MW	Constant over the year
Installed heat output	1.5 MW	For supply to the district heating grid
Rescaled heat output	0.75 MW	Scaled to correspond only to the internal cooling demand
COP_{heat}	3,7	Assumed constant
Supply temperature district heating	68°C	Assumed constant

If there had not been an opportunity to get paid for exporting the excess heat from the data center, it would have had to be cooled off to the surroundings instead. At low outdoor temperatures, the excess heat from the heat pump can be exchanged directly to the surroundings. If the outdoor temperature is higher, the temperature of the excess heat needs to be increased in order to be exchanged with the outdoor air. This entails a cost for extra bought electricity and we assume that the heat pump that is used to raise the temperature for exporting heat to the district heat grid would instead be used to raise the temperature only to be higher enough to be cold off to the outside air. It has been assumed that a temperature difference of 10° is required to dump excess heat into the outdoor air. It has been assumed that the heat pump used to raise the temperature to the outdoor temperature +10°C has a COP of 12, since a smaller temperature lift is required compared to district heating generation. This is a high COP but is also intended to include the electricity consumption in air handling units when the outdoor temperature is low enough for direct heat exchange to the surroundings. It has been assumed that the excess heat keeps a temperature of 23°C constant over the year.

The extra cost of supplying district heating with the heat pump is thus calculated as the difference between the cost of generating district heat with high enough temperature and the alternative cost of dumping excess heat to the outdoor air. The simulation determines whether heat should be dumped or delivered to the district heating grid by comparing whether the electricity cost calculated according to the equation below is greater or less than the marginal cost for heat generation in the district heating system.

$$\left(\frac{\dot{Q}_{DH}}{COP_{DH}} - \frac{\dot{Q}_{DH}\frac{COP_{DH}-1}{COP_{DH}}}{COP_{dump}-1}\right) \times Price_{el}$$

Where $\dot{Q}_{DH}$ is the maximum heat output that can be delivered to the district heating grid (0.75 MW), COP_{DH} is the COP when exporting heat to district heat grid (3,7) and COP_{dump} is the COP when dumping excess heat to the environment (12).

3.4.2 Grocery store

The data used to simulate the grocery store is based on a master thesis where the potential for exporting heat to a district heating grid has been studied (Raka Adrianto & Grandjean, 2018). The electricity use of the cooling system and the amount of excess heat from the grocery store are represented as a function of outdoor temperature for two different operating modes: excess heat is dumped outdoors and the excess heat is heated to a temperature that can be used in the district heating grid. In this study, we use the difference in electricity usage between the two cases to calculate the additional cost associated with exporting the excess heat to a district heating grid. The grocery store's capacity to supply heat to the grid varies between 66 kW and 1.2 MW depending on internal heat and cooling requirements. The system's COP for heat exports also varies greatly in a range between 2.7 and 8.1.

3.5 THE SYSTEM BENEFITS OF DIFFERENT REMUNERATION MODELS FOR ENERGY

The compensation for the heat supplied by a prosumer to the district heating company can in practice be determined by various methods which somehow reflect the value of the heat received in terms of avoided alternative costs. The avoided alternative that arises from receiving one kWh of heat from a prosumer is the cost of generating one extra kWh of heat elsewhere in the district heating grid.

In the system benefit analysis of the simulated case studies presented in this report, the marginal generation cost per hour of district heating has been used as a remuneration for the heat supplied by prosumers. It approximates a compensation that is set per hour based on heat generation planning, where heat generation scheduling has had a forecast horizon of 72 hours. The system benefit calculated thus represents a best-case scenario, where the prosumer delivers heat during all hours with positive system benefit no hours with negative system benefit. The system benefit is positive when the heat generated has been produced by the operator with the lowest cost of generation and negative if heat has been produced by an operator where the generation has not had the lowest cost. By using the system perspective when deciding on whether to export heat to the grid on, heat is produced by the source which results in the lowest cost in a system perspective.

If the compensation for delivered heat is instead set as a function of outdoor temperature or as a fixed compensation over the year, the prosumer will make the wrong decision (from a system perspective) about exporting or not exporting heat in two different ways; Either the compensation for exported heat is too *high* for one hour and the prosumer exports heat when it should not, or the compensation is too *low* for one hour and the prosumer does not export heat when it would be beneficial from a system perspective to do so.

Table 3 Overview of the different decisions that a prosumer can take every hour and the system benefit from the decision when compared to the reference; to base the decision on marginal generation cost of district heating. $C_{marg,DH}$is the marginal generation cost of district heat and $C_{marg,el}$ is the additional cost for exporting heat from the prosumer.

Case	Compensation based on marginal cost (reference)	Simplified compensation model	Changed system benefit [SEK]
1	Not exporting	Exporting	$(C_{marg,DH} - C_{marg,el}) - 0$
2	Exporting	Not exporting	$0 - (C_{marg,DH} - C_{marg,el})$
3	Exporting	Exporting	0
4	Not exporting	Not exporting	0

The change in system benefit obtained in the various cases is the alternative cost arising from the incorrect decision. Case 3 and case 4 do not make any difference in the total generation of heat in the system and the changed system benefit is equal to zero. On the other hand, revenues for both the prosumer and the district heating company change compared to the reference. In case 1, the prosumer has exported heat because the fixed compensation is higher than the marginal generation cost of district heat and the change in system benefit will be the marginal generation cost of district heating minus the cost of electricity to generate heat from the prosumer (which becomes a negative value in this case).

In case 2, the prosumer does not export heat even though the cost of generating heat for the prosumer is lower than the marginal cost of generating district heat. This is because the fixed compensation is lower than the marginal generation cost of district heating. The change in system benefit therefore becomes the marginal generation cost of district heating minus the electricity cost of producing the heat of the prosumer (multiplied by minus one to demonstrate that it is a reduced system benefit). Section 4.2.1 shows the change in system benefit if more fixed rates for compensation for exported heat is used compared to a compensation based directly on the marginal cost of heat generation in the district heating grid each hour.

4 Results

4.1 RESULTS FROM SIMULATIONS

The results present the system benefit, which is simply the value of heat exports from a system perspective minus the cost of the extra electricity used to enable heat exports. The value of the heat export is the alternative cost the district heating company would have if they had to generate the same amount of heat, i.e. the marginal cost of heat generation multiplied by the amount of heat exported by prosumers (and other heat supplier). The value of the heat export and the additional electricity cost are calculated for each hour and are summed over the whole period. No account has been taken of how the economic value that is the system benefit is distributed between the heat supplier, district heating company, potential electricity suppliers or other actors. This is instead discussed in section 4.2, which deals with remuneration models.

4.1.1 Data Center

The results differ a great deal between different archetype heat grids and for different years, but generally a significant system benefit is achieved by exporting heat as shown in Table 4. The value minus the additional electricity cost varies between SEK 580 thousand/year and SEK 1,710,000/year and the variation depends on several factors.

Table 4 Results for simulation of heat exports from one data center to six different archetype grids.

Years	Heat exports [MWh]		Value of heat export [kSEK]		Additional electricity cost [kSEK]		System benefit [kSEK] (Value of heat export - Additional electricity cost)	
Archetype grid: Extra combined heat and power without/with tank (white/grey column)								
2017	4 160	4 630	1 630	2 090	700	790	930	1 310
2016	4 990	5 370	1 930	2 490	790	860	1 100	1 630
2015	2 400	3 140	1 254	1 780	450	580	810	1 190
Archetype grid: Extra heat pump without/with tank (white/grey column)								
2017	4 220	5 440	1 670	2 490	720	930	940	1 560
2016	5 260	5 960	1 930	2 670	850	960	1 080	1 710
2015	4 390	5 180	1 670	2 490	820	970	850	1 530
Archetype grid: Extra excess heat without/with tank (white/grey column)								
2017	3 100	3 060	1 280	1 580	520	520	760	1 070
2016	2 930	3 040	1 360	1 650	490	510	870	1 150
2015	2 170	2 190	980	1 280	400	410	580	880

The system benefit is greatest in all archetype heat grids for the year 2016, which can be explained by a really cold winter with a longer period with high marginal costs for heat generation in all archetype grids, as exemplified for one of the archetype grids in Figure 8. This has a significant impact on the system benefit since the difference in marginal cost of heat generation between base load and peak load in the heat grid is significantly greater than variations in spot prices for electricity.

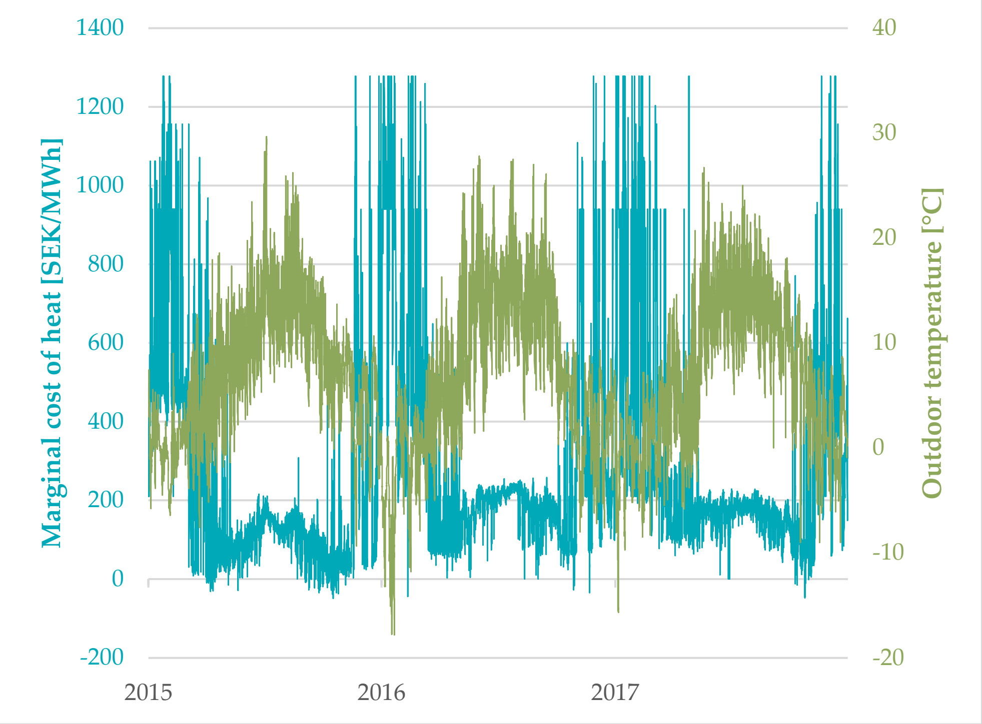

Figure 8 Marginal heat generation cost and outdoor temperature in 2015, 2016 and 2017 in archetype grid: Extra combined heat and power, without hot water storage tank.

If we investigate differences between the archetype grids, the system benefit is greatest in the archetype grids that have a hot water storage tank compare to their counterparts without. However, this is not a general conclusion that this applies to all grids with a hot water storage tank, as many effects interact, such as the generation mix and the maximum charge/discharge rate and storage capacity of the hot water storage tank. Adding a hot water storage tank to a district heating grid should always lower the total cost of generation heat thanks to the possibility to cover a larger share of the heat demand with lower-cost heat generation. On the other hand, the average marginal cost of heat generation can increase as well as decrease. The archetype grids with hot water storage tank studied in this study generally have higher average marginal cost than their counterparties without hot water storage tank, which explains the greater system benefit arising from receiving heat from prosumers in these grids.

One cause to the higher average marginal cost of heat generation in archetype grids with an hot water storage tank is that there are relatively frequent occasions when heat generation with lower operating costs operates at maximum capacity to charge the hot water storage tank but the heat stored is not sufficient to eliminate the whole next occasion when heat generation with higher operating costs needs to be used. Regardless of when during such a period heat is supplied from, for example, a producer it results in less usage of the heat source with higher operating cost. Thus, heat generation from the heat source with higher operating costs is on the margin throughout the period, even during the hours when it is not in operation.

There are also times when you can completely avoid starting heat generation with higher operating costs by using the hot water storage tank. On these occasions, the use of the hot water storage tank results in a lower marginal cost for heat generation in the hours when heat generation with higher operating costs would otherwise been operational. If these occasions are more dominant than those when more expensive heat generation cannot be completely eliminated, the use of the hot water storage tank results in lower average marginal costs. This may well be the case in district heating grids (other than the archetype grids studied) with different specifications for their hot water storage tank and production mix. This, and several other more complex effects, have been captured by estimating marginal costs in the archetype grids by using model-based optimization and studying how a change in the heat load every single hour affects the total cost of generation even for the next three days. The model never sees the heat from the prosumer as marginal generation, it checks the marginal cost of heat generation in the grid and if it is higher than the extra cost for the prosumer to export the heat, the heat from the prosumer is exported.

The fuel mix of the archetype grids also has a significant impact on the system benefit achieved by receiving heat from a prosumer. For archetype grids with hot water storage tanks, for all simulated years, the grids with a fuel mix consisting of a significant share of heat pumps shows the greatest system benefit for receiving heat from the studied prosumer. The same also applies to the archetype grids without hot water storage tank for two of the simulated years and the difference compared to the other grids is smaller. The system benefit is greatest in the archetype heat grids with central heat pump due to the fact that those grids often have a higher marginal cost of heat generation than the other archetype grids where the part covered by heat pumps is largely covered by combined heat and power. The fact that it is so profitable to export heat to its archetype grid may seem counterintuitive because their alternative heat generation is often heat from heat pumps. The reason it is so profitable is mainly due to two factors:

- The prosumer has an alternative cost to dump the excess heat outdoors that is excluded from the cost of exporting the heat to the grid.
- The heat pumps at the prosumers in this study have higher efficiency than those that are part of the heat generation in the archetype grids. This is partly because the temperature requirement is not as high for heat pumps at prosumers and that the temperature on their cold side is often higher.

The system benefits achieved should be compared with the investment cost that enables this value creation. In this case study, the following investments have been made:

- Bahnhof: SEK 3.4 million for the entire refrigeration solution

- Stockholm Exergi: SEK 1.3 million for the connection to the heat grid

It is important to take into account here that the system benefit calculated is only for the part of the heat supply that would otherwise have had to be dumped outdoors to cool the server hall (half the cooling power in the chiller does not meet a local demand but is used to produce and export district cooling). It should also be noted that the investment cost that should be taken into account is only the additional investment cost needed to enable the excess heat to be exported to a district heating grid relative to a solution that dumps the heat excess heat to the outdoor air. There are thus many uncertainties in the calculation, but it should still be possible to claim that:

- The extra investment cost should not be **less** than SEK 1.3 million as because the this is the cost for the connection to the heat grid
- The extra investment cost should not be **higher** than SEK 3.0 million (1.3 + 3.4/2) if we make the very conservative assumption that adapting half the solution should not be more expensive than half the cost of an adapted solution.

With an investment range of SEK 1.3 million to SEK 3.0 million and system benefit in the range of SEK 580 thousand/year to SEK 1,710,000/year, we then get a payback-time in the range of 0.8 years to 5.2 years in the archetype grids. This is not including any value from the fact that the prosumer could possibly guarantee a heat supply when the heat grid is at its’ design demand, which can avoid alternative investments in the district heating system.

4.1.2 The grocery store

Like the results for the data center, the system benefits vary greatly between different types grids and different years as shown in Table 5. These are the same factors that cause the variations for the data center and they are more connected to the conditions in the heat grid and variations in weather and electricity prices than characteristics of the prosumer. However, the factors have varying impacts because the grocery store have a significant variation in the amount of heat that is available for export and how much extra electricity is needed to enable the export.

Table 5 Results for simulation of heat exports from one grocery store to six different archetype grids.

Years	Heat exports [MWh]		Value of heat export [kSEK]		Additional electricity cost [kSEK]		System benefit [kSEK] (Value of heat export - Additional electricity cost)	
Archetype grid: Extra combined heat and power without/with tank (white/grey column)								
2017	430	510	200	260	90	100	110	160
2016	540	610	240	310	110	120	130	190
2015	320	400	170	240	70	80	100	150
Archetype grid: Extra heat pump without/with tank (white/grey column)								
2017	800	820	260	340	60	60	200	280
2016	810	830	270	350	60	60	210	300
2015	680	760	240	340	60	60	180	280
Archetype grid: Extra excess heat without/with tank (white/grey column)								
2017	370	420	170	220	80	80	90	140
2016	360	410	180	220	80	80	100	140
2015	250	300	130	180	60	70	70	110

The system benefit should be compared to the investments required to enable it. For the studied grocery store, no such information is available. However, there is information available for another grocery store, Coop Rådhuset, which delivers heat to Öppen Fjärrvärme:

- Coop Rådhuset: SEK 405,000 for adaptations required to be able to deliver heat to the district heating grid
- Stockholm Exergi: SEK 100,000 for the connection to the grid

We have no indication of how similar the cases are in either size or configuration, but if they are comparable, they indicate a payback times in the order of 1.7 – 7.2 years.

4.2 RECOMMENDED COMPONENTS IN THE BUSINESS MODEL

In all of the four existing concepts analyzed in greater detail in sections following section 2.4, the supplier receives a compensation connected to the amount of energy exported to the grid. In accordance with *fjärrvärmelagen* (the district heating act), the compensation should be based of the benefit for the district heating system from receiving the heat. The way in which this benefit is determined differs among the studied solutions, but in all cases the compensation per MWh of heat supplied is in some way based on the marginal generation cost of district heating in the district heating system. The level of compensation varies per year, per season or per hour. When the compensation is set per hour, this is done either by correlating a certain marginal generation cost to an outdoor temperature, or more directly from the production plan set for the upcoming 24 hours, or other specified time period.

A standardized prosumer solution at an energy company should include a remuneration models for prosumers that include at least include compensation for energy and guaranteed power. Other components that may, but do not have to, be included are components that adjust the level of compensation for the prosumer based on the temperature that is supplied to the district heating grid and fixed charges to cover investment costs for the connection to the district heating grid.

4.2.1 Remuneration model for heat energy

The compensation per unit of energy delivered can be practically determined in different ways, three of them have been identified in the overview of existing solutions (section 2):

1. Compensation per unit of energy is constant for each year or season (Tekniska verken)
2. Compensation per unit of energy is defined as a function of outdoor temperature (Stockholm Exergi)
3. Compensation per unit of energy is determined individually for each hour (Vattenfall)

The simplest model for calculating and determining the remuneration for energy is to set a compensation per unit of energy. The constant compensation can be set on an annual, seasonal, or monthly basis. The advantage of the constant remuneration model is above all its simplicity, which can be an advantage for both the district heating company and the prosumer. For the heating company, the development costs of creating an offer to deliver heat to the grid is minimized and for the prosumer the revenue from heat deliveries becomes very predictable. The disadvantage of a simplified model is, above all, that the constant price does not always reflect the real value of the heat delivered heat. If the compensation is set based on the average generation costs in the district heating grid over a year, receiving heat from a prosumer results in a loss for district heating company when their generation cost for heat generation is relatively low, which is offset by profits made during the hours when their generation costs are relatively high. For some prosumers, such as those where the exported heat is pure excess heat that does not have an alternative use and where the cost associated with exporting the heat is neglectable, what remuneration model that is used is of low importance. A fixed compensation per unit of energy may then be quite sufficient.

By setting the compensation for supplied energy at a higher resolution, the compensation better matches the actual alternative costs of heat generation each hour. The disadvantages of such models are that they are more complicated and expensive to develop for the district heating company. For the prosumer, the main disadvantage is that the revenue from heat delivery becomes less predictable and this can make it difficult to make a decision on whether to make the required investment. The most detailed remuneration model today is the one used in Vattenfall's concept SamEnergi, where the compensation for heat every hour is determined based on the planning of the heat generation one day ahead. A middle ground between compensation per unit of energy determined for each individual hour and a long-term fixed compensation is to link the compensation to the outdoor temperature each hours since the outdoor temperature has a high correlation with the alternative cost of heat generation in the heat grid. Though the reliable of weather forecasts is important for the accuracy. In addition, an outdoor temperature-based remuneration means that the prosumer and the district heating company must agree on *the* outdoor temperature source to be used – is it at the customer's property, at a district heating company or at weather station centrally in the grid?

Analysis: Impact of the remuneration model on the system benefit that is achieved

In order to quantify how much the system benefit changes when a constant remuneration model is used to compensate suppliers for exported heat, two simulations with different methods to determine the compensation for exported heat have been carried out for a data center located in the archetype grid: Extra combined heat and power without hot water storage tank. The results from section 4.1.1 is used as a reference since they represent the maximum potential system benefit. The maximum potential is achieved since the data center always export heat when its extra cost of doing so is lower than the marginal cost of heat generation in the heat grid (and never when this is not true). The results for the reference case are shown in Table 6.

Table 6 Reference: Results for a data center in archetype grid: Extra combined heat and power without hot water storage tank for compensation equal to the marginal cost of heat generation each hour.

Years	Heat exports [MWh]	Revenue heat exports [kSEK]	Extra cost [kSEK]	Revenue heat export - Additional cost [kSEK]
2017	4,160	1,630	700	930
2016	4,990	1,930	790	1,100
2015	2,400	1,254	450	810

In the two simulated cases, two different energy remuneration models are applied to the heat export; a compensation per unit of energy that is constant over the year and compensation set as a function of outdoor temperature. Both models are based on the simulated marginal generation costs used in the reference case.

The constant compensation per unit of energy has been set by calculating the average marginal generation costs in the archetype grid over the years 2015, 2016 and 2017. This gives an indication of the level at which such a compensation can be set, but probably does not represent real pricing as it needs to be adjusted to provide a profit margin for the district heating company. The this results in a compensation for exported heat of 285.6 SEK/MWh.

The temperature-based compensation is formed by mapping the marginal generation cost in the archetype grid against the outdoor temperature of the archetype grid (southern/central Sweden) for the years 2015, 2016 and 2017. This relation is shown in Figure 9.

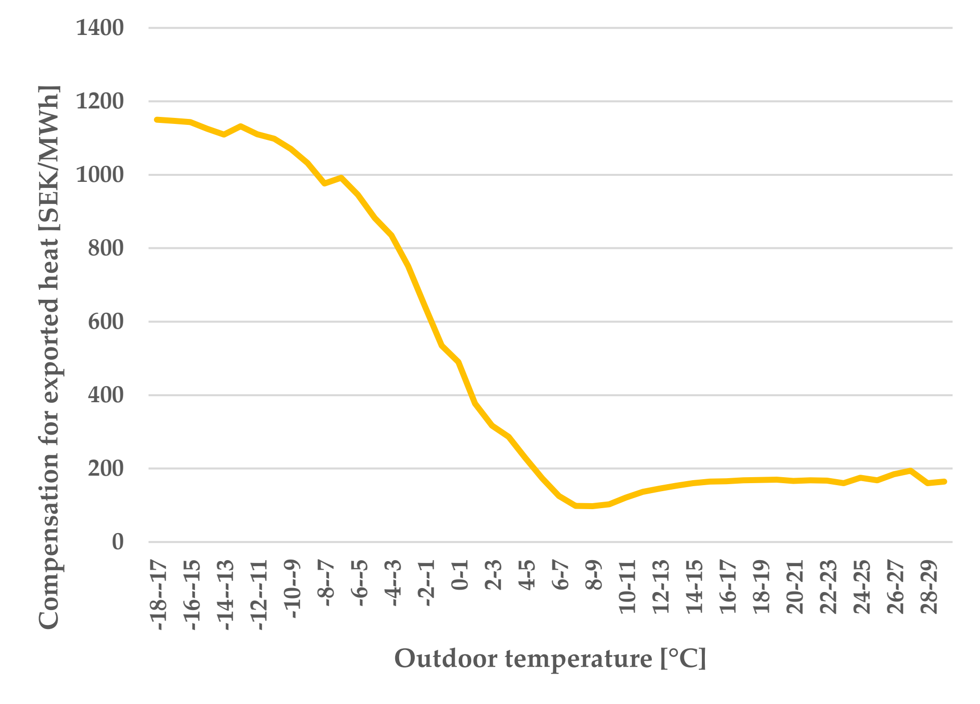

Figure 9 Compensation for exported heat based on outdoor temperature in archetype heat grid: Extra combined heat and power without hot water storage tank.

The system benefit of the reference case and the two simulated remuneration models has been calculated in accordance with the specification in Table 3 and the results are shown in Figure 10. By setting the compensation as a function of outdoor temperature, the achieved system benefit decreases by between 5 and 8 percent, depending on the year. In total, over three years, the system benefit decreases by 6 percent compared to the reference case where the compensation is directly based on the actual marginal cost for heat generation each hour. At a fixed, annual compensation per unit of exported energy, the system benefit is reduced by as much as 9 to 52 percent for individual year and a total of 23 percent over the three years. Setting the compensation as a function of outdoor temperature can thus be an adequate approximation that is close to the real conditions, but a constant compensation per unit of energy can result in a significantly reduced system benefit. However, the annual compensation used in this study is calculated in a simplified way and a more sophisticated calculation can provide better results. If a constant compensation is instead set per season or month, the reduced system benefit should be smaller.

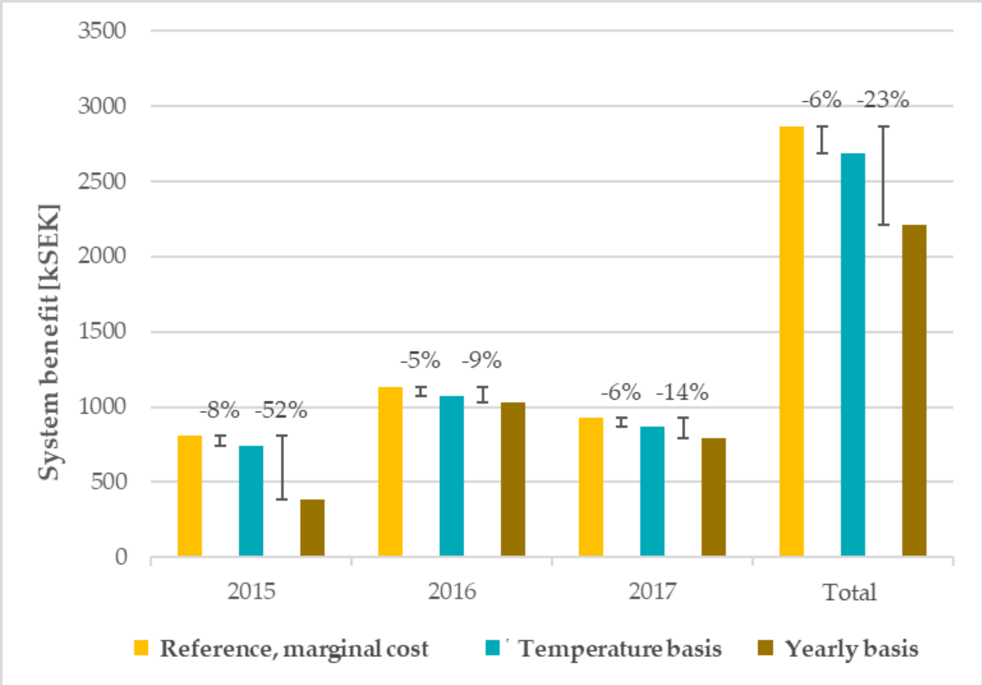

Figure 10 Changes in system benefit with different remuneration models for heat energy. Percentage values refer to the relative difference from the reference case.

More detailed results from the simulations are shown in Table 7. With compensation per unit of energy as a function of outdoor temperature, both case 1 and case 2 (defined in Table 3) occur, i.e. there are instances when heat is exported even though the cost of exporting the heat is higher than the marginal cost of heat generation in the grid (case 1) and there are instances when heat is not exported even though the cost of exporting the heat is lower than the marginal cost of heat generation in the grid (case 2). In both these instances the system benefit from the heat export is negative. The total amount of heat exported from the prosumer is lower than in the reference case. With an annual compensation per unit of energy that is fixed for the whole year, almost only case 1 occurs and exports of heat from the prosumer increase significantly compared to the reference case. With both studied remuneration models, the prosumer has reduced net revue. This is highly affected by how the level of compensation is set for the different remuneration models, though the system benefit is than in the reference case so it is reasonable the net revenue is also lower.

Table 7 Changes in amount of exported heat from the prosumer for the cases described in Table 3, as well as the changes in net revenue for the prosumer compared to the reference.

	2015	2016	2017	Total
Temperature price				
Extra exported heat with negative system benefit (case 1) [MWh]	310	350	240	900
Heat that is not exported heat even though the system benefit had been positive (case 2) [MWh]	380	730	1 260	2 380
Total heat export [MWh]	2 330	4 610	3 130	10 070
Difference in net revenue for the prosumer [kSEK]	-245	-171	-89	-505
Annual price				
Extra exported heat with negative system benefit (case 1) [MWh]	4 170	1 600	2 400	8 170
Heat that is not exported heat even though the system benefit had been positive (case 2) [MWh]	0.75	0	21	21.75
Total heat export [MWh]	6 570	6 580	6 540	19 690
Difference in net revenue for the prosumer [kSEK]	-156	-313	-177	-646

The calculations above can be seen as hypothetical, but still show the trade-offs that a small heat company can make when designing the remuneration for energy to prosumers. Ultimately, the decision is about how risk should be divided between the parties and how complicated remuneration model that is motivated for the specific case. The risks consist of the impact of the weather and unforeseen problems in generation that increase the cost of heat generation. With a remuneration model that is closer to actual alternative heat generation cost each hour the risk for the district heating company is reduced. The risk is partly transferred to the prosumer, as the complexity of the business for the prosumer increases. With a more static remuneration for the energy, the risk for the district heating company increases mainly due to the influence of weather, in a warm year the compensation to the heat suppler can be greater than the value of their heat export.

4.2.2 Remuneration model for heating power

In a case where a prosumer has a predictable supply of heat, the remuneration model may contain a component for power that is set to a level that is static over the long term or is periodically renegotiated. Often the level of compensation for a guaranteed available heating power from a prosumer is set for each case on a commercial basis. However, the value for the district heating company of having a guaranteed available heating power from a prosumer should correspond to the avoided alternative cost in the heat grid that. The avoided alternative cost is in many cases that a new peak demand heat source does not need to be built, operated and maintained. This study, through its reference group, has been able to compile typical costs for peak demand heat sources, expressed as SEK per installed heating power capacity. It has been established that a peak demand heat source in this case consists of a hot water boiler fueled by bio-oil. The average values of the reference group's estimates for these costs is presented in Table 8.

Table 8 Alternative costs for the investment, operation and maintenance of hot water boilers fueled by bio-oil. The values refer to an average of estimates from the project reference group.

Alternative cost	kSEK/MW$_{heat}$,year	Comment
Investment cutting edge production	223	Only fixed investment costs, no design costs or land costs
Fixed operation and maintenance costs	20,7	Does not include distribution costs

It should be noted that the spread among estimated alternative costs is very high and depends to a large extent on local conditions. For each district heating grid, the alternative cost will differ, and it is recommended that remuneration models for power based on this method should be based on local conditions. However, the values Table 8 can be seen as a starting point that provides an estimate of the amount of compensation that is reasonable for suppliers that can guarantee their available heating power. It is also possible that where a prosumer is located in a heat grid can affect the compensation for heating power (and perhaps also compensation for heat energy). This may be worth considering if there are transmission limitations in the grid which limits the possibility of expansion and/or sometimes require the use of decentralized heat sources that are less efficient than other heat sources currently not operating at max capacity.

4.2.3 Deduction for insufficient supply temperature

The value of the heat supply depends on the temperature at which it occurs. One way to handle this is for the district heating company to reduce the compensation for the delivered heat with factor that increases with decreasing supply temperature. The adjustment of the compensation dependency on the supply temperature should be made on a case-by-case basis for each district heating grid, as local conditions vary and thus also the importance and value of supply temperature. A prosumer that delivers heat to a section of a heat grid with high heat load has a smaller impact on the system and a relatively low supply temperature from a prosumer will have a small impact. By reducing compensation for delivered heat depending on the supply temperature, incentives are given for the prosumer to deliver a constant and sufficient temperature as possible, but the deduction does not necessarily need to reflect any direct cost arising from insufficient supply temperature.

We recommend that a deduction for insufficient supply temperature is designed based on the prerequisites of each prosumer and heat grid, but Norrenergis model can be used as a indicative example: if the supply temperature is more than 3°C lower than the requirement the compensation to the prosumer is reduced by 50%. In the event of a supply temperature that is more than 7 °C lower than the requirement, no compensation is given at all for the heat.

In addition to adjusting the compensation based on the supply temperature there should also be remuneration model for supplying heat to the return pipe in the district heating grid, if it is possible. This compensation can be set as a proportion of the compensation for supplying heat to the supply pipe. The purpose of such an offer is to enable the use of excess heat that has to low temperature to be supplied to the supply pipe. It has not been analyzed in this study how high proportion should be, but it is important that the value of supplying heat to the return pipe is taken into account on a case-by-case basis. For example, in order to supply heat to the return pipe, the prosumer must be located so that the heat can be supplied to at a return pipe with sufficient flow rate. The efficiency of different heat sources is affected differently by the return temperatures, which should be taken in consideration when setting the remuneration for delivering heat to the return pipe.

4.2.4 Other fixed fees

Other fixed fees for the prosumer may also be included to cover the district heating company's equipment and installation costs. This is comparable with a connection fee for a standard district heating customer. These fees can be determined on a case-by-case basis depending on the conditions of each prosumer and the investment that is required by the district heating company to enable the heat supply from the prosumer.

4.3 INTERFACES AND COMMUNICATION FOR PROSUMER SOLUTIONS

In order to handle prosumers and small scale heat suppliers in district heating grids, certain interfaces and communication channels between the district heating company, the prosumer and external actors are required, see Figure 11 .

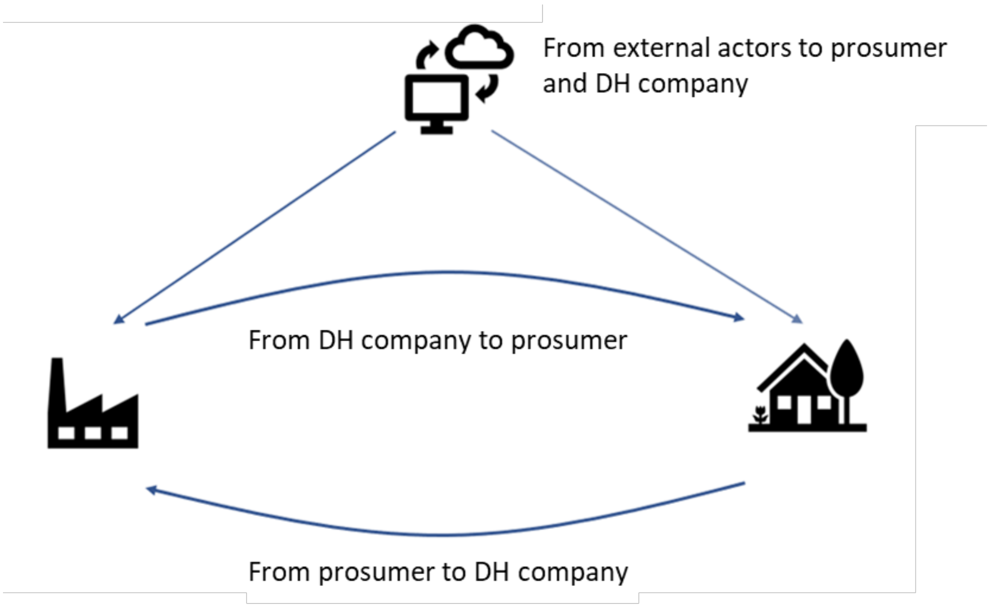

Figure 11 Interfaces and communications for prosumers and district heating companies

The following sections describe the information and data that needs to be shared between actors through the different interfaces. This information can be seen as a starting point for the design of the technical systems that make the prosumer concept possible. Each factor is briefly described and, where applicable, recommendations are made for how the interface and the data should be designed. In general, local conditions must be taken into account on a case-by-case basis in the design of the prosumer solution, and this also applies when designing the interfaces for communication.

4.3.1 From district heating company to prosumer

Compensation per unit of exported heat

The district heating company needs to notify the prosumer of the compensation that will be provided for exported heat. Depending on how the remuneration model is designed, this information can be communicated indifferent ways. With a simpler remuneration model consisting of a fixed compensation per unit of energy over a year or a season, it is enough to publish a price list that is updated annually.

There are two main options for how the information from the district heating company should be transmitted to the prosumer. Either the district heating company publishes information about compensation on a website or API service where the prosumer himself can actively collect the information (prosumer pull) or the information is sent directly to the prosumer's m facility and the information flow is integrate in the prosumer's control system (utility push).

If the compensation per unit of exported heat changes from hour to hour, the compensation to the prosumer should be updated and made available at least as far in advance as the prosumer plan the operation of his facilities. We recommend that the compensation rate for the next day are made available at 12:00 pm one day in advance since this coincides with the publication of day ahead electricity prices on NordPool spot which may affect planning for both the district heating company and the prosumer.

Supply temperature

If requirements on the supply temperature from the prosumer vary over the year or as a function of outdoor temperature, the variation can affect whether the prosumer wants to export or not. Therefore, requirements should be communicated to the prosumer on the same occasion as compensation per unit of energy are announced, in order to provide a full basis for the prosumer to plan it's operations.

4.3.2 From prosumer to district heating company

Planned heat export

Depending on the size of the prosumer's heat exports, it may affect the production planning of the district heating company. If the supply is so large that it affects what heat source the margin in district heating system, it may be necessary for the prosumer to notify the district heating company whether or not heat will be delivered for a certain hour.

Measured energy supplied by the prosumer needs to be collected by the energy company for calculating the compensation. This is not significantly different from the procedure for the traditional customer in a district heating grid.

4.3.3 From external actors to prosumer and district heating companies

Weather forecasts

If the remuneration model for energy received is based on the current outdoor temperature, forecasted and measured temperature needs to be shared with both the district heating company and the prosumer. It is important that both parties agree on the location and source for weather data.

NordPool spot prices

For a prosumer who is actively planning and trying to optimize its supply of heat to the grid, electricity price from NordPool spot market can be part of the data required if they have hour electricity prices. District heating companies most often already collects this data since it is taken into account when they plan their operation of combined heat and power and/or heat pumps.

5 Discussion

The purpose of the discussion chapter is primarily to reflect on the assumptions made and how the results produced in this study relate to what can be expected in a real application in a district heating grid.

How universal is the system benefit that have been calculated? In this study, the system benefits have been simulated for two prosumers (data center and grocery store) in six different archetype heat grids. The simulation has been performed with electricity prices and weather conditions for three different years (2015, 2016 and 2017). The results thus show a range of how large the system benefit can be under different conditions and the aim with this approach is that the most district heating companies should be able to identify with some of the cases and thus get a good estimate of the value of them. All possible conditions are, of course, not covered but it should be possible to start from this analysis and draw rough conclusions about the system benefits in other circumstances. The impact of some factors is described below:

Generation mix in district heating grids: It is above all the marginal cost that matters and for a generation mix with higher marginal cost, the system benefit from the heat received increases and vice vera for a generation mix with lower marginal cost.

Electricity prices: Can affect in several ways. The simulated years have varying electricity prices but at the time of writing (May 2020) electricity prices are lower than they were at any time during the simulation period. Many potential small-scale excess heat suppliers need to use a heat pump to raise the temperature of the heat and a lower electricity price reduces this cost which increases the system benefit. Lower electricity prices also reduce the profitability of combined heat and power, which increases the relative value of heat from other sources when combined heat and power is on the margin.

Performance of heat pumps at the small-scale excess heat supplier: this affects the cost of making excess heat possible to sell to a district heating grid. Better performance (higher COP) naturally leads to lower costs and thus greater system benefits from the heat delivery. The heat pumps located in the data center in the case study are not of the latest model and use R134a as a refrigerant. Newer heat pumps use other refrigerants, which in practice does not affect performance very much, but they usually do not provide less maximum power. This causes newer heat pumps to be larger and more expensive if they are to provide the same maximum power. It should be kept in mind that the electricity cost considered is only the additional electricity cost associated with exporting the heat and should not include electricity costs that would occur anyway. For example, if the excess heat comes from a cooling system, you will otherwise have to dump the excess heat to the outdoor air which is associated with an electricity cost.

How complex/realistic remuneration model is justified? The study of different energy remuneration models (Chapter 4.2.1) shows that there is a significant value from a system perspective to have a remuneration model that, as accurately as possible, reflects the system benefit of the heat delivered at all time. However, this only applies if the level of compensation is significant and if the small-scale heat supplier is actually able to act on a more dynamic price list. For pure excess heat deliveries or solutions that cannot handle a dynamic price list, the heat delivery will be the same regardless of which remuneration models is used. It should also be taken into account that there are costs associated with all remuneration models in the form of development costs and/or manual handling of measurement data and invoices. In order to use one of the more complex remuneration models (compensation based on outdoor temperature or forecast marginal cost), the additional cost needs to be economically justified by the increased system benefit. The results from Chapter 4.2.1 can be used to assess when this is the case. The cost of developing and applying all remuneration models can be greatly reduced through standardized IT solutions applied in several district heating grids, which is one of the objectives to develop in a second phase of this project. The absence of such solutions could be a contributing factor to the fact that only some of the largest district heating companies have developed offers for small-scale heat suppliers.

How can the value created be shared? The compensation offered by the district heating company to heat suppliers shall reflect the benefit that the supply of heat provides to the district heating company. The economic value created by the delivery from the prosumer is the alternative cost of the district heating company to produce the same amount of energy (and possibly to guarantee the same power) minus the additional cost of the prosumer to deliver the heat and the additional cost of receiving the heat. If the district heating company compensates the prosumer with the whole alternative cost for heat generation (minus their additional cost to receive the delivery), the entire economic value that is created goes to the prosumer. If the increased value is to be shared, the remuneration to the prosumer needs to then be lower than this level. How much lower is up to each district heating company to decide, but it is good to consider the distribution of investment costs between the district heating company and the prosumer when setting the level of compensation. In order to achieve a high degree of standardization it can be a good idea to allocate all (or most of) the investment cost to the prosumer and have a remuneration that is close to the alternative generation cost of the district heating company. This also provides the right incentive for a control system that decides when to export heat, since the compensation reflects real costs from a system perspective. If the compensation is significantly lower than the alternative cost of generation of the district heating company, there is a risk of missing out on heat deliveries that are profitable from a system perspective (in cases when the additional cost of exporting heat is lower than the alternative cost of the district heating company, yet at the same time higher than the compensation the prosumer would have received).

How are the cases affected if there are other activities in the same property as a prosumer? Many data centers are located in building where there are also other operations, such as an office. It might then be possible for a different operation in the same property to more easily use the excess heat since it does not need to be raised to the temperatures required in the district heating grid and exported. There are good opportunities to achieve great system benefits by using energy flows most efficiently inside buildings. In these cases, it is possible for the building owner to make double profits by charging the data center owner for cooling and using the excess heat to reduce the amount of district heating purchased. In order to create the right incentives from a system perspective, it is important that the district heating company's price models reflect the actual costs of the district heating company, which is often not the case, especially for power-related costs. It is also important to have a system perspective when analyses are carried out, systems are designed, and decisions are made regarding energy solutions in such properties.

6 Conclusions

In the overview of existing solutions, four concepts are examined in greater detail: Öppen Fjärrvärme, Delad Energi, Samenergi and Värme Tillsammans. There is a very small share of the district heating companies in Sweden that have a standardized offer aimed at small-scale heat suppliers and prosumers. This is despite the fact that both practical experience and the results of the simulation study in this report show that there are conditions for profitability in such solutions. One objective of this project is that the results should facilitate and improve the efficiency of the activities a district heating company needs to carry out in order to have an offer for small-scale heat suppliers and prosumers. A second phase of this project aims to further improve these conditions by developing the results from the first part to an IT solution that can be cost-efficiently applied to many district heating grids and manages the functions required to have a standardized offer for small-scale heat delivery.

The system benefits that can be achieved through small-scale heat suppliers and prosumers have been studied for six different archetype grids where two small-scale suppliers have been used as case studies. The resulting system benefit vary a lot but generally there is a potential for profitability from a system perspective under many different conditions. It is simply the case that the additional costs associated with exporting heat from a potential small-scale supplier are often sufficiently lower than the marginal cost of heat generation in the archetype grids studied. This is the basic prerequisite for it to be worthwhile to implement such solutions.

Based on the calculated system benefit, business model concepts and remuneration models have been described and applied to the two case studies. For compensation for exported energy, remuneration models that are close to the real value of the heat delivery every hour create the best incentives for deliver heat when it is profitable from a system perspective. If a small-scale heat supplier can guarantee to provide power when it is needed in the grid, a power component can be part of the remuneration. The suitable level of compensation for guaranteed heating power depends mainly on the alternative cost of investing in and maintaining heating power capacity in the district heating grid, which varies between grids. The report presents averages values for the alternative cost for power based on a number of grids, which may give a good general indication.

In order to technically manage small-scale heat suppliers and prosumers, only a few new signals and interfaces between district heating companies and their customers are required. The information that may need to be shared in continuous data streams is energy prices, weather forecasts, supply temperature requirement and planned heat export.

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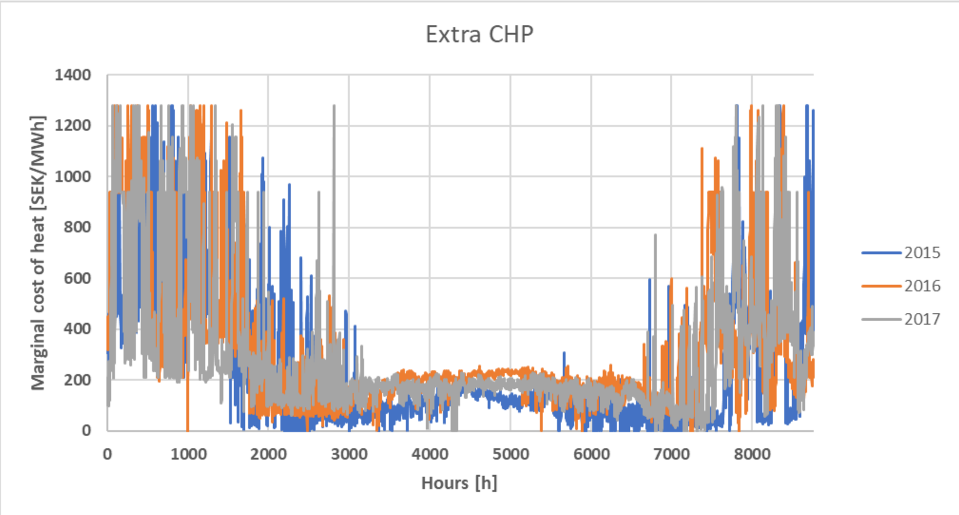
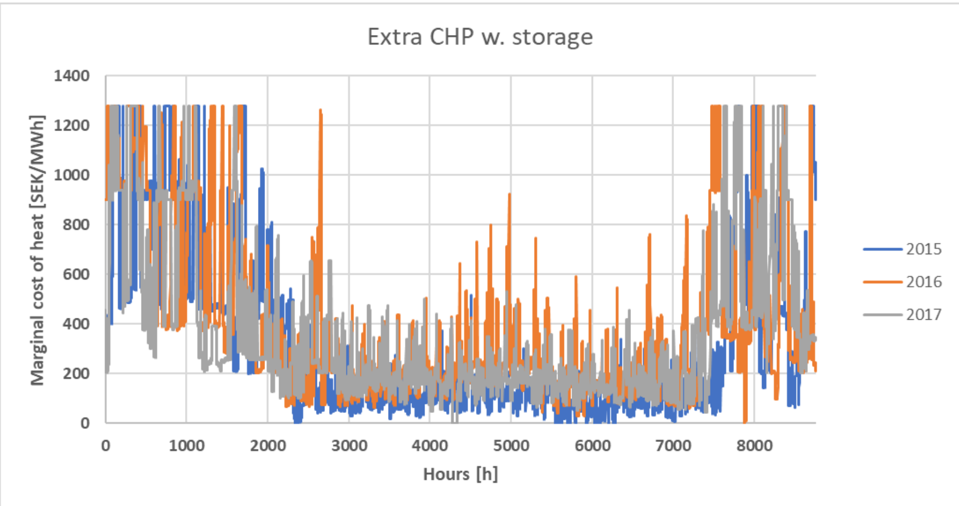
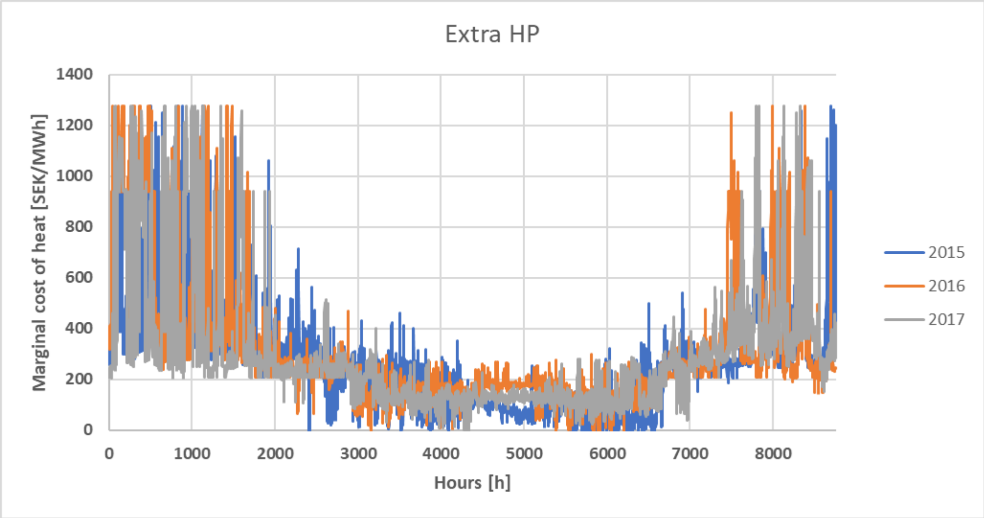
Appendix A: Marginal generation costs for archetype grids

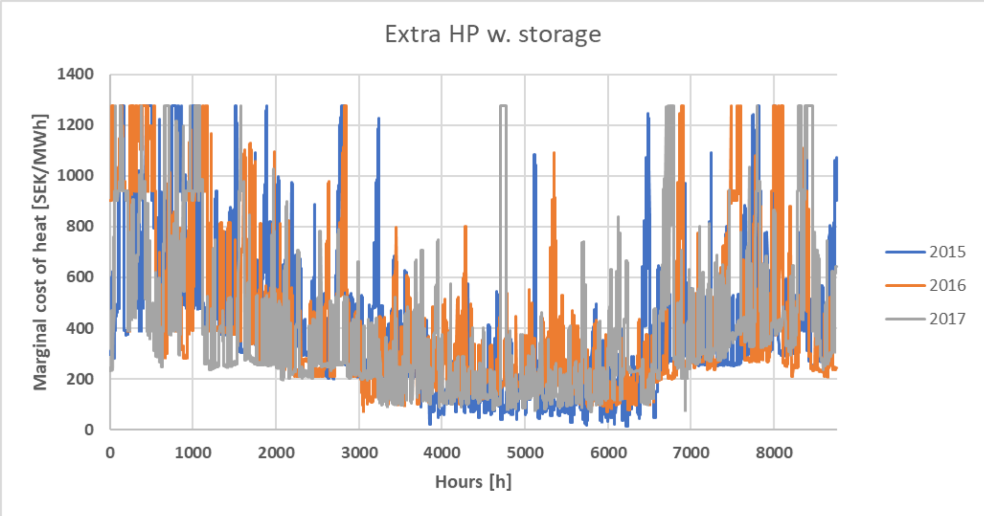
This Annex presents marginal cost for heat generation in all six archetype district heating grids used in the simulations in this study. The costs are presented as hourly costs in each year simulated (2015, 2016 and 2017), as cumulative distribution functions averaged for the three years, their correlating with outdoor temperature plotted both as a scatter and as average cost as a function of outdoor temperature.

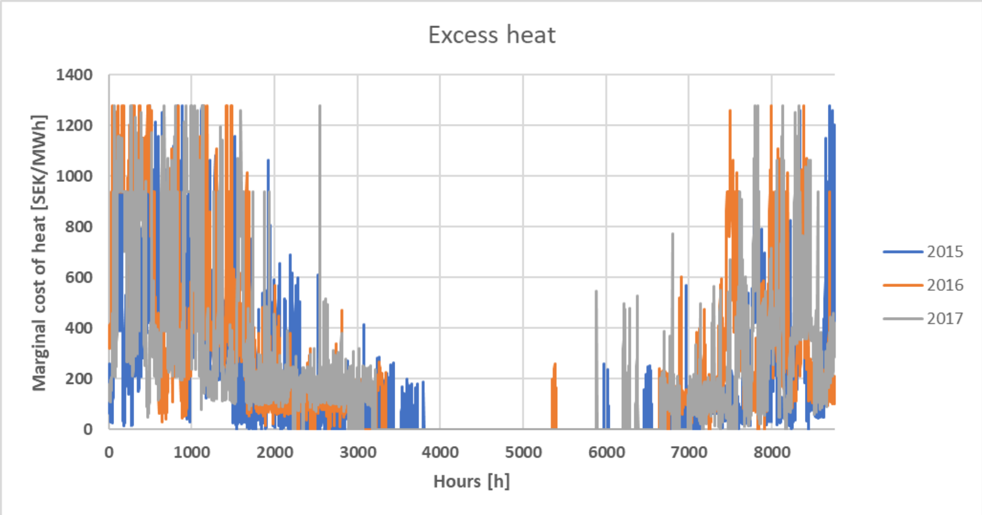
MARGINAL COST FOR HEAT GENERATION FOR EACH ARCHETYPE HEAT GRID AND YEAR






Extra HP
Marginal cost of heat [SEK/MWh]
1400
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Hours [h]
2015
2016
2017


Extra HP w. storage
Marginal cost of heat [SEK/MWh]
1400
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Hours [h]
2015
2016
2017


Excess heat
Marginal cost of heat [SEK/MWh]
1400
1200
1000
800
600
400
200
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0
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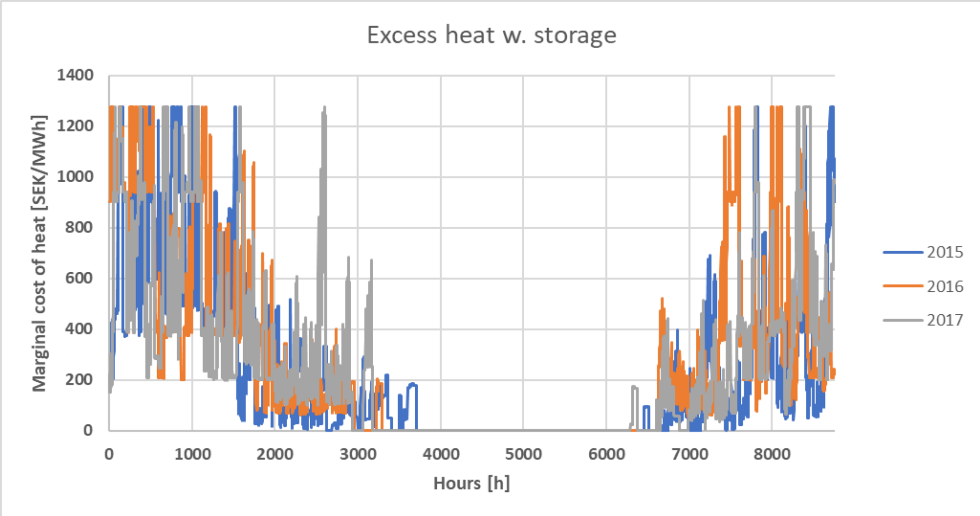
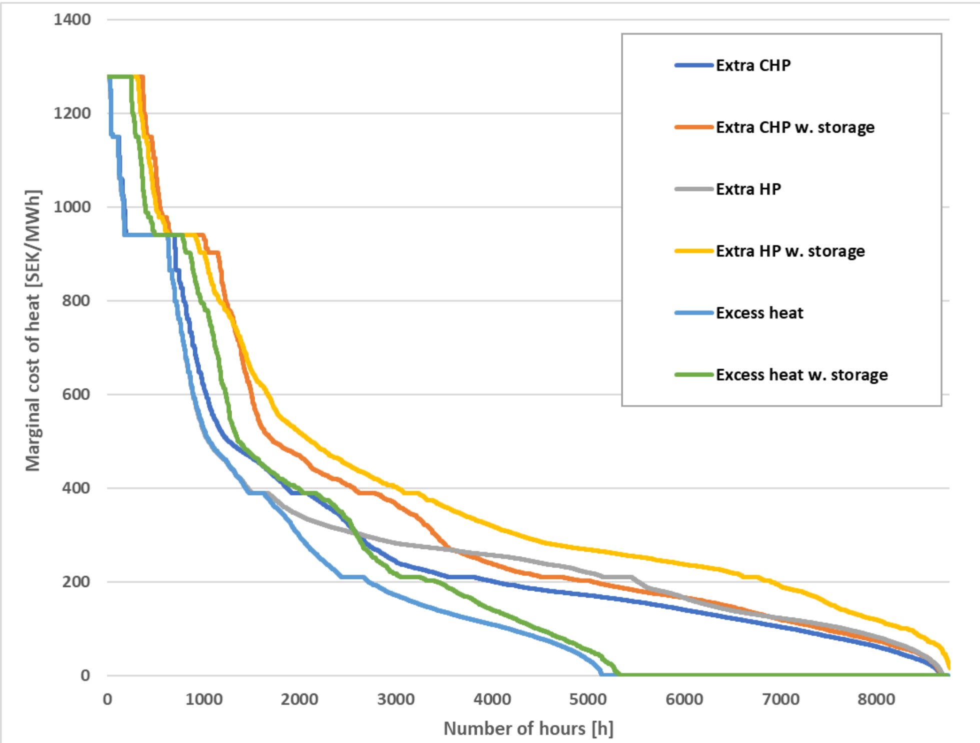
2000
3000
4000
5000
6000
7000
8000
Hours [h]
2015
2016
2017

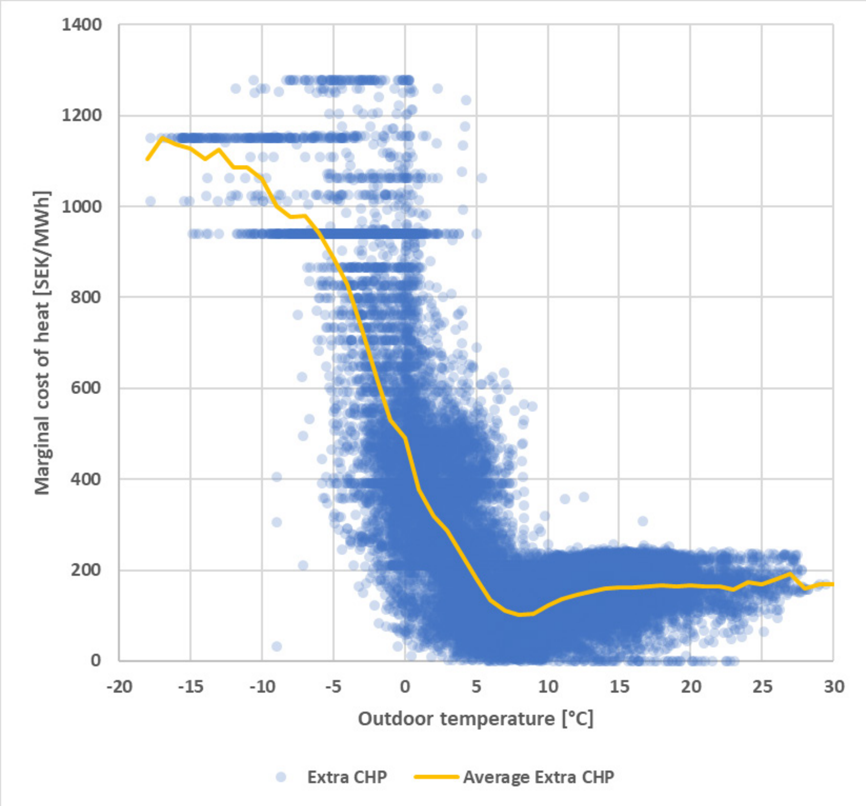


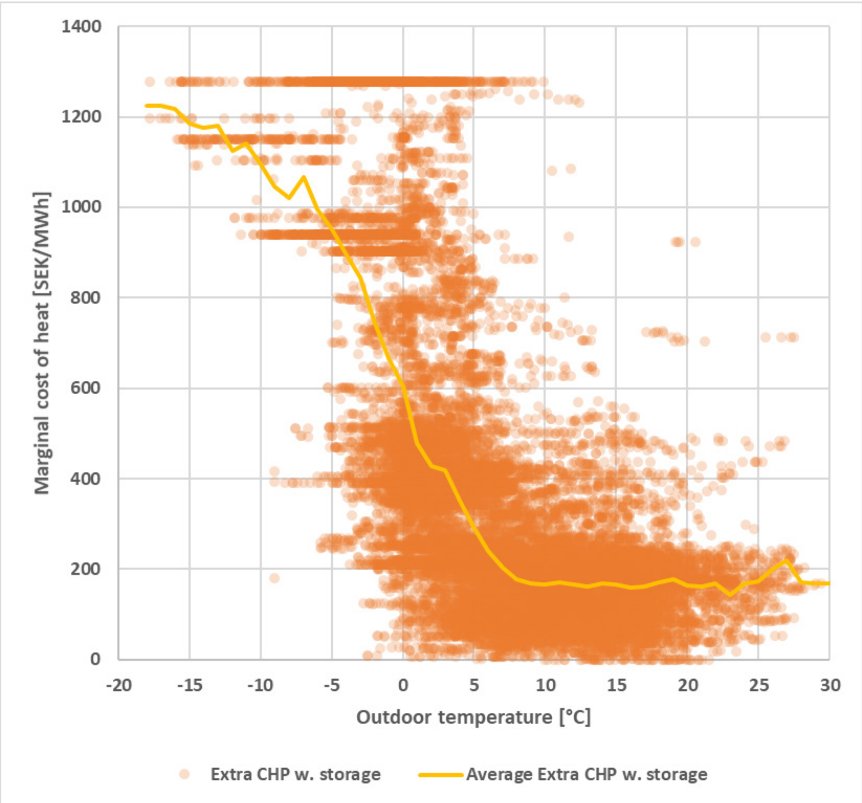
CUMULATIVE DISTRIBUTION FUNCTION

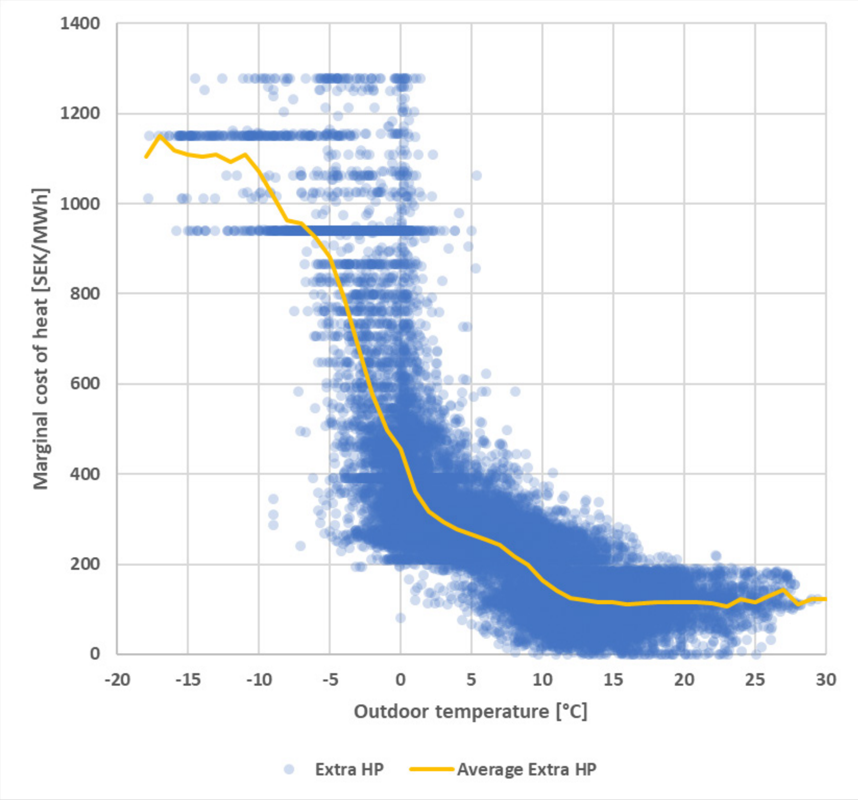
The cumulative distribution function for the marginal cost of heat generation in each archetype heat grid averaged for all three years. The average is calculated by having each hour during the three years be represented by 1/3 hours in the graph.

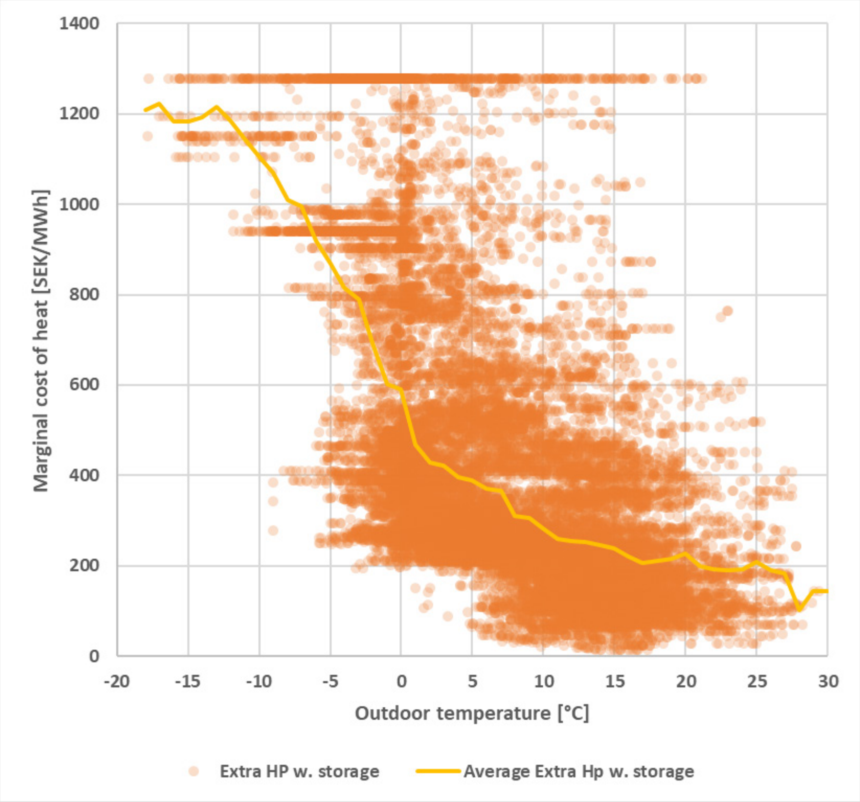


MARGINAL COST FOR HEAT GENERATION CORRELATION WITH OUTDOOR TEMPERATURE






1400
1200
1000
800
600
400
200
0
Marginal cost of heat [SEK/MWh]
-20 -15 -10 -5 0 5 10 15 20 25 30
Outdoor temperature [°C]
Extra HP
Average Extra HP


1400
1200
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200
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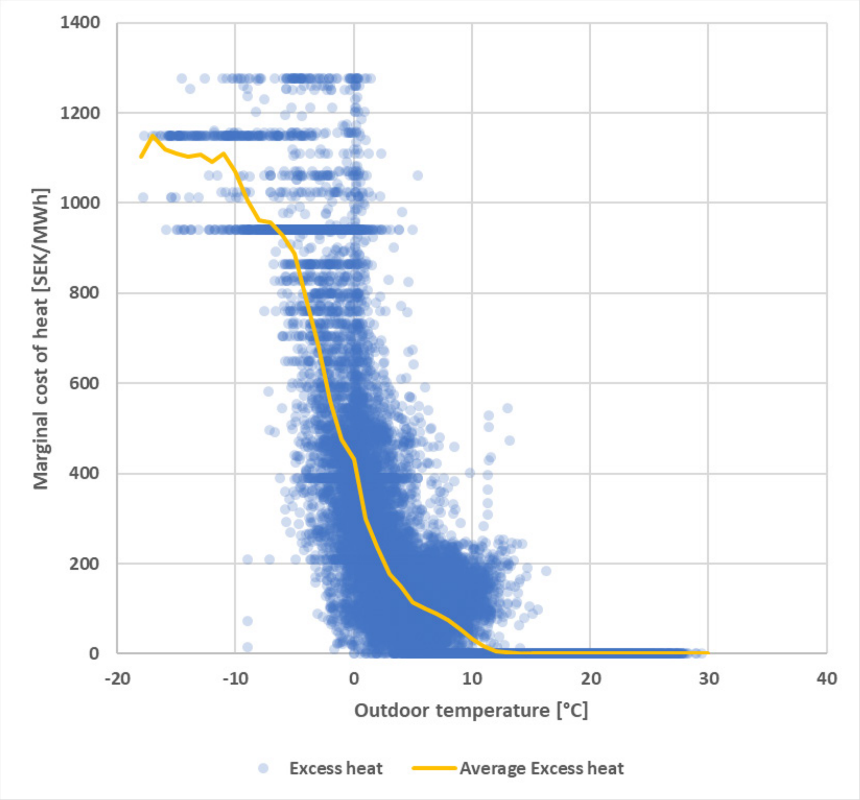
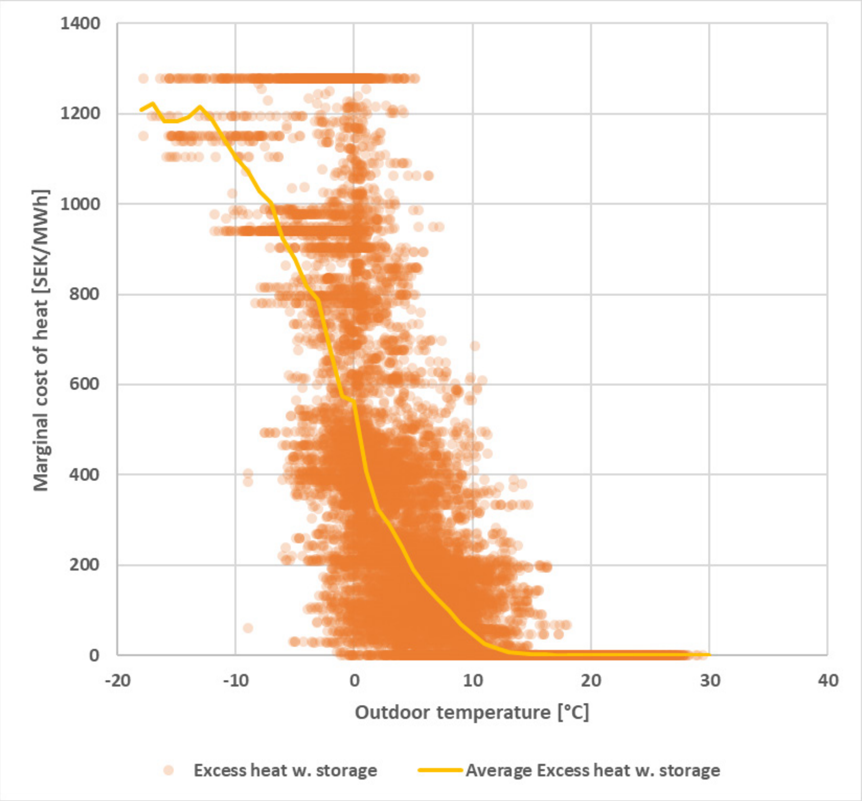
Marginal cost of heat [SEK/MWh]
-20 -15 -10 -5 0 5 10 15 20 25 30
Outdoor temperature [°C]
Extra HP w. storage
Average Extra Hp w. storage



1400
1200
1000
800
600
400
200
0
Marginal cost of heat [SEK/MWh]
-20
-10
0
10
20
30
40
Outdoor temperature [°C]
Excess heat
Average Excess heat



1400
1200
1000
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400
200
0
Marginal cost of heat [SEK/MWh]
-20
-10
0
10
20
30
40
Outdoor temperature [°C]
Excess heat w. storage
Average Excess heat w. storage

TOOLBOX FOR PROSUMTION IN DISTRICT HEATING

This report intends to provide district heating companies with tools for designing standardized offers for small-scale delivery and prosumption. Utilizing excess heat that would otherwise have been wasted is one of the most important aspects of district heating systems.

In many district heating systems, there are ongoing collaborations between industries and local district heating companies. Several larger-scale sources are already connected to the district heating grids but there are also small-scale sources that can be utilized.

To connect and utilize surplus heat from a variety of different smaller suppliers and prosumers, simple and standardized processes are required. In the report, existing standardized offers for small-scale heat deliveries to Swedish district heating grids are described.

In addition, the economic potential of two different types of prosumers, a data center and a grocery store, in six typical district heating networks have been calculated by simulations in the project.

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