BUSINESS MODELS FOR COMBINING DISTRICT HEATING AND HEAT PUMPS IN BUILDINGS

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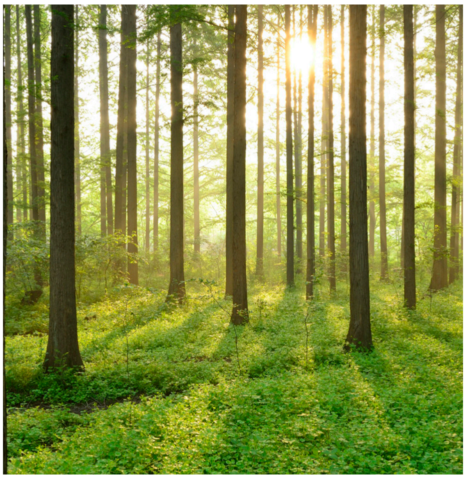

FUTUREHEAT

Energiforsk

Business models for combining district heating and heat pumps in buildings

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Foreword

It is desirable to heat properties as efficient as possible and in properties with both district heating and heat pumps, the heating can be optimized with respect to the energy price. Ensuring the energy source being the most profitable for the moment are being used for heating. The optimization could be carried out by a utility that produces district heating and, in this project, corresponding business models have been investigated.

The project was led and conducted by Jonas Ottoson, IVL Swedish Environmental Research Institute, together with Linnea Johansson and Johan Kensby from Utilifeed and Kristina Lygnerud, Johanna Nilsson and Anna Nilsson from IVL Swedish Environmental Research Institute.

A reference group consisting of Per Örvind, Eskilstuna Strängnäs Energi & Miljö (chair); Agneta Filén, Halmstads Energi & Miljö; Ann Björnsjö, Telge Nät; Cecilia Ibanez Sörenson, Vattenfall; Chirster Boberg, Stockholm Exergi; David Edsbäcker, Kraftringen; Emil Berggren, Tekniska Verken i Linköping; Johan Thelander, Karlstad Energi; Lena Olsson Ingvarsson, Mölndal Energi; Magnus Gunnarsson, Öresundskraft; Mattias Tellrud, Norrenergi; Petter Hansson, Göteborg Energi och Stefan Hjärtstam, Borås Energi och Miljö 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.

Sammanfattning

Vårt energisystem består av flera olika delsystem och vilket av dessa som bör utnyttjas för mest effektiv uppvärmning av fastigheter varierar beroende på väder och pris på energi. Ju fler energisystem en fastighetsägare har tillgång till, desto mer optimerad kan uppvärmningen göras. I fastigheter där uppvärmningen kan ske både genom att utnyttja ett fjärrvärmesystem och elsystemet finns det möjlighet att göra optimeringar som är till nytta för båda system samtidigt. Ett energiföretag som producerar fjärrvärme har därför en unik position för att erbjuda sådan optimering. Denna studie utreder hur affärsmodeller för detta kan se ut.

I studien har två olika koncept identifierats, vilka tillåter kontinuerlig växling mellan värmekällor så att den som är mest lönsam för stunden används i fastigheten. Växlingen kan ske genom olika grader av involvering från ett energiföretag. En möjlighet är att erbjuda en produktorienterad lösning, där en optimeringsprodukt installeras och drifthålls hos kunder av ett energiföretag. Samtidigt kan nya prismodeller med högre tidsupplösning än vad som är vanligt idag utvecklas. Alternativt kan växlingen av värmekälla inkluderas i ett mer heltäckande tjänsteerbjudande där kundens fastighet värms upp genom ett komfortavtal, där energiföretaget nyttjar kundens egendom (värmepumpen).

Båda koncepten innebär att energiföretag behöver utveckla och bredda sin portfölj av erbjudna energitjänster. Energiföretag har kommit olika långt i arbetet med tjänsteutveckling och för vissa innebär det produktorienterade konceptet färre hinder än tjänsteavtalet. Oavsett vilket koncept som används, blir relationen och samarbetet mellan energiföretag och kunder allt mer viktigt och kan för ett energiföretag innebära det största värdet i affären, även om det är svårt att sätta siffror på.

Ett hinder för att energiföretag ska kunna erbjuda kunder att optimera driften av kundens anläggningar ligger i att lagstiftningen inte är helt anpassad till att exempelvis kommunala energiföretag ska kunna erbjuda tjänster där flera värmekällor ingår samtidigt. Analyser i denna studie visar att det bör gå att utforma erbjudanden som inte bryter mot konkurrenslagstiftning, fjärrvärme- eller ellagarna eller LOU, men det är viktigt att göra en juridisk bedömning av erbjudandena från fall till fall.

Genom simuleringar baserade på marginalproduktionskostnader för fjärrvärme och spotpriser på NordPool visar denna studie att fastigheter med en värmepump och fjärrvärme kan minska sina årliga totala uppvärmningskostnader med mellan 2 – 33 % om uppvärmningen optimeras för lägsta uppvärmningskostnad. Storleken på besparingen beror mycket på hur det lokala fjärrvärmenätet ser ut. För samma fastigheter kan utsläppen av CO_2-ekvivalenter minskas med mellan 0 – 75 % till följd av växlingen. Minskningen beror mycket på hur det lokala fjärrvärmesystemet är utformat, störst minskning fås i fjärrvärmenät med tillgång till industriell spillvärme.

Summary

Our energy system consists of several different subsystems. Which subsystem that should be used for the most efficient heating of buildings varies depending on weather and price of energy. The more energy systems a property owner have access to, the more optimized heating can be achieved. In properties where the heating can take place both by utilizing a district heating system and the electricity system, there is an opportunity to make optimizations that are useful for both systems at the same time. A utility that produces district heating therefore has a unique position to offer such optimization. This study investigates what business models for such offers can look like.

The study has identified two different concepts, which allow continuous shifting between heat sources so that the most cost-efficient heat source for the moment is used in a building. The heat source shifting can take place at different degrees of involvement from a utility that provides district heating. One possibility is to offer a product-oriented solution, where an optimization product is installed and operated by customers of a utility. At the same time, new pricing models with higher time resolution than is usual today are developed. Alternatively, the heat source shifting can be included in a more comprehensive service offering where the customer's building is heated under an energy performance contract, where the utility uses the customer's property (the heat pump).

Both concepts mean that utilities need to develop and broaden their portfolio of energy services. Utilities are at different stages in the service development process and for some, the product-oriented concept poses fewer obstacles than the energy performance contract. Regardless of which concept is used, the relationship and collaboration between utilities and customers is becoming increasingly important and, for a utility, can give the greatest value, although it is difficult to quantify this value.

One obstacle for utilities to offer customers optimization of the operation of the customer's equipment lies in the fact that legislation is not fully adapted to, for example, municipal utilities being able to offer services where several heat sources are included. Analyses in this study show that it should be possible to design offers that do not violate competition law, district heating or electricity laws or LOU, but it is important to make a legal assessment of the offers on a case-by-case basis.

Through simulations based on marginal production costs for district heating and spot prices from NordPool, this study shows that buildings with a heat pump and district heating can reduce their annual total heating costs by between 2 - 33% if the heating is optimized for lowest heating cost. The size of the savings depends heavily on what the local district heating network looks like. For the same buildings, emissions of CO_2 equivalents can be reduced by between 0 and 75% as a result of shifting heat sources. The reduction depends on the nature of the local district heating system, the largest reduction is obtained in district heating networks with access to industrial waste heat.

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1 Introduction

To remain competitive, energy companies need to work actively with new solutions that exploit the opportunities that the digitalisation of the energy system entails in a profitable and sustainable way. One such opportunity is to participate to a greater extent and optimize customers' energy use, by offering the use of different heat sources and a cost-optimized control of these. One possible development is cost-optimized control of customer facilities where heat pumps and district heating are combined.

The technical prerequisites for offering optimized solutions and services are already in place and will become increasingly relevant in the future. The difficulties soes not lie in technical details but rather in the design of the new type of business that such a service entails for energy companies. Increasing knowledge of business and legal aspects of service delivery is highly relevant to district heating companies and their future competitiveness. This study therefore examines how business models of energy companies change if customers heating equipment are optimized by the energy company. In addition, the value that the service creates for customers, energy companies and the energy system as a whole is highlighted.

The purpose of this study is to investigate and show how customers' equipment (i.e. heat pumps) can contribute to the optimization of the district heating system. The study shows how the agreement between an energy company and a customer can be designed when the control of the customer's equipment (heat pump and district heating) is made with regard to production conditions in the district heating system and the electricity system. In addition, the benefits and value that the control and optimization can provide for both the energy company and the customer are quantified.

This study includes:

- an interview study with district heating companies and property owners
- a legal analysis and review of contract design and competition aspects
- a simulation study of the potential for a building owner to switch heat loads from heat pumps to district heating more frequently, expressed both economically and environmentally.

The study identifies two different concepts that allow load shifting between district heating and heat pumps to be carried out in buildings with different degrees of involvement from an energy company. One possibility is to offer a product-oriented solution, where an optimization product is installed and operated by the customer of an energy company. The energy company time also develops new price models with higher time resolution than is usual today. Alternatively, the load shift can be included in a more comprehensive offer where the customer's building is heated under a comfort agreement, where the energy company has the right to use the customer's heat pump.

According to the interview study, the impact on energy companies' existing business models will be relatively small, but this may differ from case to case depending on how far the company has come in its process of developing and offering energy services. Business models for district heating in combination with customers' heat pumps will affect the customer relationship by increasing the proximity between the energy company and the customer. This relationship can potentially represent the greatest value in the business for energy companies since increased proximity can lead to increased transparency, trust, and long-term commitment from customers. These aspects all strengthen the competitiveness of district heating companies compared to other forms of heating. Some legal barriers, such as uncertainties regarding the competitive situation in the procurement of combined energy services, for offering the optimization services proposed in the study have been identified. These should, according to the legal review, be overcome for each individual case through the adaptation of agreements and the offer's packaging. In particular, it is important that the value the form of increased system benefit is highlighted in the offering to customers.

For all properties used as case studies in the study, optimization of heat pumps provides cost savings for building owners, assuming that energy companies offer optimization solutions that allow optimization to be performed based on marginal production costs in the district heating network. The optimization has been carried out with the aim of minimizing the cost of heating in a single building, which also means that the overall system costs are also minimized. The savings potentials reported are thus the highest achievable savings and can be reduced depending on how other fixed charges for district heating and electricity are designed. Three case studies show that property owners with heat pump and district heating can make annual savings through load shifting of between 2 - 33%, depending on the heat pump installation in the property and which district heating network it is connected to. Load shifting operation means that heat pumps are switched off in favour of district heating use. Load shifting operation can also mean the opposite, that district heating use in a building decreases in favour of a heat pump if this gives the lowest system cost. The highest saving potential exists for a ground source heat pump in a district heating grid with large amounts of excess heat available and the lowest saving potential exists for an exhaust air heat pump in a network with a high share of large, central heat pumps.

Load shifting between heat pumps and district heating based on its marginal production costs also gives rise to reduced emissions of CO_2 equivalents from energy use in buildings. For an individual building, emissions can be reduced by 0 - 75% per year from a system perspective, where calculations are made according to consequential LCA. The reduction of emissions is highly dependent on the type of network in which a building is located. The reduction of emissions is mainly attributable to reduced marginal electricity use in heat pumps in favour of district heating use. In a district heating network with accessible waste heat, the greatest reduction of emissions is achieved, since the heat use in buildings is often shifted from the electricity system to hours when there is unused waste heat available in the district heating system during spring, autumn and summer. The lowest emission reduction is achieved in a network with a large proportion of central heat pumps. Electricity prices in the spot market also have an effect on the results, for the building with a ground source heat pump the savings potential for the building owner varies by 10% between 2015 and 2016. Thus, the distribution in the resulting savings is large between case studies and especially between type networks, so it is recommended that the benefit of shifting loads between district heating and heat pumps are studied in each case.

In a building where a ground source heat pump, in addition to being controlled based on marginal costs in the district heating network and spot prices on the electricity market, additional savings for the building owner and the system as a whole can be obtained by performing a cost optimization in a second step based on the regulating power market mFRR. A ground source heat pump in a building would be switched off additionally between 65 and 770 hours for one year in favour of local district heating use if the heat pump could have been used as a down-regulating power reserve on the regulating market. However, the extra revenue from this regulation is relatively small compared to the savings from optimizing against the spot market. In addition, today's demand for minimum bid volumes on regulating power markets is too high for individual heat pumps to be able to participate in the trade. However, by aggregating several heat pumps in an area, the potential can be utilized in a future scenario. There are also other ways for energy companies to benefit from flexible control of heat pumps that are supplemented with district heating, for example by avoiding penalties for high power outages against overlying electricity distribution networks.

Keywords

District heating, heat pump, business model, simulation, optimization, load shifting, comfort agreement, energy services

2 Theory and Methodology

2.1 REPORT STRUCTURE

This report is divided into 4 chapters. Chapter 1 is introductory, in Chapter 2 the theory and methodology used are described. In an introductory section, 2.3 Review: Optimized heat pumps with district heating in properties, a brief review of research and existing offers that deal with the load shifting between heat pumps and district heating in properties is made. Then, in section 2.4, the theoretical frameworks with which energy companies' business models and service development are described in the report is presented. Section 2.5 briefly describes how heat pumps can participate in electricity markets other than NordPool's spot market. Chapter 3, Implementation describes the case studies that have been used as the basis for the study along with interviews, simulations and analyses that were performed based on these cases. All results are reported in Chapter 4 and divided into results from interviews, proposed revenue concepts based on interview results and simulated results in the form of financial and environmental savings for a property owner. Section 4.9 provides an overview of technical requirements and aspects that need to be considered to implement the proposed concepts. Finally, section 4.10 presents the factors that are important to consider regarding the legal aspects of the proposed concepts.

2.2 PURPOSE OF THE PROJECT AND SUMMARY OF USED METHODOLOGY

This study is a continuation of the work described in the FutureHeat-report “The value of flexible heat demand”, (Kensby, Johansson, Jansson, & Carlsson, 2019). In the previous report, the potential for economic and environmental savings from three different types of demand flexibility in district heating networks was calculated; heat storage in buildings, borehole storage connected to buildings and load shifting between district heating and heat pumps in buildings with both heat sources available. In the previous work, the types of flexibility were studied on an overall level and the potential was expressed based on reduced variable costs from a system perspective, savings for an individual building were treated in lesser detail.

The purpose of this study is to extend the analyses carried out in the previous study and to study how energy companies' business models can be designed to enable demand flexibility from load shifting between district heating and heat pumps in buildings. Here, the potential for load shifting in a single building is studied in detail, which is a complement to previous study. The study includes an interview study, a qualitative analysis of contract issues and a simulation study based on real case studies from four Swedish district heating networks.

In the interview study, factors that affect the energy companies' business model are mapped if they choose to offer an optimization service for district heating and heat pumps to their customers. Respondents in the interview study have been energy companies and their customers (building owners). Both respondent groups have mixed experiences of optimizing services. One respondent among the energy companies and a building owner had experience of solutions with optimized combinations of district heating and heat pumps. Other respondents had experience of district heating and heat pump in combination and/or energy service agreements, but not both factors in the same offer. Based on the interview study, two different possible business models are proposed for energy companies that want to offer the optimization to customers.

The analysis of how agreements for new business models can be formulated is based on a compilation of existing agreements for energy services from Swedish district heating companies. The analysis has been verified and supplemented by independent contract lawyers.

In the simulation study, four buildings were placed in six different types of networks, which are representative of a large part of district heating networks in Sweden. For each combination of the four buildings and the six type networks, the potential cost savings and avoided CO2 emissions that a building owner can obtain by actively shifting between district heating and heat pump are calculated. The potentials are calculated under the assumption that the energy company has developed a price model with energy prices based on hourly marginal production costs. The assumption has been made to describe the maximum savings or system benefit that can be achieved by shifting between heat pumps and district heating. Developing a new price model is a major task that can take several years from an initial decision to change price model until it is fully implemented. Thus, fully developing price models are outside the limitations of this project and a simplified price model based on marginal costs for district heating production is adopted and used in simulations and calculations. The case studies have been used as a starting point to map the impact on energy companies' business models, development and verification of revenue concepts and calculations of the potential for savings achieved by optimized control of heat pumps together with district heating.

2.3 CURRENT SITUATION: OPTIMIZED HEAT PUMPS IN COMBINATION WITH DISTRICT HEAT IN BUILDINGS

Combining heat pumps with district heating is not uncommon in Swedish district heating networks, both in the central production system for district heating (DH) and in individual buildings. At least 3% of Swedish multifamily homes have both a heat pump and a district heating connection installed, based on energy declarations (Boverket, 2018), and it is common that an existing property where only district heating has been used previously is supplemented by a heat pump (Boss, 2012). Reasons for property owners choose to install heat pumps as a supplement to a district heating connection is, among other things, to achieve financial savings and to meet energy use requirements. Combined installations can be made in several different ways, with a heat pump and district heating connected in series or in parallel relative to each other. Depending on the type of heat pump, the property's other heating systems and price levels on electricity and district heating, the heat pump is used to varying degrees to produce both domestic hot water and space heating, or space heating only. As the heat pump's installed power is not sufficient to meet the need for space heating or domestic hot water, district heating is used (Boss, 2012). A heat pump installed in combination is not dimensioned to cover the entire yearly energy demand, partly because the heat pump's coefficient of performance (COP) decreases as the temperature of the heat pump's heat source drops, or as the supply temperature in the building increases. This occurs at low outdoor temperatures and it will then be profitable for the property owner to use district heating instead of the heat pump (Boss, 2012). The most common type of heat pump combined with district heating is exhaust air heat pumps (EAHP), on average they are dimensioned to cover 56% of multi-dwelling buildings' space heating needs, provided that they are only used to produce room heating and not tap hot water (Kensby, Trüschel, & Dalenbäck, 2017). Other types of heat pumps, such as ground source heat pumps (GSHP), generally have higher efficiency and can be used for domestic hot water production to a greater extent. Typically, a GSHP is designed to cover 95% of the total annual energy demand in a property and 65 - 70% of the maximum power demand (Energikontoren, 2020).

From the perspective of the DH supplier, a so-called partial conversion (when a heat pump is combined with district heating) is often problematic, for several reasons. Depending on the connection of the heat pump, the return temperatures of DH from the building may increase, which reduces the efficiency of the DH system. In addition, a partial conversion means that the amount of energy delivered drastically decreases for the DH supplier. Before the partial conversion was carried out, the DH supplier has invested in the connection of the property to the DH network and with reduced energy delivery, the profitability of the investment is negatively affected. In addition, DH delivery often only occurs when the property has a large total heat demand, which cannot be covered by the heat pump, at the coldest hours of the year. During these hours, peak production plants with high variable costs are typically operating in district heating production (Boss, 2012).

By introducing tariffs based on the peak power demand for DH, the profitability of installing a combined heating solution decreases, as the power peaks for DH do not decrease to the same extent as the energy consumption in a partial conversion. Boss also points out that seasonally differentiated energy prices for DH are a decisive reason why profits from using heat pumps for domestic hot water production in the summer time decrease (Boss, 2012).

Combined heating solutions also offer advantages, through the combination a local district heating system is coupled with the overlying electrical system and it is possible to draw benefits from both systems. Heat pumps are very efficient within certain operating intervals and provide very low heating costs at low electricity prices, while district heating is very reliable for delivery and often has environmental benefits compared to using electricity for heating (Kensby, Johansson, Jansson, & Carlsson, 2019). Some property owners take advantage of this to a certain extent, for example by manually switching off heat pumps during the summer months, as many district heating suppliers offer very low energy prices during that time period (Lindahl, Gustafsson, Markusson, & Haglund Stignor, 2017). A disadvantage of supplementing district heating with heat pumps is that the electric power demand increases, which contributes to an increased risk of power shortages and exceeding subscribed power limits in local electricity networks (Axelsson, Blomqvist, & Unger, 2018).

However, there is room to benefit even more from combining HP and DH if more sophisticated methods of minimizing heating costs in a building with combined heat sources are used. Electricity prices on the NordPool spot market vary by hour, and although district heating prices offered to customers do not vary more than between seasons, district heating production costs do. If the heat source that gives the lowest production costs in both the electricity system and the local district heating system is used, sub-optimizations of two systems are avoided and an overarching system benefit can be achieved (Kensby, Trüschel, & Dalenbäck, 2017). In addition to provide system benefits (for example, that more waste heat can be used for heating instead of being cooled off, or that more electricity can be produced in biomass fuelled combined heat and power plants) optimizing combined HP and DH connections in buildings can also render reduced heating costs for a building owner (Kensby, Johansson, Jansson, & Carlsson, 2019). To carry out the optimization, the DH company must in some way expose the customer to the production situation in the system, by creating new price signals or other solutions.

Optimizing the use of heat pumps and district heating in properties has been investigated previously. In addition, there is experience from both Gothenburg Energy and Kraftringen in the form of pilot projects. Three theoretical studies and two pilot projects are summarized below. The studies and pilot projects have been identified through a literature search with keywords such as "combination", "heat pump", "district heating", "optimization" in different combinations and by suggestions from the projects reference group.

2.3.1 The value of flexible heat demand

In the project "The value of flexible heat demand", it was studied how often exhaust air heat pumps in buildings with a DH connection would switch heat source if they were optimized based on marginal production costs for DH (Kensby, Johansson, Jansson, & Carlsson, 2019). Simulations in six Swedish typical networks (the same typical network is also used for simulation and analysis in this study) were performed and the conclusions were as follows:

Based on energy declarations from four studied Swedish cities, there should be 81 properties with both EAHP and DH in a typical DH network with an annual heat generation of 500 GWh. These heat pumps are estimated to have a total maximum heat output of 1.8 MW. If these heat pumps are controlled flexibly, the system's total operating cost (district heating + heat pumps in buildings) can be reduced by 0.22–1.12 kSEK/year. The reduction is greatest for typical networks with a large share of excess heat and least for networks with large-scale centralized heat pumps. The cost reduction will be about the same in a typical network with an accumulator tank as in a type network without one. The savings per utilized heat pump is 2.7–13.6 kSEK/year, which can also be expressed as 120–610 kSEK per year and MW of flexible heating power in heat pumps in buildings. In total, emissions of CO_2 equivalents of 0.4–2.3 ktons/year are also achieved. The balancing effect that the optimization has on the electricity grid is questionable as the heat pumps in the buildings consume relatively more electricity at high electricity prices when they are flexibly controlled. This is because the marginal cost in the district heating network tends to vary more and be low at low electricity prices. However, the balancing effect on the electricity grid from electric power production in CHPs in district heating networks increases if the heat pumps in the properties are controlled flexibly.

2.3.2 Potential study: Gothenburg

The potential for switching between EAHPs and DH in buildings was studied in 2017 in the city of Gothenburg's DH system (Kensby, Trüschel, & Dalenbäck, 2017). The potential was calculated by comparing marginal production costs for DH and the cost of producing heat with the HP based on electricity prices on the spot market.

The most common combination of HP and DH in Gothenburg is EAHP connected in parallel with district heating and the HP is only used for space heating. The reason for this is that the local DH supplier demands that the connection principle is to be used to avoid elevated return temperatures in the DH network and the very low energy prices for DH during the summer months in Gothenburg due to a large amount of available waste heat. Among all multi-dwelling properties in Gothenburg, 2.7% have an EAHP installed in combination with DH. Across Sweden, the corresponding figure is stated to be 2.2%. If the EAHPs had been controlled optimally based on marginal production costs for district heating and spot prices for electricity in 2013 and 2014, an average multi-dwelling property could have lowered its annual heating costs (DH and electricity for the HP) by 3.2%.

2.3.3 Effsys expand

The Swedish Energy Agency's research program focusing on the development of heat pump technology, Effsys Expand, included the project "*Heat pumps in district heating systems*" (Lindahl, o.a., 2018). In the project, an algorithm was developed, which calculates when it is most cost efficient with regard to energy prices to use DH or HP in a property that has both DH and an EAHP installed and has the opportunity to shift between the two heat sources.

The algorithm developed in the project chooses the heat source with the lowest variable cost on an hourly basis, the heat from either DH or the HP should cover both space heating and domestic hot water demand. For evaluating the algorithm, a case study was used in the form of a modelled multi-family house with DH and EAHP. A fictitious EAHP was applied in the case study and weather data and spot prices on electricity from NordPool in 2015 were used. The algorithm considers only the variable part of the electricity price and not fixed costs such as electricity certificates, energy tax, the electricity company's surcharge, or transmission fees.

In the evaluation of the algorithm, the price of DH was set according to actual prices from the local DH supplier in Linköping, where only the variable parts of the price were included, i.e. energy and flow prices. In reality, the DH price also included a power tariff, which the algorithm did not take into account.

In the case study, with weather data and electricity prices from 2015, the HP was used for space heating and domestic hot water from October to April. From May to September, district heating is used as it gives lower variable costs. However, during a large share of the year additional heating from DH is required.

The project also carried out several sensitivity analyses. The heat pump's COP was varied and electricity prices from several different years were used as input. It was found that heat source shifting gave the greatest savings potential as electricity prices are high and vary widely, as was the case in 2010. The heat pump's COP, in comparison to electricity prices, had significantly less impact on the potential.

The savings potential for heat source shifting was calculated in comparison with a traditionally connected HP in combination with D. That is, the HP is prioritized during all hours of the year and district heating is only used when the HP capacity is not sufficient to cover the entire heat demand. In addition, a comparison was made with the case where only district heating is used for all heating. In the studied building, the annual savings in heating costs amounted to 2 - 4% with heat source shifting compared to traditional control of the heat pump. The highest savings were obtained during a year with high and varying electricity prices, the lowest savings were obtained during a year with low electricity prices.

The project is also described in a scientific publication where the conclusions are discussed further. In the project, the property owner achieves savings by switching loads, but the authors believe that there may also be benefits for DH companies when HPs are prioritized over DH as expensive peak load production of district heating can potentially be avoided. It is also mentioned that if prices for both DH and electricity vary more than they do today, the benefit of heat source shifting increases (Lindahl, Gustafsson, Markusson, & Haglund Stignor, 2017).

2.3.4 Gothenburg: SmartHeat

In a pilot project called SmartHeat, GSHPs are combined with DH at one of Sweden's largest tenant-owner associations, HSB Brf Backadalen. In the project, the tenant-owner association has collaborated with Göteborg Energi and the contractor Energiförbättring Väst. In 2014, Brf Backadalen partly converted from FH to a conventional GSHP installation for heating part of the association's buildings, to cover peak demands, the DH connection was kept. The alternative to the DH connection was to cover peak loads with an electric boiler, which was considered risky with regard to future electricity prices. DH was also seen as a reliable backup to the HPs (Fahlberg, 2020).

In a second phase, 2017, the remaining buildings were also partially converted from DH to GSHPs. Göteborg Energi then approached the customer with an offer to co-optimize the customer's HP with the rest of the DH network. Brf Backadalen owns the HPS and associated borehole thermal storage, and Göteborg Energi has a right of use to these by an agreement. The borehole storage is charged during summer with DH from industrial excess heat. During autumn and winter, the heat used is used to raise the temperature of the HP heat source and thus their efficiency (Hansson P., 2019).

2.3.5 HybridFX

Kraftringen pays through and collaborates and solution for multi-dwelling properties that combines EAHPs with DH, called HybridFX. Kraftringen acts as a reseller of the HybridFX solution and customers invest in the solution at a one-time cost. The heat pump solution in HybridFX is specifically designed in collaboration between the supplier (Högfors GST) and Kraftringen to be combined with the DH system. The installation, for example, has no effect on return temperatures in the DH system. Kraftringen considers offering HybridFX as part of a comfort agreement as an alternative business model to the one-time cost. HybridFX also allows optimization of the heating system based on current electricity and district heating prices (Edsbäcker, 2019).

2.4 BUSINESS MODELS

The examples given here all show a technical and economic potential in various ways of load shifting between heat pumps and district heating. Except for the two examples from Kraftringen and Göteborg Energi, there is little empirical knowledge and information about how energy companies can offer load shifting to customers. How are the energy companies existing business models affected if the optimization of customers' facilities is to be offered by an energy company? To answer this question, we begin by examining what the existing business model for energy companies look like and what the meaning of offering more and more advanced services to their customers can be.

2.4.1 What is a business model?

The term business model is used in many different industries and contexts. According to Teece (2010), all companies, explicitly or implicitly, use a business model that describes how the company delivers value to customers, creates a willingness to pay for services or products and generates profit. The concept of a business model lacks a clear and universal definition and is used in many different ways and with different purposes in both theory and practice (Zott, Amit, & Massa, 2011). A well-designed business model will be successful if it is differentiated, difficult to imitate and creates profits in an efficient way (Teece, 2010).

A business model is, in summary, a description or reflection of the organizational and financial architecture of a company that I set up to deliver a customer value. The business model is based on assumptions about customers, revenues, costs, customer needs and competitors (Teece, 2010).

Business models are more generic than a business strategy and the business model must often be linked to the overall strategy of the company. Teece points out that an analysis of strategy is necessary to perform when designing a long-term sustainable business model. However, the business model is not to be confused with strategy itself.

Developing a new business model is not an easy task and requires a great deal of knowledge about customers, competitors, and suppliers. The most effective business model often does not show itself directly, but its development is an iterative and incremental process where the model is constantly changed, adapted and improved (Teece, 2010).

2.4.2 Business Model Canvas

A common tool or framework for illustrating a company's business model is the so-called Business Model Canvas. According to the framework, the general business model for a company can be described by 9 building blocks that reflect the company's business logic, see Figure 1 (Osterwalder & Pigneur, 2013).

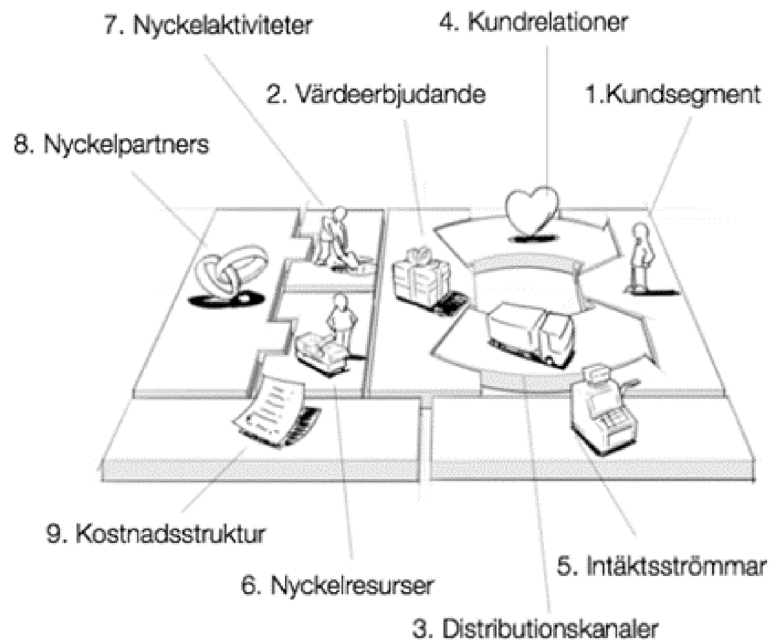

Figure 1 Business Model Canvas (Osterwalder & Pigneur, 2013)

By describing each building block in a structured way, it is easier to get an overview of how a company is supposed to function. Each building block is briefly described here:

1. **The value proposition** is central to the model and is the reason why customers choose a particular company over another. The value proposition describes the combination of the product(s) and/or services that create value for a customer. For DH companies, the value proposition has historically been the delivery of space heat and hot water.

2. **Customer segments** indicate the target group for the company's offer. Some customer segments may be more attractive and profitable than others, and it may be worth putting extra focus on those customers (so-called premium segments). For DH companies, the majority of customers are commercial property owners, although in some locations there is also a significant small-house segment.

3. **Distribution channels** refer to both communication channels and sales and distribution channels. Therefore, for a DH company, channels involve both communication channels such as customer meetings, advertisements, and customer service as well as the physical delivery of heat.

4. **Customer relationships** describe the types of relationships a company establishes with customers. The relationship is affected by the type of business - i.e. the relationship in business associated with products is characterized by greater distances than relationships linked to services. Over time, customer relations have become more important for DH companies. DH companies have gone from considering the customer as a heat sink in the DH system to being an actor with whom, to an increasing extent, holds a dialogue with.

5. **Revenue streams** refer to how the company's revenue is generated, and when. Oesterwalder and Pigneur divide revenue streams into transaction revenues and fixed revenue. Transaction revenues are a result of one-off payments from customers, while fixed revenue is the result of ongoing payments to deliver a value offer or provide support to customers after the purchase. A DH company's pricing model can be said to contain components within both of these revenue streams. Revenues for energy deliveries for a given period constitute transaction revenues while a power charge or a fixed charge can be categorized as a fixed income. Connection fees and service contracts should also be designated as fixed income.

6. **Key resources** are the most important assets of a company. It can be anything from production facilities to financial or intellectual resources. In the DH sector, production facilities and distribution networks are important resources. In addition, knowledgeable staff is important. Regarding staff, the need for knowledge to handle customer dialogue, over time, has proven to be a key to success in the sector.

7. **Key activities** describe what a company must do for the business model to work. For a DH company, key activities are to produce and deliver heat to customers. Other key activities that take a bigger place in the business model are the development and provision of services to the customers.

8. **Key partners** are the network of suppliers and partners that make the business model work. For a DH company, for example, key partners can be fuel suppliers or an electricity grid company within the same parent organization.

9. **Cost structures** describes the costs that arise when the business is conducted in accordance with the business model. Typical costs for a DH company are variable fuel costs and large fixed costs for investment in production plants and distribution networks (Gåverud, Sernhed, & Sandgren, 2016), (Lygnerud, 2018), (Osterwalder & Pigneur, 2013).

DH companies' historical business models and how they can develop over time have been studied in a Swedish context in (Lygnerud, 2018). From an analysis of the development of five DH companies, a development trend is identified in that the focus of the value proposition is shifting from the supply of heat and hot water towards additional sales of services, flexible heating solutions and energy efficiency measures. Previously, the dialogue with the customer was limited to invoicing and targeted campaigns, the customer dialogue is now strengthened, and the customer relationship is now increasingly based on long-term confidence building. From the fact that technical resources (in the form of production plants and distribution network) and key activities (operations, maintenance) have been dominant, an increased focus is identified on resources that effectively carry out value-creating activities in relation to, or together, with customers. This is a development that is identified by five progressive district heating companies in Sweden and it is likely that more and more companies in the industry will move in the same direction in the future (Ibid).

2.4.3 Servitization

Offering customers different types of optimization of their equipment becomes, depending on how the offer is designed, a type of service in addition to the ordinary district heating value delivery. Therefore, the concept of servitization, i.e. a transition from delivering manufactured products to delivering services, becomes relevant to look at in this report. Below is a brief overview of what the development of services looks like in the heating industry and among DH suppliers. In Chapter 3.4, *Results* we comment on how the proposed new business models in this report relate to the development of services in the sector in general.

Servitization of the heating industry

The energy sector and the DH sector in particular have traditionally had product-oriented business models, which has meant that DH companies have offered their customers an initial sale of a product, a DH substation, and then continuously sell and deliver a consumer product, thermal energy and/or power (Rydén, o.a., 2013), (Lygnerud, 2019), (Kindström, Ottosson, Thollander, & Kienzler, 2015). The reason for this focus is that DH companies have held advantages compared to other alternatives through, for example, simple and clean heating at a competitive price. This has been made possible through large-scale production and distribution of heat. Historically, the alternatives to DH were individual heat sources such as burning of wood, oil or coke, but the alternative sources of heat that constitute competition for DH today are more and more environmentally friendly and have significantly more competitive cost situations (Rydén, o.a., 2013). In addition, energy efficiency improvements in existing buildings today and in the future, warmer climates and the fact that newly built buildings require less and less energy for heating have reduced the competitiveness for product-oriented business models, solely based on the amount of sold heat. This has been argued by, for example, Kindström that energy companies are forced to move from product-oriented business models to more customer- and service-oriented models (Kindström, Ottosson, Thollander, & Kienzler, 2015). This transition can also be termed a servitization of the DH business and the new services that are thereby developed can be called energy services (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019).

The concept of servitization

Including services in a company's customer offering can provide benefits to a company versus its competitors because services can be more difficult to copy than pure products. The services can also create basic conditions for delivering a higher customer value and finding new customer segments. By supplementing products with services, it is possible to extend the product life cycle and the company that manufactures the product is given new revenue without necessarily increasing production costs for the product itself (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019). Offering services does not only mean benefits for a manufacturing company. The services that have the highest potential for generating increased revenue are also associated with high risk as such services are generally more advanced and require more resources and insights on the customers' real needs. The additional risk is that the company's total profit will be lower if the services offered require more human resources than the manufacture of a product does (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019). When companies that have historically had a product focus switch to offering more services, there are demands for structural, organizational and strategic changes that shift the focus from the production of a product to the lowest cost to understand and respond to customer needs and desires. It can be said that value creation changes from starting with the motto "manufacture and sell" to "perceive and respond" (Alvarez, Marins, & Silva, 2015). Many customers do not just want a product, but a customized solution that meets a specific need (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019).

In terms of business model, the servitization means that the contents of the different components in the business model canvas change. The big change lies in the customer value, the relationship with the customer and in the resources that the DH company needs to supplement.

Service offers can be divided into three levels based on how advanced the services offered are. The categorization in these levels is based on research (Coreynen, Matthyssens, & Von Bockhaven, 2017) and is described as a service pyramid according to Figure 2. In the first level are the simplest types of services where a company only performs an action for the customer, i.e. based on input to the customer. For example, the company performs repairs of the delivered product to the customer or consultations. At the second level, the services focus on maintaining a certain performance of the customer's product, for example by performing preventive maintenance of the product or providing consumables. In the third and highest service levels, the customer and the supplier agree that a certain result will be achieved through the service. The result may be that a reduction in the customer's energy use must be achieved through new solutions where products and services are offered in packages. The results can also be achieved by integrating the customer and supplier systems with each other, and the supplier can access data from the customer which in turn can lead to the development of new services (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019). An example from the energy sector at this level is energy performance contracts or EPCs (Kindström, Ottosson, Thollander, & Kienzler, 2015).

In addition to how advanced or to which level the services belong, the service pyramid also makes a second categorization. The second dimension in the service pyramid reflects whether the services offered are designed to support the delivered product's functions, or to support the customer's own processes. On the product side, for example, repairs, preventive maintenance and lowering of energy use can be classified as such. The services that can be said to have a focus on the customer's processes are consultant service before a product is bought and delivered, supply of consumables and at the top of the pyramid there are services that aim to integrate the customer's and supplier's systems to provide benefits for both parties. According to (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019), services focused on customer processes create more value and competitiveness than services with product focus.

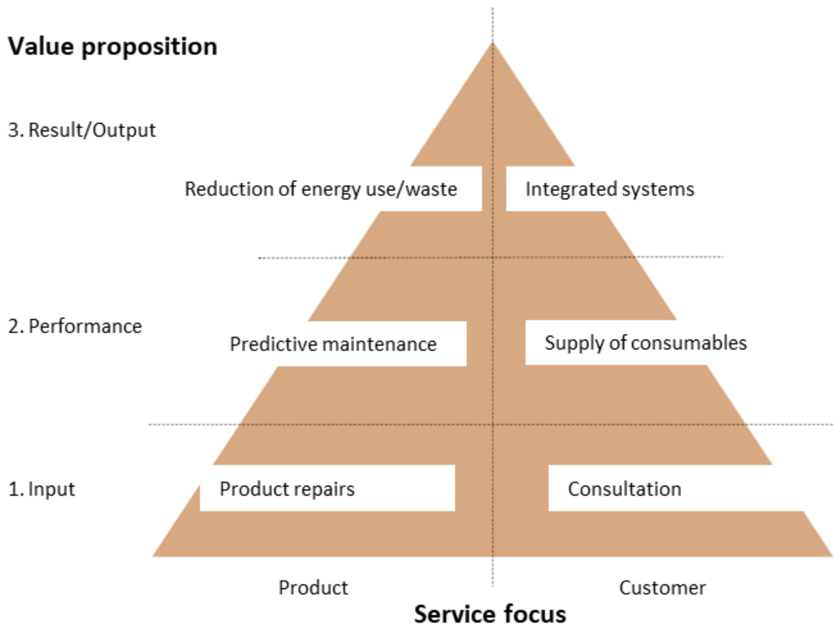

Figure 2 The service pyramid. Image source (Hansson, Lindesson, Halldórsson, Haraldsson, & Ludvig, 2019)

Energy services

Common examples of energy services that Swedish energy companies offer DH customers are shown in Table 1 (Kindström, Ottosson, Thollander, & Kienzler, 2015):

Table 1 Energy services from Swedish energy companies

Installation of substations	Energy audits
Adjustments	Energy statistics and information
Function verification and control	Education and training
Repairs	Surveillance and control of customers equipment
Performance optimization	
Energy analysis and consultation	Maintenance agreements
Supervision agreements	On-call maintenance services
Measure data services	Functional contracts (comfort agreements)

These services can be divided into the service pyramid according to Figure 3.

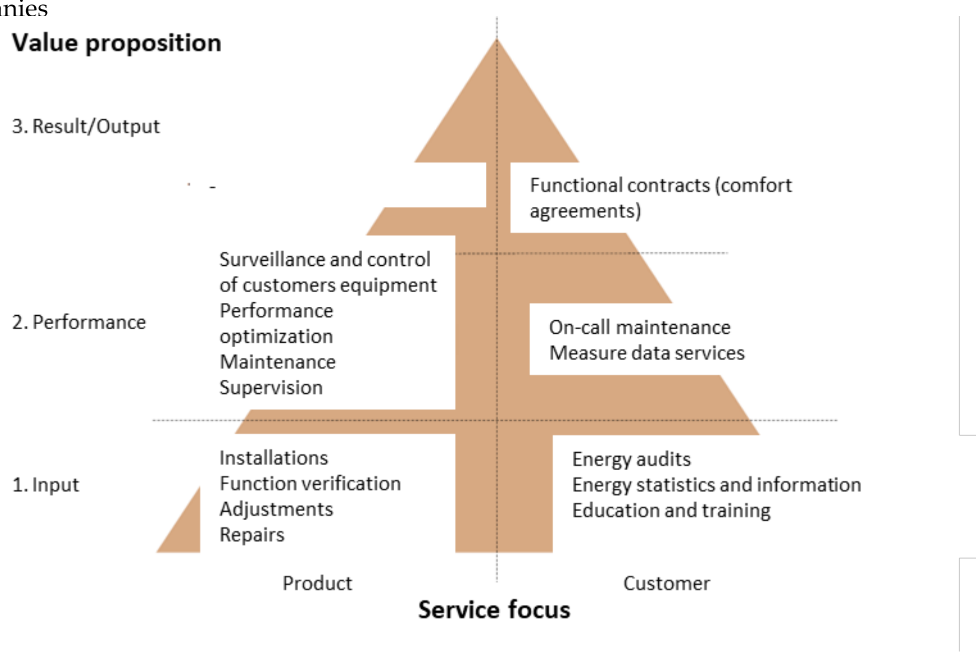

Figure 3 Energy services offered by Swedish energy companies

In the service pyramid's base are simpler services such as installations and repairs of the products that a DH company provides to a customer. Among simpler, input-based, energy services with customer focus are various types of analysis, consulting, and energy audit services. At the second level of service, there are services that provide direct improvements for customers through operation optimization, operation and maintenance agreements for the products that have been installed. An example of a service with a customer focus on the performance level is to share the energy company's measurement data with customers in order to support customers' internal processes. The energy services offered at the highest level are functional agreements in the form of comfort agreements, in Kindströms et al:s survey, 10 of 23 surveyed energy companies stated that they offered comfort agreements in 2015 (Kindström, Ottosson, Thollander, & Kienzler, 2015).

2.5 HEAT PUMPS AS A SOURCE OF FLEXIBILITY IN THE ELECTRICITY SYSTEM

In the previously described cases and studies, the operation of the building heat pumps, and DH is optimized based on the electricity spot price in the NordPool market. In addition to this market, NordPool also provides several markets where electricity power and energy can be traded in order to maintain balance in the electricity grid on different time scales and to provide resources for power reserve markets. Can heat pumps in buildings combined with DH also be involved in these markets? The following sections summarize the possibilities for heat pumps in buildings to constitute a controllable effect on the balance and power markets. For a more detailed description, see Appendix A.

Building owners, or other operators who can control a larger amount of heat pumps, could provide the flexibility of heat pumps in the regulating markets, primarily by acting on the mFRR market, according to today’s market situation. Other markets pose larger barriers for inclusion, FCR-N requires symmetrical bids which can be an obstacle to a heat pump which must then be able to be regulated both up and down. FCR-D is only procured for capacity, which means that there are lower opportunities for revenue. In the aFRR market, it is currently not possible to act with consumption flexibility as the existing IT systems at Svenska Kraftnät cannot handle this.

What may constitute an obstacle for operators to bid flexibility from heat pumps even for mFRR may be technical requirements, requirements for being a balance responsible party or having an agreement with the balance responsible party as well as requirements for minimum bid size. These barriers apply to both building owners who manage heat pumps themselves, but also to district heating companies who, through agreements with customers with heat pumps, could offer flexibility on mFRR.

The technical requirements that are set should be evaluated in relation to how heat pumps can be put into operation in practice. Activation time can be a requirement that can prohibit certain technologies in markets such as aFRR and FCR markets. On the other hand, the requirement for activation is at least 15 minutes for mFRR, which a heat pump could fulfil.

Furthermore, demands for the minimum bid size on mFRR are an obstacle at present, especially for individual building owners who have a limited number of flexibility providers at their disposal. For mFRR, 5 or 10 MW is required depending on the electricity area, and only objects within the same electricity area can be aggregated. For example, in the KlokEl project, it was estimated that around 2 kW of flexibility is available per villa customer with a heat pump (Wolf & Andersson, 2018), which means that around 2,500 villas would have to be aggregated in order to reach the lowest bid level of 5 MW. However, it may be somewhat less challenging for an aggregator to come up to this level, as it may be able to dispose of more objects within an electricity area, and perhaps even larger heat pumps.

A district heating company can act as an aggregator by signing bilateral agreements with the owners of heat pumps and a balance responsible aggregator. They could thus have a greater opportunity to achieve the minimum bid size in an electricity area. However, the requirement remains that those who act in the regulator markets are responsible for the power balance or have agreements with the regulator's balance responsible party, this also applies to building owners or other actors who want to contribute with system services. In practical terms, this means that the district heating company, unless it is the balance responsible party, must sign an agreement with each heat pump owner but also each balance responsible party for each individual heat pump owner. Usually, one of the major electricity traders is responsible for the balance of their electricity customers (Sweco, 2018). When the customer changes electricity dealers, which he or she is free to do, this can be made even more difficult as they can also change balance responsible party. In summary, it is thus a relatively large administrative burden to act as aggregator of heat pumps in the regulator markets today. In addition, the minimum bid volume in the markets is a major obstacle. Whether this will change in the future remains to be seen.

3 Implementation

The project is based on four case studies from Swedish district heating networks. Each case study consists of a building or area where heat pumps have replaced part of the energy supply that was previously met by DH only.

The case studies have been used as a starting point for mapping the impact on energy companies' business models, development and verification of revenue concepts and calculations of the potential for savings from optimized control of HPs in combination with DH.

3.1 CASE STUDIES

An overview of the case studies is given in Table 2.

Table 2 Case studies in the project

	Energy company	Customer	Type of customer	Description
1	Norrenergi	Brf Tornbacka	Tenant-owner association	GSHP, DH for peak demand
2	Kraftringen	Lunds Kommuns Fastighet AB	Municipal housing company	EAHP, DH for peak demand
3	Karlstads Energi	Karlstad Bostad AB	Municipal housing company	EAHP, DH for peak demand
4	Mölndal Energi	Husvärden AB	Private property owner	Energy district with GSGPs for heating and cooling, heat storage and DH for peak demand.

3.1.1 Case study 1: Tenant-owner association with GSHP

In the first case study, a tenant-owner association located in Sundbyberg, a partial conversion from DH only to using two GSHPs in combination with DH was carried out in 2007. The tenant-owner association consists of three apartment buildings in two floors with a total heated area of 2000 m^2. The GSHPs are two NIBE F1330 with a maximum power of 60 kW heat and a COP of at least 4.5 at 0/35 ° C. The total maximum heat output of the heat pumps is thus 120 kW. The heat pumps are used for both space heating and domestic hot water.

The property's total heating load is calculated by summing the delivered heat from DH with delivered electricity to the HPs divided by the heat pump's COP. Since only the total electricity delivered to the property is known (not including electricity used by tenants), assumptions for other electricity use have been made and subtracted from the electricity supplied. The total annual heat load including domestic hot water in the property is approximately 650 MWh and the highest measured total heat power during the period 2015 - 2018 was an average of 170 kW. Based on historical operations in the property, the HP has covered about 95 percent of the annual heat energy and has a power coverage ratio of about 70 percent.

3.1.2 Case study 2: Municipal housing company with EAHP 1

The second case study consists of a building owned and managed by a municipal housing company. In the building, Kraftringen installed an EAHP in 2019 in combination with the building's existing DH connection under the HybidFX offer. The EAHP is installed in parallel with the DH substation and is used for both space heating and domestic hot water. The choice of heat source (heat pump or district heating) is made based on current, manually set, fixed electricity and district heating prices but is intended to be controlled according to spot prices from the electricity market in the future, for which the installation is prepared. There are no plans to change the pricing model for DH specifically for the HybridFX offer. A major reason why the HP was installed in the property is to utilize waste heat in the property's exhaust air ventilation.

The property is a three-story apartment building with a heated area of approximately 2500 m2. The HP is a Thermia M model and has a maximum heating power of 35.4 kW, however, the HP can only deliver this maximum power 1 hour per day and at all other times it has a maximum power of 28.8 kW heat. In our simulations, the HP uses its highest power during the hour with the highest heat demand. As no data for the HP’s heat production is available, the property's heating needs are obtained from delivered DH from the period prior to the installation of the HP. The property's annual measured heat demand including domestic hot water was 230 MWh during the period 2017 - 2018 and the highest measured power was 70 kW. The installed EAHP is intended to cover about 75 % of the annual heating energy in the property and 43 % of the highest power demand.

3.1.3 Case study 3: Municipal housing company with EAHP 2

The third case study consists of a property owned and managed by a municipal housing company. In 2018, an EAHP of the type IVT Geo 238 was installed with a maximum power of 40 kW heat. The HP has a COP of 3.6 at 7 ° C outdoor temperature. Previously, an EAHP had been installed in the property. The installation in 2018 was done to replace the old HP, whose performance had deteriorated over time.

The property, located in Karlstad, consists of a 6-story apartment building with a heated area of about 7000 m2. The HP is connected in series with the DH connection and the HP produces both domestic hot water and space heating. The use of the HP is prioritized up to the point where the requested supply temperature for either hot water or space heating cannot be achieved, when DH is used to top up temperatures. The property's total heat demand is obtained from the period prior to the installation of the HP from the delivered DH to the property. The heat demand for the period following the installation of the HP is obtained by summing the delivered DH and the hourly average of the HP's heat production per month. The total annual measured thermal energy used in the property during 2018 - 2019 was 430 MWh and the highest measured power was approximately 170 kW. The EAHP thus has an energy coverage ratio of 64 percent and a power coverage ratio of 24 percent.

At present, the EAHPs are switched off manually during the summer months, using only DH as the DH price in Karlstad is low during this period. While the HPs are switched off, maintenance and repairs are also carried out.

3.1.4 Case study 4: Private property owner, GSHP

This study initially included a fourth case study in which a local district previously supplied with only DH was partially disconnected from the DH network in favor of an advanced solution where central HPs and cooling machines distribute heating and cooling in the district. The disconnection from the DH network took place in 2014, partly through funding from the Sustainable Cities delegation, and was then seen as an innovative example of efficient energy districts. The district consists mainly of office properties and smaller industries, where a large part of the buildings is either newly constructed in accordance to Environmental Building Level Gold or older buildings that have been renovated for low energy use. Most buildings in the district use low supply temperature heating systems and are heated only by HPs, but an older building has a radiator system that requires high supply temperatures and is heated with DH. In the area, about a third of the useful heat is DH, other heat is supplied by HPs (Olsson, 2019).

In a central energy hub in the area, heating and cooling are produced in three HPs with nominal effects of 480 kW heat and 466 kW cooling, respectively. The HPs are connected to boreholes which are used to increase the COP in the HPs in the heating mode and for cooling production through free cooling. About 80 % of the districts’ cooling needs are covered by pure heat exchange with the boreholes. The boreholes are also used as heat storage by heating them with waste heat from the cooling production in the HPs. In addition to heat storage in the form of boreholes, there are central and local accumulator tanks in the system for equalizing daily variations in the heat load. At present, there is an opportunity for energy production in the area to be controlled with regard taken to spot prices on the electricity market, but this is not used.

Due to problems with data collection from the districts systems, the case study could not be included in the simulations of this study. However, the case study is represented in the interview study and possible business models for similar districts are included in the report's discussion chapter, Chapter 5.

Heat demands and technical conditions for the three case studies included in the study's simulations are summarized in Table 3.

Table 3 Case study overview

Case study	A_{temp} [m²]	Power HP [kW_{heat}]	Total heat demand [MWh/yr]	Peak heating power demand [kW_{heat}]	SCOP HP [-]	HP energy coverage ratio, annually [%]
1: GSHP	2000	120	650	170	4.5	95
2: EAHP 1	2500	30	230	70	3.8	75
3: EAHP 2	7000	40	430	170	3.6	64

3.2 INTERVIEW STUDY, BUSINESS MODELS

Ten semi-structured interviews were held with energy companies and their customers. The selection of energy companies consists of the companies included in the project's case studies, as well as their associated customers. In addition, two customers who are not involved in the project's case studies have been interviewed, both of whom have experience of the combination of DH and HPs. The interview study was used to map how energy companies consider their business model to be affected by offering control and optimization of customers' HPs, based on the Business Model Canvas framework, described in section 2.4.2. By including customers in the interview study, the energy companies view of the business model can be compared and verified against customers' expectations and wishes. Among the customers, all elements of Business Model Canvas were mapped except for cost structures and revenue streams as these components are business secrets and contain information that respondents do not want to share.

The following representatives from energy companies participated in the interview study:

Table 4 Energy company representatives in interview study

Energy company	Role
Norrenergi	Product owner
Kraftringen	Project manager
Karlstads Energi	Head of distribution
Mölndal Energi	Head of distribution
Mölndal Energi	Market manager, private customers

The following energy companies' customers have participated in the interview study:

Table 5 Customer representatives in the interview study

Company	Role
Brf Tornbacka	Former chairman of the board
Karlstads Bostads AB	Technical specialist, heating
Husvärden AB	Technical consultant, board member
Kalmarhem AB	Project manager, energy, and environment
Brf Backadalen	Board member, responsible for the SmartHeat project

3.3 SIMULATIONS

To investigate the value of flexible control of heat pumps buildings, three case studies are simulated, for the years 2015–2017. Each case study is simulated in the six typical DH networks used in the report "The value of flexible heat demand" (Kensby, Johansson, Jansson, & Carlsson, 2019). By generating a marginal price vector for each typical DH network, it can be compared with the operating cost of the heat pump in each case study. The following section contains information on the six typical DH networks, the calculation of marginal costs and optimization calculations.

3.3.1 Typical DH networks

The six typical DH networks consist of three different fuel mixes that are simulated with and without centralized accumulator tanks for heat storage. The fuel mixes are based on the national average of Swedish DH networks in 2017 and the typical networks are designed to represent a majority of Swedish DH networks. The typical networks all have the same load profile and an annual average heat production of about 500 GWh. All six typical networks contain six heat-only boilers (HOB) with a total installed power of 95 MW. Table 6 shows a summary of the installed power of the six typical networks and their variable operating costs. Excess heat is assumed to be heat where the variable operating cost is negligible, for example waste heat from industry or municipal waste incineration plants. The accumulator tanks in three of the networks have a storage size of 11,300 m3 or 500 MWh. Table 7 contains a summary of all production plants and fuels used. A detailed description of the networks can be found in (Kensby, Johansson, Jansson, & Carlsson, 2019).

Table 6 Overview of 6 typical DH networks used for simulations (Kensby, Johansson, Jansson, & Carlsson, 2019).

Fuel mix	Installed power	Yearly variable operating costs without accumulator tank	Yearly variable operating costs with accumulator tank
Large share of CHPs	95 MW HOB 80 MW CHP	99.7 Mkr/yr	92.7 Mkr/yr
Large of central HPs	95 MW HOB 40 MW CHP 40 MW HP	109.1 Mkr/yr	104.6 Mkr/yr
Large share of excess heat (EH)	95 MW HOB 40 MW CHP 40 MW EH	40.7 Mkr/yr	42.4 Mkr/yr

An important difference made here to the typical networks described in the above-mentioned report is that fossil oil and natural gas in the typical networks are replaced by bio-oil and biogas in this study. This is to reflect the ambitions of the heating industry's roadmap for a fossil-free sector, where the goal of the industry is to become fossil-fuel-free by 2030 (Fossilfritt Sverige, 2019). It has been assumed that fuel costs for fossil-free alternatives (oil and gas) are the same as for fossil-based fuels, whereby the merit order in DH production is not affected by the change of fuel. Table 7 gives a summary of the production plants used in different combinations in the type networks and the fuels used in each plant.

Table 7 DH production plants used in the typical DH networks in Table 6

DH production plant	Fuel
HOB (10 MW)	Wood chips
HOB (5 MW)	Wood pellets
HOBs (20 MW and 10 MW)	Biogas
HOBs (40 MW and 10 MW)	Bio oil
CHP	Wood chips
HP	Electricity
Excess heat	Excess heat from industrial processes

3.3.2 Marginal costs of heat production

District heating

To calculate the marginal production cost for DH in the different networks, an optimization model for DH production is used. To generate the marginal cost, the total operating cost of the system is simulated and calculated first during normal operation and when the load is increased by 1 kW for a single hour. This is done for all simulation years (2015, 2016 and 2017). A comparison between the total system cost of normal operation and the system costs when the load was increased gives the marginal cost per kW for all hours of the simulation years.

A basic assumption made is that the heat load applicable to the buildings with HP stand is very small in relation to the entire network heat load so that whether the HP is on or off does not affect which heat source lies on the margin in the DH system.

To simplify the simulation, the simulation horizon is set to 72 hours. This means that when we examine how the system cost changes when the load is increased by 1 kW for each individual hour during a day, only the production cost changes during the current day and for the two subsequent days is calculated. Thus, an increase in the heat load for one hour is assumed to affect the production system for a maximum of 48 to 72 hours.

As the production mix contains cogeneration and revenue for electricity sold is included in the total production cost, the marginal cost can become negative. Since it is not considered reasonable that a DH company would offer a negative price for delivered heat, negative marginal costs are corrected to zero.

DH operating cost is calculated according to:

$$\sum_{1}^{n}\left[Start\ up\ cost_{plant\ 1} + \left(OM\ costs_{plant\ 1} * Load_{plant\ 1}\right)\right] - Revenue_{sold\ el}$$

where n is the number of plants in operation and $OM\ costs_{plant}$ is calculated according to:

$$OM\ costs_{plant} = Fuel\ costs + Energy\ taxes + CO2\ taxes + Emission\ allowances + Overhead\ and\ maintenance\ costs$$

For the production plants described in Table 7, fuel costs have been assumed and the following total operating costs are calculated to the values in Table 8:

Table 8 Operating costs per DH production plants. The operating costs include an assumed fuel cost, energy taxes, CO2 taxes, Emission allowances, Overhead and maintenance costs

DH production plant	Fuel	Operating cost [SEK/MWh$_{DH}$]	Note
HOB (10 MW)	Wood chips	200	
HOB (5 MW)	Wood pellets	400	
HOBs (20 MW and 10 MW)	Biogas	900	
HOBs (40 MW and 10 MW)	Bio oil	1200	
CHP	Wood chips	200	Excluding revenue from sold electricity
HP	Electricity	0	

Heat pumps

To calculate the marginal cost of heat production in building HPs, the electricity price and COP are used for each case study. The electricity price is calculated according to:

$$El.price = El.price_{spot} + El.certificate + El.grid\ fee + Energy\ tax + O\ and\ M$$

The cost of useful heat from a HP is calculated by dividing the electricity price (defined above) by the COP of the HP. The COP of the heat pump varies with outdoor temperature and supply temperature in a building. Based on (Gustafsson & Karlsson, 2015) and (Lindahl, o.a., 2018), the COP is assumed to vary by 0.05 per ° C for both EAHPs and GSHPs. Product specifications for each HP in the case studies have been used to calculate the COP for a specific outdoor temperature. This relationship applies mainly when the heat pump is used for space heating. In the production of domestic hot water, higher supply temperatures are required for the HP, which causes the COP to decrease and vary very little with the outdoor temperature. In this study, this effect is ignored, with the consequence that the efficiency of HPs is overestimated. If the HP is controlled based on its marginal cost compared to the cost of DH, the savings potential is underestimated by this assumption.

The COP as a function of the outdoor temperature for the various case studies can is calculated as follows:

$$COP_{Case\ 1} = 0.05 * T_{Out} + 4.10$$

$$COP_{Case\ 2} = 0.05 * T_{Out} + 3.45$$

$$COP_{Case\ 3} = 0.05 * T_{Out} + 3.25$$

3.3.3 Cost based optimization

For each case study in each typical network, the use of DH and HP is simulated in what is termed "normal" and "shifting" operation mode. Normal operation refers to the control strategy used in many buildings with both heat sources. That is, the HP covers as much of the heat demand as it has capacity for each hour and DH covers the remaining heat demand. In shifting operation mode, a system provided by the energy company chooses whether the heat pump should be used every hour based on the marginal cost of district heating versus the cost of producing heat from the HP. If the HP is the cheaper alternative but its capacity cannot cover the heat demand, DH is used for the remaining heat demand.

The value of shifting operation of the heating system is calculated as the difference between normal and shifting operation.

3.3.4 Assumptions made for calculating cost savings – New and current price models for DH

A basic assumption in this study is that the highest potential savings for a building owner and the highest system benefit arise when customers' HPs are optimized by considering the actual circumstances of the production in the DH system. This in turn leads to the assumption that the marginal production cost for DH is an indicator that can be used to describe actual production conditions, which has been argued by, among others (Sjödin & Henning, 2004) and (Rydén, o.a., 2013). Prices on the electricity market vary with a resolution of one hour and optimization of customers' HPs should therefore be carried out with the same resolution. Therefore, in order to investigate the greatest potential from the optimization, information on the price or cost of DH should also be made available with the same resolution. With this in mind, it is thus required that customers with HP and DH in some way need to be exposed to DH prices that are set per hour, which is generally not done in the Swedish district heating market today (Rönning, 2016).

The DH market in Sweden is characterized by a high degree of heterogeneity. There is a large variance of production facilities, size of distribution networks and not least of price models. Between different DH networks, not only the price levels for customers vary, but also the structures of the price model. In previous research (based on a Fjärrsyn project, , (Li, Wallin, & Song, 2017)), a survey of Swedish DH companies' price models (Song, Wallin, & Li, 2017). was conducted. At the time of the study, 33% of the 80 largest DH companies in Sweden had price models built up with seasonally varying energy prices and 87% of them applied a power tariff (51% then used category number to determine the tariff setting power). In the 2017 project, new price models were tested and a general price model employed to reflect the general trend in the industry was a price model with two different seasonal prices for energy and a power tariff based on the measured maximum daily average effect. A follow-up study carried out in this study of 80 district heating companies' price models shows that 65% of the companies have introduced a price model with seasonally differentiated energy prices in 2020. Nearly all companies apply a power tariff. Among the companies with seasonally differentiated prices, 54% divided the year into three seasons. Examples of other price components used are high/low load tariffs for energy, fixed energy tariffs, fixed charges, flow charges and various forms of return temperature charges.

The simulations in this study are carried out with the intention of examining how large cost savings a building owner can achieve by optimizing the operation of his or her HP based on hourly rates for both DH and electricity. There are two major complications to this:

1. The typical networks on which the simulations and calculations are based are not real networks and no actual price models exist for them. It is therefore not possible to employ a reference for the savings that would be obtained if a customer were to change the price model and then optimize the operation of their HP.
2. Developing a new pricing model is a major task, which can take up to 3 years from a first decision to change the pricing model until it is fully implemented. Only the stage of investigation of the work, where the price model itself is developed, can take up to one year (Rydén, o.a., 2013). Thus, fully developing pricing models are outside the limitations of this project and a simplified price model based on marginal costs for district heating production is adopted and used in simulations and calculations.

To address these problems, some assumptions have been made in the project in order to be able to calculate a savings potential for each building owner in the six type networks. These assumptions are summarized:

1. A customer who is offered an optimization service is also offered a new price model, which differs from the existing price model in the typical network.
2. No specific existing price models are defined for the six typical networks. It is assumed that the existing price model is based on a power tariff and energy prices per season.
3. A new price model that enables optimization, meaning that the energy price for DH is set dynamically per hour, has been developed.
4. The new price model is designed so that the total cost of DH for one year remains unchanged for a customer who does not change his energy use. That is, the customer does not optimize the operation of his HP based on the new prices but operates the HP in the same way as before.

The assumptions above are described in more detail here:

New price model - marginal cost with adjusted fixed charge

It is assumed that a new price model will be introduced in all typical networks that is available to all customers in each network. The price model consists of:

- An energy price varying per hour based on marginal production cost [SEK / kWh]
- A fixed fee per year, the fixed fee is set to cover investment costs and other fixed costs in production and distribution that can be accounted to the specific customer.

It is assumed that the new price model will be adjusted by designing the fixed part of the price model so that the customer's total cost for DH is unchanged when switching from the existing price model to the new price model, if no change in the energy use of the customer occurs. Consequently, the new price model consists of a fixed part that provides cost coverage linked to investments for the DH company, while the variable energy price corresponds to the DH production costs without profit margin, that is, the absolute lowest price that could be set for DH. This DH price is compared in the optimization against the customer's electricity price, which consists of spot price, electricity grid fee, energy tax and electricity certificate. The electricity trading company's possible surcharges are ignored.

Based on the assumptions above, it is possible to calculate the savings obtained from optimizing the operation of the customer's HP between the existing, seasonal price model and a new price model with optimized operation, and between a new price model without optimized operation and a new price model with optimized operation. Although the savings are hypothetical, it is possible to express them both in absolute terms and as a percentage of the customer's total cost. Figure 4 below shows an example of what the assumption looks like for a building owner who has a total cost of SEK 100,000 per year for district heating with the current price model that is set as a reference. With a new price model, the total cost remains unchanged if the property owner does not perform any optimizations, but the distribution between energy and power fees changes. If the property owner, in addition to switching price model, also optimizes HP operation, the cost of DH increases as more DH is used, but the total cost of all heating decreases as electricity consumption decreases.

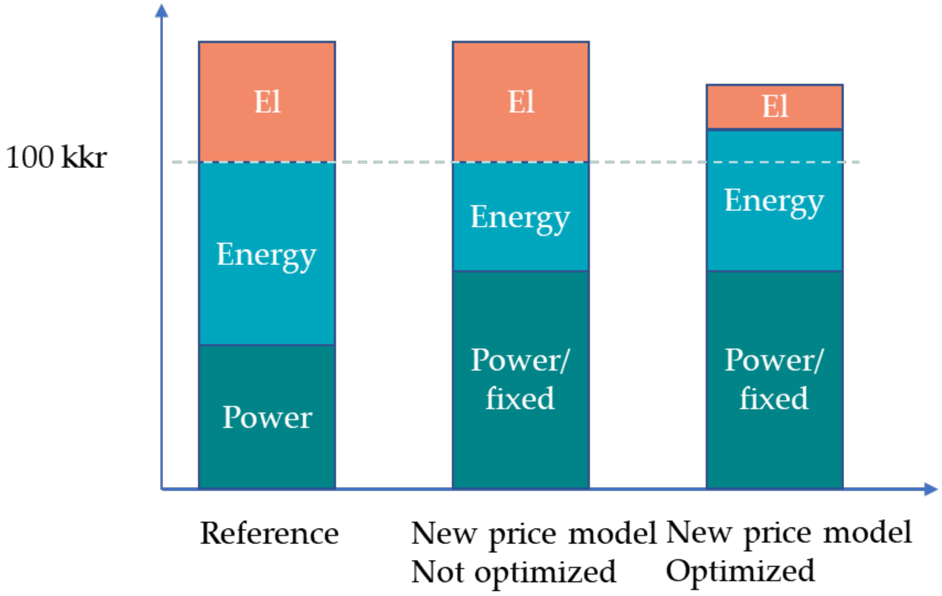

Figure 4 Total heating costs for a customer with an existing price model (reference), new price model without optimizing HP/DH operation from the new price model and if the customer acts on the new price model and optimizes HP/DH operation (leftmost).

A similar price model based on marginal costs and fixed fees was investigated in a thesis (Rönning, 2016). It was found there that price models with this structure provide correct incentives for customers to improve energy efficiency by increasing the prices of energy at low outdoor temperatures. In contrast, the volatility of DH company profits increases and becomes more weather dependent than with less differentiated pricing models. Compared to a seasonal pricing model, with a margin-based pricing model, very large profits for the district heating company are obtained during a cold year, since the energy price is then more often set after the cost of peak production, which gives profits for all other production. On the other hand, very low profits are obtained during a hot year. It should also be noted that, according to certain recommendations, the distribution of fixed and variable revenue from a customer should be distributed so that 60% of the total DH price consists of energy parts to achieve cost accuracy compared to the production costs of the energy company (Gåverud, Sernhed, & Sandgren, 2016).

3.3.5 Handling of missing data

To simulate the case studies, the heat demand is required for all simulation years with hourly resolution as well as knowledge of the HP's properties. For all case studies, parts of the time series for the heat load are missing, so this data has been estimated by means of simulation. Depending on how much data is missing, different methods for estimating data have been used, these are described in Table 9.

Table 9 Overview of the treatment of missing data in the case studies

Type of missing data	Method for replacing missing data
Full year of data missing	The known heat demand for other years has been distributed based on temperature data for the missing year.
Single hours or days of data missing	Missing data is replaced with data for nearby hours or days (extrapolation).
Data is only available as monthly aggregates	In cases where information is available about the load distribution of the system in the case study or similar systems, this is used to distribute the total monthly load on the hours of the month, otherwise the load is evenly distributed during the month.

3.3.6 Emissions of CO_2 equivalents

To account for the impact on global emissions of greenhouse gases or CO_2 equivalents that a product or service has, in simplified terms, two different methodologies can be used. Either the emissions that an activity has contributed to, in retrospect, are considered through so-called attributional analysis or the consequence of a change is the focus of a consequential analysis.

In a consequential analysis, the effects of changing something in a system are studied. For buildings, this means that effects that arise in the energy system for different choices of technologies or their use are studied. These effects vary, among other things, depending on the time horizon studied. In a consequential analysis, effects are usually classified as either short-term or long-term. Energy solutions implemented in buildings have a long service life, which means that they affect the energy system in both the short and long term. Because of this, a division into operating and building margins is usually made. The operating margin studies which technologies in the existing energy system will change their production based on the energy solution's energy use. The construction margin studies which techniques are being built or demolished due to changes over a longer period of time (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017).

Attributional analysis is another way of assessing environmental impact from energy use. In an attributional analysis, resource use and emissions are mapped for a system belonging to an actor or function. The result is an environmental profile for the operator or function that specifies how much environmental impact they are responsible for. The attributional analysis does not normally consider the merit order of different plants, or at what time they are run, but averages for emissions over an entire year are used. Using attributional data as a basis for analysing the environmental consequences of different building solutions is common, but risks leading to erroneous conclusions (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017).

By changing the operation of HPs, emissions of CO_2 equivalents from heating the building also changes. Since it is a change to an existing system, the changed emissions should be quantified from a consequential perspective. This means that the marginal emissions from heat and electricity production that are affected by a change in energy use must be used to calculate a possible emission reduction. A common method for estimating such changes in a building that uses district heating is the Tidstegen method (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017), (Gode, Nilsson, Ottosson, & Sidvall, 2020). The method is also used in this study by using the emission factors for DH production and the production mix on the margin of the Northern European electricity system in the simulations. Another commonly used and similar methodology used in many energy companies is the Klimatbokslutet (Profu, 2020). In Klimatbokslutet, similar impact assessments are made from the perspective "what would have happened if a district heating company had not existed in a certain place?" In Klimatbokslutet, the use of DH in buildings is compared to other alternative heating forms in order to compile the entire direct and indirect climate impact of a DH system. In Tidstegen, greater focus is placed on the effect of individual properties on changing energy use, which is why Tidstegen is used in this study.

Tidstegen

From a consequential perspective, reduced use of electricity in a property in Sweden means that marginal electricity production in the northern European electricity system will decrease in the short term because electricity consumption decreases, but also in the long term as the underlying basis for taking more production plants into operation decreases. If electricity consumption in a HP is replaced by locally produced DH, the consequence will be that the emissions of CO_2 equivalents decrease with the net difference between the emissions for DH and the marginal mix in the Northern European electricity system during the hour when the change takes place.

Tidstegen have a long-term perspective and consider how emissions from electricity generation in the Northern European electricity system can develop in the future. In Tidstegen, emission factors are given for three different possible scenarios that depend on the technologies in the electricity system. The scenarios are a climate heavy, a climate-low and a reference scenario that lies between the two previous scenarios. In this report, mean values for emission factors from marginal electricity generation over the period 2020 - 2040 are used from the reference scenario in Tidstegen. These depend on which time of day and time of year in which electricity is produced and used, and are summarized in Table 10. All emissions are calculated from a life cycle perspective and consider upstream emissions such as production and transport of fuels and downstream emissions in, for example, the combustion of the fuel.

Table 10 Emission factors for marginal electricity generation in the Northern European electricity system according to the time scenario's reference scenario, average over 2020-2040 (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017).

Time step	Emission factor marginal electricity production, [kg CO_{2e}/MWh_{el}]
Winter, night	982
Winter, day	650
Spring, day	750
Spring, night	136
Summer, day	515
Summer, night	127
Autumn, day	750
Autumn, night	136

Emission factors for DH production per production plant have been set from a life-cycle perspective according to Tidstegen and "agreement in the heat market committee" (överenskommelse i värmemarknadskomittén) (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017), (Värmemarknadskomittén, 2019). Table 11 shows employed emission factors for heat production in the DH system and for HPs in both customers' buildings and central DH production.

Table 11 All emission factors are given from a life cycle perspective and are taken from (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017). The emission factor for industrial waste heat is taken from "agreement in the heat market committee 2019" (heat market committee, 2019).

DH Production	Fuel	kg CO2e/MWh
HOB (10 MW)	Wood chips	11
HOB (5 MW)	Wood pellets	19
HOBs (20 MW and 10 MW)	Biogas	10
HOBs (40 MW and 10 MW)	Bio oil	9
CHP	Wood chips	11
HP	Electricity	Northern European marginal mix according to Table 10
Excess heat	Industrial excess heat and municipal waste CHP	0

One difficulty in using consequential analysis is that the consequence of a change must be compared with an alternative. This becomes clear when municipal waste is used as fuel for DH and electricity production in CHP plants. Assume that a taken measure in a building would reduce the total heat load in the DH system. This, in turn, would reduce the basis for producing electricity and heat from waste. What happens with the waste instead? In Tidstegen, three scenarios are defined for what would happen with waste instead of incineration in Sweden. In short, these scenarios mean that waste instead of being imported to Sweden for incineration is either incinerated in another European country, put on landfills in another European country or that the amount of waste incinerated in Sweden is independent of the heat load in a DH network because the DH company has an obligation to handle the waste, which is considered as the reference scenario. The reference scenario thus means that no matter how large the demand for DH, the same amount of waste will be incinerated in DH production. If the heat demand is too small, the excess heat from the waste incineration is simply cooled off. For heat production through waste cogeneration, the Tidstegen reference scenario for waste management has been used. That is, both heat and electricity from waste cogeneration have the emission factor 0 g CO2e / kWh. See (Hagberg, Gode, Ekvall, Adolfsson, & Martinsson, 2017) and (Gode, Nilsson, Ottosson, & Sidvall, 2020) for further discussion on emissions from waste cogeneration. By using the Tidstegen reference scenario for alternative waste management for incineration, the results and method in this study differ from what is used in Klimatbokslutet for energy companies. In Klimatbokslutet, for each studied DH network, an analysis is made of what the alternative scenario for the waste is in the current DH network and in many cases, this is regarded as landfill in the UK. In this alternative scenario, incineration of waste in Swedish cogeneration plants results in a reduced climate impact from a consequential perspective, as emissions from the landfill are avoided. The reference scenario used in this study means that the consequence of a change in heat input when waste incineration is on the margin is equal to zero. As a result, our calculations give a lower reduction in emissions than a Klimatbokslutet report would give.

3.3.7 Power regulation markets

To investigate the economic potential of allowing HPs combined with DH to act on power regulation markets, a simplified simulation of this is also performed. After simulating the optimized operation of a HP based on electricity spot prices and marginal costs for DH, the activated bids on the regulation market mFRR in the electricity area SE3 are taken into account in one of the case studies in the project. For every hour of the buildings optimized operation based on spot prices, in a second simulation, the property is also given the opportunity to change operation if a lower total cost is obtained by switching off the HP and instead using DH, to obtain revenue from the mFRR market. This represents an additional saving for the building owner, which can be distributed depending on the agreements entered between energy companies, property owners and a possible flexibility aggregator. The revenue is thus obtained by compensating the property owner for its up- or down-regulated power from the HP according to the current hourly price on the mFRR market in the electricity area SE3 during the years 2015 - 2017. Figure 5 shows how the price for up- and down-regulation of electricity has varied during the year 2015. It should be noted that during the year there are prices and bids for every hour, but the offered power is not always cleared by the TSO Svenska Kraftnät. The simulation only allows a building owner to receive compensation for his supplied flexibility for hours when a bid has actually been activated. For example, in 2015, regulation was activated up or down during 4914 of the year's hours. The average price for down-regulation was SEK 180 / MWh and for up-regulation SEK 229 / MWh on mFRR in SE3 in 2015.

Energiforsk

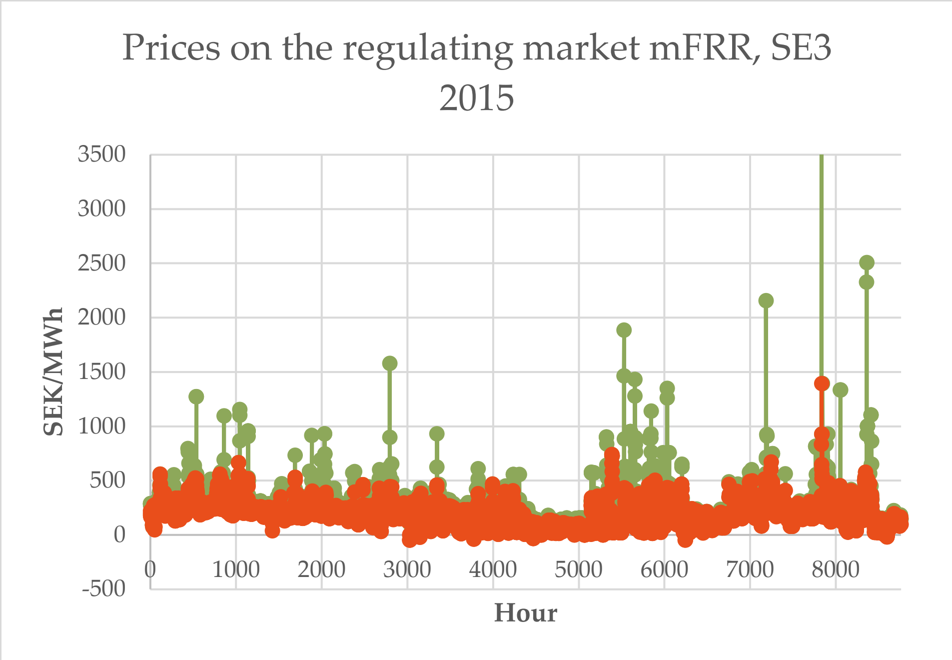

Figure 5 Prices for up (green) and down (red) regulated power on the power regulation market mFRR in SE3 in 2015.

The savings or revenue from the regulation market for a single building owner is hypothetical, as the minimum bid size for mFRR in SE3 is 10 MW, which requires a large number of HPs to be aggregated. Discussed future developments in the regulation markets, however, indicate that the minimum bid size may be reduced, perhaps to as little as 1 MW, which would provide increased conditions for the potential calculated in this project to be realized.

3.4 CONTRACTS

A qualitative analysis of how agreements between customers and energy companies are affected by the fact that customers' HPs are controlled by the energy company was conducted by compiling and studying existing agreements for DH supply, energy services and comfort agreements in the case studies and the reference group. The analysis was reviewed and supplemented by the law firm Glimstedt in Gothenburg and is reported in the results chapter, 4.

4 Results

4.1 RESULTS: INTERVIEW STUDY, BUSINESS MODELS OF ENERGY COMPANIES

The four energy companies whose customers are included as case studies in the project were interviewed to identify how their business models are affected when control and optimization of customers' HPs are included in offers to customers. The interviews were designed based on the business model canvas and are summarized in the following sections under the respective heading of the canvas.

4.1.1 Value proposition

During the interview study, the following, additional, values were identified when a customer's HP is optimized by the DH company:

- Reduced heating costs as the heat source is shifted based on current prices.
- If it can be quantified and proven: a green value in the form of reduced emissions of CO2 equivalents - the green value.
- The energy company focuses on customer needs.
- The customer can influence his or her heating system to a greater extent.
- The knowledge of the customer that one can contribute to a more efficient use of existing infrastructure.
- Security of supply and the prolonged presence of a DH supplier compared to just the installed heat pump.

The values listed above are general and will play a greater or lesser role depending on the individual customer's needs and current customer relationship as well as how the local heating market is designed. Each value is developed and discussed based on this in the following section.

Reduced heating costs

The most obvious value in having a HP turned off more often in favor of DH when it is cost effective is that the customer's heating costs decrease. This value is easiest to convey in the form of cost savings calculations and pre-studies.

The green value

Depending on the customer and what the local energy system looks like, the green value can be significant. First and foremost, it should be pointed out that the green value in the form of, for example, avoided emissions of CO_2 equivalents must be quantified for each local energy system as the DH market in Sweden is very heterogeneous and the production mix for DH can differ greatly between different networks. For example, some energy companies have succeeded in converting their DH production to be completely fossil-free, while others have some fossil-based production to cover the highest peak loads in the grid. In this context, it can also be pointed out that a high price or a high production cost does not always mean high emission levels. At an interviewed energy company, the peak production consists of a hot water boiler fueled with bio-oil, an expensive but environmentally friendly fuel. Also, the fact that the emissions from the electricity used in the HPs may vary depending on the production of intermittent renewable electricity, the import and export situation in the Nordic electricity system and the overall demand for electricity.

At the same time, many energy companies state that the green value is increasing in importance for customers. For some customers, the green value can be just as important if not more than the value of a direct cost savings. All interviewed energy companies have a clear environmental profile and point out that DH is in many respects an environmentally friendly alternative to heating with electricity as the primary energy source. As mentioned, DH production is completely fossil-free among some of the interviewed energy companies, which is used to strengthen the company's brand. Offering customers to optimize their plants to potentially make further savings of climate-impacting emissions is seen as a further step in strengthening the DH company's brand.

In one case, the surveyed energy company believes that HPs are sometimes sold among customers in their networks as a measure with a green value. This is especially true for installations of GSHP, since geo-energy which is the heat pump's heat source is regarded as a renewable energy source that is otherwise not utilized. In order to be able to argue for the green value of switching from the HP to DH, it must be proven that DH during those times has a lower climate impact than the electricity that would have been used in the HP.

In general, the interviewed energy companies agree that the green value of controlling HPs can be an important factor for their customers. Many customers, both smaller and tenant-owner associations, as well as larger property owners have the green value high on their agenda. The challenge for energy companies lies in conveying the benefit of using DH instead of electricity by using HPs during times when the DH marginal fuel mix produces less emissions than the marginal mix in the electrical system.

Adaptation to the customer's needs and opportunities for the customer to influence

Among the interviewed energy companies, there is a consensus that the value that customers experience by being seen, heard and having their needs met by their energy company may be the single greatest value in optimizing and controlling their heat supply. The energy companies suspect that the financial potential for their part in managing and optimizing customers' HPs will be relatively small compared to other costs and revenues in the DH system, although the savings potential for an individual building can be significant. If the relationship and dialogue with the customer is expanded and deepened, customers can see great added value in the energy company showing good will and interest in offering solutions that provide benefits to the customer and a more efficient use of existing infrastructure. An interviewee expressed the value of a more customized offer as follows:

> *"We see this as something that will be very important in the future. We cannot continue to be a company that just wants to safeguard our own production. We must adapt to the customers and their needs to a greater extent and investments like these are part of that. "*

However, it should be mentioned that the size of the value differs between customer groups, since the value of having an engaged energy supplier is greater among customers with lower technical knowledge about their technical systems than a more technical customer who wants to improve and change their system on their own. At the same time, it is possible to design offers in a way that also appeals to the latter customer group, after which the value of supplier flexibility increases again.

By controlling heat pumps and perhaps even becoming a heat pump retailer, customers are given more choice and greater opportunity to influence their own heating. DH has been and is the subject of debate about its monopoly situation. By being open to other alternative sources of heat, the feeling of a monopoly for customers is reduced. The fact that it is then the energy company that controls the operation of the HP need not necessarily be seen as an increased monopoly situation, the purpose of which is primarily to increase the security of the customer that the plant is run in an efficient and optimized way. The energy companies possess great knowledge in the area which can benefit their customers.

The value of efficiently utilized infrastructure

One value of probably less importance for end customers is that, with an optimized operation of HP and DH, existing infrastructure is utilized more efficiently. This is in the form of an increased supply of DH during hours when a HP gives a more expensive heat production. In addition, if HPs are switched off for the benefit of DH when there is a shortage of electricity on a system level, the effect of this value will be doubled. However, the interview study points out that few customers see this as a value since their own direct benefit from it is difficult to quantify.

Security of supply and future assurance

Compared to the installation of a HP, a DH connection means a longer-term relationship between the customer and the supplier of the heating solution. Once the HP is installed and the warranty period is over, contact with the HP installer will often end, unless service agreements or similar are signed. On the other hand, a DH connection means that a supplier, the energy company, constantly and for a long time to come will be present in the property to some extent. This is thus not a new value but reflects the existing value with DH which is, "safe, secure and stable". By offering solutions that involve the energy company to an even greater extent in the operation of a customer's plant, the energy companies' competitiveness towards, for example, a HP supplier increases.

4.1.2 Customer segments

All energy companies see that the most important customer segment to offer HP control are owners of multi-dwelling properties. Depending on what the local market looks like, this means either private property owners, public housing companies or tenant-owner associations. The majority of the energy companies interviewed (3 out of 4) see larger private property owners and public housing companies as the main customer segment, since in many cases there is a closer relationship between the energy company and such customers than with the more diverse tenant-owner associations.

One energy company sees tenant-owner associations as the main customer segment, largely due to a large proportion of tenant-owner associations among existing customers, and that in the energy company's experience it is somewhat easier to offer services and products that can provide direct cost savings to these customers. In the energy company's opinion, larger property owners can often have more evaluation reasons when choosing an energy solution than just direct cost savings. Other reasons may be to increase the value of the property over time or to increase the property's operating net. This makes the assessment of the solution's potential more complex, which in turn makes it more difficult to quantify the value of the solution offered.

The customer segments that can be exposed to offerings regarding control and optimization of HPs can roughly be divided into two subcategories: technicians and non-technicians. The technicians are customers who are familiar with the operation of their heating system and who today may even make their own optimizations manually or through different degrees of automation. Non-technicians have little knowledge of how their heating system works and have no particular interest in how it works or should be operated. The offers presented to these two customer groups are likely to be designed in different ways. Technicians probably value only being offered a new signal that they can control their plant more efficiently from, while non-technicians value offers where energy companies are more present in the long perspective.

A natural segment within the customer segment of larger property owners to begin with is existing customers in DH networks who also have a heat pump installed. After the offer has been tested among these customers, the service or product can then be offered to new customers at, for example, new construction areas.

All energy companies agree that the detached house market is too small in this context to be relevant to offer control of HPs. Property owners with management contracts of a more short-term nature are also seen as uninteresting in this context.

4.1.3 Channels

The offer to control and optimize customers HPs is likely to be a niche offering that does not appeal to all energy companies' customers and potential customers. Active outreach work will be required at the energy companies to first identify possible customers that may be receptive to the offer and once contact has been established, the distribution of the offer will be characterized by a long-term dialogue between the customer and the energy company. An energy company states that it is believed that the potential customers will be technically skilled and then personal communication between the parties becomes important where credibility and responsiveness play major roles.

4.1.4 Customer relationship

Among the expected customer values identified by energy companies, an extended and deepened relationship with customers was one of the greatest values. For energy companies, an increased dialogue with their customers is always positive, as one interviewee expresses.

One energy company expresses that many customers who actually contact the energy company are generally satisfied with the relationship. However, there is a large hidden statistic in the form of customers who are dissatisfied but choose not to express this to the energy company. In this statistic, a large proportion of the customers who have chosen to install a HP in combination with DH may be present. By approaching these customers with an offer that can help them optimize their operations and lower their costs, it is likely to turn a bad relationship into a good one.

Another energy company already offers similar services. The company states that the main driving force behind offering optimization of HPs and DH is to strengthen the relationship with the customer. The value for the customer in a close relationship leads to increased cooperation regarding energy solutions between the energy company and its customers.

4.1.5 Revenue streams

During the interviews, the energy companies were asked to comment on several possible concepts for revenue structures developed by the project. The concepts range from a product orientation to a customer-focused offering to customers. Generally speaking, energy companies advocate that the price model used should be as simple as possible to be offered to and understood by the majority of the company's customers. For complicated revenue structures, there is a risk that customers will not accept the offer, either because they do not understand how it works, or because they get the feeling that the energy company is trying to maximize its own profit at the customer's expense. Energy companies that have more experience in energy services, such as comfort agreements, are more favorably disposed to apply such revenue structures also in the case of HPs in combination with DH.

The revenue structures are presented and discussed in more detail in Section 4.3.

4.1.6 Key resources

Depending on how the business model and the customer offering are set up, the key resources of the energy companies will be more or less affected compared to the current situation. For offers where the energy company only designs a new price model or only offers control and optimization of customers' heat pumps as a product, no major new key resources in the form of hardware and software are likely to arise. On the other hand, the energy companies' organization may need to be strengthened with competences, in particular regarding building HPs as well as IT solutions for communication with the HPs.

If customer offers are designed where the energy company takes over ownership or responsibility for the customers' HPs to some extent, the HPs themselves become a new key resource for the energy company. This is also true under the assumption that the energy company acts as a supplier of the HP together with the optimization solution. This also means that the energy companies fixed capital increases in comparison with the current situation, since the energy companies often do not own the customers' substations.

New key resources in the form of increased competence among the energy company's personnel regarding building technology are likely to arise because of the increased presence of the company's customers. In general, it is expected that the energy companies' departments for the development and sale of energy services will increase in importance and become a key resource.

An optimization solution will also mean that the energy company handles more data from the customer's equipment, this data itself can constitute a new resource for the energy company that can be used to design new additional services and offers.

4.1.7 Key activities

Offering optimized control of customers HPs will entail certain new key activities for energy companies, many of which will, however, be similar to the activities already undertaken by the energy company.

One of the new key activities that must be carried out is to generate calculated marginal costs for heat production. The higher the resolution and precision of the marginal costs calculated, the greater the potential for the optimization service. Since the daily production planning is done on an hourly basis at all the energy companies in the interview study, the activity does not in itself make a big difference to current activities. The big difference lies in the fact that, if the costs are to be used directly as a price signal to the customers HPs, the costs must be packaged in a format suitable for the communication interface that the HP control uses. It should also be added that the marginal cost can often be complex to calculate, especially when the DH network includes storage in the form of, for example, accumulator tanks.

After the creation of a cost signal, the key activity remains to carry out the optimization itself. This optimization must be as automated as possible, so that the key activity for the energy company when the optimization is in operation only consists of following up, evaluating and, if necessary, correcting and improving the optimization. One energy company points out that the volume of controlled energy in customers with HPs will be small compared to the rest of the system and their optimization could face the risk of being overseen.

The two-way communication that occurs poses a challenge, since the HPs can have indirect connection to the energy company's larger production planning. The indirect connection occurs if the operation of HPs affects the forecast of heat demand used in production planning. This requires that communication is carefully designed to avoid intrusion and data security becomes an important factor to consider.

If the offer from the energy company entails increased responsibility for the customer's equipment, either by owning the plant or having a supervisory and operational responsibility, the energy company's key activities will change significantly. For many energy companies, it will be a major change to monitor, control and service customers' facilities, as in many cases today the supply boundary lies at the shut-off valve between the customer's equipment and the energy company's distribution network. If it also means that heat pumps of varying makes, age and type are to be maintained, this activity can be extensive and resource demanding. For energy companies with experience in offering comfort agreements, the change is less significant, even though heat pumps may be outside the organization's area of expertise. Probably many energy companies choose to enter a partnership with a service provider instead of including the service commitment of customers' equipment in the internal key activities.

4.1.8 Key partners

Regardless of how the offer is designed, optimized HPs will mean several new partnerships for the energy company.

The energy companies will need to enter into partnerships with suppliers that can develop and implement the optimization algorithm to be integrated with customers' HPs, which can differ significantly from customer to customer. Some energy companies carry out their production planning with the help of key partners, which naturally could potentially integrate customers' HPs into the regular production mix. For other energy companies, a key partner would only supply a platform that acts as a bridge between the energy company's production planning and the decentralized HPs.

If the offer is designed in such a way that the energy company also supplies a new HP to the customer, a partnership must be entered with a HP supplier and installers for this and other necessary equipment. Such a partnership probably also facilitates the integration of the heat pump's control together with DH since the energy company can potentially influence the design of the heat pump's communication interface.

Since the optimization includes signals from both the heating and electricity system, an electricity trading company can become a key partner. Energy companies with electricity trading companies within their group can enter into partnerships with these and offer customers package solutions that include heat, electricity, and an optimization of the two.

In the case of offers where the energy company takes over responsibility for the supervision and operation of the customer's plant, new key partners in the form of service providers can be associated with the energy company.

4.1.9 Cost structure

Most interviewed energy companies do not see that the actual optimization of customers' equipment means a significant cost change, compared to today's costs. The actual installation of the required hardware will of course involve a cost, but it is not expected to be large in this context and in comparison with other fixed costs for the production and distribution of district heating.

If, on the other hand, the offer involves an increased maintenance responsibility, the energy company's costs will increase, compared to today's business model. The largest change in the energy company's costs is achieved if the energy company takes over ownership of customers' HPs in the form of higher capital costs.

4.2 RESULTS: INTERVIEW STUDY, CUSTOMERS VIEW OF A CHANGED BUSINESS MODEL

To complete the business model canvas, energy companies' customers were also interviewed. Three interviews were conducted with customers from case studies in the project and to supplement the analysis, two interviews were also conducted with customers who were not included in the case studies, but have experience with the combination of HP and DH in their buildings.

4.2.1 Values

All surveyed customers were asked to rank the three factors that they valued most in energy companies' DH offer in general. The resulting assessments are shown in Table 12.

Table 12 Customer ranking of DH values

Factor in DH offering	Rank (1: most important, 3: least important)
Security of supply	1, 1, 1, 2
Competitive price	2, 2, 3
Adaptation to the customer's needs and opportunities for the customer to influence	1, 2, 3, 3
The green value	1, 2, 3, 3

The security of supply of DH is seen by the customers as most valuable, after which the results are mixed. All the requested customers have partly converted from DH to HP and the motivation for this was to lower their heating costs. All customers state that costs primarily control the choice of heating system and none of the customers have ranked pricing as the largest value with DH. On the other hand, customers value getting to feel that the energy company as a supplier listens and understands their needs and is at the same time prepared to adapt to them. All customers state that this factor is the one that has changed most over time at energy companies. The energy companies have increased their will and ability to adapt recently, which gives great value to the customers.

Equal value is added when DH can, depending on the situation, be a more environmentally friendly alternative than others. If it can be demonstrated, it is a factor that customers value highly:

> *"Sustainability is not something that we put directly count in dollars and cents, but it permeates all our work and is well incorporated in our organization".*

A public housing company ranked the green value of DH as the highest. In that case, the housing company and the energy company had a close relationship and the interviewee at the housing company had good knowledge of the local DH system. This knowledge made it easier for them to put a high value on the environmental benefits, which also goes hand in hand with the housing company's stated sustainability profile. An example of what can happen if the customer has less knowledge about the DH system can be found at the other municipal housing company:

> *"Most often it is the energy company that takes up the environmental benefit with district heating. Environment is on our agenda, too, but it is difficult to know what actually happens when using district heating instead of electricity. It needs to be communicated more clearly; it is difficult for us to know what impact we make through our different choices."*

Therefore, the municipal housing company where this view was found valued the green value low, despite the fact that the environment was on the company's agenda.

Customers were also asked how they valued other services offered by the energy companies in relation to the list in Table 12. The other service offerings were generally not valued at the same parity as the other factors. However, this may be because the requested customers have had no experience of the services actually offered and therefore have difficulty in putting a value on them. Two customers expressed that the services offered to them correspond to activities that the customer performs internally, and they have considered themselves able to carry out those activities more efficiently themselves, without the energy company.

It should also be mentioned that different customers value different factors. In particular, the two tenant-owner associations emphasized that the desire of the energy company to be more involved and involved in the operation of their equipment was seen as very positive. The tenant-owner associations valued an extended relationship with the energy company highly, especially the smaller tenant-owner association expressed it:

> *"What I value most is that there is someone who takes the time to answer questions and actually provide relevant answers to them. As a tenant-owner association, you often have low technical know-how and there is no time, skills or resources to do more complex investigations and installations, so it is important to find good suppliers who can take on these roles. Compared to other suppliers, the district heating company has been very good in that regard lately."*

Also, among the larger property owners, it was seen as positive that the energy companies show greater flexibility and willingness to adapt to the needs of the customers. Although for them, it is more about sharing resources or providing access to each other's equipment. In the case of the tenant-owner associations, for example, it was valued to receive higher support and assistance in processes.

If customers were offered a service or product that optimizes the operation of their HPs, all customers state that the greatest value to them lies in the cost savings that can be achieved. The smaller tenant-owner association sums it up:

> *"I think that it is mainly the potential for savings that should be shown in order for the offer to be attractive"*

Customers also see a value in the security of supply that is obtained from the combination of DH with HPs, since DH is seen as a good backup to the HP which may be more prone to operational interruptions.

In interviews with energy companies, it was suggested that customers can see a value in using existing resources more efficiently, but this value was not seen as significant by any of the customers surveyed. One customer argued that one could see it for a public housing company, but that it was difficult to apply it for private businesses. Above all, the value of the value is overshadowed by direct cost savings.

4.2.2 Customer expectations on energy company activities

Customers were asked if they considered that, by using internal resources alone, they could have optimized their plant for cost minimization, given that they had access to the right price signals. The private property owner and a municipal housing company felt that they had sufficient resources to do so, but other customers felt that they did not. The two first-mentioned customers can be said to be divided into the customer category "technical customers". On the other hand, all customers surveyed except the two tenant-owner associations considered that if they were offered an optimization product installed by an external party, their organizations would probably be able to handle the operation of this.

Regardless of how the optimization service is offered to the customer, customers expect the energy company to be present for a longer period of time than just during, for example, installation and commissioning. Customers expect the energy company to take responsibility for the optimization working in the intended and agreed manner. This was also noticed by the energy companies themselves. In particular, a municipal housing company expressed it as:

> *"[The energy company] must ensure that the heat pump is operated properly, for example, they must not run the compressor too hard as it affects the service life of something we have invested in. It is important to sign agreements that accurately allocate responsibility in such situations."*

Ensuring functionality means that energy companies need to follow up on the performance of the optimization that is being carried out and inspect equipment on-site, which can mean new activities for an energy company. At the same time, all interviewed energy companies noted this as conceivable additional activities in the business model. If the energy company were to take responsibility for the entire property's heating system, the property owner expects the energy company to take on a large responsibility and to provide services such as to remedy emergency faults. Technical customers in the public sector see a risk in referring to an external operator when tenants complain about lack of comfort:

> *"We want control of our own equipment ourselves. I do not have enough confidence in the energy company to completely hand over control of all our equipment to the energy company. When our customers call and complain that their apartments are cold, what should we say if another company is responsible?"*

All customers considered that there should be a green value in optimizing the operation of a HP in combination with DH, but the size of the green value must be clearly communicated by the energy company, which may mean additional activities for energy companies.

4.2.3 Channels

If energy companies optimize customers' equipment, new channels arise for communication between the customer and the energy company that have not been in place before. This provides opportunities for the extended relationship that was identified earlier when monitoring the performance of the customer's facility. The follow-up will be an opportunity for dialogue between the energy company and the customer, and potentially additional energy services can be offered because of this dialogue. However, relying solely on the fact that an IT solution is sufficient as a communication channel can be associated with risk as customers value being seen as individuals, it is then expected to be personal contact between the customer and the energy company, in addition to the exchange of just data.

4.2.4 Key resources

In offers where the energy company takes over the responsibility for the entire property's heating system, the question arises as to who will be responsible for the ownership and investment of the costly equipment that a heat pump constitutes. In the interview study, the larger tenant-owner association is a customer of Göteborg Energi in the project SmartHeat, where the agreement is designed so that the tenant-owner association owns the HP, but the energy company may use it. When asked if it was ever relevant for the energy company to own the HP, the answer was that it was never up for discussion. If the energy company had owned the HP, the customer would have had to commit to the agreement with the energy company for a considerably longer period, which the customer wanted to avoid. It was not relevant on the part of the energy company either, since it had entailed a large fixed capital in the customers property.

4.2.5 Customer relationship

All interviews with energy companies 'customers indicate that energy companies have a clearer focus on expanding the relationship with their customers, compared to customers' previous experiences. An example is given by the smaller tenant-owner association:

> *"Historically, we have not had a deep relationship. In general, they installed a substation in the 1980s and after that the district heating company did not appear again. Right now, however, things have started to change: […] I felt*

> *that someone cared about me and my needs and I always got relevant answers to my questions. It was something that I really appreciated. "*

The smaller tenant-owner association described his relationship with the energy company as minimal historically, the only real exchange occurred when the monthly invoice arrived. In recent years, however, the relationship has changed significantly, after the tenant-owner association consulted the energy company regarding an item on an invoice that needed to be explained. After this contact, a stronger relationship developed, as the energy company assisted the customer with smaller types of services such as energy calculations and follow-up of how the customer's facility performed.

A municipal housing company described its relationship with the energy company as a partnership, with a great deal of exchange between the actors that often resulted in solutions that favored both parties. The private property owner and the larger tenant-owner association described how the energy companies have historically acted without particular flexibility and without listening to their needs, but that the development has recently taken a completely different direction. They feel that energy companies "have begun to realize" that they must change their way of thinking to be competitive and be open to many different types of solutions.

> *"They have understood that if they are to cope with the competition, they must have a completely different approach to customers than they have had before. Then they behaved more like authorities and were more controlling. Now, they have started to open up more and listen to us customers and what we need."*

All customers also felt that if the energy company offered to optimize the operation of their existing HPs, it showed a willingness to understand the customer's system and needs, which has positive effects on the relationship between the actors. Depending on which segment the customer belongs to, there are different perceptions about how deep the relationship needs to go, non-technical customers may want to let the energy company take over responsibility for the operation of the property's heating system. More technical customers express a desire to retain control of their own facilities and are happy to see collaborations where the energy company acts more as a supplier of an optimization service rather than take over the overall responsibility for the property.

4.2.6 Key partners

Two customers, a municipal housing company and the private property owner, expressed that the relationship between the energy company and the customer may certainly develop into a partnership. The municipal housing company considered that they were already working in a partnership with the local energy company, while the private property owner was happy to see greater cooperation on energy issues:

> *"We would love to see that they have a broader perspective and see the possibilities of sharing energy in the best way in more ways than is done today. Wouldn't we be able to buy and sell energy from each other when it is best for society at large?"*

The private property owner considered that co-optimization between DH and their HPs would be a good first step, but that more could be done. For example, energy companies could help design energy districts that optimize energy use at the system level.

4.3 RESULTS: NEW REVENUE MODELS

Based on the results of the interview study and through dialogue with the project's reference group and the energy companies that have contributed to the project's case studies, two possible revenue concepts for energy companies that offer optimization of customers' HPs together with a DH connection have been developed. In principle, the concepts can be described by positioning them along an axis that goes between the extremes "Product Oriented Offer" and "Customer Oriented Offer", see the service pyramid presented in Section 2.4.3, Servitization. Regardless of the way in which energy companies choose to charge to optimize customers equipment, at least two practical aspects are required to keep in mind:

- For a building owner's HP to be controlled based on an external price signal, external hardware must be installed. This may include:
  - × that the HP's outdoor temperature sensor is replaced or modified and used to indirectly control the HP by providing it with modified temperature signals.
  - × Extra control equipment and modification of the customer's DH substation.
  - × internet connection for control and monitoring.
  - × Possible HP and peripherals (if the offer include a new HP)
- To maximize the potential of heat source shifting from HP to DH, energy companies must be able to estimate or calculate an energy price for customers with the same resolution as electricity prices in the market vary. That is, per hour. How this pricing is designed or used can vary with revenue concepts.

The two concepts that have been developed and evaluated in the project are referred to as *The Product* and *The Service*. The concepts are described in the following sections.

4.3.1 Concept 1: *The Product*

In *The Product* concept, the energy company offers the customer a package solution that connects the customer's HP and DH substation to a new control system with all necessary hardware. The control system means that the energy company takes over control of the customer's HP and gives it signals for when it should be off, on or run in partial load mode if the HP allows this. The property's control system still produces signals describing the property's total heating needs, which must be met by the two heat sources DH and HP, for example expressed in the form of a supply temperature. In practice, the choice of heat source can be made without forecasting the need for the property, since the choice only involves prioritizing the heat sources where one choice does not exclude the other.

If the HP is to be used because it has the lowest operating cost for the moment, heat requirements that cannot be covered by the HP can still be covered by DH.

The solution must consider the HP's performance in different operating cases, which affects its operating cost.

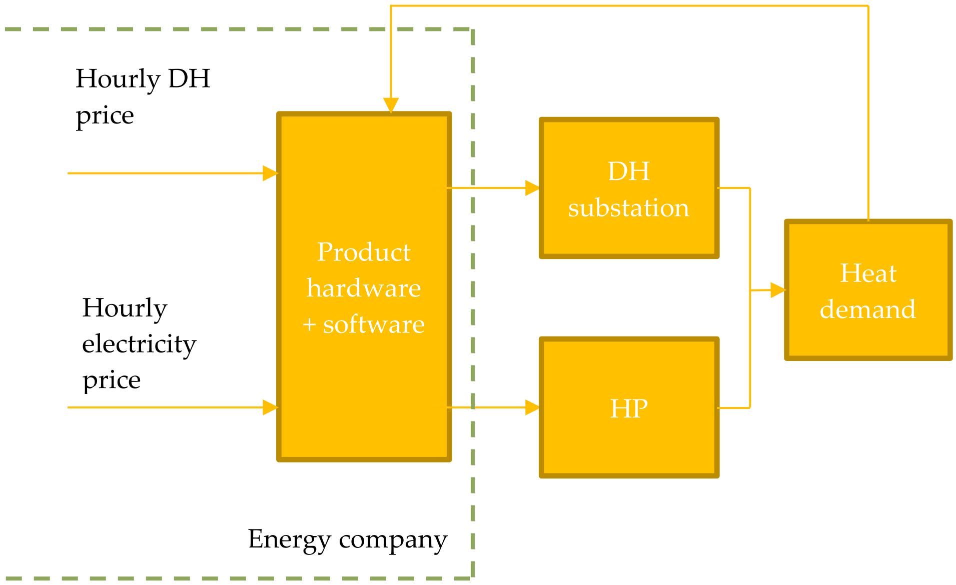

Figure 6 Principal sketch of *The Product* concept. The energy company's liability limit lies at the control signals leaving the optimization product to the HP and DH substation.

In the concept, the energy company acts as a reseller of the product HP optimization, which includes hardware and software that generate control signals for the two heat sources in the customers building. It is proposed that *The Product* is offered to customers at a monthly cost, which is intended to cover the energy company's costs for purchasing or developing and installing the optimization package at the customer over a set period in par with the energy company's other requirements for payback times.

In addition to the revenue from the fixed monthly cost for the optimization package, *The Product* also means increased revenue for the energy company in the form of increased volumes of DH delivered, compared to the alternative that the HPs operation is not optimized. The monthly cost must therefore be related to this increased revenue and set to a level that provides reasonable fixed monthly earnings for the energy company. The customer's savings from optimization must also be considered when determining the monthly fee.

In the product concept, the energy company does not take over responsibility or ownership of the customer's building technology, but is responsible for the correct control signal being generated to the DH substation and the HP. Alternatively, the monthly cost of *The Product* may include an agreement on supervision of *The Product*'s function with the customer, which would in that case entail an increased monthly fee for the customer.

The concept includes that the energy company develops new price models where the energy price is set on an hourly basis, for example according to a projected marginal production cost. One way to simplify dynamic pricing of DH on an hourly basis is to base the pricing on outdoor temperature, which has been done by, among others, Umeå Energi and Stockholm Exergi (in Stockholm Exergi's case, this is done to value heat delivered *to* their networks) (Umeå Energi, 2019) (Stockholm Exergi, 2019). The DH marginal production costs follow the total heating demand in the system, which in turn is dependent on the outdoor temperature. However, this simplification is associated with uncertainties, as local DH production does not always follow the outdoor temperature, for example because the system contains heat storage. The marginal production cost then also depends on how the heat demand has varied before the actual delivery hour and how much heat is stored in the system. The need for domestic hot water in properties also has a stronger connection to what day of the week and time of day it is than what outdoor temperature applies. *The Product* concept can also be implemented without the development of new energy pricing models for DH, but this reduces the potential of optimization for cost savings and utilization rate.

Electricity prices can be obtained from NordPool's spot market regardless of the electricity contract the customer has, as long as it is a variable contract. If the customer has a fixed electricity contract, the potential for savings in optimizing operations is less likely than for variable electricity contracts.

The customer's cost structure when *The Product* is implemented can be summarized in Figure 7, which shows how a customer's costs are distributed from a normal present situation to the arrangement in *The Product*. If the offer from the energy company is to be attractive, the customer's total cost must be reduced from the case when no optimization takes place. The energy company can influence its revenues by setting the monthly fee for *The Product* and the marginal premium for DH per hour, so that the customer still receives some total savings.

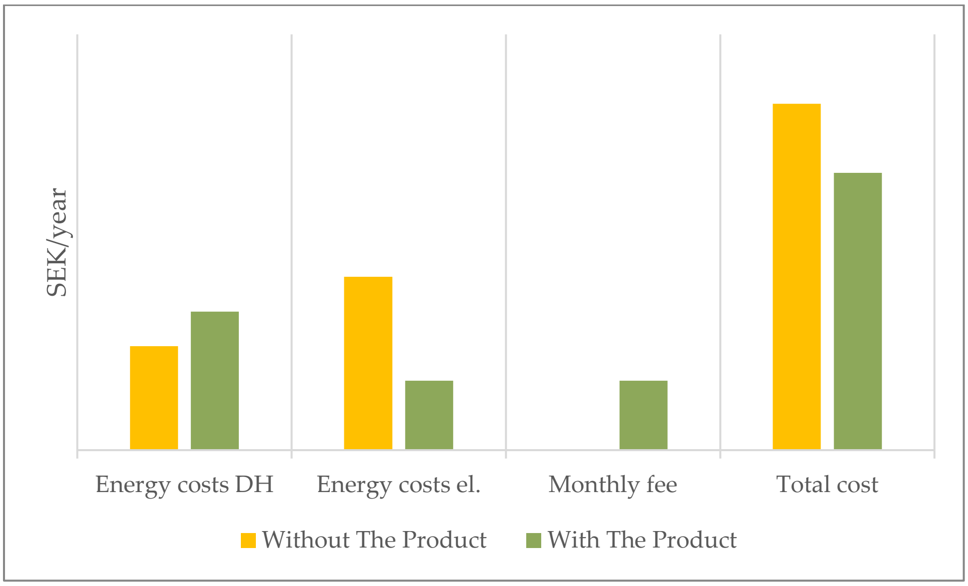

Figure 7 Principal costs for customers with and without optimization with *The Product* concept

In the project, *The Product* is evaluated by calculating the savings that a customer can get from optimizing the operation of his HP. The savings are based on results from simulations of the operation of a HP and district heating connection in the project's type network and case study properties. The simulations are performed by comparing the marginal production cost for DH in the typical network with spot prices on the electricity market and having the customer's HP turn off when the cost of supplying heat to the building through the DH connection is lower. This will give a cost reduction for the customer, compared to the reference case: not to control the HP optimally. Through the subscription fee, *The Product* generates stable revenue for the energy company, while at the same time increasing the supply of DH.

In a further development of the business model, profitability calculations can be drawn up from the energy company's and building owner's perspective. The calculations may form the basis for how the offer of *The Product* to the customer is formulated in detail and will be influenced by the factors listed in Table 13, assuming that the property owner owns the HP, regardless of whether it is a new or existing HP:

Table 13 Overview of cost and revenue structure for the energy company and the property owner in *The Product* concept

	Building owner	Energy company
Costs	Possible investment and installation costs for heat pump	Costs for purchasing and/or developing and installing optimization product
	Cost of investment and installation of optimization product	Personnel costs to operate, maintain and follow up optimization and control internally
		Personnel costs for supervision and service, may include the HP
Revenue/saving	Savings in the form of reduced electricity costs compared to normal operation	Increased volume of DH sold
		Sales margins from optimization product and possibly HP
		Sales margin for service and supervision

4.3.2 Concept 2: *The Service*

The second proposed concept is called *The Service* and means that the energy company takes a greater responsibility for the heating of the customer's building. The concept means that the energy company offers the customer a comfort agreement and guarantees, for example, that a certain indoor temperature will be kept in the property during all hours of the year. It is up to the energy company to maintain and optimize the property's heating system, including a possible HP. A similar concept has been implemented by Götborg Energi in the pilot project Smart Heat and Kraftringen is considering offering the customer a package solution where HybridFX can be combined with comfort agreements (Hansson P. , 2019), (Edsbäcker, 2019).

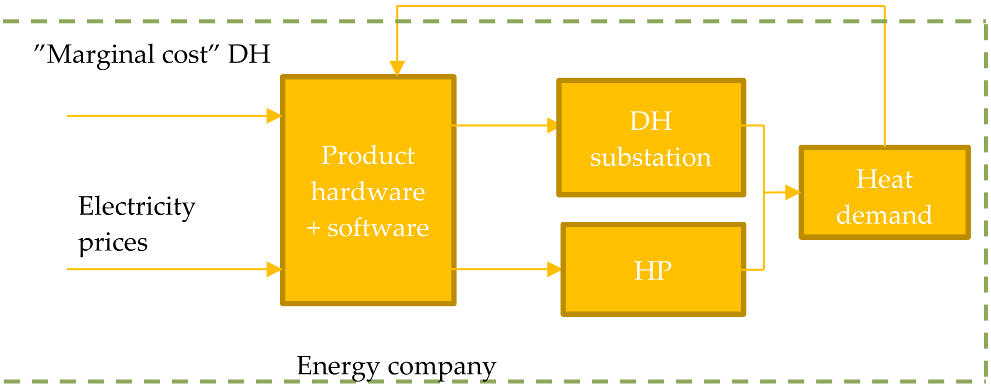

Figure 8 Principal sketch of *The Service* concept. The energy company's liability limit is moved further into the building and includes the entire heating system.

With a comfort agreement, the customer pays a fixed monthly fee for the energy company to supply a specific indoor temperature. The arrangement provides an incentive for the energy company to deliver heat to the building at the lowest possible cost to achieve revenue from the fixed monthly fee. If the customer has a HP that can supply heat, this is also included in the cost minimization. The HP can be regarded as a production plant among the energy company's regular production mix and is optimized together with other plants in the same way that the energy company optimizes the rest of its production at present. This ultimately means that the property's HP and DH connection are optimized against marginal costs in DH production and hourly spot prices on the electricity market.

The fixed monthly fee for the customer is set by the energy company based on the customer's alternative cost, i.e. using the HP in a conventional way with DH for peak demand only. The monthly fee must be set at a level that provides lower total heating costs than if the Service had not been implemented. See Figure 9 for a sketch of the customer's cost structure with and without *The Service* concept. If the energy company fails to optimize the energy supply at a lower cost than the fixed monthly fee, a loss is made. In addition to producing and delivering DH to the customer's property, the energy company must also take over the costs of operating the HP in the building. Note how the customer's energy costs for electricity in Figure 9 are equal to zero, as these costs are transferred to the energy company.

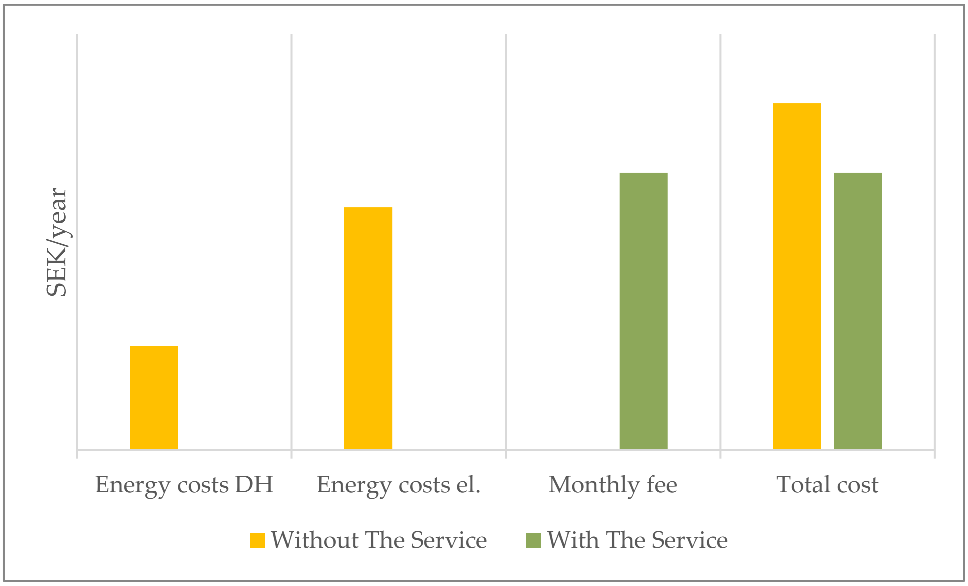

Figure 9 Principal costs for customers with and without optimization with *The Service* concept

In many cases, the service concept means the greatest differences in where the energy company's liability limit is drawn, compared to a usual DH supply setup. With *The Service*, it is in the energy company's interest that energy efficiency measures are carried out in the property and that the entire property's heating system is maintained and operated optimally. The limit of liability can be moved as far as the customers' radiators, which places new, greater demands on the energy company's organization when it comes to competence and knowledge about the heating systems and service services of the properties. It may also mean that additional new hardware needs to be installed in the customer's property.

The concept is evaluated in the project by studying the savings that can be achieved by optimizing the operation of the heat pump. The savings consist of the changed operation that is obtained by controlling the property's HPs regarding spot prices on electricity and marginal production costs for DH without margin surcharge. Compared to the product concept, the customer's HP becomes a more integrated part of the energy company's DH production and no new, direct pricing for DH on an hourly basis is needed.

For *The Service* concept, it is assumed that a new HP will be installed in the property, the profitability calculation will change depending on whether the property owner or the energy company is responsible for owning it. It is not assumed that energy companies in *The Service* concept would take over ownership of customers' existing, old, HPs. Factors affecting profitability for both parties are listed in Table 14.

Table 14 Overview of cost and revenue structure for the energy company and the property owner in *The Service* concept

	Building owner	Energy company
Costs	Possible investment and installation costs for heat pump	Costs for purchasing and/or developing and installing optimization product
	Cost of *The Service* including optimization, control, operation, and maintenance.	Costs of DH production
		Electricity costs for HP
		Costs for technical upgrade of customers building, e.g. indoor temperature sensors
		Personnel costs to operate, maintain and follow up optimization and control internally
		Personnel costs for maintenance of building systems
		Risks expressed as costs: unexpected tenant behaviour, technical performance, weather
Revenue	Savings in the form of reduced electricity costs compared to normal operation	Profit margin between monthly fee for *The* Service and the cost of supplying comfort
		Sales margin for service and supervision

4.4 CUSTOMER SEGMENTS FOR THE CONCEPTS

The identified customer segments from the interview study are divided along the dimensions "Bigger / smaller" property owners and "technical / non-technical" property owners according to Figure 10. The concept *The Service* is aimed at more non-technical customers such as tenant-owner associations and smaller private and public building owners who value the security of transferring the risk of operating the heating system itself entirely to the energy company. The concept *The Product* is more relevant to offer technical customers who express an unwillingness to hand over control of their equipment entirely to an external actor.

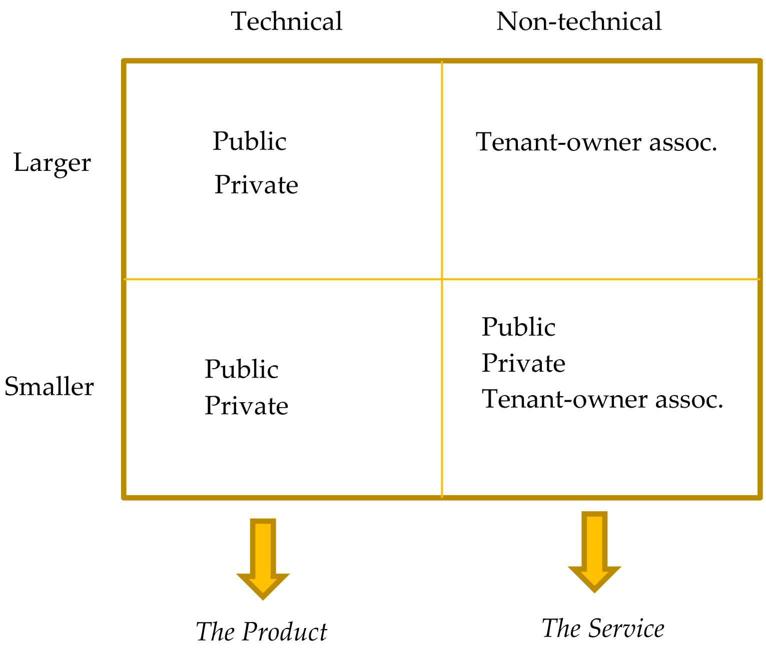

Figure 10 Customer segments for each concept

4.5 SUMMARY OF BUSINESS MODEL CHANGES

In summary, the interview study points out that energy companies' business models should be complemented by the factors shown in Table 15. So far, both concepts have described how energy companies optimize customers' HPs by following electricity prices on the spot market. Regardless of whether energy companies choose to offer customers *The Product* or *The Service*, this means that the business model is primarily changed in the way that value is created for the customers. Although there is an obvious value in the form of cost savings, there is a great value in being offered services and solutions, which means that the energy company adapts to the customer's needs through dialogue and deepened relationships. The green value, which may be difficult to define, grows in importance but is valued differently by different actors.

Table 15 Additional factors in energy companies 'business model when optimizing customers' heat pumps, compared to the conventional business model mapped in section 2.4.2

Key partners HP suppliers System suppliers Customers Maintenance suppliers	**Key resources** Competences IT-infrastructure	**Value proposition** Cost reductions The green value Flexibility	**Customer segments** Technical Non-technical Private, public, tenant-owner.
	Key activities Services Customer dialogue Supervision, maintenance	**Channels** Evaluation Control	**Customer relationship** Dialogue, trust, and long-term commitment

The energy companies' new business models are to a large extent focused on increasing and nurturing the relationship with customers and increasing the number of key partners. The energy company goes from operating in a value chain to becoming part of a larger, more integrated value network where the energy company becomes the hub for conveying value to customers in more advanced ways, through exchanges with all actors in the network.

4.6 THE CONCEPTS AND POWER REGULATION MARKETS

Both concepts have so far described how energy companies optimize customers' heat pumps by following electricity prices on the spot market. By entering into partnerships with aggregators or Balance Service Providers (BSPs), such as Power2U (Power2U, 2019), which acts on power regulation markets, for example, trading on the mFRR market can also generate extra revenue for the energy company under *The Service* concept, since the energy company stands for the electricity trade and grid contracts for the HP. Through a bilateral agreement with the aggregator, revenue from trading on the regulation market is shared between the energy company and the aggregator and the profit margin can increase for the energy company in the comfort agreement with the building owner.

In *The Product* concept, it is more likely that the building owner enters into an agreement with an aggregator to provide its HP as a managed load on the regulation market, since the energy company does not stand for electricity contracts. If the energy company enters into bilateral agreements and acts as an intermediary between the building owner and the aggregator, the energy company can take advantage of the profits from the HP power trade, but since this is to be shared between the aggregator, the energy company and the property owner, the profits for each operator decrease.

4.7 THE CONCEPTS IN TERMS OF SERVITIZATION

By offering *The Product* or *The Service* concept, energy companies are taking steps towards an expanded range of offered services.

The product can be said to belong to the second level of service, where the focus is on optimizing the performance of the customer's technical installations. Performance in this case means reduced heating costs. In Figure 11 this is marked as "Surveillance and control of the customers equipment".

The service concept is placed here in the highest level of services, with focus on the customer side, see Figure 11. Here also conventional comfort agreements are placed where only DH is included in the agreement. *The Service* concept is distinguished in the figure by making the comfort agreement more advanced when HPs also are included.

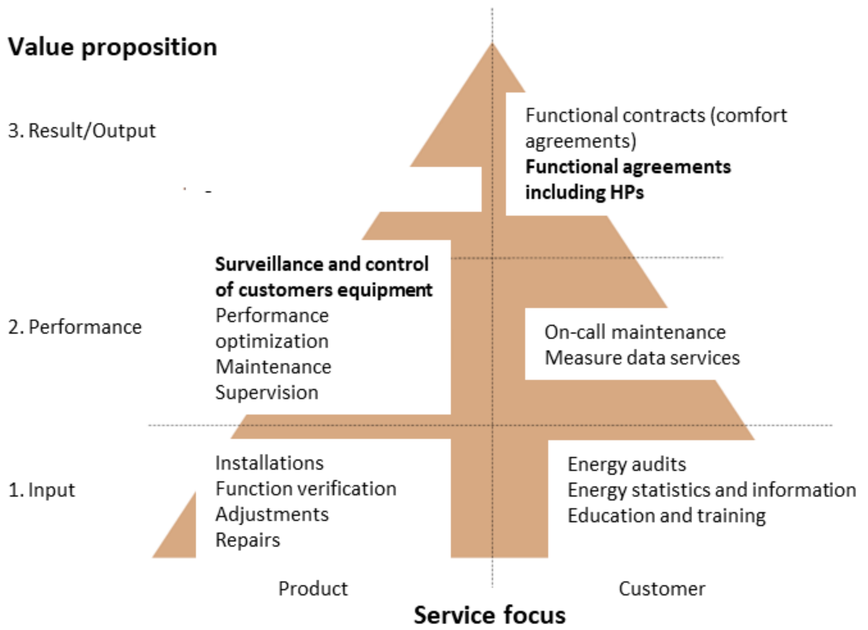

Figure 11 The concepts *The Product* and *The Service* are highlighted in the energy service pyramid

Traditionally, energy companies have worked with servitization by developing new technology incrementally and have had a product focus. Thus, the development has taken place vertically on the left side of the service pyramid. Here you will also find the concept *The Product*, which has a clearer focus on technology than the comfort agreement *The Service* has. In order to offer *The Service*, that is, a comfort agreement that includes other heat sources than DH, it is necessary for the energy company to shift its focus from *The Product* to the customer's needs, to obtain an indoor temperature, which can be difficult for energy companies according to the interview study. The arrows in Figure 11 show how the development of services needs to make a shift to come to the service concept.

In the interview study, the following barriers were also identified to reach higher levels in the service pyramid by optimizing customers' HPs:

- Price models that fully support optimization do not exist for many energy companies
- Today's IT infrastructure cannot handle a diversified stock of building HPs
- Customers, especially technical customers, have the opinion that the energy company does not have sufficient expertise regarding HPs and building systems. It is also shown in the fact that two public housing companies in the interview study stated that they were worried about having to refer to an external actor if their residents had complaints of impaired comfort due to problems in the property's heating system. This may be due to the fact that HPs have long been a major competitor to DH and conversions from DH to HP have been met with scepticism from the energy company. If the customer has an existing HP that the customer has invested in, there is a concern that the energy company's control of the HP will damage the fixed asset that the HP constitutes.

It should be added that, although the historical technical focus may be an obstacle to reaching the highest levels of the service pyramid, it has also meant a possibility. Without the long-term technical development of DH, it would not have been the reliable and often price-competitive solution that it is today. Without these conditions, perhaps no energy services could have been developed at all. The trend towards more advanced services is incremental, as was also pointed out by (Kindström, Ottosson, Thollander, & Kienzler, 2015).

4.8 RESULTS: SIMULATIONS

All simulation results are presented in this chapter. For each case study, typical network and year, normal operation has been compared to shifting operation. The simulation results are presented by three comparison parameters: Heating cost, Heat load distribution between heat sources and Emissions of CO2 equivalents. For each parameter, the average value for the three simulated years for each case study and typical network is reported. For each parameter, the case study and type network are also reported where the largest and smallest change on the comparison parameter is recorded between normal and shifting operation.

For the case study where the greatest change was noted in the comparison of normal and changing operations, further simulations have been carried out where the opportunity to participate on the regulation market mFRR in the electricity area SE3 is also included. The case study with the largest changes in the first simulation stage (comparing DH cost to spot market prices) is Case Study 1 and therefore for this case study a simulation has been carried out where the operation of the HP and DH is allowed to change based on possible revenue from mFRR. For the case study, the number of extra hours that an economic potential arises to shut down and start the HP, respectively.

4.8.1 Marginal costs for DH and HP

The parameters that determine how the shifting between DH and HP should take place in a property is the cost of heating with the respective heat source. Therefore, here is an account of how marginal production costs for useful heat relate to each other in the different types of networks and case studies.

The comparison is made for case study one to three for "Type network: CHP without accumulator tank".

The marginal production cost for DH is stated per MWh of heat produced and is based on the variable operating cost per production plant. The marginal cost of produced DH varies more compared to the marginal cost of produced heat from HPs over the year. This becomes clear both when comparing the marginal cost variation by outdoor temperature, see Figure 14, and over time, see Figure 12. The marginal cost of heating with a HP is lowest for a GSHP and highest for an EAHP.

The marginal cost of heat production with a HP is affected by two factors, the electricity price, and the COP. Both factors have relatively small variations over both time and temperature, under the assumptions made in this study, see section 3.3.2 for details. The marginal cost of DH depends on the heat production mix. An example of this is seen in a comparison of the shape of the marginal cost curve for district heating in Figure 12 and the shape of the heat production curve in Figure 13. In the type network shown, “CHP without accumulator tank”, low marginal production costs appear during summer in particular, and more expensive peak load during winter from HOBs.

It becomes clear that during the colder months of the year, DH is always significantly more expensive than heat from all three heat pumps studied. During the summer months, DH is usually the cheapest option, while in spring and autumn it often varies between which heating option gives the lowest cost.

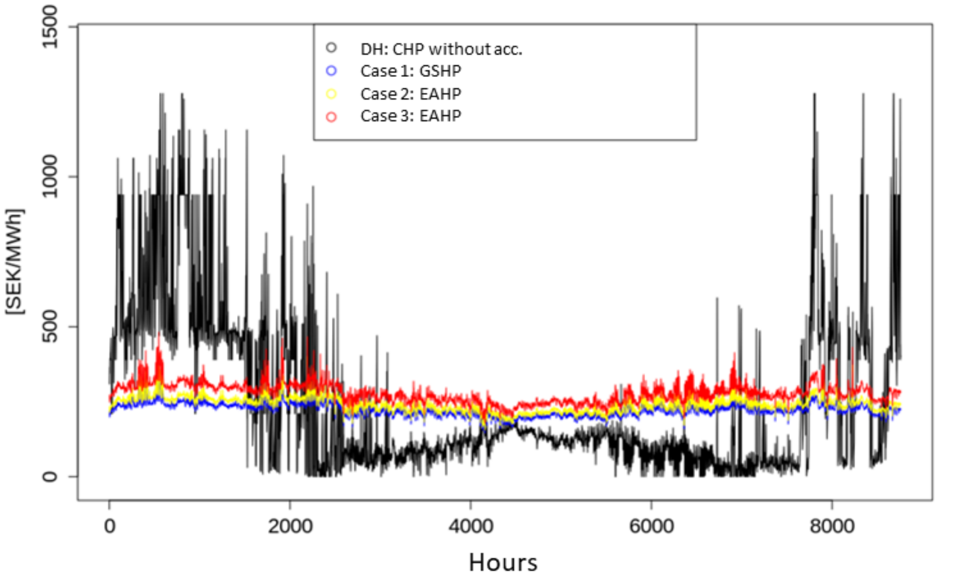

Figure 12 Marginal production cost for DH as well and heat from HPs for case study 1-3, in 2015 in the type network CHP without accumulator tank.

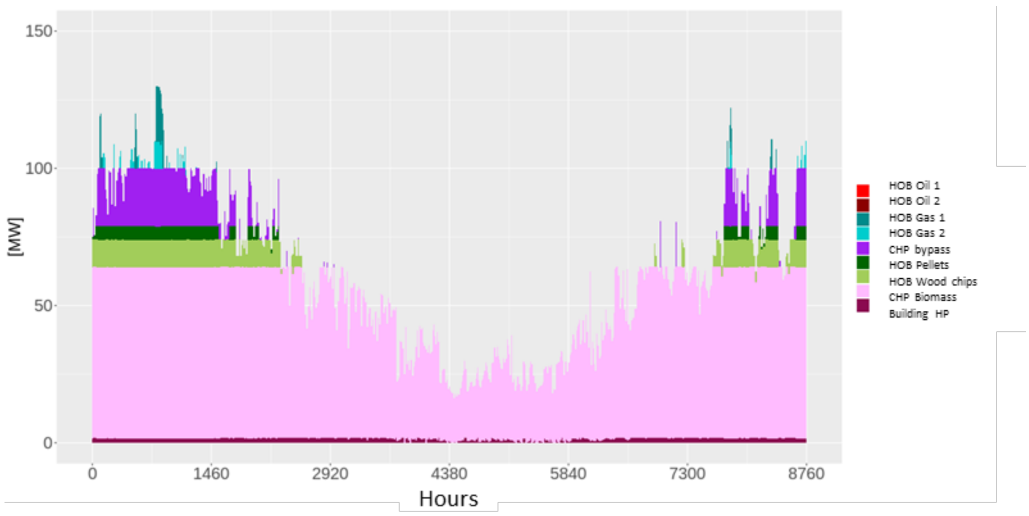

Figure 13 Heat production 2015 for Type network: CHP without accumulator tank

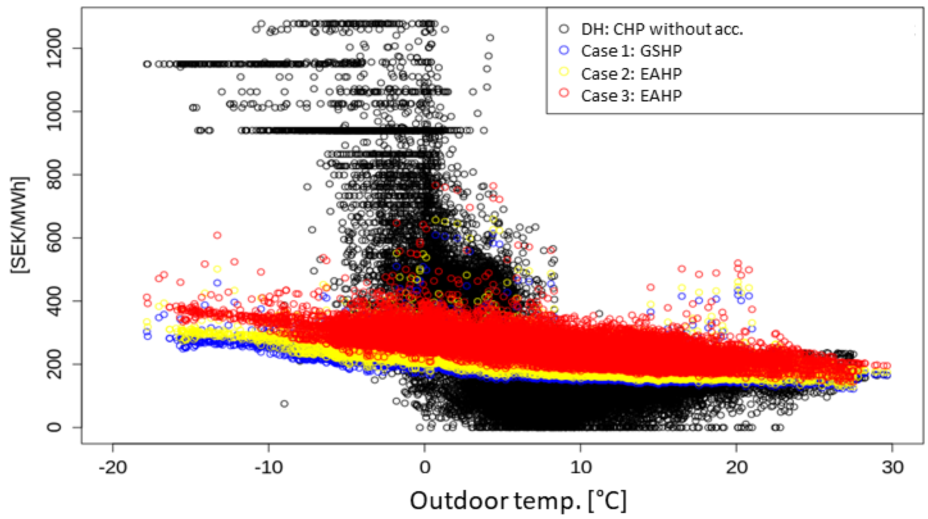

Figure 14 Marginal production cost for DH and heat from HP for case study 1-3 as a function of outdoor temperature during 2015-2017.

Note that the marginal cost of heating with HPs has a linear relationship with outdoor temperature in Figure 14, even at higher outdoor temperatures, since the heat load in a building then often consists solely of domestic hot water. For hot water production, the COP typically drops in a HP due to the high temperature lift required. In this study, this effect has been disregarded, which means that a HP may have been selected for heat production when DH is actually cheaper. However, the heat load during hours with high outdoor temperatures is relatively small and is expected to have a small impact on the results.

4.8.2 Heating costs

During shifting operation, the operation of the buildings heating system has been optimized for the lowest total cost based on marginal production costs for DH and HP per hour. The calculation of the heating cost only regards the marginal cost of DH versus HP, described in section 3.3.2, no other costs are included. A comparison of the total heating costs in normal and shifting operations shows the potential savings for a building owner.

Table 16 shows a summary of the average heating cost for the three simulated years for each case study and type network. In terms of percentual reductions, it is clear that Case Study 1 is the case study where the greatest reduction in heating costs has been calculated. This is even though the case study includes a GSHP with a significantly higher COP than in other case studies. This is believed to be due to the fact that the GSHP in Case Study 1 are dimensioned to cover a larger part of the property's heat load than in the other case studies and there is thus a greater amount of heat energy to shift from HP to DH. Case study 2 has similar relative cost reductions as Case Study 3: "Municipal housing company, EAHP 2". Comparing the different type networks, it can be seen that the type network with the lowest variable operating cost (see Table 8) gives the largest reduction of heating cost when using shifting operation, namely Type grid: “EH without accumulator tank”. In practice, this means that the HP in the building has been switched off during summer in favor of the use of DH from industrial waste heat. It can also be seen that type network “Central HPs” have the smallest reduction in heating costs, which is expected as the cost of heat from the type network follows the cost of heat from the building HPs.

Table 16 Annual reduction of total heating costs with shifting operation compared to normal operation in all case studies in all type networks. The cost reduction in the table is reported both as absolute figures per year (SEK/year) and relative reduction and refers to the period 2015-2017.

Case study	Type network CHP w/o acc	Type network CHP w acc	Type network HP w/o acc.	Type network HP w acc	Type network EH w/o acc	Type network EH w acc
1: GSHP	25 000 -16%	17 000 -10%	11 000 -7%	5 000 -3%	50 000 -33%	43 000 -28%
2: EAHP	8 000 -12%	6 000 -7 %	3 000 -4%	1 000 -2%	15 000 -23%	13 000 -18%
3: EAHP	19 000 -12%	14 000 -8%	9 000 -6%	5 000 -3%	33 000 -23%	29 000 -18%

Figure 15 shows the difference in heating costs for Case Study 1: “GSHP” in normal versus shifting operation for Type network: “Excess heat without accumulator tank”. This is the combination of case study and type network that resulted in the largest reduction in heating costs of the property during a transition to shifting operation, as shown in Table 16. Case study 1: “GSHP ”shows the biggest change due to the fact that the HP in the case study have a higher degree of energy and power coverage than in the other case studies and that the type grid with excess heat has very low marginal costs during the summer.

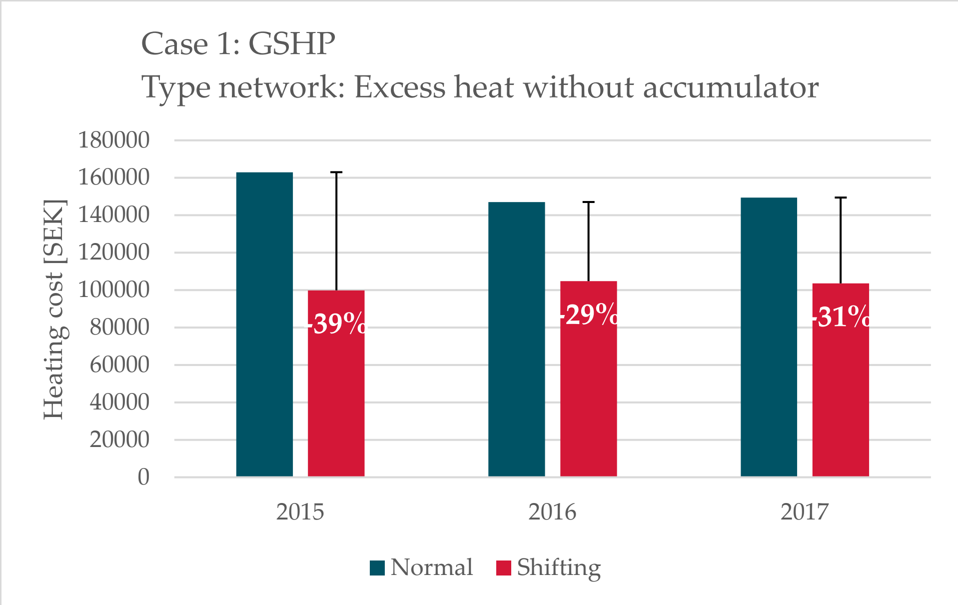

Figure 15 Heating cost for Case Study 1: GSHP in normal and alternating operation for Type network: Excess heat without accumulator tank.

Figure 16 shows the difference in heating cost for Case Study 2: EAHP 1 for normal versus shifting operation for Type network: HP with accumulator. This is the combination of case study and type network that resulted in the smallest reduction in heating costs. Type network: HP with accumulator has during the summer months, which are the months when DH is the cheapest, central HPs on the margin, which makes it the least profitable fuel mix to optimize against. Case studies 2 and 3 have many similarities and the percentage difference in heating costs between them is so small that it is within the margin of error for the simulation. Therefore, it is difficult to say whether one of the two has greater potential than the other. In this case, it was case study 2 that show the smallest reduction.

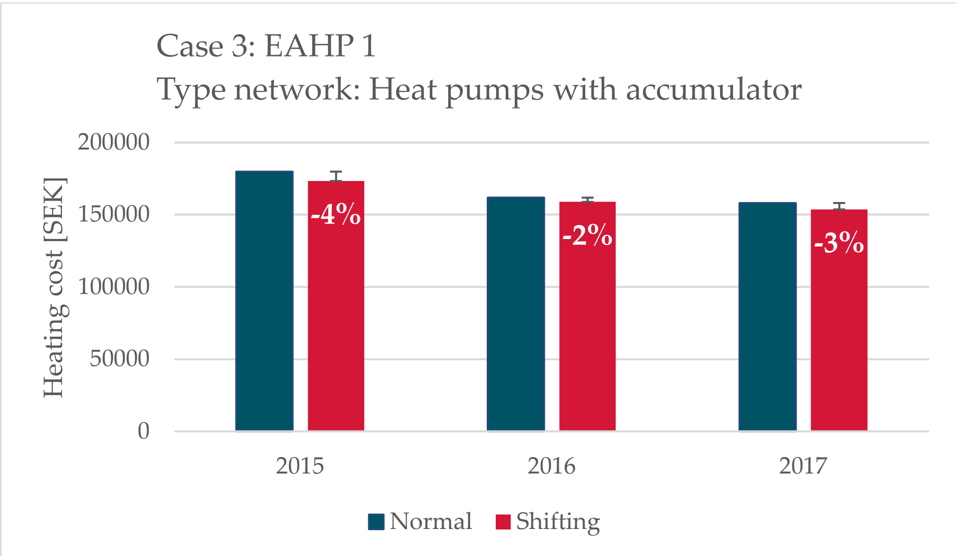

Figure 16 Heating costs for Case Study 2: EAHP 1 for normal and shifting operation for Type network: Heat pumps with accumulator

4.8.3 Shifted heat

In normal operation, HPs deliver the maximum proportion of the heat load that they have the capacity to cover. Therefore, in shifting operation, the use of DH always increases compared to normal operation.

Table 17 shows a summary of the average yearly amount of heat that has been shifted from HP to DH for the three simulated years for each case study and type network. When studying the relative increase of used DH, it is clearly seen that Case Study 1: GSHP is the case study where the largest increase has taken place. Case study 2: EAHP 1 has an equal percentage increase compared with Case study 3: EAHP 2. This is because the two heat pumps in Case Study 1: GSHP are designed to cover a higher proportion of the annual energy and maximum power than the HPs in the other two case studies.

If the different types of networks are compared, it is possible to draw the same conclusions as for the case study's changed heating costs. Type grid: Excess heat has the largest increase and Type grid: Heat pumps gives the lowest increase and thus also the least difference in how the operation changes between normal and shifting operation. This is in line with the results shown in Table 16 where the heating cost had been reduced significantly more for Case Study 1: GSHP compared to other case studies. As the shifting operation has been optimized based on the operating cost, it is expected that the largest change in the load distribution will be for the type networks with lowest variable operating cost.

Table 17 Annual increase of DH use during shifting operation compared to normal operation. The DH use in the table is reported both as absolute figures per year [MWh / year] and relative increase and refers to the period 2015-2017.

Case study	Type network CHP w/o acc	Type network CHP w acc	Type network HP w/o acc.	Type network HP w acc	Type network EH w/o acc	Type network EH w acc
1: GSHP	+250	+190	+120	+66	+360	+300
	+929 %	+720%	+451%	+245%	+1343%	+1124%
2: EAHP	+76	+59	+32	+19	+100	+89
	+133%	+104%	+56%	+33%	+184%	+156%
3: EAHP	+150	+120	+126	+80	+190	+170
	+96%	+79%	+82%	+52%	+122%	+107%

Figure 17 shows heat use from DH and HP for Case Study 1: GSHP in normal and shifting operation for Type network: Excess heat without accumulator tank. This is the combination of case study and type network where the use of district heating increased the most. Case Study 1: GSHP shows the biggest change due to the HPs high energy coverage ratio in the normal case and that the type network with excess heat has very low costs for DH production.

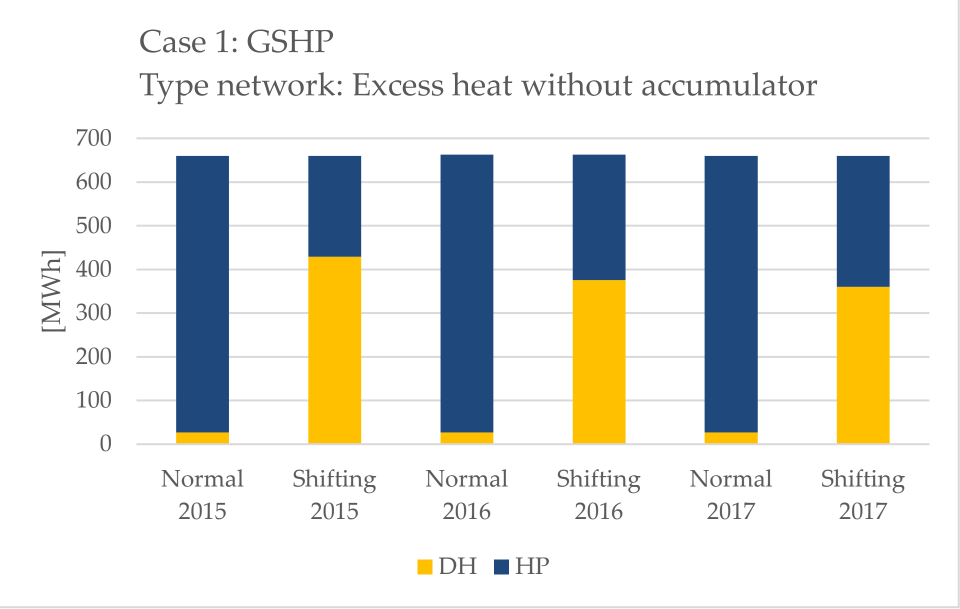

Figure 17 Use of DH and HP for Case Study 1: GSHP in normal and shifting operation for Type network: Excess heat without accumulator tank.

For the same case study in Type network: Excess heat the use of heat in the building during each hour in 2015 is shown in Figure 18 and Figure 19. Case Study 1: GSHP in Type network: Excess heat without accumulator tank in 2015, was the case that generated the largest percentage difference in heat production cost. In normal operation, district heating is only used as peak load during winter months, while in alternating operation district heating is used for most of both spring and autumn and even for longer periods in the autumn-winter. There are also several periods when the priority between heat from the HP and DH changes frequently.

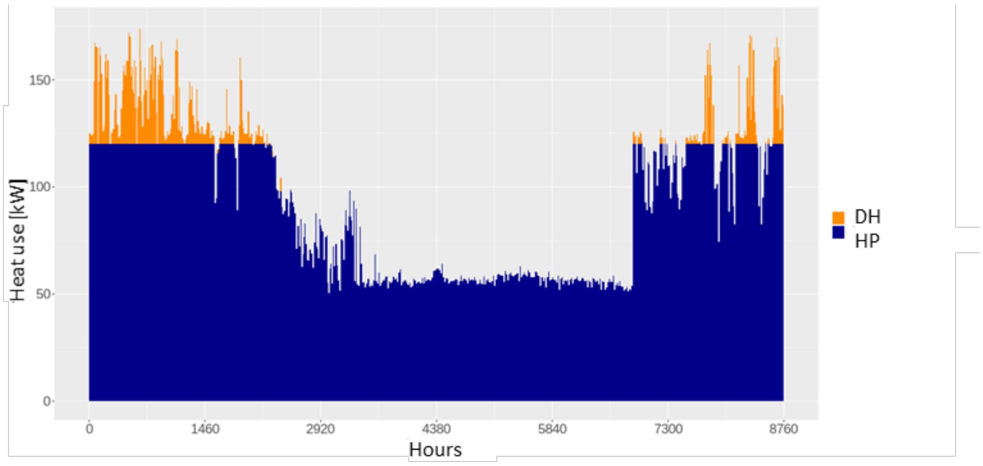

Figure 18 Normal operation during 2015 for Case Study 1: GSHP and Type network: Excess heat without accumulator tank.

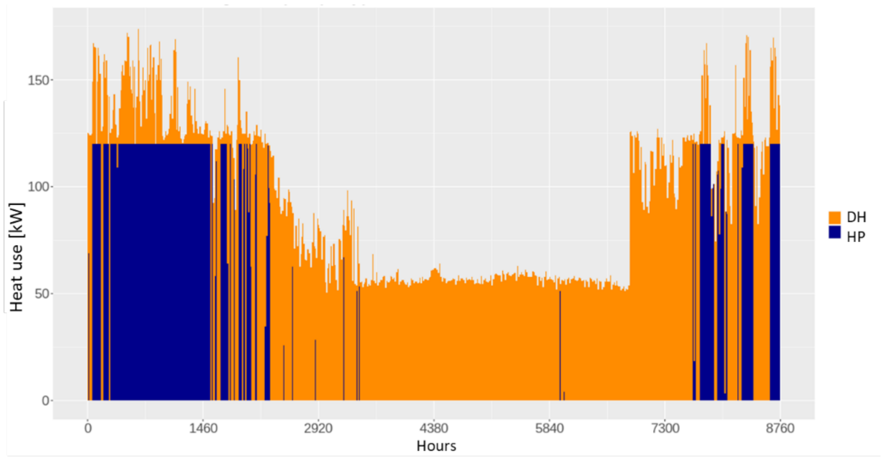

Figure 19 Shifting operation during 2015 for Case Study 1: GSHP and Type network: Excess heat without accumulator tank.

Figure 20 shows use of DH and HP for Case Study 2: EAHP 2 and Type network: Heat pumps with accumulator tank. This is the combination of case study and type network where the use of DH increased the least, for the same reasons that cost savings are smallest for the combination. In the case study, heat is shifted from the HP to DH primarily during spring and autumn. During the summer period, the building HP does actually give a lower marginal cost of heat production. During summer, large HPs make up the marginal production plants in the DH system and it is not cost efficient to shift from building HPs to DH during these periods. See Figure 21 and Figure 22, where the heat usage in the property per hour for one year is shown. Case study 2: "Municipal housing company, extract air heat pump 1" and Case study 3: "Municipal housing company, extract air heat pump 2" have many similarities and the percentage difference in heating costs between them is so small that it is within the error margin for the simulation. Therefore, it is difficult to say whether one of the two has greater potential than the other. In this case, it was Case Study 2: "Municipal housing company, exhaust air heat pump 1" that had the smallest reduction.

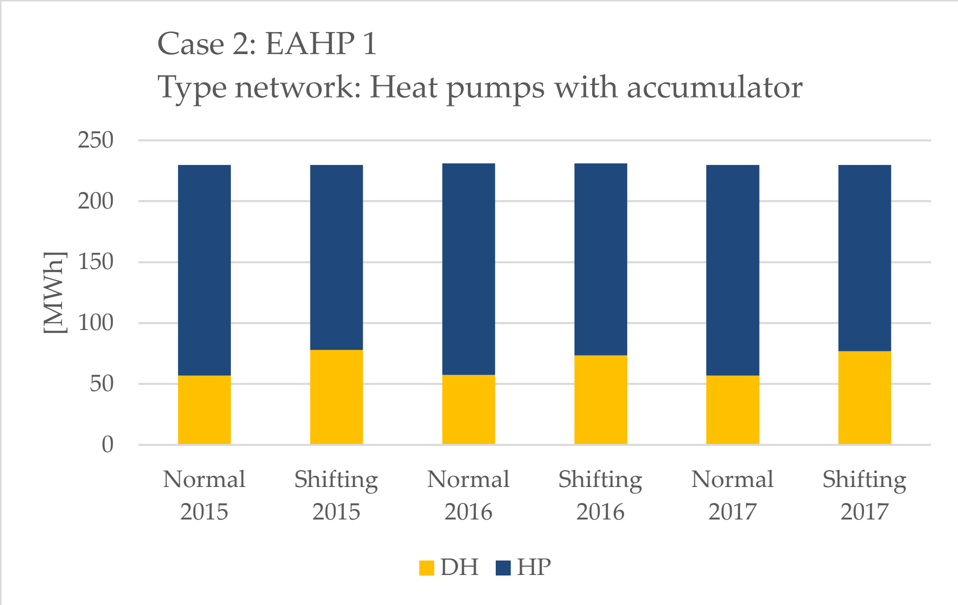

Figure 20 Use of DH and HP for Case Study 2: EAHP 1 in normal and alternating operation for Type grid: Heat pumps with accumulator.

Case Study 2: EAHP in Type network: Heat pumps with accumulator tank in 2016 generated the smallest relative difference in heating costs. In Figure 21 and Figure 22, the hourly use of DH and HP for normal and shifting operation are shown and compared.

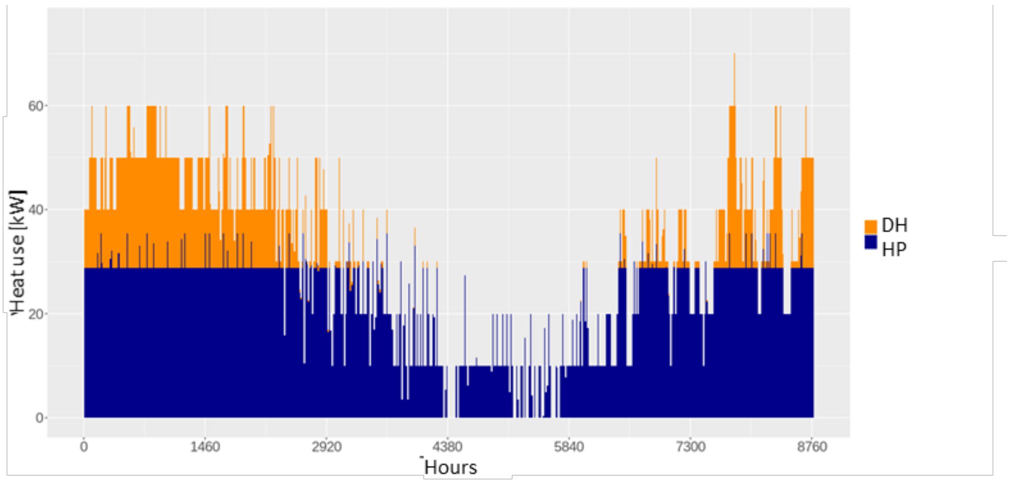

Figure 21 Normal operation in 2016 for Case Study 2: EAHP 1 in Type network: Heat pumps with accumulator tank.

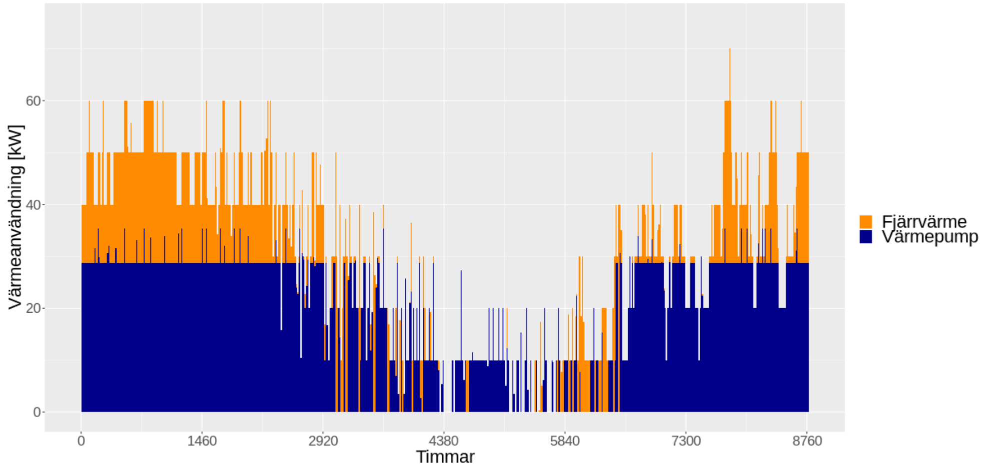

Figure 22 Shifting operation in 2016 for Case Study 2: EAHP 1 in Type network: Heat pumps with accumulator tank.

4.8.4 Emissions of CO_2-equivalents

Table 18 shows a summary of the average value during 2015 - 2017 for the change in emissions of CO_2 equivalents when changing from normal to shifting operation for the three simulated years for each case study and type network. In all cases, emissions decrease during shifting operation compared to normal operation. The reduction in emissions of CO_2 equivalents is largely proportional to the reduction in heating costs shown in Table 16. This is because the production plants' operating costs are often proportional to their emissions, since CO_2 tax, energy tax and emission rights are included in the DH operation cost. For the same reason, it can be noted that, similar to the results in Table 16, based on the relative reduction in emissions of CO_2 equivalents, Case Study 1: GSHP is the case study where the greatest reduction has taken place. Case study 2: EAHP 1 and Case study 3: EAHP 2 show relatively similar emission reductions. However, the relative reduction in CO_2 equivalents is greater than the relative reduction in heating costs. From a consistency perspective with the assumptions made in this study, avoided electricity use in favor of DH use results in reduced emissions. The amount of emissions that can be avoided depends more on the type of network that a property is connected to than what type of HP is used. In type networks where a large part of the heat production consists of central HPs, emissions are reduced the least not only because the least amount of heat has been exchanged, but also because emissions from the production of heat in the DH network and in the building are based on the same fuel. It should be noted that emissions from marginal production of DH are calculated for each hour for the type networks in the simulations, while emissions from the marginal mix in the electricity system only vary between 8 different values, based on time of day and year.

Table 18 Annual reduction of total emissions of CO_2 equivalents [kg CO2e/year] in shifting operation compared to normal operation in all case studies in all type networks. Emissions in the table are reported both as absolute figures per year and relative reduction and refer to the period 2015-2017.

Case study	Type network CHP w/o acc	Type network CHP w acc	Type network HP w/o acc.	Type network HP w acc	Type network EH w/o acc	Type network EH w acc
1: GSHP	-67 -64%	-53 -49%	-30 -28%	-15 -13%	-78 -75%	-61 -56%
2: EAHP	-18 -43%	-14 -30%	-6 -12%	-3 -5%	-23 -61%	-18 -39%
3: EAHP	-36 -40%	-30 -30%	-7 -7%	-0.2 -0.2%	-40 -54%	-33 -34%

Figure 23 shows emissions of CO_2 equivalents from heat use during normal and shifting operation for Case Study 1: GSHP and Type network: Excess heat without accumulator tank. This is the combination of case study and type network where the reduction of emission of CO_2 equivalents is largest. The reduction in emissions from the building is inversely proportional to the use of DH, which is presented in Figure 20. In 2015, the largest amount of heat was shifted from HP to DH was shifted, which gave rise to the largest amount of avoided emissions. In 2017, the smallest amount of avoided emissions from the property was achieved, as the least amount of heat was shifted from HP to DH.

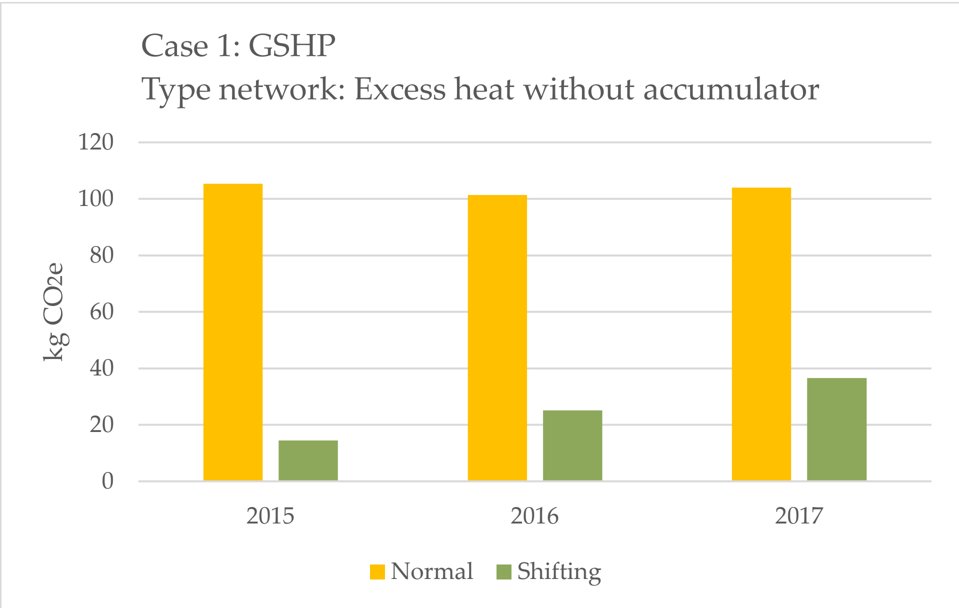

Figure 23 Emission of CO2 equivalents for Case Study 1: GSHP in normal and shifting operation for Type network: Excess heat without accumulator tank

Figure 24 shows the change in emissions of CO_2 equivalents at normal and shifting operation for Case Study 3: EAHP 2 in normal and shifting operation with Type network: Heat pumps with accumulator tank. This is the combination of case study and type network where the reduction of emissions of CO_2 equivalents were smallest. In 2017, emissions actually increased by shifting operations compared to normal operation during the year. In shifting operation, which minimizes heating costs in the building, loaf has shifted from the building HP to central HPs since that is the cheaper option, even though the COP of central HPs are generally lower than building HPs. However, it is assumed that central HPs have a lower electricity grid fee than building HPs, which gives lower costs, but a higher use of marginal electricity on a system level and therefore also increased emissions. This showcases how important it is to make an analysis for each building and DH network when calculating avoided emissions from changed energy use.

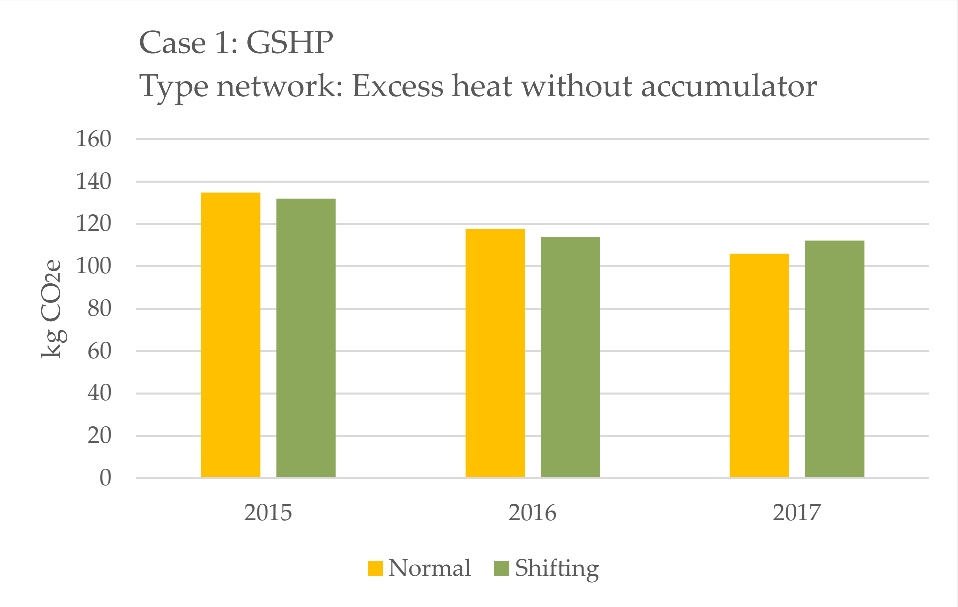

Figure 24 Emissions of CO_2 equivalents for Case Study 3: EAHP 2 in Type Network: Heat pumps with accumulator

4.8.5 Regulating market mFRR

Analysis of the effect of the regulation market mFRR in electricity area SE3 has only been carried out for Case Study 1: GSHP, as this is the case study where the largest reduction in heating costs was achieved. The two type networks containing central HPs are not included in the analysis because HPs spend a significant part of the year on the margin in these grids, which would result in one heat pump being switched off at the same time as another being started, which has no balancing effect on the electricity grid.

Table 19 shows the number of hours per year and the type of network that the HP was switched off because the bid on mFRR made it a cheaper alternative than having it operate. However, it is important to note that all bids to reduce electricity consumption, i.e. switch off the HP, are not activated during all hours of the year. In 2015, there were a total of 2387 hours when there were activated bids on mFRR to reduce electricity consumption. The corresponding number of hours was 1561 and 1889 for 2016 and 2017, respectively. It is only during these hours that the HP has been allowed to be switched off in favor of DH use in the simulations.

Table 19 Number of hours per year and type network that the GSHP was switched off due to prices on the regulation market mFRR in electricity area SE3

	Type network CHP w/o acc	Type network CHP w acc	Type network EH w/o acc.	Type network EH w acc
2015	65	78	77	46
2016	329	340	114	166
2017	446	451	282	309

Table 20 shows the number of hours per year and type networks that the HP was switched on because the bid on the regulator market made it a cheaper alternative than using DH. Bids to increase electricity consumption, i.e. start the heat pump are not available for all hours of the year. In 2015, there were a total of 2617 hours when there were bids on mFRR to increase electricity consumption. The corresponding number of hours was 2873 and 2079 for 2016 and 2017, respectively. During these hours, it is allowed in the simulation that the HP is switched on if it was chosen in the previous optimization step that it should be switched off.

Table 20 Number of hours per year and type network that the GSHP was started due to prices on the regulation market mFRR in electricity area SE3

	Type network CHP w/o acc	Type network CHP w acc	Type network EH w/o acc.	Type network EH w acc
2015	36	54	16	25
2016	103	81	59	59
2017	141	108	44	34

In Figure 25 and Figure 26, two examples of the annual reduction in operating costs are shown when comparing shifting operation with alternating operation, including bids on mFRR in the electricity area SE3. Figure 25 shows the cost savings in the Type network: Excess heat without accumulator tank and Figure 26 shows the same result for Type grid: CHP with accumulator tank. The economic gain is on the order of 1 percent of the total energy cost and this applies to all simulated cases.

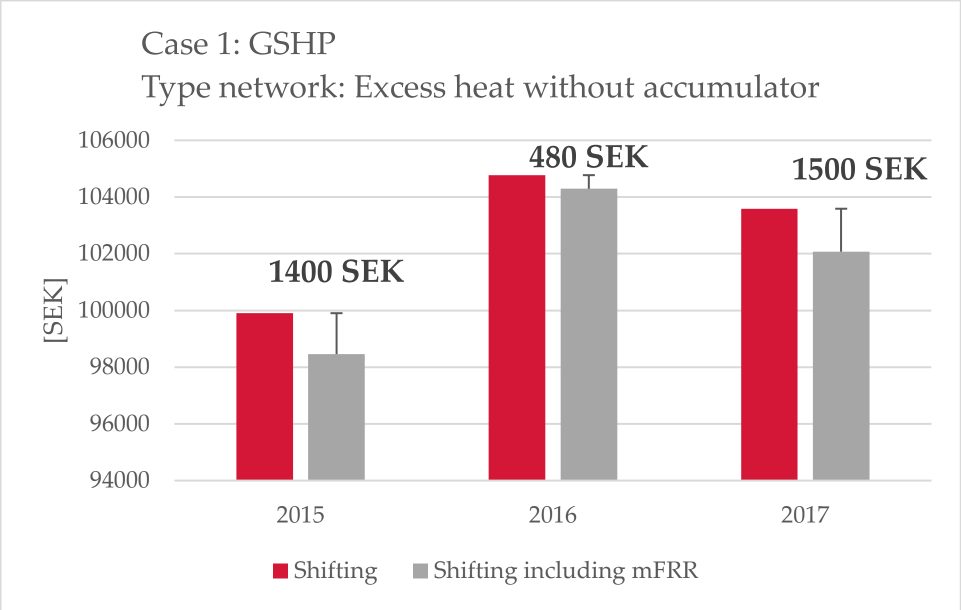

Figure 25 Annual operating cost for shifting operation and shifting operation, including the regulation market mFRR in electricity area SE3 for Case Study 1: GSHP in Type network: Excess heat without accumulator tank.

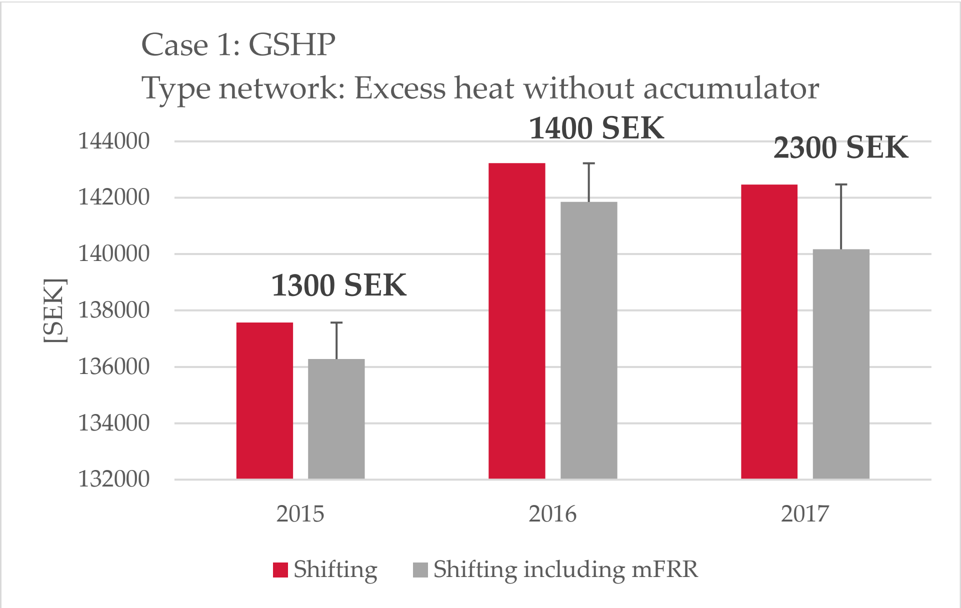

Figure 26 Annual operating cost for shifting operation and shifting operation, including the regulation market mFRR in electricity area SE3 for Case Study 1: GSHP in Type network: CHP with accumulator tank.

Figure 27 and Figure 28 show the heat consumption per energy source in the property for about 3 weeks in May 2017. If these two figures are compared, it can be noted that during this short period there are both hours where the heat pump is switched off and starts due to the prices on mFRR. Thus, there have been hours when it has been both profitable with regard to the regulation market to move heat load both to and from the DH system.

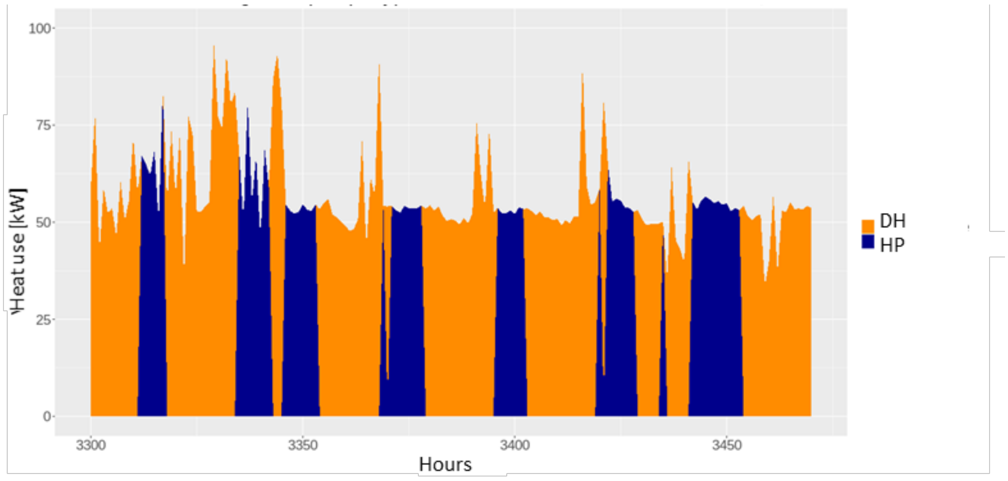

Figure 27 Heat use in shifting operation per source in the building for about 3 weeks in May 2017 for Case Study 1, GSHP in Type network: CHP without accumulator tank.

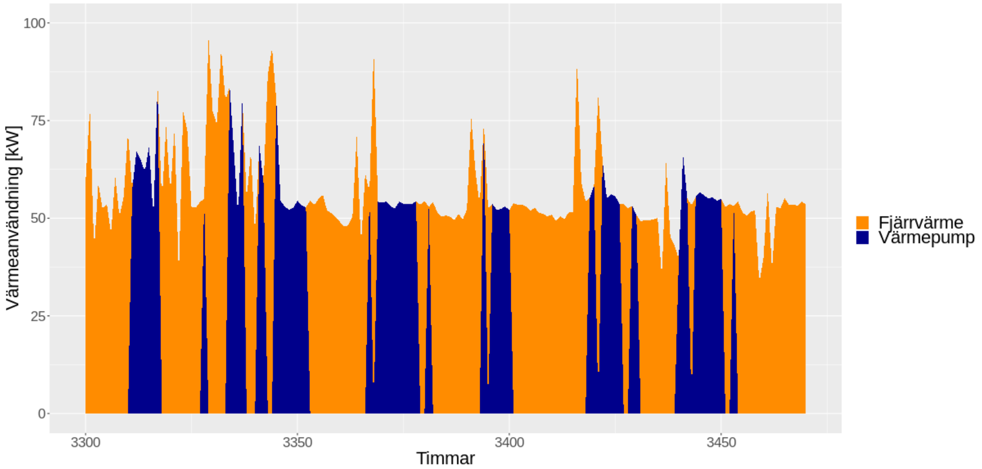

Figure 28 Heat use in shifting operation including mFRR per source in the building for about 3 weeks in May 2017 for Case Study 1, GSHP in Type network: CHP without accumulator tank.

4.8.6 Cost savings in relation to *The Product* and *The Service* concepts

The potential cost savings calculated are valid regardless of which of the revenue concepts *The Product* or *The Service* that have been implemented. For *The Product*, the saving potential of a property owner gives an indication of the price level that the energy company can offer the optimization product to customers. The reader should remember that the results presented are based on the fact that DH is priced at the marginal production cost and that a profit margin on DH price may be added. In addition, the DH price may also include a fixed fee of some type, but it has been assumed that this fixed fee will remain unchanged for a customer who switches heat source compared to a customer who does not.

For *The Service*, the savings potential gives an indication to an energy company what space there may be to include HP control in a comfort agreement. Whether it is profitable or not to offer a comfort contract for a building is very much affected by the other conditions in the property, which must be investigated on a case-by-case basis.

4.9 TECHNICAL REQUIREMENTS FOR LOAD SHIFTING

For energy companies to be able to control equipment in customers' buildings, new signals and interfaces need to be implemented. The following sections are intended to provide a general overview of what these signals and interfaces are, and what requirements should be placed on them. This section can be seen as a first starting point for further work on the detailed development of the optimization product.

The signals needed for the optimization product can be divided according to which actors are active and in which direction the information flow goes:

1. From the energy company to the customer's building
2. From the customer's building to the energy company
3. From external sources to the energy company

External control of heat pumps

External control of HPs can be done by either indirect control or direct control. For example, indirect control means that the HPs external sensor is manipulated to adjust the heat output according to a specific heat curve. In theory, indirect control can be applied to all types and models of HPs. However, the disadvantages of indirect control are that different HPs give different responses to changes in control signals and the response is always associated with a certain delay. Older HPs are often simply controlled by so-called on/off cycling. The HP cannot be operated in partial load mode, it is either fully off or fully on, to regulate the heat output between maximum power and zero, the compressor can be cycled. This means that the compressor is switched off and on repeatedly over a period of time, on average to give a lower power than the maximum. This control wears on the compressor and in most modern HPs frequency control is used instead. With frequency control, the speed of the compressor and thus the heat power of the heat pump can be controlled linearly. Many heat pumps in the premium segment are connected and allow the user to control their HP externally through, for example, a mobile application. Often, indirect control is then applied by changing the heat pump's heat curve (Lindahl, 2020).

Direct control means that the HPs compressor and thus the heat output can be controlled directly by an external signal through an interface. Direct control provides faster response and greater accuracy than indirect control and is believed to be a prerequisite for allowing HPs to constitute greater flexibility in the electrical system. To improve the conditions for this, for example, the German HP association Bundesverband Wärmepumpee has developed the SG (Smart Grid) Ready standard. The standard specifies that a HP can be run in different operating modes depending on the situation in the electricity grid; “Blocked” (switched off), “normal operation”, “low cost operation” (optimized against electricity prices) and “overcapacity in the grid” (prioritize the HP and utilize building thermal inertia) (Lindahl, 2020).

The control itself is carried out by sending electrical signals to two inputs on the Hp and has been shown to provide good opportunities for controlling larger clusters of HPs (Fischer, Wolf, & Triebel, 2017). The control should be used for the concepts in this report, where possible.

4.9.1 Signals from energy companies to the customer's building

The Product

- **Energy price DH**. The energy company must send energy prices with an hourly resolution to the building where the optimization product is installed. This can be done by setting up an API where all optimization products that have been installed in buildings in the DH network can retrieve the information. The hourly prices can be published 24 hours in advance, synchronized with when prices on the NordPool spot market have been set. In the optimization product, an hourly production plan for the heating of the building is made. DH is charged monthly in retrospect.
    - Requirements for the signal:
        - Time resolution: must be at least one value per hour
        - Refresh Rate: Once per day
- **Spot price NordPool**. The energy company must ensure that the optimization product has access to price data from NordPool's spot market. The spot market is based on hourly values and prices are set for the next day. Spot prices can be distributed to the building using the same API used to share DH prices with the buildings.
- **Prices regulation markets**. Through collaborations with aggregators and balance service providers, the energy company should also send information on prices in power control markets to the building with the optimization product. These signals are sent every hour within the day before the delivery hour and the set plan for the building in the optimization product is updated if the prices on the regulator markets make it cost-effective to switch off the HP and use DH instead, and vice versa.

The Service

- **Production plan for the building**. In *The Service*, the energy company may draw up a production plan for the building at the same interval as other production plans in the system are established. If the total installed power of HPs to be controlled is small enough in relation to the production facilities that are on the margin at each hour, the overhead production planning is not affected by whether DH or HP is chosen for the heating of buildings. If the total effect becomes larger, feedback effects in the production optimization will have to be addressed.

4.9.2 Signals from the customer's building to the energy company

The Product

- **The heat pump's COP**. The HPs COP depends on the supply temperature in the building and the temperature of the heat source. To be able to make a forecast of the heat effect that the HP can provide, and at what cost, the optimization product needs to get information about or calculate the COP for the HP in the building where the optimization product is installed. A HPs COP is not communicated from the HP through any interface, and in most cases needs to be calculated externally by comparing the electricity consumption in the HP with the delivered heat power. The optimization product therefore needs to be able to establish a model of the HP that is adapted to how the heat pump to be controlled behaves. This can be easily achieved by installing a sub-meter that measures electricity consumption from the HP alone and using the DH meter in the property. During a tuning period, the HP is switched on and off at various operating conditions and outdoor temperatures. By studying how much the DH use increases when the HP is switched off, the model can be adapted through machine learning.
    - Requirements for the signal
        - Time resolution: must be at least one value per hour, should be one value per 15 minutes.
        - Update frequency: the model of the heat pump's COP should be updated weekly.
        - Number of value digits: must be at least 1 decimal place (x.x), should be 2 decimal places (x.xx).
- **Heating requirements, space heating and domestic hot water**. The installation of the HP and HP connection affects the performance of the heating system in different operating cases. The optimization product therefore needs detailed information on the building heating needs, specified by demand for domestic hot water and space heating at all times. The information should be collected from the property's existing property management system and translated into a cost for DH or HP.
- **Operating conditions for the heat pump**. The optimization product needs to include a model for the HPs behaviour in different operating cases. A decisive factor for how the control is to be designed is the response time of the compressor, the time it takes for the compressor to go from lowest to highest speed can vary between tenths of seconds to over one minute depending on the HP model (Lindahl, 2020). To minimize wear and current spikes when starting the compressor, it is necessary that the optimization product considers the limitations of the HP control. For example, a minimum time that the HP must be switched on at one occasion can be defined, or each start and stop of the HP can be associated with a cost in the optimization algorithm.

- **Status and performance**. From the optimization product, information about the status of the HP and optimization product should be communicated to the energy company and the customer. Automated alarms that indicate deviating performance of the HP, DH substation and the optimization product itself should be set up. Signals that can be used for fault detection include used DH, used electricity in the HP, COP, DH volume flow, return and supply temperatures.

- **Customer interface**. Information on how the optimization product has performed should be presented to the customer. Interfaces should provide information on how often the optimization has shifted heat source, how much estimated cost savings and avoided CO_2 emissions this has meant. The savings should be calculated compared to the alternative to using the HP in a conventional manner. The information in the interface should be updated daily and compiled into monthly reports.

- **Information on electricity contracts**. In the product concept, the energy company does not have control over which electricity contracts the customer's HP is under, nor what costs these entails. Therefore, the optimization product must include an interface where the customer can enter information about their electricity contracts. The interface must be designed to handle different types of electricity contracts and have pre-set categories for the different costs for the HP's electricity consumption. In addition to manually entering this information, the collection can be done through APIs if the customer's electricity retailer and grid operator provide it. Changed conditions for the optimization product can then be updated automatically, by gathering information from the customer's profile at the electricity company. This requires that the supplier of the optimization product (the energy company) is authorized to collect this information and that the data is processed in accordance with GDPR.

  By default, optimization can fall back on simply following spot prices in the electricity market. If the energy price for DH in the price model consists of marginal production cost without any profit surcharge, this means that the DH supplier will not increase or decrease its profit as a result, while the customer will receive an increased electricity cost. This means that the incentive to give accurate information about the agreements lies with the customer, while the DH supplier does not benefit from the situation.

The Service

- **Heat pump COP**. With HPs that are part of a contract under *The Service* concept, signals that describe the heat pump's COP need to be processed centrally at the energy company as these will be included in overall production planning. In the same way as for *The Product*, the installed optimization product needs to create a model of the characteristics of each individual HPs different operating cases. Each model must be collected centrally by the energy company in a database. Each time a new HP is to be optimized, the database is updated and updates of all collected models can be done monthly. In the database, HPs with similar properties can be aggregated into clusters. The clusters of HPs then form production plants in production planning systems such as EnergyOpticon[1] or Aurora[2]. Based on the production plans from the systems, control signals are sent to the HPs each time a new production plan is generated.

  - Requirements for the signal:
    - Time resolution: must be at least one value per hour, should be a value per 15 minutes in each building.
    - Update frequency: Decentralized data is collected for central production planning once a month.
    - Number of value digits: must be at least 1 decimal place (x.x), should be 2 decimal places (x.xx).

- **Heat demand, space heating and domestic hot water**. For each building where an optimized HP exists, the total need that could have been covered by either DH or HP must be added to the total heat load in the central production planning. In the production planning, conditions must state that each decentralized HP can only be used to cover the heat load in the property in which it is installed. The heating demand in the property must be forecast to be included in the production planning and this should be done as early as possible. That is, when a sufficiently reliable weather forecast for the location of the property is available. It should be clear to the customer which temperature meter is used to collect data so that it is perceived as representative of the building.
  - Signal requirements:
    - Time resolution: must be at least one value per hour, should be one value per 15 minutes in each building.
    - Update frequency: As early as possible in advance for production planning, 7 days. Updated with the same frequency as other production planning.
    - Number of value digits: must be at least 10 kWh per time period, should be 1 kWh per time period.
- **Operating conditions for the heat pump**. In the central production planning, conditions should be set for how individual and clusters of HPs can be run. This can be done by estimating the start and stop costs and the minimum operating time for the HPs in the same way as for other production facilities in production optimization and planning.
- **Status and performance**. In *The Service* concept, signals for the status and performance of the HP, DH substation and optimization product become

[1] https://www.energyopticon.com/energy-optima-3/produktionsoptimering/

[2] https://opt.aurorabysigholm.se/v

even more important, as this can give early indications of when service and maintenance must be performed. This can streamline the work for which the energy company is responsible through the comfort agreement.

- **Customer Interface**. In order to increase the transparency and trust of the customer, it can be very valuable in *The Service* to be able to communicate how the equipment in their property have been managed, even if the customer cannot influence the management. The interface can be used to avoid divergent situations regarding simultaneous supply of electricity and DH by providing in the interface information about which electricity contract currently applies to the HP.

4.9.3 Signals from external sources to the energy company

In both concepts, no additional signals from the outside world need be retrieved to the energy company. Prices from electricity markets are already used in the daily production planning of DH production. Fuel prices, weather forecasts, temperature data and load forecasts that are also needed in the concepts are all examples of signals and data already used by energy companies.

4.10 LEGAL REQUIREMENTS AND AGREEMENTS

What will be important to consider when energy companies offer the new concepts *The Product* or *The Service* and control the customer's HP in combination with DH?

Optimized HPs in customers' buildings is new territory for many energy companies, when it comes to technology, business models and, not least, contractual agreements. Because the technology and solutions have a relatively low degree of maturity, there are few standardized agreements that are adapted to allow customers' equipment to be controlled by an energy company. This means that in some cases the agreements need to be drawn up from a blank canvas, which increases the risk that vital clauses in the agreements are forgotten or completely ignored (Lygnerud, Wheatcroft, & Wynn, 2019). However, the concepts presented and tested in this project have similarities to some existing services and accompanying agreements for the delivery and optimization of DH, which may facilitate the design of new agreements. The following sections list and discuss important aspects to consider when drafting contracts for the two different concepts. The discussion is based on an analysis of existing, similar agreements, discussions with the project's reference group and a final review by independent contract lawyers.

The following definitions apply to the analysis of agreements. It should be noted that the definitions are only used for clarity in this report, they should not be seen as definitions to be used in individual agreements.

Definitions

The following definitions are used in the analysis (Energiföretagen Sverige, 2018):

The contract	the contract between energy company and consumer including attachments
Property	land that the customer owns or has rights to use, including buildings and other facilities
Substation	unit that transfer heat from the supplier's plant to the property's heating system
The consumer	the legal entity who has entered into an agreement with the supplier
Consumer equipment	equipment for receiving, producing, and distributing heat, which the customer owns or has rights to use, within the property limited by the supply boundary
Supplier	the customer's counterpart in the agreement
Supply boundary	boundary between the supplier's equipment and the customer's equipment

Supplier equipment	equipment for the production or distribution of district heating, which the supplier owns or has the right to use, up to the delivery boundary or to a third party. The supplier's equipment also includes heat meters and such communication equipment for measuring values, which the supplier owns
Service	the service(s) that the supplier under the agreement provides to the customer regarding supervision, operational supervision, operation and maintenance of the customer's technical installations or comfort service
Operation	measures aimed at achieving the function of a particular equipment, which includes operation optimization, operation monitoring, supervision, management, and supply of commodities
Operation optimization	control and adjustment of settings of the customer's or supplier's facilities to reach agreed requirements for indoor climate and operating economy
Supply of commodities	supply of energy commodities such as electric power, water, fuel, heating, or cooling
Maintenance	measures designed to maintain the function of equipment which includes scheduled maintenance and fault-correcting maintenance
Optimization product	equipment supplied by the supplier for control of a district heating substation and a heat pump, based on signals from district heating prices, electricity prices and control signals from the property's heating system

4.10.1 Common points for *The Product* and *The Service*

Regardless of the revenue concept, all work should begin with a cost-free feasibility study or technology inventory carried out by the energy company for the consumer to see what the possibilities for controlling a specific consumer's equipment are. In some cases, it may be necessary for a new HP to be installed at the consumer and it must then be clarified how the ownership of this, sometimes expensive, facility looks. In general, the interview study in this report has shown that energy companies do not want to invest large capital in the form of equipment in consumers properties (which is why many DH substations are historically owned by consumers, not energy companies). This means that the consumer will probably have to bear the investment cost of a new HP, but at the same time the consumer must give permission to the energy company to control the HP.

The contract must clarify what responsibility for the HP's performance and operation the energy company should take. If the consumer owns the HP, the agreement may contain clauses that impose the consumer being responsible for ensuring that its function can be guaranteed. It may also be important that clauses are drawn that clarify responsibility and liability if the energy company's control in any way would damage the consumer's HP, or otherwise affect the function of the HP. The consumer's right to use, modify and carry out work on his or her HP may be limited in relation to the manufacturer/retailer of the HP due to the warranty and or insurance terms provided by the manufacturer/retailer or insurance company. Warranty conditions often require that the product must be handled in accordance with the guarantor's specific instructions and that maintenance and work on the product is performed by a manufacturer authorized technician. If the HP has been financed with the help of a lender or bank, the credit agreement may also contain restrictions on the use and changes to the HP.

If a new HP is to be installed, the energy company can be given the opportunity to recommend a suitable model that works well with the optimization solution. However, how this is done must be carefully considered as there is a risk of perceived restriction of competition if an energy company recommends a particular model or manufacturer of HPs, since the energy company has a unique position in the market (no competitors can offer both DH and HPs). The energy company should not specify a specific HP supplier as it may risk being seen as a collaboration that restricts competition and also limits for consumers who are contracting authorities to procure correctly. An alternative to recommending or selling HPs is that the energy company instead establishes a requirement specification that a new HP must fulfil in order to be relevant to the offer.

The responsibility for the function of the HP, proper installation of the same, and performance should lie with the consumer - when the consumer owns the HP. The consumer may in turn direct any complaints regarding the HP to the supplier of the HP.

Components that are part of the heating system in a building (such as the Optimization product, meters, heat pump and DH substation) are of such a nature that they usually constitute building accessories and thus real property in accordance with Chapter 2, Section 2 JB of Swedish law. There is a risk that the energy company may lose its so-called proprietary protection of property that it owns but which is added to the consumer's property during the duration of the contract. Legal protection is a prerequisite for the energy company to have the right to recover the property by means of executive measures if the consumer fails to make payments or go bankrupt. This means that if the energy company has installed equipment in the consumer's property and needs to foreclose it, the equipment can be considered to have transferred to the consumer and therefore cannot be directly foreclosed. This is a risk that the energy company should consider more closely when drawing up the agreement with the consumer. The energy company can choose to accept the risk, but there is then an incentive to secure a larger part of the payment early during the contract period.

In addition to what is stated in this analysis, the contract also need to contain general contractual terms regarding order matters such as transfer of the agreement, amendment of the agreement, how messages are sent, confidentiality and handling of dispute (general court or arbitration).

The following sections discuss items that are more specifically important in contract signing for *The Product* and *The Service* concept, respectively.

4.10.2 Contracts: *The Product*

Responsibility for operation and maintenance of technical installations

In a contract for the concept *The Product*, it must be clarified what responsibility the supplier assumes. This can be limited to the control system for optimization between DH and HP, here called the Optimization product.

The supplier then undertakes to optimize, monitor, and inspect only the equipment that the Optimization product entails, which does not include the consumer's HP. This does not differ much from how many conventional agreements for DH supply are drawn up, where, for example, the heat meter is considered to be the Supplier's property, and its operation and maintenance is thus the Supplier's responsibility (Energiföretagen Sverige, 2018).

Since the optimization product's function is affected by how the consumer's HP performs (for example, in terms of efficiency), it may also be relevant that the contract adds that the Supplier undertakes to supervise the HP operation. It should then be stated how the supervision is performed, how any errors are reported to the consumer and at what intervals the supervision is performed. If the concept *The Product* has been sold to the consumer together with a HP, a service contract can also be included for the HP, which is administered by the supplier but performed by the HP supplier or other subcontractor.

If the energy company intends to provide additional services such as maintenance, troubleshooting of the Optimization product and/or the consumer's other equipment, this should be stated. The agreement then needs to regulate the scope of the service agreement, response time, cost of emergency personnel and cost distribution of materials. Here, a distinction is likely to be made between the distribution of cost and responsibility for the products provided by the energy company (the Optimization product) versus the products for which the consumer is responsible (for example, HP and DH substation).

The contract should contain provisions that limit the consumer's use of the Optimization product. In particular, it should be stated that only the energy company may perform maintenance and repair of the optimization product. The consumer must not intervene on the equipment himself or through a third party. Furthermore, it should be stated that the consumer should care, keep the equipment protected and immediately notify the energy company if a fault or damage is noticed.

Compensation and ownership

In conventional DH supply agreements, the supply boundary determines where the consumer's equipment begins and ends and where the supplier's equipment begins and ends. In the concept *The Product*, the delivery limit is set for control signals sent to the DH substation and the HP, see Figure 4. The supplier should then be responsible for the ownership of the optimization product. In similar solutions, such as Norrenergi's VärmeSmart service through NODA, consumers rent optimization- and control equipment from the supplier to an annual fee, to minimize the investment cost for the consumer. The supplier then still owns the equipment and is responsible for maintaining it, possibly through the subcontractor who supplied the equipment. The contract should clearly state whether the optimization product is rented or paid by the consumer during the contract period. If ownership is to remain with the energy company, it must be made clear that this is a rental agreement and that the optimization product must be returned at the end of the contract, or that the consumer has the right to purchase the product. The agreement will be deemed to represent a purchase if it contains a clause that the ownership transfer to the consumer at the end of the agreement.

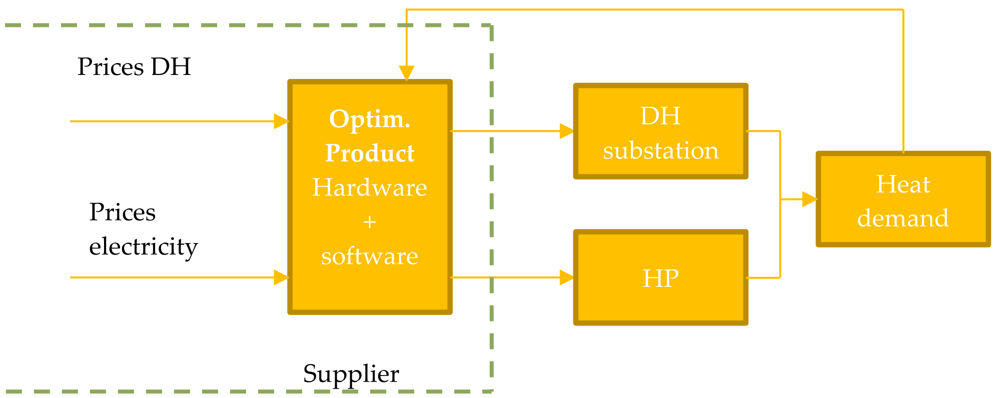

Figure 29 Supplier boundary in the concept *The Product*

Consumer obligations

For the concept *The Product*, it is important to describe what the consumer's obligations are in the contract text. In its most limited design, *The Product* is designed so that the consumer's facility (the property's heating system including control system) generates a signal reflecting the heating demand in the property by, for example, a setpoint for the supply temperature on the secondary side. Conventional agreements for the supply of DH indicate that the consumer installs, pays for and owns the consumer's equipment, and is responsible for the maintenance thereof (Energiföretagen Sverige, 2018). The equipment required to generate the control signal for total heat demand is thus included as part of the consumer's equipment and the responsibility for this can remain with the consumer under the concept *The Product*. If an initial inventory shows that the consumer's heating system management and/or HP needs to be supplemented with equipment to generate signals for the Optimization product, this equipment should be paid for and owned by the consumer. The consumer is then also responsible for maintaining its function. That a correct control signal is generated to the supplier's Optimization product will be decisive for its performance and a suitable clause to include in the agreement may be that the consumer must "actively work for that the service (control) to be implemented in the intended way". This means that the consumer's obligations for supervision and maintenance of the equipment must be specified.

The product concept means that a new tariff list for DH on an hourly basis is developed and used by the consumer. If the new tariff list is public for all consumers in the DH network or not, strict confidentiality clauses may be needed that prevent the supplier's other agreements with, for example, industrial waste heat suppliers from being compromised. The consumer must undertake to treat information about the supplier's business or operating conditions as confidential.

Responsibilities at faults

If the delivery of the energy company does not comply with the agreement, there is, in contractual terms, an error for which the energy company is responsible. A basic task is to try to create descriptions of the consumer's - and possibly also the supplier's - obligations and obligations regarding maintaining functionality of the equipment. The purpose is to be able to determine the cause of any lack of performance and delivery with the Supplier. The supplier shall not be liable for lack of performance or other commitments, in case it is attributable to the consumer's equipment, such as incorrect control signals.

As a supplier, there is reason to want to introduce provisions that limit liability for errors and or create predictability. There are various mechanisms for this, and some are suitable to combine. For the supplier, it is likely to be of interest to first and foremost rectify the fault, while the consumer may wish to be compensated for the damage suffered. The right to compensation can be limited to only material injury and personal injury. Another way is to limit the damage to direct damage and up to a certain cost limit. The right to compensation can be combined with an obligation for the consumer to make a claim within a certain time from the discovery of the fault.

If the consumer's dissatisfaction with *The Product* cannot be linked to a fault or breach of contract by the energy company, the consumer will have to fulfil the agreement (i.e. pay the fee) during the remaining contract period. For the energy company, this does not need to be explicitly regulated in the agreement. There may be commercial reasons why the energy company still allows the agreement to terminate prematurely (for example, reputation) or conclude a settlement, but the main rule is that the contract should continue unless otherwise agreed.

Dismantling of the Optimization product and restoration of the consumer's facility can be regulated in a provision called "Consequence of termination of the agreement". The provision regulates what is incumbent on each party upon termination of the agreement. For example, the consumer needs to provide access to the property and plant for the energy company to dismantle the optimization product and restore the consumer's equipment. Who is to bear the cost of such work is of a purely commercial nature. The notice period is also of a commercial nature and can be agreed upon in a manner accepted by both parties.

In addition to the above, the agreement should contain provision for sanction in case of breach of contract by the consumer.

Contract periods

The contract must specify the duration of the contract. The contract period could be determined by the repayment period that the supplier needs to have to cover the costs incurred when *The Product* is installed and to provide long-term profitability. For this type of product, it may be appropriate to state that the contract is automatically renewed for some time if no other notice is given by the customer.

Supply of electricity

In the concept *The Product,* the customer is free to choose an electricity trade contract as long as it is an electricity agreement that can be assumed to follow the prices on the NordPool spot market. With fixed electricity contracts, the economic potential for optimizing the heating of the property is likely to decrease, depending on the volatility of the electricity price.

4.10.3 Contracts: The Service

The following material and discussions are based on existing functional comfort agreements that the project reference group has shared with the project. For reasons of confidentiality, these agreements are not reported as references.

Provision of The Service - indoor temperature

The concept *The Service* is designed as a comfort agreement where the Supplier undertakes to ensure that a specified indoor temperature is maintained within the consumers property. Such an agreement must therefore specify which temperature is intended to be kept and if and how much it may deviate from the target value during certain circumstances. This can be done, for example, by:

- Setting the agreed upon temperature as an interval (lowest temperature and maximum temperature allowed).
- A certain number of permissible deviations per [month/quarter/year] e.g. X number of temperature deviations of max X [min/hour].
- Another variant is to specify that the agreed temperature should be maintained within X% per [month/quarter/year], the percentage is set to less than 100%, which gives the energy company room for deviations.
- The energy company should not be liable for deviations due to conditions which depend on the consumer or for which the consumer is responsible.

In the contract, the supplier must undertake to investigate and rectify underlying faults that cause deviations from the agreed temperature.

As a HP now becomes part of the system used to provide the indoor temperature, the HP is also included within the responsibility for investigating and rectifying faults. This in turn may require that the supplier must employ subcontractors with specific technical competence to carry out such investigations and measures. Therefore, the contract also needs to contain clauses which state that the supplier is free to use subcontractors and sub-suppliers.

Responsibility for operation and maintenance of technical installations

For the concept *The Service*, as well as for other DH comfort agreements, the contract for the service must be clear regarding the technical system boundary and supply boundary that applies to the contract. Conventional comfort agreements may include the Supplier undertaking to carry out the operation of:

- Heating system, primary (DH substation)
- Heating system, secondary side (radiators)
- Ventilation system (fans, air treatment units)
- Water (Cold water, hot water, and hot water circulation)
- Sewage (wastewater)
- Control system (controls for heating systems, secondary side, and hot water)

With *The Service*, the consumer HP must also be included in the list above, for example under the section heating system, primary side. In addition, the point control system will also contain the Optimization product used to co-optimize the operation of the HP and DH. The definition of operation must clearly determine to what extent this applies to the HP. Should the supplier, consumer or supplier of the HP be responsible for the HP performing as specified? For example, in the pilot project SmartHeat, Göteborg Energi offers a maintenance contract for the consumer's HPs, but is not responsible for the HP performing properly (Hansson P. , 2019).

In addition to undertaking the operation of the equipment, the contract should also specify whether, and if so, how often planned maintenance of the equipment should be performed. It should also be clarified how urgent faults and faults outside regular working hours should be remedied. The supervision of the equipment should also be specified and agreed upon. This means, for example, a specification of how often the function of the equipment in the property is inspected and reviewed, the way the supervision is performed and how the result of the supervision is reported to the consumer. In particular, control of the function of indoor temperature sensors should be described, as well as the function of the communication equipment which ensures that price signals for DH and electricity are available to the property's control system, including the Supplier's optimizing equipment. It should be the responsibility of the Supplier to propose service intervals and what maintenance activities that are required.

If the Supplier finds improvement measures that can be made to reduce, for example, the property's energy use during the term of the contract, the contract may include clauses on how and when such measures should be performed and by which party. The incentive to reduce energy use lies with the Supplier, but the measures should be agreed with the consumer before they are performed. The measures can be dealt with by specific agreements in each case.

Compensation and ownership

To provide the concept *The Service*, certain technical installations and modifications to the consumer's existing equipment are likely to be needed. Indoor temperature sensors, communication equipment, measuring equipment for electricity use and recalibration of thermostats are some of the installations and measures that may be relevant. The contract for *The Service* must therefore state which of the parties pay for these measures. For example, the Supplier can be responsible for the cost of the measures and the installation, but charge for this through the customer's fixed fee for *The Service*. The customer then pays for the installation during the contract period and when the contract has expired, the installed equipment becomes the property of the consumer.

In addition, the contract may need to determine how the Supplier's commitments regarding emergency remediation and emergency calls outside regular working hours should be paid for. Either it is agreed that such commitments are included in the fixed fee for *The Service*, or that compensation is paid on each occasion according to agreed remuneration levels.

As the contract for the Service is likely to extend over a long period of time, it may be relevant to include a clause that specifies whether and how the compensation levels in the contract should be adjusted according to index during the contract period.

Again, it can be pointed out that there is a risk for the energy company to be able to foreclose installed equipment in the consumer's property in the event of a bankruptcy of the consumer. The problem can affect the energy company's choice of pricing; there is an incentive to want to secure a greater part of the contract value early in the contract period through, for example, installation costs or down payments.

Consumer obligations

A contract for the concept *The Service* must address the obligations that the consumer commits to by entering the contract. Existing comfort agreements indicate, for example, that the consumer must ensure that the customer's technical installations and equipment is configured to meet the heat demand at design outdoor temperature. In practice, this means that the secondary side must be adequately designed when entering the contract. This should also apply when a HP is optimized through *The Service*.

Unforeseen behaviour of residents in the property poses a risk to the Supplier when offering *The Service* or conventional comfort agreements. This risk can be dealt with through a clause in the agreement which states that the consumer undertakes to use the property and its technical installations in the intended manner. This means, for example, that residents should not open doors and windows for long-term ventilation. The clause may stipulate that in the event of the consumer's failure to do so, the Supplier may reduce its responsibility to provide *The Service*.

The consumer should also be required to provide all necessary documentation regarding equipment and technical installations for which he or she is responsible.

The consumer must provide floor space for the heating system and give the Supplier access to the property in the manner required to perform maintenance activities according to the contract.

Obtaining the Supplier's approval of changes made to building and heating systems should, as a starting point, be an obligation of the consumer, as these can affect the conditions for delivering the agreed upon comfort or temperature.

Responsibilities at faults

As in most contracts, the responsibility, and consequences for deviations of provided services also need to be accounted for in the contract if the Supplier optimizes a consumer's equipment externally. If the consumer discovers that the control of the heating system or other systems included in contract does not function as agreed, he or she may require the Supplier to rectify the fault, demand deduction of the compensation for the Service or terminate the contract altogether. This should also apply when a HP is part of the agreement. First, it must be assessed whether there is an error or a breach of contract, see comment on "Provision of The Service - indoor temperature" above.

If it is found that there are errors or other breaches of contract, the penalties that the parties have agreed are actualized. Similar to the concept *The Product*, the Supplier will likely want to limit the sanction to remediation (including the costs of remediation). In addition to remediation, the consumer is likely to be compensated for the damage he has suffered. The Supplier should, as a starting point, limit the compensation to a certain amount and to direct damages.

The resulting damages can be combined with an obligation for the consumer to make claims within reasonable time, limit their damage and claim compensation within a certain time.

The consumers right to cancel the contract can be limited to material breach of contract and after the energy company has been given the opportunity to remedy the error.

Amendments

An important part of *The Service* contract is the section that concerns any changes and amendments made to *The Service* during the term of contract. For example, comfort agreements can be designed in such a way that the Supplier has the right to adjust the fixed fee for *The Service* if the Supplier and the consumer agree on a new target temperature, if the consumer or third party makes changes in the heating system without the supplier's consent, the property is rebuilt or the heat use in the property changes drastically.

For example, this could mean that the set fee for the service can be adjusted if the HPs functions or settings change during the contract period for any reason, which affects the heating cost for the property.

As previously mentioned, the remuneration levels in the agreements should be able to be adjusted according to index annually.

Contract periods

The Supplier takes a greater risk with a comfort agreement, compared to conventional agreements and contracts. A major risk in this regard is that the energy company makes energy-efficient measures in a property at a high cost and the consumer then breaks the agreement. The investment in the measures then stands without opportunity of payback for the supplier. Therefore, in similar comfort agreements, the contract period is often relatively long. For example, in its pilot project SmartHeat, Göteborg Energi applies a contract period of 10 years, mainly because the investments made by Göteborg Energi in the project will need to provide payback during the project's duration (Hansson P., 2019). Other energy companies have applied a five-year contract period in comfort agreements.

From both the consumer's and the Supplier's perspective, the agreements should be drawn on a long-term horizons as significant investments are being made. It can often be that a HP system is tailored to the consumer. If these conditions change significantly, the Supplier's pricing for DH will also change. If the Supplier distributes the energy use between heat sources, this can mean that the HPs power will be lower than if the consumer bought the HP.

For this type of service and delivery agreement, it may be appropriate to state that the agreement is automatically extended if not terminated by the consumer.

Supply of electricity

In a comfort agreement, the Supplier undertakes to provide heat, and in *The Service* concept, also electricity to the property. This gives rise to the question of how the consumer's electricity contracts should be handled in a comfort agreement that also includes electricity for a HP. To provide simplicity in operations, invoicing and calculating and setting of the customer's monthly fee, the Supplier could within the comfort agreement also offer an electricity trade agreement separately for the HPs electricity use. The supplier can simply be made the contractual owner of the HP from an electricity grid perspective. Without knowing the electricity prices that apply to each consumer, it is not possible to set a price on the comfort agreement for the consumer. This means that the consumer is locked into an electricity trade agreement during the contract period, but does not have to bear any of the costs of the electricity consumption for the HP. Other electricity use in the consumer building and residents' individual electricity use can be treated with separate electricity contracts. An example of this is found in SmartHeat, where Göteborg Energi acts as the owner of the HP electricity contract and the consumer has a contract for other building electricity and tenants sign individual agreements for electricity grid fees and electricity trade (Hansson P. , 2019).

If the Supplier acts as the electricity contract owner of the HP, it also means that the supplier signs an electricity grid fee contract for the HP. If the property has existing electricity trade and grid contracts, these must be transferred to the Supplier. If any existing contracts means that such a transfer cannot take place, the contract for *The Service* must contain clauses dealing with such a situation. For example, the supplier may stand as a third party in the existing agreement and ensure that the consumers obligations in the existing contract can be fulfilled.

Finally, the contract should also address the division of responsibility in the event of a power failure, which can be addressed in the clause that clarifies the division of responsibility in the event of force majeure.

4.10.4 The concepts in relation to competition law and public procurement (LOU)

The following analysis was carried out by the law firm Glimstedt in Gothenburg. The question for the analysis was: "Do the concepts The Product and The Service conflict with LOU and competition legislation, since the offers may include resale of heat pumps by energy companies and offers where electricity contracts and district heating agreements are formed within the same municipal group?"

A municipal energy company is covered by the provisions of the law for procurement of utilities (LUF) and must comply with the regulations when purchasing goods and services. However, based on the given conditions, it is not primarily a question of whether the energy companies follow LUF within the framework of their operations, but whether and in what way LOU limits the ability of the energy companies to provide *The Product* and/or *The Service* to consumers.

In cases where the consumer is a public operator, such as municipal property companies, generally, their purchase is regulated through LOU, whereupon the procurement regulations may apply for both *The Product* and *The Service*. The scope for providing goods and services to public operators through direct and/or additional sales is generally limited since the purchase of goods and services must be subject to competition in a public procedure.

However, there are some exceptions to this general rule on the public procedure. Direct assignment of a contract may take place if the value of the contract is less than SEK 615,312 ("direktupphandling"). A contracting authority may also directly assign a contract in cases where the provisions for technical reasons in Chapter 16. Section 14 LOU is applicable. It provides the opportunity to directly assign a contract by using a negotiated procedure without prior announcements ("direktivstyrd direktupphandling "). A prerequisite for technical reasons is that what is to be procured can only be provided by a particular supplier and that the lack of competition is not "designed". The burden of proof that circumstances exist which allow exemptions to be applied in the individual case always lie with the contracting authority.

In some cases, a contract may consist of several parts, one or more of which fall outside the scope of LOU. A crucial question in these cases is whether the agreement is divisible or indivisible. When deciding whether the procurement should take place in accordance with the rules of the LOU or not, the contract must be tested in its entirety. Firstly, the various elements of the agreement must, objectively, be considered difficult to separate and necessary to treat in one and the same business that they form an "indivisible unit". In the case of such an indivisible entity, the main purpose of the agreement (main purpose principle) or dominant element (dominant part principle) will determine whether procurement is to be subject to competition under LOU or not. However, an agreement must never be constructed in such a way that the purpose of the arrangement is to try to circumvent the procurement legislation.

For example, when a municipal housing company is to procure a service or product from another municipal company within the same municipal group, exceptions to LOU can be made in certain circumstances. This is called the provisions regarding so-called internal procurement - the regulations can be found in Chapter 3. 11-16 §§ LOU and is a codification of the so-called Teckal criteria. The possibility of so-called horizontal purchases between "sisters" are regulated in 3:15 LOU. A prerequisite is that both the controlling and the operational criterion are met, i.e. that the parent company (the municipality/municipal parent company) has control over all of the companies, and that the companies carries out more than 80 percent of their activities for the controlling person (i.e. the parent company) and that the counterparty does not have some private ownership interests. As far as the operational criterion is concerned, an assessment needs to be made in the individual case and based on what is stated in 3:16, i.e. based on the average total turnover for the past three (3) years. In short, it is usually on the operational criterion that such arrangements fall short, especially in the case of energy companies that frequently provide services to the private market. 3:15 LOU can only be applied when the parent company is the only controlling authority - in cases where control is shared between several contracting authorities, the provision cannot be applied (see prop. 2015/16: 105 p. 963). Lastly, the regulations do not mean that the companies can freely use each other's framework agreements, even though the rules on internal procurement are fulfilled, since framework agreements are usually so-called closed entities.

Specifics regarding The Product

As far as *The Product* is concerned, the included services can hardly be seen as an indivisible contract. The customer signs a separate supply agreement for DH and the parties sign a separate agreement for the HP optimization service, which includes hardware, software, and possibly additional services. When calculating the contract value, the entire value of the contract during its entire term shall be summed up. Since the customer in this concept has signed a separate electricity contract with regard to electricity trading, this cost should not be included in the calculation of the contract value.

In cases where the customer lacks a HP and needs to acquire a new and optimized HP, our recommendation in relation to the customers covered by the procurement regulations is that they themselves take care of the purchase of the product without interference from the energy company. For example, the energy company can provide information on what performance and other technical conditions are necessary for compatibility with the developed system on its website or in other information material without, for that matter, pointing out or recommending a particular supplier.

It is deemed that there is no procurement law impediment for an energy company to act as a representative and thereby carry out a framework contract procurement according to LOU and thus provide HPs to the customers, public as well as private who so wish.

In this regard, it can be noted that several industry organizations have worked together to develop common frameworks for the procurement of HPs in buildings. The space for the energy companies to act as a retailer / wholesaler for heat pumps themselves and thus gain a sales margin is considered less appropriate from a LOU standpoint.

Specifics regarding The Service

As far as the Service is concerned, the energy company takes overall responsibility for the heating of the property and in doing so, the energy company combines the entire heating system including DH, electricity agreements regarding electricity trading, HP optimization (hardware and software) where the HP is viewed as a production unit for which the energy company takes full responsibility.

Unlike the concept *The Product*, it is not as easy to distinguish the different parts in an objective way from a procurement law perspective as the procurement object is a function where all parts are integrated in an overall solution. Since the energy company takes over existing contracts for DH and electricity trading at the start of the contract, these parts should also be seen as an integral part of the function that is provided. Should DH be considered the main part, *The Service* would not be required to be subject to public procurement. Otherwise, a customer who is a public authority must procure the entire contract according to LOU, and this should be done through the procurement of the heating/indoor temperature function. The energy company should be able to make a competitive bid, but it complicates the sales process.

The assessment bases stated above regarding divisible and indivisible contracts can also be applied to *The Service*. Whether which constituent is to be seen as dominant cannot be judged at present. Thus, parts that do not need to be procured can be exempted from advertising. Violation of LOU may result in the agreement being invalidated.

Even though it is only the customer who must comply with the procurement regulations, an agreement that should have been legally announced can be annulled after the application for invalidation in a public administrative court. In the event that the agreement is declared invalid, all activities, from the start of the contract, shall be returned between the parties and the financial balance shall be restored. In our opinion, the scope for an energy company to receive damages as a result of unused investments and other costs is very limited, since they can probably not assumed to have acted in good faith regarding the actual conditions.

Within LOU, there are no stipulations on how long a contract period can be. Since neither *The Product* nor *The Service*, in our judgment, is to be regarded as a framework agreement, there is an opportunity to justify a contract period exceeding 4 years. The length of the contract period that can be justified can be determined separately and primarily with regard to the procurement object and the investments that a supplier must make in order to fulfil his obligations in accordance with the contract. However, a contract awarded must always be limited in time, whereby no prior agreement is allowed.

Competitive law issues

The question is whether there may be competition law issues, given that customers are locked into long-term agreements, which may mean that they for example cannot switch electricity contracts for their HP.

Since an energy company providing DH has a monopoly position, the company must carefully analyse whether its additional services can be considered to constitute measures that directly or indirectly restrict neighbouring markets, especially in relation to their existing DH customers. For example, the Swedish Competition Authority has stated in a case against Tekniska Verken in Linköping (dnr 533/1998) that different types of discount terms for DH in cases where customers also signed electricity contracts constituted abuse of a dominant position. The reason was, among other things, that it was considered to limit the freedom of DH customers when purchasing electricity at the same time as it created lock-in effects and made it difficult for competing electricity trading companies to operate in the market.

The design of *The Service*, in particular the fact that the energy company takes over or alternatively signs agreements regarding electricity trade in the customer's place, may be interpreted as hindering DH customers in their choice of electricity supplier in a market-disadvantageous way. Since the contract periods will be made dependent on the investment costs of the other components, which means long-term agreements, this can also be seen as a limitation, provided that the design of *The Service* and the duration of the contract cannot be fully justified for objective reasons in all aspects. The risk of penalties in the form of a penalty charge or invalidation due to a breach of competition law provisions is greater with regard to *The Service* concept, if it means that the energy company must be a part of the electricity supply agreement.

In addition, a municipal energy company must comply with the provision in Chapter 3. Section 27 of the Competition Act, or the KOS provision, which regulates public sales activities. One point of departure for municipal public sales activity to be permissible is that it is competence-based. i.e. that the overall purpose is to provide public utility facilities or services to the members of the municipality or that the product and/or service in question has so-called connection competence, i.e. has a close and natural connection with existing and recognized municipal activities. Case practice stipulates that attachment competence can exist if an activity which is not in itself self-competent in nature has a close and natural connection with the existing and recognized municipal activities, provided that these activities are of limited scope and are not intended to make a profit. In a 2012 report from the Swedish Energy Agency, "Are there any barriers to competition in the energy services market?" (ER 2012: 26), the Swedish Energy Agency states that “It is unclear whether the municipal authority's connection competence allows, for example, municipal energy companies to sell certain energy services in addition to energy. Where the border goes is not fully clarified at this stage”. No clarifying practice has emerged since the Swedish Energy Agency published its report, so the legal situation may still be considered unclear.

The background to the so-called KOS provision assumes that public actors generally have other opportunities than private companies to act independently of market conditions. In order for a procedure in a public sale operation to be prohibited, it must be distorted or be liable to distort the conditions for effective competition in the market or to inhibit, or is liable to inhibit, the existence or development of such competition. However, prohibitions may not be issued for procedures that are justifiable from a public point of view.

The purpose of the provision Chapter 3 Section 27 of the Competition Act is to deal with distortions of competition that can occur when public operators conduct sales activities in competition with private actors. The provision may, for example, apply where the energy company participates in a tendering process and the tender price is lower than its competitors, and this can be assumed to be due to the fact that the energy company does not act commercially by applying a non-market pricing. The ability of public actors to make a loss can make it financially unreasonable for private actors to act in the same market.

As far as *The Servi*ce and *The Product* are concerned, it is important that the pricing, whether it is a bidding process or direct sale to customers that are not covered by the procurement legislation, is made solely on the basis of market conditions and that the energy company does not use its position and other conditions in order to directly or indirectly create benefits over private actors.

Concluding comments on both concepts:

The Product concept appears to provide better conditions for legally managing commercial risks through agreements. Given that the customer in *The Product* concept owns the components of the heating system, with the exception of the Optimization product, there are, for example, better opportunities for the energy company to limit its responsibility. The concept is also advantageous in that the energy company does not have to guarantee a certain result. The responsibility of the energy company is thus limited to providing a functioning product, the Optimization product and, where applicable, to perform service and maintenance of this and/or the customer's heating system. The forms for maintenance work can also be designed in a way that is advantageous and less risky for the energy company.

One of the cornerstones of *The Service* concept is that the customer buys a wholesale concept in which risks and responsibilities regarding function and results are placed with the energy company. Naturally, this means that the energy company takes a greater risk. The energy company can work with limited liability provisions such as indemnity limits determined to a certain amount. Such a restriction must, of course, be commercial so that it is accepted by the customer, unless it is to be the subject of contract negotiations in each individual case.

5 Discussion

5.1 BUSINESS MODELS AND ENERGY SERVICES

The two revenue concepts presented represent two models that are similar to some existing services offered by energy companies. This means that their implementation may be relatively straightforward, but one could ask whether the two concepts represent the highest potential for energy services that involve the interaction between DH and HPs. In particular, in the case of construction of new buildings, there may be other concepts that are based on cooperation between the energy company and the customer at an early stage, which gives rise to values that can be shared by both parties. In such concepts, the importance of an open relationship becomes great, where system utilization in the form of efficient resource use should be prioritized. Our interview study has shown that both customers and energy companies already understand the relevance of this and give opportunities for such collaborations.

The simulations in this study focus on how the use of HPs is shifting the use of district heating, leading to an increased supply of district heating for an energy company, savings for a property owner and avoiding emissions of marginal CO_2 equivalents. Allowing operation to be controlled by marginal costs for DH and heat from a HP is just one of many ways that system benefits can be achieved. Examples of other driving forces for energy companies to control customers' HPs may be to increase the premises for electricity generation in CHP plants or to make use of waste heat that otherwise would have had to be cooled off. Other arrangements that can be tested are various forms of agreements where the energy that has been exchanged from a HP is deducted and replaced by DH at a discounted price.

In addition to being able to offer customers the ability to optimize the operation of their equipment, the offers can also be combined with other offers that in turn provide the conditions for a fossil-free energy system. One such example could be that the energy company in the offer *The Product* or *The Service* also offers green-labelled electricity to the HP by offering the customer part-ownership in a solar- or wind electricity facility. With the co-ownership, more long-term agreements can be signed with the customer and the offer is partially decoupled from trading at NordPool. The latter may mean that the offer avoids being a source of distorted competition. However, such a solution risks giving incentives to a control that is suboptimal from a system perspective because a HPs use of electricity affects the electricity system on the margin, regardless of how a co-owned solar or wind facility produces at the current time.

Energy services such as a comfort agreement can pose new risks for an energy company in the form of increased responsibility for maintenance and that heat delivery to the building cannot be performed in a cost-effective way due to, among other things, unforeseen problems in the property's heating system and behaviour of residents. At the same time, however, a comfort agreement poses a lower risk to the energy company because the fixed fee for the comfort agreement provides a secured revenue stream that is to some extent independent of external circumstances. The alternative, not to develop similar services, could pose a risk to energy companies in and of itself. In many energy companies, a warm winter can mean lost revenue due to the design of existing price models. It may then be safer to offer a comprehensive solution where the income statement depends more on how well the energy company can fulfil its commitments rather than relying on the weather. Failure to develop energy services in itself also poses a risk to the energy company in the form of reduced competitiveness, which must also be considered in the decision to develop and offer customers advanced services described in this study.

Developing energy services is becoming increasingly important for energy companies and will be a prerequisite for being able to develop and offer services that connect several different parts of the energy system. Energy companies are in a unique position in that they often have the opportunity for an overall system view of heat and electricity production as their business bridges both aspects of the energy system. However, shifting focus from products to customers 'processes and needs may be associated with obstacles in their own organization and in customers' perceptions of the energy company's knowledge of their processes. DH energy services have in many ways been developed with a technical focus, and in order to take energy services to higher levels it requires even more collaboration between suppliers, energy companies and customers. A future energy system is likely to be characterized by value networks that create value and benefit for society at large rather than value chains that optimize the profits for each individual actor in the chain.

Designing composite offerings that include several different technologies and services such as HPs and electricity trading in combination with DH is associated with some legal and competitive uncertainty. The district heating law may need to be clarified with respect to what constitutes associated competence for DH operations, in accordance with what is stated in the electricity law. Competition legislation and precedents have previously had a certain "silo division" where one type of energy has been completely decoupled from another. This has contributed to the fact that energy services that handle several types of energy at the same time are more uncertain legally (as this study has shown) and a development of legislation that better enables service development that avoids sub-optimizations of systems is desirable. At the same time, it is also the case that the precedents for DH companies that offer a discount on electricity trade in package deals with DH and electricity are now relatively dated (no. 533/1998) and electricity trading is no longer as profitable in general. A large portion of energy companies' revenues already come from the heating business. If heating and electricity contracts are offered to customers in a package together with optimization, discounts on electricity trading are unlikely to be attractive, which makes the issue of competition in electricity markets less important.

5.2 REGULATION MARKETS

In this study, only the effects of exposing HPs in real estate to one of several balancing or regulating markets for electricity were included. At the time of writing, which regulation market is best suited for smaller HPs in buildings is unclear and several markets may become more or less suitable depending on their immediate development. In addition to bidding in a market for regulating power and balancing the networks, there may also be other ways for an energy company to optimize HPs in properties to increase system utilization. For example, an energy company with its own renewable electricity generation could design an offer and optimization on the basis that the renewable electricity will be used before other electricity when it is available.

Another possibility for energy companies with their own electricity production in CHP plants is that the controllable power from the HPs in the DH network is included in the otherwise traded effect in the energy company's production. This makes it easier to reach the minimum necessary bid volumes that apply for participating in markets like mFRR and the various FCR markets without having to interact with an external aggregator. However, since the HPs are affected by other factors such as response times and availability, it may still be relevant to engage an aggregator to gather the distributed effect for the energy company's trade.

Another alternative to bidding on balancing and regulating markets for an energy company is to, in a local collaboration with a electricity grid owner, control the power use from HPs at times when local electricity networks risk exceeding the subscribed power to overlying networks, which leads to penalty fees. However, it is important to point out that a resource, such as HPs in this case, should only be controlled for one purpose at a time, it is not certain that control based on revenue optimization in a regulation market provides benefits for the power use in the local network and vice versa.

5.3 ENERGY DISTRICTS

In the study, the savings potential for three different buildings with HP and Dh has been calculated. A fourth case study is described, but no simulations for the case study have been performed. The case study consists of an area that was previously heated with DH only and which has since been partially disconnected from the DH network in favour of a solution where central HPs and cooling machines distribute heating and cooling within the area. The case study is thus an example of an energy district or micro grid with local production and distribution of heating and cooling. Energy districts are an interesting addition to the energy system, which gives rise to many new opportunities for optimized resource utilization, but also challenges for the traditional DH business model where a continuous supply of heat is the focus.

The energy district in this study has a relatively large need for DH because a property in the area requires high supply temperatures, for this type of supply the potential for utilizing DH in a more optimized way is limited, the need for heat is difficult to influence. Instead, the large potential for DH in energy districts lies in other, innovative, solutions to provide the greatest possible system benefit from a larger perspective. Such solutions must be designed to maximize the utilization of existing resources and to create conditions for, for example, increased installation of renewable electricity generation and utilization of intermittent production from these.

An example of such collaboration with a DH supplier is to allow storage in the form of boreholes and heat storage in buildings in the energy district to constitute a heat sink for the DH network. In a DH network with CHP based on biomass, great environmental benefit is gained by local electricity production with low emissions replacing electricity production in the Northern European margin mix with higher emissions. However, it is required that there is provision for the heat that is produced at the same time as electricity in the cogeneration plant, which can be stored in the energy district. It is important that the energy district and the DH supplier can find agreements for how the energy district should receive compensation for providing resources that will benefit the DH producer (and benefit at the system level with the avoidance of emissions in the electricity system). One possibility for this is that the energy company offers discounts on sold DH to the energy district for hours when electricity generation could be increased on a larger heating demand. Another possible setup may be that the energy company and the energy district form a joint optimization company where the profits from the optimization are shared between the two actors. It has not been calculated what this value is in a case study or type grid, but the potential should be greatest in a type grid with a large proportion of CHP and lowest in a type grid with many central heat pumps. For such business models to be effective, transparency and an open dialogue between the energy company and the customer is important, which has also emerged from the interviews in this study. One difficulty may be that both parties must already be involved at the planning stage for a project in which an energy district is to be designed, so this has not always been the case before, but may change as more and more energy companies start to become more advanced business with customers who have different need of heat at different times.

One scenario that may be relevant for a building or energy district where boreholes of GSHPs can be used for seasonal heat storage is to use DH with a low marginal production cost during the summer months to heat the boreholes for use during other times of the year. Göteborg Energi’s pilot project SmartHeat is an example of this, which has been described earlier in the study. By utilizing the customer's boreholes, a greater system benefit is obtained because heat that would otherwise have been wasted is used. In the energy district of this study, however, the potential for this process is less because there is a cooling requirement in the district during the summer months and the boreholes are charged with excess heat from the local cooling production that otherwise would have been cooled off.

5.4 LIMITATIONS FROM ASSSUMPTIONS

All DH production used for simulation in the type networks use fossil free fuels. It has been assumed that the load switching implemented will be in operation throughout the entire life of the buildings, which means that the type networks used in the simulations also need to reflect a scenario that may apply to the corresponding period. In the DH industry's roadmap for fossil fuels, the ambition is that all district heating in Sweden will be fossil-free by 2030 and by 2045, the DH sector will constitute a carbon sink. Therefore, it is not unreasonable for many Dh networks to have converted from fossil fuels to fossil-free such as bio-oil and biogas in a 10-year period instead of heating oil and natural gas. One assumption made in this study is that the fuel costs for fossil-free alternatives are the same as for their fossil-based counterparts. This holds reasonably well at present, but in a future scenario with higher competition for fossil free fuels this may change.

Savings represent the maximum potential. In the study, it has been assumed that the shifting between HPs and DH in buildings is performed based on the marginal production cost of heat for both technologies. Pricing that only corresponds to marginal production costs will not generate revenue for the energy company and a profit margin may be added to the marginal production cost. However, the savings that have been reported represent the absolute highest potentials that are possible through load shifting and should represent an operation that becomes cost-effective from both the building owner's and the energy company's perspective. A large part of the work on being able to offer customers services that are designed according to *The Product* concept is to develop a completely new price model, which has been beyond the scope of this study, but is probably in the interest of several energy companies. More dynamic energy pricing can provide incentives for energy efficiency improvements and reduced energy use at times when the system is under highest load but may have the disadvantage of being less predictable.

Avoided CO_2 equivalents. The avoided emissions that have been estimated to occur when electricity use is shifted to DH are achieved without reducing energy use in the property. It should be pointed out that load shifting between DH and HP is just one of several measures that can be taken to reduce emissions from energy use from a consequential perspective. Measures that reduce energy use of all kinds in absolute terms, such as additional insulation and window renovation, also give rise to reduced emissions. However, this has not been addressed in this study. What is worth mentioning, however, is that part of the estimated avoided emissions from shifting originates from the fact that electricity from the Northern European electricity system has been replaced by electricity produced locally in CHP plants in the DH system. The methodology used gives large reductions of emissions when this occurs, especially if the CHP uses biomass as fuel (which is the case in all type networks). The methodology does not consider that the biomass used as fuel in the CHP plant may have other uses and may be a resource that is subject to greater competition in the future.

6 Conclusions

It has been found that there are good opportunities for allowing heat pumps in customers' properties to have a more flexible role in the local energy system. In practice, energy companies should be able to offer customers who have a heat pump and a district heating connection installed in their building an optimization services that utilize the cheapest heat source at every opportunity at a reasonable price. Depending on the conditions of each individual energy company, such an offer will entail minor or major changes to the existing business model of the company.

The biggest change for many energy companies is that a greater focus must be placed on developing and maintaining a portfolio of energy services, as optimization of customer equipment will require offers in the form of services. For optimization services that are relevant in this study, the greatest value for an energy company may lie in deepening the relationship and expanding the exchange with its customers. This is a shift that requires a changed business logic, from a cost-optimizing perspective to always putting the customer's needs in focus.

The concepts for shifting between heat sources that has been identified means that an energy service is developed and offered to the customer. The concepts differ in that the responsibility for different parts and aspects of the heating of the customer's building is divided between the energy company and the customer. In the product-oriented *The Product* concept, an energy company needs to develop a new price model where an energy tariff for the customer is set per hour based on production conditions and an optimization product is installed at the customer, which generates control signals indicating whether the heat pump or district heating connection should be used to cover heat demand in the building each hour. Revenue is generated for the energy company by payments for the optimization and the optimization product in a subscription. The building owner achieves cost savings by switching from more expensive electricity to cheaper district heating. By assuming hourly prices for district heating, the greatest possible system benefit can be achieved since the marginal production in both the district heating system and the electricity system forms the basis for which energy source is to be used. Reaching hourly resolution for district heating prices seems to be the biggest barrier in this, not the technical implementation itself.

The second concept proposed is a more advanced energy service and is called *The Service*. The concept includes the optimization of the customer's heat pump in a comfort agreement where the energy company promises to deliver an indoor temperature for a fixed fee. The energy company can thus take responsibility for the customer's entire heating system, including radiators in residential apartments in a multi-dwelling building. By doing so, the customer's heat pump can be seen as part of the energy company's other production mix and the customer's heat pump is optimized in the same way as other production plants in the district heating system, at the lowest total cost for the district heating system and the heat pump. This can in many cases, depending on the network in question, also mean the highest system benefit. Offering comfort agreements can mean a secure revenue stream for an energy company, but in many cases, obstacles in the form of a lack of competence regarding building systems can exist for energy companies to be able or willing to offer them. This offer connects customers to the company and represents a strong competitive advantage over other heating options over time.

When it comes to contracts, *The Product* concept is easier to handle than for *The Service* concept, where the division of responsibilities between the energy company and the customer must be carefully studied. For concepts such as *The Service*, where an energy company can take over electricity trading for the customer's equipment, the legal situation at the time of writing is more unclear. A combined offer for simultaneous delivery of district heating and electricity must be designed transparently and give possibilities carry out measures and optimizations that provide system benefit, not to provide benefits for the district heating business in the energy company. If this is done, a distorted competitive situation may arise if the energy company operates in a local monopoly through its district heating operations. It is recommended that in each case it is investigated whether a risk of distorted competition in the local market may arise. For *The Product*, on the other hand, competition problems may arise if a particular heat pump supplier is recommended by a municipal energy company. In summary, no major barriers have been identified that completely exclude services that allow load shifting, but the recommendation is that offers that are designed in practice are carefully analysed from a competition perspective on a case-by-case basis.

For all buildings used as case studies, optimization of heat pumps provides cost savings for building owners, assuming that energy companies offer optimization solutions that allow optimization to be performed based on marginal production costs in the district heating network. The savings potentials that are reported are the highest possible to achieve and can be reduced depending on how other fixed district heating charges are designed. Three case studies show that building owners with heat pump and district heating can make annual savings through alternating operations of between 2 - 33%, depending on the heat pump installation in the building and which district heating type network it is connected to. The highest saving potential exists for a ground source heat pump in a type network with large amounts of excess heat and the lowest saving potential exists for an exhaust air heat pump in a network with central heat pumps. The shifting between heat pumps and district heating based on its marginal production costs also gives rise to reduced emissions of CO_2 equivalents from energy use in buildings. For a single building, emissions can be reduced by 0 - 75% from a system perspective. The reduction in emissions is very much dependent on the type of network in which a property is located. In a district heating network with a large share of excess heat, the greatest emission reduction is achieved, the lowest emission reduction is reached in a network with central heat pumps. Electricity prices in the spot market also have an impact on the results, for the property with a geothermal heat pump the savings potential for the property owner varies by 10 percentage points between 2015 and 2016. In 2015, electricity prices were generally lower than in 2016. The distribution in the resulting savings is thus large between case studies and especially between type networks, which is why it is recommended that the benefit of shifting between district heating and heat pumps must be studied in each case in practice.

In a building where a ground source heat pump in addition to being controlled based on district heating costs and spot prices on the electricity market, additional savings can be obtained by performing a cost optimization in a second step on the regulating power market mFRR. A ground source heat pump would be switched off further between 65 and 770 hours for one year in favour of local district heating use if the heat pump could have been used as a down-regulating effect on the market. However, the extra revenue from this regulation is relatively small compared to the savings from optimizing against the spot market. In addition, today's demand for minimum bid volumes in regulator power markets is too high for individual heat pumps to be able to participate in the trade. However, by aggregating several heat pumps, the potential can be utilized in a future scenario. There are also other ways for energy companies to benefit from flexible control of heat pumps that are supplemented with district heating, for example by avoiding penalties for high power outages against overhead distribution networks.

In summary, it is concluded that heat pumps can be an effective element of a district heating company's production mix. The values that can be created can be quantified (reduced costs and reduced environmental impact) but also those of a non-quantifiable nature are important, such as the strengthened customer relationship. District heating companies operate in a changing market and one of the most important changes to consider is the customer's needs. If these are not met, then eventually there is no customer to sell heating to. The servitization of the sector has begun and this means that a shift in business logic is required. How fast the shift from the conventional production logic towards the customer's needs can go depends on the maturity of the district heating company. A first step in maturity can be to take the first step in the service pyramid through *The Product* concept in order to develop over time, together with the customer, towards *The Service* concept.

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Appendix A: Heat pumps as flexibility on power regulation markets

BRIEFLY REGARDING ELECTRICITY TRADING IN SWEDEN AND THE NORDIC COUNTRIES

In the Nordic region, physical trade of electricity is organized on the Nord Pool Spot marketplace. This includes Sweden, Finland, Norway, Denmark, Estonia, Latvia, and Lithuania. The exchange is owned by the member countries' grid operators, which in Sweden is the Svenska Kraftnät (SvK). Actors that trade with electricity are electricity producers, large electricity users and electricity brokers.

ElSpot

On Nord Pool Spot or ElSpot, market prices for electricity are balanced between supply and demand through an auction procedure. On the exchange, the common system price as well as spot prices in the individual electricity areas are set one day in advance for each hour for the next 24 hours. Every morning until 12:00, actors submit their bids for the following day. Each bid specifies the volume (MWh/h) that the operator is willing to buy or sell at a specific price level (EUR/MWh) for each individual hour. At 13:00 each day, Nord Pool presents the prices for the coming day. Since the bids are submitted the day before delivery, the spot market is called a "day-ahead market" (Energimarknadsinspektionen, 2019).

Intraday

In addition to the spot market, there is an adjustment market for trading up to one hour before the delivery hour, this market is called the "intraday market". This regulatory market is also called Elbas and is organized by Nord Pool. Elbas exists because operators may need to adjust the contracts that they have entered on the electricity spot market according to how the production or use situation changes during the day of delivery. (Energimarknadsinspektionen, 2019). Trading on Elbas opens at 14.00 the day before delivery and closes one hour before the delivery hour. Trading takes place continuously during this time - bids are matched as soon as a counterparty is found, which means that trading takes place between two parties without any price impact on other transactions. The intraday market is mainly used by balance responsible partners, although it is not a requirement to be a balance responsible partner to participate. Trading on the intraday market is associated with fees. The volumes on the intraday market are relatively small (4.9 TWh/year) compared to the day-ahead the market (361 TWh/year), but this may change (Energimarknadsinspektionen, 2016).

Balance responsible party (BRP)

According to the Electricity Act, an electricity supplier is obliged to supply as much electricity as the electricity supplier's customer (the electricity user) consumes. To fulfill the obligation, there must be someone who undertakes the balance responsibility for the electricity supply. The electricity supplier can either take that responsibility himself, and thus become a balance responsible party, or hire a company that is already such a party. In both cases, there must be an agreement on balance responsibility with SvK. For every minute of the day, there must be electricity balance in the mains. However, it is seldom that a balance responsible party manages to plan for perfect balance, SvK then intervenes by buying or selling electricity during the hours of imbalance. The actor who caused an imbalance will pay for what it costs for SvK to restore the balance. SvK calculates this cost in the so-called balance settlement (Svenska kraftnät, 2019).

The companies that want to become a balance responsible party must apply for this and then sign a balance responsibility agreement with Svenska Kraftnät. Requirements for becoming a BRP relate, among other things, to financial security in relation to the risk level and scope of the balance responsibility as well as the opportunities to communicate via the electricity market's standard information exchange system Ediel (Svenska kraftnät, 2019).

Balance service providers (BSP) and aggregators

Aggregators are actors that collect and manage the production and use of electricity to participate in organized markets for electricity by buying and selling energy or capacity (Sweco, 2018). Aggregators become particularly interesting in markets that require high bid sizes and where an individual smaller actor cannot participate.

In an investigation, the Energy Market Inspectorate (Energimarknadsinspektionen) emphasizes that a prerequisite for electricity consumers to act on the intraday market, for example, is that they have the ability to control their consumption. Aggregators should be able to control their contracted demand flexibility thorough automation, which means that technology solutions are required to regulate, for example, heating systems. There is a requirement for communication to participate in the intraday market, and in addition, those who offer the flexibility need to agree with a BRP regarding demand flexibility management (Energimarknadsinspektionen, 2016).

Another condition for an aggregator to be able to participate on regulation markets is that it is the acting BRP for the traded electricity or has an agreement with the acing BRP. Balance responsibility is required to act in most markets, and this is something that today is perceived as an obstacle by aggregators. The fact that aggregators have had to be responsible for balance, or have an agreement with an electricity trader who is usually the ones responsible for balance, has meant reduced incentives for independent aggregators to participate in the markets as they were then forced to participate on the terms of the electricity traders (Sweco, 2018).

In December 2017, a new European guideline for balancing electricity, GL EB, came into force. One of the aims of GL EB is to: "facilitate the participation of demand flexibility, including aggregation of facilities and energy storage, and at the same time ensure that they compete with other balance services on equal terms and, where necessary, act independently when serving a single one". With this, however, one should begin to separate the financial and physical responsibilities at each point to give aggregators more incentive to participate. This has been done by defining two new roles in the guideline: the balance responsible party (BRP) who is financially responsible for the balance at each point, and the system service provider (balancing service provider, BSP) who is physically responsible for the balance at each point. Aggregators will thus rather be treated as system service providers (Sweco, 2018). It is up to each member country to decide what the exact conditions for these should look like, and in Sweden, proposals are now being discussed between Svenska Kraftnät and the Swedish Energy Market Inspectorate regarding the design of these. Decisions on the matter are expected to be made in 2020 (Energimarknadsinspektionen, 2019).

The model used in the Nordic countries today, when the balance manager, or BRP, and system service provider, or BSP, must be the same party, is usually called the integrated model. In short, this means that all imbalances that result from aggregation will only affect the party who is responsible for the imbalance. The financial and physical flows can thus be described in accordance with Figure 30. The grid operator (TSO), i.e. Svenska Kraftnät, compensates the balance manager (BRP/BSP) for delivered down or up regulation of power or energy. The balance responsible party cold also reimburse the flexibility owner or Balance Resource Owner (BRO), which could be a building owner. However, this is something that can be settled between the balance manager and the flexibility owner in a separate agreement. There is also an exchange of information between the grid operator and the balance manager, as well as between the balance manager and the flexibility owner. In addition, the balance manager purchases electricity on the intraday or day ahead market and therefore an exchange of money and electricity is also exchanged between the electricity exchange and the balance manager (Energinet, Fingrid, Statnett, Svenska kraftnät, 2018).

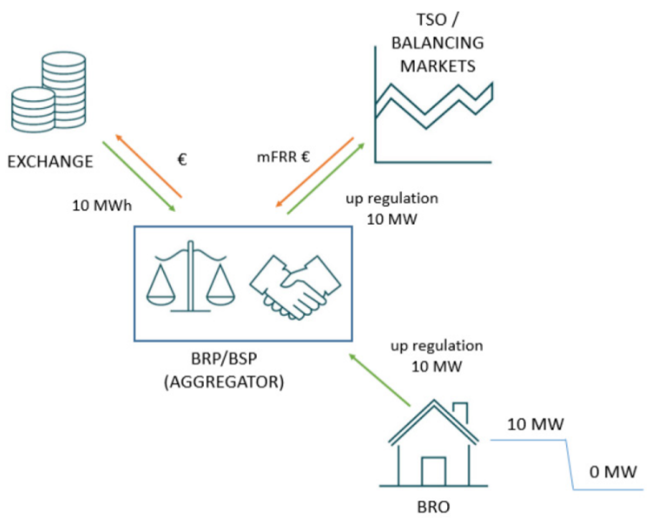

Figure 30 The integrated model. Orange arrows represent financial flows and green arrows represent physical flows. The flexibility owner (Balance Resource Owner - BRO) buys electricity from the spot market through its electricity trader. An aggregator acts as the balance manager (BRP/BSP) or has an agreement with the balance manager for the BRO as well as with the BRO. BRP/BSP purchases electricity for the BRO on the spot market a day in advance, at the hour of delivery it turns out that BRO can renounce 10 MW of its procured electric power and states this as an up-regulation bid through its aggregator. The aggregator can then offer this power volume to a regulation market and receive compensation for it. How thee profit from this trade is split between the aggregator and the BRO is stated in a separate agreement (Energinet, Fingrid, Statnett, Svenska Kraftnät, 2018).

The integrated model is considered to be a first step to achieve more aggregation on the regulation markets, and as mentioned, it is the model used in the Nordic countries today. However, Nordic grid operators believe that there is room for improvement in this model, especially since there are still not many aggregators of demand flexibility operating in the regulation markets. The barriers mentioned are that the markets are only open to balance managers, thus a third party cannot participate in the markets directly. In addition, it is usually not allowed to aggregate both electricity production and consumption in the same bid, even if they belong to the same balance controller. In addition, it is only allowed to aggregate within one electricity area at the time, which reduces the possibilities for aggregation (Energinet, Fingrid, Statnett, Svenska kraftnät, 2018).

Balance and regulation markets

Svenska Kraftnät (SvK) holds system responsibility for electricity, which means responsibility for the Swedish electricity supply to operate reliably and that the input and output of electricity is always in balance, i.e. the frequency in the electricity grids is 50 Hz. To keep this balance in the electricity system, SvK buys reserves from balance controlling companies. Reserves can, for example, consist of production plants or industries that can adapt their electricity use. There are different types of reserves (FCR-N, FCR-D, aFRR and mFRR) with different requirements for, among other things, duration, and speed of response. The automatic reserves are the fastest and are thus those that are first activated in the event of a frequency deviation. The manual reserves are used to restore the automatic reserves, so that they are always ready to be reactivated.

Figure 31 shows an overview of the requirements for these reserves. To deliver reserves, the requirements in the current balance agreement with its associated appendices and regulatory documents need to be met. General requirements for all reserves are approved pre-qualification, real-time measurement, and electronic communication. For the power regulation market, the requirement for real-time measurement at activation time is 15 minutes.

Table 21 Overview of balance and regulation markets (Power Circle, 2019).

Market	Bid size (minimum)	Procurement	Activation	Design	Future development
FCR-N	0,1 MW	One/two days ahead Total 200 MW	Active +/- 0,1 Hz Within 18o sec.	Symmetrical	New technical requirements
FCR-D	0,1 MW	One/two days ahead Total 400 MW	Active below 49,9 Hz Within 30 sec.	Up-regulation only	Down-regulation in 2021
aFRR	5 MW	Once per week Total 150 MW	Restores FCR-N Within 120 sec.	Up- or down-regulation	Procurement in all hours, increased volume, and minimum bid 1 MW
mFRR	10 MW (5 MW)	During hour of delivery Volume by need	Procured as needed Within 15 min.	Up- or down-regulation	Electronic activation and minimum bid 1 MW

Comparison of markets

In their report “Aggregators in the Swedish electricity market - a report to the forum for smart electricity grids”, Sweco has investigated the various regulation markets from an aggregator perspective. For mFRR, strict requirements are placed on minimum bid size and response time, which makes it suitable for, for example, hydropower and CHPs. In the report, Sweco highlights that the production specifications that may be an obstacle for an aggregator to offer its services in the mFRR market are:

1. Registration of the aggregated flexible load as a control object with the domestic system operator
2. Create real-time measurement for the object and make it available to the system operator.
3. Relatively high requirements on minimum bid of 5-10 MW depending on electricity area.

On the mFRR market, volatility is typically higher than on the intraday market because of trading taking place closer to the hour of delivery. In addition, cancelled bids on the mFRR market are compensated according to marginal pricing, which means that the highest or lowest called bid for the given settlement period will be price setting. An appropriate tactic for an aggregator would then be to place a bid with a price that ensures profitability in the deal with its electricity users and other potential actors involved.

For the aFRR market, system operators place different requirements on the traded electricity compared to mFRR. The main difference is that the control object must have control equipment that enables the system operator to control the system by sending a set value to the system's systems. The regulator must also comply with a strict specification (Sweco, 2018). According to SvK, it is not possible at present to place consumption bids on aFRR (Svenska kraftnät, 2019).

For FCR-N and FCR-D, the aggregated capacity must have a controller that can regulate based on the instantaneous frequency in the network, and is not centrally controlled from the system operator's control room as is the case with aFRR. The frequency in the network is an indicator of whether there is an instantaneous surplus or shortage in the network and is therefore good as a quick reserve that can be used to correct imbalances. FCR-N is more or less always activated to some extent. FCR-D is only activated in cases where there is a large instantaneous deficit in the network. For FCR, the aggregator offers the flexibility to the national system operator in two auctions, one occurs two days before the day of delivery and one occurs the day before the day of delivery. The bid size is smaller than for both mFRR and aFRR and should thus be easier to aggregate. However, the bid must be symmetrical, which means it must be able to contribute to both up- and down-regulation (Sweco, 2018).

Tertiary regulation, mFRR

Manual control (mFRR) is performed through a bidding procedure. SvK wants to increase competition in reserve markets and therefore welcomes new types of resources, such as consumption flexibility. The concept encompasses many different types of resources where the use of electricity, depending on some form of external signal, is changed, and/or moved over time. This can be (individual or aggregated) electricity use in, for example, households and industries. In order to submit a bid to SvK, the bidder must currently be responsible for balance (Svenska kraftnät, 2019) The section on aggregators and system service providers describes how this will change in the future.

Facilities participating in the regulating power market must be under the responsibility of the balance responsible party. Facilities should be assigned to a regulatory object in connection with the facility being connected to the network in accordance with SvK's main principles for establishing regulatory objects (Svenska kraftnät, 2015).

The up and down regulation bids on mFRR shall meet the following requirements in accordance with the balance agreement:

- Bids can be submitted, changed, or withdrawn continuously via the web interface at Svenska kraftnät's site for market and trade information before the outcome of the day's market for the relevant delivery day is announced. After the marketplace outcome, bids can also be submitted electronically. The bids can be changed up to 45 minutes before the hour of delivery, after which they are financially binding.
- Bids must contain information on volume (MW) that can be adjusted up or down, price (SEK/MWh or €/MWh), activation and regulation times and which control object the bid refers to. The agreed-upon volume must be able to be delivered during the entire delivery hour in question.
- Bids that are accepted must be fully activated within the specified activation time of the bid.
- Up-regulation bids are submitted with a positive sign. Upon activation, SvK buys power from the BRP.
- Down regulation bids are submitted with a negative sign. Upon activation, SvK sells power to the BRP.
- • The maximum allowable price for an up-regulation bid is 5000 € / MWh.

The bids are called off in the price order and the highest up-regulation bid and the lowest down-regulation bid will be priced according to marginal pricing (Svenska kraftnät, 2016). For both mFRR and aFRR, it is being discussed to reduce the minimum bid size to 1 MW (Power Circle, 2019).

Examples of heat pumps used for flexibility

Heat pumps as an aggregate flexibility resource have been studied in the projects Klokel (2014 - 2018) and VäxEl (2017 - 2020) in Uppsala. The Klokel project involved installing load control on 500 heat pumps. The technology provides about 2 kW per villa as flexibility during the cold season. For the project, this means that the heat pumps can deliver 1 MW of flexibility in a 60 MW electricity grid. Nationally, it would mean about 3 GW as flexibility resources if all villas with water-based heat where to be controlled. In the subsequent project VäxEl, the heat pumps are also connected to electric cars, batteries, and solar panels in the system. The project looks at the complexity of optimizing these parameters and at the same time considering local and national conditions. The goal is to create the world's largest test bed for distributed flexibility. Project partners in Klokel were Sustainable Innovation, NGenic and Upplands Energi. In, VäxEl the same partners participated, plus Chargestorm and Ferroamp (Wolf & Andersson, 2018).

There have been previous studies in which the potential for heat pumps on power regulation markets are studied. A thesis from Uppsala University has investigated at the benefits for grid owners and the balance responsible party to use consumption flexibility from heat pumps in apartment buildings and to examine how it affects end consumers. The study was conducted for a specific grid owner and electricity price area. The studied local network included 174 apartment buildings with heat pumps that could reduce their maximum peak power by 2.9 MW. The results show that the benefit for grid owners is primarily the opportunity to lower potential penalty fees, reduce their power subscription to overlying grids and to be able to connect more consumers to the grid without having to expand the electricity grid to the same extent. The study also highlights that there are several markets where the balance responsible party can use consumption flexibility to stabilize the energy balance in the electricity grids. The markets that were identified as optimal for consumption flexibility from heat pumps in SE3 were the mFRR market and the power reserve market. SE3 consists of 10 146 multi-family houses with heat pumps. The mFRR market in the calculations gave an average income of SEK 2.7 million per winter season, while the power reserve market gave an annual administrative compensation of SEK 1.1 million and SEK 104 000 per activation. The study points out that to use consumption flexibility from heat pumps, it is important to evaluate the role and responsibilities of the actors. The same resource cannot be used for different purposes at the same time and it is therefore important that there is clear communication between the grid owner and the balance responsible party. There is also a need to evaluate potential practical implementation opportunities and costs to analyze practical feasibility and profitability (Grill, 2018).

Another thesis from Uppsala University has evaluated the potential for consumption flexibility that arises from simultaneously turning off a large number of heat pumps in apartment buildings. Simulations to generate load profiles for an aggregated number of heat pumps in a grid area with 174 multi-dwelling houses with heat pumps and an electric area (SE3) with 10 146 multi-dwelling houses with heat pumps were performed. The results show that 174 multi-dwelling houses with heat pumps in a grid area can free up to a maximum of 10 MW for one hour, and that 10 146 multi-dwelling houses with heat pumps in an electricity area can give rise to 169 MW of flexible power for one hour. The simulations also show that there is a risk that larger power peaks will be created after the heat pumps have received an off signal and are thereafter switched on again. The author emphasizes that it is important to keep this in mind when using heat pumps as a consumption flexible load, and that further studies are needed to investigate the possibility of minimizing the power peaks caused by synchronization of the heat pumps after an on-off cycle (Oehme, 2018).

There are examples of actors offering services for building owners to participate in the frequency control market. Within the project Living lab and development arena, Power2U, InnoEnergy and ÖrebroBostäder have developed the CODES framework (Control and Optimization of Distributed Energy Storage). The project studied the benefits of using battery storage to optimize ÖrebroBostäder's buildings, store energy and load balancing of the grid. During the project, a cloud-based control system was developed to control and aggregate distributed battery storage. The aim of the project was to deliver added value and services to both building owners with battery storage, electricity grid owners and SvK, among other things by enabling new sources of revenue for the building owner by occasionally allocating part of the battery capacity to SvK through load balancing in the FCR-N market (Power2U, 2019) (Wolf & Andersson, 2018).

Another example of an initiative where heat pumps can act as flexibility in the electricity system can be found in E.On's Switch project, which is run in the larger E-project CoordiNet (E.On, 2020). The project has created a digital marketplace for local electricity trading. Participants in the marketplace are compensated for lowering their electricity consumption or raising electricity production for hours with local capacity shortages. One participant in the marketplace is Kraftringen in Lund, who can bid on the market when central heat pumps in district heating production are switched off (Edsbäcker, 2019).

BUSINESS MODELS FOR COMBINING DISTRICT HEATING AND HEAT PUMPS IN BUILDINGS

In buildings having both a heat pump and a district heating connection installed, the operation of the two heat sources can be optimized by an energy company to reduce system costs and in many cases reduce emissions from the heating of the buildings.

Energy companies that produce and sell district heating can design new business models that enable the use of heat sources in the buildings for increased system utilization. The business models mean that energy companies need to develop and broaden their portfolio of energy services offered. Energy companies are at different stages in the service development process and for some, product-oriented business models present fewer obstacles than pure services.

Regardless of which concept you use, the relationship and collaboration between the energy company and your customers is becoming increasingly important. For an energy company this can be the greatest value of the business model.

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