New Business Model for District Heating Firms Stabilizing the National Energy System with a Future Variable Electricity Production

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Abstract

Human impact on the environment is a highly discussed topic and it is politically encouraged that the energy system is based on renewable resources. Energy generated from renewable energy resources such as wind and sun has entered the Swedish national energy system with an increasing volume. Due to the variable production nature of these energy sources arrangements need to be made in order to have a more stable and secure energy supply.

The aim of this thesis is to develop a new business model for district heating and cooling firms which can contribute to a stabilization of the Swedish national energy system. The business model is developed for a district heating and cooling firm and is exemplified with Fortum Heat. The theoretical investigation around the topic creates a rigid base for following qualitative empirical studies. Osterwalder’s canvas for business model generation is used together with a Casual Loop Diagram to identify a number of business opportunities which stabilizes the national energy system. One of the business opportunities is developed into a business model.

The study results in a business model which offers Svenska Kraftnät an increased volume of electricity production through free capacity in CHP plants. This stabilizes the national energy system when the electricity production from renewable energy sources is low. Free capacity occurs due to more and more energy efficient buildings and investments in new production capacity. Heat from the electricity production is loaded into thermal storages to cover a part of the future need for heat. Heat can also be rejected as surplus heat into water if the demand for electricity is high. Renewable biofuels turn CHP plants into bio-condensing electricity power plants.

A general exemplification of this situation at Fortum Heat shows positive economical results. Producing electricity independently of the current demand of heat makes it possible for Fortum Heat to be a part of Svenska Kraftnät commercialization of the power reserve. A finalizing discussion highlights aspects needed to be considered when implementing the business model at Fortum Heat.
Preface

This master thesis has been conducted and written at Fortum Heat in the first half-year of 2012. We want to thank our supervisor Åsa Blomgren at Fortum Heat.

We also want to thank professor Per Lundqvist at the Royal Institute of Technology for feedback and support during the project.

Finally we want to thank all involved persons at Fortum Heat for giving us the opportunity to collect required information and being a part of your project, flexible energy.

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Per Lohmann Zami Sarker
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Nomenclature and Abbreviations

- $\alpha$: Electricity-to-heat production ratio at CHP plant KVV6, Värtan
- $\beta$: Part of coal in the fuel of CHP plant KVV6, Värtan
- $\Delta T$: Temperature difference [K]
- $c_p$: Specific heat of water [kJ/Kg*K]
- $CC$: Carbon credit price which is related to the fuel (SEK/MWh)
- $CH$: Customers channel
- $CR$: Customer relationship
- $CHP$: Combined heat and power
- $CT$: Carbon tax which is related to the fuel [SEK/MWh]
- $CS$: Customer segment
- $C$: Cost structure
- $D$: Depreciation [Million SEK/year]
- $DC$: District cooling
- $DHC$: District heating and cooling
- $DH$: District heating
- $E$: Revenues related to electricity production [SEK/MWh]
- $E_{electricity\ price}$: Electricity certificate price [SEK/MWh]
- $E_{grid}$: Revenues related to the electricity grid [SEK/MWh]
- $E_{price}$: Electricity price [SEK/MWh]
- $EB$: Electric boiler
- $ET$: Energy tax which is related to the fuel (SEK/MWh)
- $HP$: Heat pump
- $HOB$: Heat-only boiler
- $KA$: Key activities
- $KP$: Key partnership
- $KR$: Key resources
- $n_{electricity}$: Efficiency for electricity production
- $n_{heat}$: Efficiency for heat production
- $NOX$: Mononitrogen oxide tax [SEK/MWh]
- $\dot{m}$: Mass flow of water [m$^3$/second]
- $OM_{electricity, \ Värtan}$: Operating and maintenance cost related to electricity production at CHP plant KVV6, Värtan [SEK/MWh]
- $OM_{heat, \ Värtan}$: Operating and maintenance cost related to heat production at CHP plant KVV6, Värtan [SEK/MWh]
- $OM_{electricity, \ Brista}$: Operating and maintenance cost related to electricity production in the CHP plant in Brista [SEK/MWh]
- $OM_{heat, \ Brista}$: Operating and maintenance cost related to heat production in the CHP plant in Brista [SEK/MWh]
- $P$: Profit [Million SEK/year]
- $P_{electricity}$: Electricity power [MW]
- $P_{coal}$: Coal price [SEK/MWh]
- $P_{fuel}$: Fuel price [SEK/MWh]
- $P_{heat}$: Heat power [MW]
- $P_{max, \ rejection \ heat}$: Maximum allowed rejected heat power into the water in Värtan [MWh/h]
- $P_{olives}$: Olive stones price [SEK/MWh]
- $PC_{electricity}$: Production cost for electricity at CHP plant KVV6, Värtan [SEK/MWh]
- $PC_{heat}$: Production cost for heat at CHP plant KVV6, Värtan [SEK/MWh]
RS  Revenue structure
ST  Sulfur tax which is related to the fuel [SEK/MWh]
VPC Variable production cost of heat at CHP plant KVV6, Värtan [SEK/MWh]
VC_electricity Variable production cost when only electricity is generated at CHP plant KVV6, Värtan [SEK/MWh]
VP  Value proposition
Introduction

This chapter provides the necessary background to the project called “Flexible Energy” at Fortum Heat. This master’s thesis is a subproject within this overlying project. After this brief description, the aim and problem statement of thesis is presented. The intention is to show the conditions and the setting in which this master thesis must function within, forming the basis so that the assignment can be specified and so that the project goal can be achieved.

1.1 Background

A new city district is currently under construction where sustainability and the energy system play an important role. The district is known as the Stockholm Royal Seaport (Norra Djurgårdsstaden) and is one of 18 projects around the world, selected by the Clinton Climate Initiative to display how cities have the possibility to reduce their CO₂ emissions and minimize the impact on the environment. This will contribute to a positive development of the climate. (Dahlberg, 2012b)

Fortum Heat is conducting a feasibility study during the spring of 2012. This feasibility study that goes under the name Flexible Energy is carried out together with fragments of Fortum Heat, Svenska Kraftnät and KTH. This master thesis is a part of this feasibility study. (Dahlberg, 2012b)

One of Fortum Heat’s subprojects is to investigate the possibility to stabilize the national energy system in a future context where there is an increased supply of variable renewable power production, for example wind and solar power. These generation methods are rapidly increasing in scale as a response to global warming and reducing our carbon footprint in order to fulfill the environmental targets set, such as the “20-20-20” target. The nature of variable power production presents challenges with its fluctuations as there is an uncertainty in the size and availability of the power that is being generated, because throughout a day wind speed and solar radiation varies to such a large degree. More variable power production and strained electricity grids imply that a different management in the production and storage of energy needs to be examined. This may require Fortum and other district heating and cooling firms to review their current business models in order to remain commercially viable while still benefiting the energy system and providing society and its inhabitants with necessary heating and cooling. (Ib.d)

1.2 Aim of the Thesis

The ambition of this feasibility study is to transition it from an explorative and investigative phase, into a development phase. The objective of the thesis is to provide an appropriate design to a future business model, which in a later stage will be hands-on properly assessed and that in turn verifies the practicability of the business model. The study is exemplified through the Stockholm Royal Seaport that offers an arena to test sustainable solutions, while also providing the context of increased supply of variable electricity production.

1.3 Problem Statement

Developing a business model for a district heating and cooling (DHC) firm where the relationship between DHC and electricity are contributing to a stabilization of the national electricity system in a future context of increased supplies of variable renewable power.

Models for sales and production of electricity are to be considered in the business model as these are key factors for creating revenue. The business model is in this study exemplified with Fortum Heat with a time perspective around year 2020.
1.4 Delimitations

The study has not investigated specifically how energy can be stored in thermal or electrical storage, since there is no current storage method that has established itself for long term and large volumes of storing energy (disregarding accumulators) within the DHC and electricity market. By disregarding details on storage, added uncertainty in the model will be avoided.

Financial instruments used to reduce risks of different kinds when selling or buying electricity, have not been included or considered in this study due to the complexity in their nature while providing little value to business model.

The proposed improvements have not been directed towards constructing and coordinating a complete and functioning system, the emphasis has rather been put on enhancements at a plant level i.e. distribution and consumer behaviour have been disregarded. These in order to better pinpoint the direct measures that a single DHC firm can take, in order for it to aid in the stabilization of the energy system.
2 Methodology

This chapter gives an insight around how the problem statement is approached and achieved. An outline of the practical approach is presented, giving an overview for how the thesis process has been conducted. The end of the chapter describes what sources have been used and how these can be viewed in a critical manner.

2.1 Positivism

The research paradigm is the philosophical framework that guides how scientific studies should be carried out. The philosophical framework is in turn “the use of reason and argument in seeking truth and knowledge, especially of ultimate reality or of general causes and principles” (Collis & Roger, 2009). The philosophical framework can be approached by two main perspectives, a positivistic or an interpretivistic. Positivisms include a view where the reality is independent of us and the goal is the discovery of the theories based on empirical research, meaning gathering knowledge through direct or indirect observations. Statements can be scientifically proved by logic or mathematical proofs. A contradistinction towards positivism is the interpretivistic perspective. The interpretivistic perspective is underpinned by the belief that the reality is shaped by our perceptions as the researcher investigates how the reality affects the subject (Collis & Roger, 2009).

The study has been approached with a positivistic view. Since the thesis is a feasibility study the assignment requires verification and the argumentation needs to be clearly supported in order to be considered justifiable when pursuing the recommendation given in this report. The goal of the study is to determine a business model and has therefore been based on empirical research as the data gathered can then be either supported or refuted.

2.2 Qualitative Study

A study can be based on qualitative or quantitative data. Qualitative research is connected to situations where data in a non-numerical way or data that not have been quantified, is used to solve a problem. The data can range from a list of responses to open-ended questions, more complex data such as transcripts or policy documents. (Collis & Roger, 2009) Quantitative research is based on numerical data or data that could be quantified in a useful way to answer the research question. The quantitative data can be obtained from one or more research strategies. For example frequencies of occurrences can be used in order to establish relationships between variables. An easy way to distinguishing between the qualitative and the quantitative way is to consider if non-numeric (words) or numeric (numbers) data have been used. There are possibilities to combine qualitative and quantitative approaches. Individual qualitative and quantitative techniques and procedures do not exist in isolation. (Saunders, et al., 2007)

This study has used a qualitative approach to solve the research question. In a future context quantitative forecasts tend to be uncertain and with a longer time frame even more uncertainty is presumed, since there are too many unforeseen circumstances and ever changing parameters that determining the future. A good indication of the future scenario can be delivered by relying on expert and specialist qualitative empirical data together with current quantitative data as support. The practical approach is described in section 2.4 and gives the specifics of how the methodology has been applied.

2.3 Interviews

Some research areas have a complex nature. In situations like this, interviews is a good method to obtain necessary information. Interview situations can offer valuable insights based on specialist knowledge and delivery of requested raw data. The possibility to exchange ideas with individuals contributes significantly to the development of a study. (Collis & Roger, 2009)

Interviews have in this study been conducted in the form of semi-structured interviews. This way is considered as a good approach to further develop initial knowledge because it is a loosely prearranged two-way communication. However, because of the individuals’ specialization they were often a bit
reluctant to make statements outside their direct line of work. This frequently led to references to other
persons. These persons where in turn interviewed. It was sometimes time-consuming to arrange
interviews and integrate information from different interviews.

The interviews were prepared a priori. The interviewees were informed about the topics to be covered
without revealing specific details. This decision was made in consent with the interviewee to make the
respondent a bit mentally prepared. Most of the interviews were conducted with both authors of this
report present. One interviewer took notes while the other one had a more commanding role, which
involved asking the questions and steering the interview in an appropriate direction. This made the
interview process fluent when both authors complemented each other with different roles.

Due to the explorative manner of the research topic, interviews form a vital foundation of this study.
Semi-structured interviews help to cover the examiners initial thoughts while also being able to pursue
interesting threads that became apparent during the course of the interview. It in involves the best of both
worlds from structured interviews rigidness of sticking to the topic and the non-structured interview’s
explorative nature of being able to pursue what the interview subject considers relevant. The human-to-
human contact also gives less room for misinterpretation that e-mails and to a lesser extent telephone calls
provide. For these reasons semi-structured interviews were considered the best method of solving the
research question as it offers powerful knowledge transfer between two parties.

2.4 Practical Approach

The practical approach is showed in Figure 2.1. Data for the theoretical investigation was collected from
relevant literature, external reports and documents, internal documents from Fortum Heat and interviews
at Fortum Heat and Svenska Kraftnät. The theoretical investigation did not only cover areas, which were
directly connected to the problem statement. The investigation involved information that in some way is
connected to the Swedish national energy system, which in turn forms the atmosphere around the
problem statement. Providing the setting and the guidelines that the problem issue in question must
comply after. General information around concepts relevant for our research area was also considered as
it adds to the description of the setting. This combination of information created a framework for the
following empirical studies.

The theoretical investigation is considered a good initial approach since it shows what the utilities industry
already knows, what information is lacking and what needs to be complemented. Thereby pointing
towards what areas the researchers need to investigate and gather data on how to solve the given
assignment. These tended to be written sources such as journals, reports, books and websites since it
provides a good foundation and the knowledge basis to continue further exploration in the subject.

Empirical studies were carried out in close relation to the problem statement. There are different phases
to the empirical studies. In this case primarily through data gathering by the use of positivism this
culminates into a qualitative study with the support of quantitative data. The goal of the empirical studies
is to better understand the different features at Fortum Heat and the national energy system and how it
relates back to the problem statement. It will then come to head in identifying a business opportunity,
which created the foundation for the consequent business model. The empirical studies and theoretical
investigation have for certain periods of time been conducted concurrently. The empirical studies have
throughout the work process needed additional new information, which means the theoretical
investigation has continuously been complemented.

The business model was constructed with respect to earlier obtained information from the theoretical
investigation and empirical studies, conducted under a positivistic and qualitative perspective. The
business model was exemplified in a quantitative manner to show the gains that are to be made and in
some way to put it all into context. This will help ease the comparison between the existing business
model and the proposed future business model, making the new business model more graspable and not
too much in visionary term.
It should here be highlighted that the quantitative exemplification did not influence the qualitative studies before the construction of the model. The quantitative perspective was only used to economical exemplify the constructed business model.

Finally an integrating discussion takes place, which highlights what needs to be considered when the business model is integrated at Fortum Heat.

![Figure 2.1 Practical approach.]

### 2.5 Criticism of Sources

When information was obtained from different sources it was important to remember that organizations or divisions within an organization by nature and for their own survival tend to highlight information that benefit themselves. No matter if the organization is profit driven, non-profit driven, governmental or municipal. In the study a broad spectrum of sources have been used from a multitude of different stakeholders, which have been compared between each other. This has led to eliminations of the described phenomena above to the extent of which it is possible.

Another aspect is that the assignment is to deliver a future business model that stabilizes the energy system with a future of variable electricity production. This business model is supposed to be applied to any arbitrary DHC firm and not only Fortum. Much emphasis has been put on Fortum since a lot of the internal work that different DHC firms make is confidential. However Fortum gave us valuable insight in how it conducts its business and there was a strive in this study as mentioned, to have multitude of varying sources from different stakeholders to get different perspectives and to see how a general and typical DHC firms works. Fortum therefor became a starting point in achieving a business model that can be used for any DHC firm in Sweden.
3 Theoretical Investigation

This chapter presents the theoretical investigation. This investigation builds a foundation for the consequent chapters. The idea is to show the DHC industry’s current situation, what stresses and issues it is subjected to in relation to the assignment and then give an inclination towards what needs to be supplemented.

Initially this chapter will describe Fortum and concepts around DHC. This to understand how typical DHC firms conduct their business and provide a sense into the current business model that will be mapped in the following chapter. This will in turn lead to an explanation of the Nordic Electricity Market, which is the space the DHC firms must function within. Moving on is issues within this marketplace and what means are being made towards stabilizing the energy system. Afterwards Fortum Heat Scandinavia’s DHC management will be presented in order to link back to the previous issues and give a better hands-on feel towards its direct activities. Finally different concepts will be presented that cover the gaps that are highlighted by the theoretical investigation and used in creating the future business model

3.1 Fortum Corporation

Fortum Corporation (Fortum Oyj) is a Finnish public and limited liability energy company. Its business involves generation, distribution and sale of electricity and heat as well as the operation and maintenance of power plants and energy-related services. The company primarily operates in Finland, Sweden, Norway and Poland. Fortum distributes electricity to nearly 1.6 million customers in Estonia, Finland, Norway and Sweden. As of 2012 the company holds power generation capacity of approximately 13,766 MW whereas about 10,981MW is located in the Nordic countries. The company is headquartered in Espoo, Finland (Global Data, 2012)

Fortum’s business is divided into 4 divisions: Power Division, Heat Division, Russia Division and finally Electricity Solutions and Distributions Division. The power division is principally responsible for power generation and trading in the Nordic wholesale electricity markets but also providing specialist services to electricity and heat producers globally. The Heat Division focuses on combined heat and power (CHP) production and the distribution of district heating and cooling. The Russia Division produces and sells electricity and heat in Russia’s biggest industrial regions. Electricity is sold on Russia’s wholesale market while the heat is sold on the local market. The Electricity Solutions and Distribution Division are responsible for Fortum’s electricity distribution and sales activities. The division consists of two business areas namely Distribution and Electricity sales (Fortum, 2012g).

Fortum Heat is owned to 100 % by AB Fortum Heat Holding, which in turn is owned to 90.1% by Fortum Power and Heat AB and 9.9% by Stockholm City. Fortum Power and Heat AB is included in Fortum Oyj. Stockholm City has preferred stock in Fortum Heat Holding that gives it as much economist interest as Fortum Power and Heat AB and the right to warrants that result in equal ownership to Fortum Power and Heat AB (Swedish Energy Markets Inspectorate, 2013).
### Table 3.1 Key Facts Fortum Corporation and Fortum Heat (Fortum, 2012d)

<table>
<thead>
<tr>
<th></th>
<th>Fortum Corporation</th>
<th>Fortum Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Address</td>
<td><a href="http://www.fortum.com">www.fortum.com</a></td>
<td><a href="http://www.fortum.com">www.fortum.com</a></td>
</tr>
<tr>
<td>Sales Fortum Corporation</td>
<td>6,159 EUR Million</td>
<td></td>
</tr>
<tr>
<td>Number of Employees</td>
<td>10,371</td>
<td>2,212</td>
</tr>
</tbody>
</table>

#### 3.2 Price Components of the District Heating and Cooling Market

This chapter describes the price components of typical DH and DC firms. It describes how major components relate to the total energy cost and how each individual price component relates to each other. Showing their relationship to customers and the revenue stream of the current business model is a good way to initiate the literature review by highlighting how money flows into the business. Further information around principles and policies regarding the price level is found in section 3.11.13 and 3.11.14.

### 3.2.1 Price Components of the District Heating Market

Reko Fjärrvärme is a project with an aim to develop the relationship between DH providers and customers. (Svensk Fjärrvärme, 2012a) This organization has investigated the pricing components of 189 DH firms in Sweden. Price components are used in a variety of combinations in order to create specific outcomes. The price components are listed below. (Fjärrsyn, 2011)

**Fixed price** – is sometimes divided into intervals based on the customer’s yearly heat consumption. This price component is fixed for the current year, but variable for a long time frame

**Energy price** – a price component that is the same during the whole year or varies over a few levels depending on the season. The DH production is usually cheaper during summer, which is also reflected in the energy price by some DH firms

**Power price** – set from a category number or a measured value over a period of time. A power price based on a category number means that the demand over a longer period of time is measured (a number of months or a year) and is divided by a category number with respect to the demand pattern of the customer. Real measured values, hourly or daily, becomes more common instead of using a category number.

**Flow- or temperature price** – a price component that is controlled by the amount of DH water that flows through the heat exchanger of the house. The intention is to create an incentive for the customer to keep the system in a good condition. A high heat transfer reduces the flow and return water temperature, which means low heat losses in the grid.
There is a difference between how big the price components are in relation to the total energy cost, comparing private houses and commercial buildings. This is shown in Figure 3.1 and Figure 3.2 where around 80% of the energy cost is related to the energy demand for a general private house. Around 90% of the energy cost is related to the energy demand for a general commercial building. The price component named “Other” is related to earlier year demand of energy and the price component “Other (energy)” is related to the flow. (Fjärrsyn, 2011)

![Figure 3.1 The price components part of the total energy cost for a general private house (Fjärrsyn, 2011).](image1)

![Figure 3.2 The price components part of the total energy cost for a general commercial building (Fjärrsyn, 2011).](image2)

### 3.2.2 Price Components of the District Cooling Market

Due to the similarities between DHC, the price components of the two are fairly identical. Price components are listed below. (Folkesson, 2009)

**Fixed price** – a fixed component that depends on the total agreed power consumption (Fortum, 2012b).

**Energy price** – a component that is the same during the whole year or varies over a few levels depending on the season (Norrenergi AB, 2012).

**Power price** – based on the peak demand of the previous year (Folkesson, 2009).

**Flow- or temperature price** – the flow charge is calculated with respect to the amount of cooling water that circulates through the cooling central of the customer (Norrenergi AB, 2012). The temperature price is dependent on how well the cooling water that passes though the cooling central is heated, relative to the average of all the customers in the DC network. According to this, a customer can either be charged or receive a bonus (Fortum, 2012b).
3.3 General Concepts around District Heating and Cooling

This chapter will describe the general concepts around district heating (DH) and district cooling (DC).

The basic concept of DH is to generate heat at a central plant. Use of fuel locally can be of a benefit financially and environmentally, as fewer transports are used and energy otherwise wasted can be captured. The centrally produced heat is distributed through a network of pipes at the local marketplace (Werner, 2004). This means that in a district, every building does not need to have its own boiler. Instead heat is supplied from a central plant, which may be run on different fuels. Households are benefited by avoiding purchasing individual boilers and maintaining them. The environment is benefited when a central plant often has a high efficiency. (Svensk Fjärrvärme, 2012a).

The same principle applies to DC. The fluid is cooled in a central plant and is distributed in a network of pipes. (Fortum, 2012f) Cold water from a lake or the sea, known as free cooling can be used as a coolant. (Werner, 2012) DC means no local noise as the large machines are instead used centrally, freeing up valuable space which individual cooling machines otherwise occupy in non-DC facilities. (Fortum, 2012f) The coolant in DC grids can also be cooled through heat pumps (HP) or absorption chillers, the main methods of cooling which are described in this chapter.

3.3.1 How District Heating is produced

Fuels are burned in one or several central boilers, as seen in Figure 3.3. The incoming water is heated to between 80 and 120 °C, depending on variations such as the weather and time of the year. This heated water is distributed under high pressure through a culvert system to the consumers, through a system of well-insulated pipes (Karlsson, 2012). The hot water is spread to a DH center in each property. At these places heat exchangers utilize the hot water by warming radiators in the building and also heat the water for the taps. The culvert system between the hot water central (HOB) and the central of the subscriber is known as the primary system e.g. a residential building. The system of the customer is known as the secondary system e.g. a condominium. (Svensk Fjärrvärme, 2012b)

![Figure 3.3 Sketch of a DH system, which also produces electricity. The production is to the left and the heat exchanger at the location of the consumer is found to the right (Karlsson, 2012).](image)

The heat losses from the supplied energy in a DH network becomes smaller with better insulation in the conduits, shorter grids and an increased number of customers. A high number of customers in urban areas therefore leads to that the relative heat losses are very small. (Euroheat & Power, 2012)

In processes with pure electricity generation much of the energy in the fuel is not used which leads to surplus heat.
The fundamental idea of a combined heat and power (CHP) plant is to better take advantage of this surplus heat through a use of the heat in a DH system (Euroheat & Power, 2012). Figure 3.3 shows a plant where DH and electricity are produced at the same time, a CHP plant. Next section describes CHP plants.

### 3.3.2 Combined Heat and Power Plants

A CHP plant generates electricity and heat, which is distributed through a DH grid. This combination makes it possible to use 80-90% of the energy in the fuel, compared to a maximum use of 50% of the energy in the fuel when only electricity is generated. (Engström, 2012)

The traditional type of CHP plant is the steam plant. Steam expands through a turbine while still being at a high temperature, about 100 °C. The warm steam that is condensed and thereafter re-pumped into the boiler, heats the water in the DH system. The same type of power plant is used within industries that have a need for steam such as for drying paper pulp. The boiler can burn with almost any occurring fuel such as oil, coal, gas or bio fuels. (Engström, 2012)

CHP plants are considered to have a planned unavailability of 10-11% (e.g. scheduled maintenance) and unplanned unavailability of between 4 and 6% (Hawkes & Leach, 2008).

### 3.3.3 Heat Pumps

A heat pump is a device that makes it possible to use heat energy from heat sources with low temperature. Examples of such sources are free of cost such as outdoor air, water from lakes and ground water. Return heat from buildings, sewage water and industrial waste heat are other examples (Granryd, 2012). Heat pumps (HP) use electricity to move heat from one space to another, making the cool space cooler and the warm space warmer. HP:s move heat, not generating it, which means they can supply up to 4 times the amount of energy that they consume. (U.S Department of Energy, 2012)

Cooling machines can be seen as reverse HP:s and follow a similar principle. The major mechanical components used are an evaporator positioned in the space intended to be cooled, a compressor with a motor and a condenser, where all the heat that is supplied to the evaporator and the energy supplied to power the compressor is released. (Nationalencyklopedin, 2012b)

### 3.3.4 Combined Generation of District Heating and Cooling through Heat Pumps

Figure 3.4 shows combined generation of DH and DC through the use of HP:s. The HP showed in the middle part of the figure has a cold evaporator side and a warm condenser side (as described in the previous section). The cold from the evaporator side is distributed to DC customers through a DC grid. It is possible for a cold storage to be used. The DC customers use the cold through a coil, which may be a plain cooling ceiling or a cooling baffle. The heat from the condenser side is distributed to DH customers through a DH grid. The same principle goes here, that heat storage can be used. DH customer uses the heat through a DH substation. The heat is used in radiators, for heating water to taps and eventually for preheating air. (Jonson, 1998) The efficiency of the system is high in a situation like this, when a system produces more than one energy product (Werner, 2012).

A problem with combined heat and cooling production is that the demand of cooling is at the highest level when the demand of heat is at the lowest level, during summer. If there is surplus heat from burning of household waste and industrial processes, HP:s will give an even larger amount of surplus heat. If heat from the condenser is not absorbed in a proper manner the HP will provide less cooling from the electricity it uses, compared to that of a situation where heat is absorbed in an appropriate way. (Jonson, 1998)
3.3.5 District Cooling Production

Corporate buildings and increase in the usage of electric appliances has led to an increase in the demand of comfort cooling (e.g. air conditioning) in commercial spaces, providing a balance to the excess heat the electronics generates. Refrigerate equipment’s have a broad variety of usage areas and associated costs. In many cases air equipment is only used for a number of weeks during temperature peaks in the summer. Refrigeration equipment may also be used the entire year to maintain the temperature for cold storage. (Berthammar, 2008). In most cases, the main concern is to keep room temperature at a comfortable level regardless of the outdoor temperature (Nilsson, 2001).

Buildings with office and commercial premises are common users of DC. The cold is distributed by circulating cold water (+5-7 °C) or as an ice mixture (0 °C) in buried pipelines. Slightly warmer water with a temperature normally between +14-16 °C is returned to a central cooling system with compressor or absorption chillers. (Werner, 2012) The slightly warmer water may also be cooled again through free-cooling, which is mentioned in section 3.3. (Fortum, 2012f)

For a customer, the principle of DC leads to low maintenance cost, low need of electricity, more usable facility space and relieves the responsibility connected to handling refrigerants. In addition to these benefits, the cooling capacity can easily be adapted to the cooling load. (Werner, 2012).

3.3.6 Compressor Chillers

Compressor chillers are similar to HP:s (earlier described in section 3.3.3) but instead with a focus on the cold side, the evaporator side. The working medium in compressor chillers is vaporized at a pressure that gives a evaporation temperature slightly below that of the district cooling’s desired temperature of supply. The heat for the vaporization is taken from the DC fluid and thereby cooling the DC fluid. The pressure of the working medium is then increased in the compressor. The condensed heat can then be applied to heat a DH network. This means a condensing temperature that is slightly above the district heating’s desired supply water temperature. The pressure of the working medium is lowered with the aid of a valve, which makes the condensation occurs at the right temperature. After this process the coolant starts a new cycle (Jonson, 1998).

3.3.7 Absorption Chillers

Conventional compression chillers are powered by electricity (SWEP, 2010). Absorption chillers primarily use high-temperature heat to generate cooling (Nationalencyklopedin, 2012a). They provide a high performance but at a premium cost (Rydstrand, et al., 2004).
There are different types of absorption chillers. They can be powered as single-effect indirect systems (using steam or water) or as double-effect direct systems (using gas and/or oil burner). Single effect systems have one single generator/concentrator while double-effect systems use two generators/concentrators.

An absorption chiller consists of a condenser, evaporator, absorber, a circulation pump and a generator. The process of cooling the water occurs in the evaporator and can be applied to a DC system. Here the coolant is evaporated at a low temperature and a very low pressure. The thermal energy for the evaporation is taken from the returning DC water. The vaporized coolant is moved to the absorber where it is immersed by a transport medium. The absorber is cooled externally by a so-called heat sink, for example a cooling tower, mentioned in section 3.4.2 Rejection of Surplus Heat through Cooling Towers. The solution is pumped to the generator where heating power is supplied from an external source. The coolant is evaporated and moves on to the condenser while the concentrated medium is returned to the absorber. A heat exchanger is placed between absorber and generator in order to reduce the heat consumption of the generator. A high concentration of the transport medium in the absorber increases the efficiency of the absorber. After the coolant has been condensed against an external heat sink it proceeds to the evaporator through an expansion valve, finally closing the circuit. (Rydstrand, et al., 2004)

3.3.8 Waste Management

Waste disposal is today a key service that some DH firms provide. Waste is considered as an excellent fuel for DH firms since it has a negative operating cost. DH firms receive earnings by the disposer for managing their waste (Nyström, et al., 2011). In cases where waste is a fuel for CHP plants, three positive aspects occur. Production of heat, production of electricity and waste incineration. This is beneficial for the energy system as a whole, because the energy in waste is captured (Avfall Sverige, 2012).

Barriers for waste incineration in CHP plants have been lowered in recent years. The tax connected to incineration of waste has been removed (Granström, 2011). Sweden has a leading technology within energy recovery from waste. This means Sweden has become an attractive destination for export of sorted waste. In Europe, around 150 million tons of waste is put into landfills every year. This has negative impact on the environment. Methane can be formed which is a greenhouse gas. Additional harms are chemical and hazardous residues, which can come into circulation in the environment. The energy for maritime transport is small in comparison to the energy that is recovered. Waste incineration is always a better alternative than putting waste into landfills, because poisonous organic substances are burned away and the contaminants that are not burned, for example heavy metals, are separated into several purification steps (Fortum, 2012c).

3.3.9 Use of Combined Heat and Power Plants is Politically Encouraged

CHP plants harmonize several of the requirements set by the European Commission’s for a sustainable energy policy. The energy policy includes saving energy, a reduction of the carbon dioxide emissions and a secure supply of energy. The strength with CHP plants is that it is a contemporary and established technology. Too much focus has been around technologies that lie too far ahead in the time. (EU Energy, 2007)

In year 2004 the European Union established a directive that promoted the use of CHP plants. The directive was implemented in year 2007 and intended to increase the use of CHP plants within the European Union. Members of the union are supposed to provide reports, which give detailed information around CHP plants in their country. The reports include information with what needs to be done in order to remove barriers for CHP plants and present how the country behaves in their energy market with CHP plants. (Claverton Energy Research Group, 2011)

In year 2013, the carbon dioxide tax for CHP plants will be removed further lowering the barriers for CHP plants (Axelsson, et al., 2012).
3.4 Rejection of Surplus Heat

Thermodynamic processes in different kind of plants may generate a varying amount of surplus heat. A rejection of the heat into water or sea and use of cooling towers are the most common ways to reject surplus heat. These methods are reliable and well established as they can lower the temperature close to that of the surroundings. However, these methods have a negative impact on the environment. Heat rejection into water can raise the temperature affecting the bio-equilibrium of the water and its living organisms. Cooling towers are an costly and use a lot of water through evaporative techniques. (Leffler, et al., 2012)

3.4.1 Rejection of Surplus Heat into Water

When water is available it is common that this is used as a heat sink. It can be the sea, a lake or some other kind of water stream. Depending on the local environmental conditions this can be an effective way to reject surplus heat. The ambient temperature and the radiation from the sun impact the effectiveness. If the temperature of the water is raised, the efficiency of the water as a heat sink is reduced. (Hayes, et al., 2012)

3.4.2 Rejection of Surplus Heat through Cooling Towers

A cooling tower is a tower or a construction looking like a building. A cooling tower uses circulating atmospheric air that is the receiver of the heat and it directly or indirectly connects with warm water, which is cooled. There are two basic types of cooling towers. The first type transfers heat from warmer water to cooler air by an evaporating heat transfer process (named evaporative or wet cooling tower) and the other transfers heat from warmer water to cooler air by a sensible heat transfer process (named non-evaporative or dry cooling tower). These two processes can be combined and used in parallel (mechanical) or separately. Evaporative cooling towers have the greatest thermal efficiency but use great amounts of water, while non-evaporative ones uses minimal amounts of water and therefore have less thermal efficiency. The mechanical combination of the two has a thermal efficiency between that of evaporative and non-evaporative towers. (Sebald, 2008)

In evaporative processes, the moisture content of the air that enters the cooling tower is lower than the saturation temperature. The cooling occurs as incoming air is saturated and the air temperature rises in the process of absorbing heat from the water. At the same time, there is a rise in its capacity for holding water, making the evaporation process continuing. This evaporative process accounts around 65–75% of the total heat transferred and the sensible heat transfer process transfers the remaining heat. (Sebald, 2008)

Non-evaporative processes separate warmer water from cooler air through the use of thin metal walls, usually in the form of circular tubes. Sensible heat transfer takes place through the walls of the tubes and the extended surface stimulates the heat transfer from the water, which is absorbed by the cooling air. The water temperature is reduced and the air temperature is increased. (Sebald, 2008) is the receiver of the heat and connects it directly or indirectly with warm water, which is cooled. There are two basic types of cooling towers. The first type transfers heat from warmer water to cooler air by an evaporating heat transfer process (named evaporative or wet cooling tower) and the other transfers heat from warmer water to cooler air by a sensible heat transfer process (named non-evaporative or dry cooling tower). These two processes can be combined and used in parallel (mechanical) or separately. Evaporative cooling towers have the greatest thermal efficiency but use great amounts of water, while non-evaporative ones uses minimal amounts of water and therefore have less thermal efficiency. The mechanical combination of the two has a thermal efficiency between that of evaporative and non-evaporative towers. (Sebald, 2008)

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3.5 The Nordic Electricity Market

This chapter will describe the Nordic electricity market and the way it works. This provides a macro perspective and how DHC fits into the large electricity scheme.

3.5.1 Svenska Kraftnät

Svenska Kraftnät (SVK) is a governmental owned company and is responsible to maintain and distribute electricity in Sweden. Electricity is transported from power plants through the national, regional and local grid to the consumers. These relationships are shown in Figure 3.5. The grid is monitored in order to maintain a balance between supply and demand. Svenska Kraftnät is supposed to contribute to an electricity market where participants can act in free competition. The market place which facilitates this is called Nord Pool. A power reserve is also provided to be able to produce electricity in emergency situations.

The parliament sets the framework for Svenska Kraftnät’s activities around investments and finance. The government communicates guidelines for the activities every year. Fees from the regional grid and large electricity producers finance the activities described above. (Svenska Kraftnät, 2012c)

Svenska Kraftnät is also responsible for the natural gas system in Sweden and the coordinating of the country’s hydro dam safety (Svenska Kraftnät, 2012c).
3.5.2 Nord Pool

Nord Pool runs a power market which includes the Nordic region, Estonia, Germany and Lithuania. 74% of the energy production in the Nordic region is traded here. The rest of the energy production is traded through bilateral contracts between suppliers, retailers and end consumers. The total energy traded during 2010 was 310 TWh. System operators are responsible for the high voltage grid (the transmission grid) and the security of supply. Statnett SF is operator in Norway, Svenska Kraftnät in Sweden, Fingrid in Finland, Energinet.dk in Denmark and Elering in Estonia. (Nord Pool, 2012a)

Elspot, the day-ahead market, is the main arena for electricity trading. Contracts are settled between seller and buyer for delivery the next day. A system price for every hour is determined. The price is set and the trades are settled. All the bids and offers are aggregated and the intersections of these two curves determine the system price, which can be seen in Figure 3.6. The system price is set with no consideration of the trading capacity between the countries. If the trading capacity is limited, area prices are calculated. (Nord Pool, 2012a)

![Figure 3.6 Aggregated bids and offers at Nord Pool. The intersection determines the system price (Nord Pool, 2012a).](image)

The intra-day market, Elbas, is a compliment to the day-ahead market in order to maintain the balance between supply and demand. (Nord Pool, 2012a) The system price from Elspot is used as a reference price in the intra-day market, Elbas. After each hour a revision takes places around what actually happened during the hour. The balance between supply and demand may have been interrupted and the economical aspect around this is handled. Unbalances leads to actions regarding regulations. (Svenska Kraftnät, 2010) These regulating actions are described in the next section 3.5.3. Incidents which interrupt the balance can be a problem in a nuclear power plant or weak winds that may cause a low production from wind turbine plants. The intra-day market is becoming increasingly important with more and more wind power plants in the grid. Wind power is unpredictable by its nature with its fluctuations in wind strength throughout a day. Imbalances between planned production and actual production often need to be offset. From 2006 to 2009 the total wind power installations in Europe increased by 36 % and reached 76 GW. (Nord Pool, 2012a)

3.5.3 Electricity Balancing

In order to maintain the electricity balance two types of regulations take place, a primary and a secondary. The primary regulation is automatic and the secondary regulation is done upon request from Svenska Kraftnät. (Svenska Kraftnät, 2012 a) How the economic aspects around the primary and secondary regulation are handled, is stated in detail in the contract regarding electricity balance, which is signed between the actor responsible for electricity balance and Svenska Kraftnät. Every point for selling electricity or buying in the Swedish electricity grid has to have an actor responsible for the electricity balance. If the actor not can do this by their own, this kind of service needs to be bought from someone else. (Svenska Kraftnät, 2010)
The primary regulation determines the unbalances the variation in the frequency. When the demand increases and the supply of electricity are constant, the frequency in the grid decreases. This change in frequency is registered and the plants that are a part of the primary regulation increase their production. This results in a raise of the frequency and the electricity system is stabilized. This type of regulation is done within seconds. Each plant has a specific capacity to handle the primary regulation. The primary regulation is done automatically. (Ghandhari, 2006)

Secondary regulation handles the unbalance in the electricity grid in a way, which takes more time. The time perspective is minutes. After stabilization through the primary regulation the frequency in the system has been changed and at the same time a part of the primary regulating capacity has been allocated. In order to release capacity in the primary regulation for coming unbalances the secondary regulation is used. The secondary regulation contributes to regulate the frequency back to its nominal value, after a regulation through the primary regulation. (Ghandhari, 2006) The secondary regulation needs to be commenced 30 seconds after the unbalance has occurred and fully regulated after 15 minutes. (TSOs in Denmark, Finland, Sweden and Norway, 2007)

### 3.5.4 Electricity Regions in Sweden

Electricity Regions were introduced in Sweden to let markets forces better control where produced electricity is used. Dansk Energi argued that the electricity export from Sweden was limited which earlier benefited domestic customers, working against a free market (Alpman, 2011)

The system with electricity regions indicates where in Sweden there is a need for additional electricity production to better meet the demand in a certain area. This leads to a reduction of the need to transfer electricity long distances. The borders between the regions are set in congested areas where the transfer capacity is limited. This means where bottlenecks exist. (Jäderberg, 2011) Bottlenecks occur when the market desires that more electricity than is physically possible needs to be transferred over certain areas. (Granström, et al., 2012)

In northern Sweden there is a surplus of electricity production compared to the consumption. In southern Sweden, it is the other way around. There is a shortage of electricity production compared to the consumption. During certain hours there is a high flow of electricity through Sweden and the transmission capacity is not always enough. The electricity regions in Sweden are seen in Figure 3.7. (Ibid.)

![Figure 3.7 Electricity regions in Sweden (Jäderberg, 2011).](image)
Svenska Kraftnät sets a maximum transmission capacity between the regions. This cannot be exceeded under any circumstance. This maximum transmission capacity can vary according to the configuration of the grid. Circuit lines can be intact or detached for service. When there is a risk that the transfer capacity will be exceeded different prices occur between the electricity regions. (Granström, et al., 2012)

A key activity for handling bottlenecks in the national electricity grid is counter trading during the real-time operation. The system responsible actor orders an increased or decreased level of consumption at one side of the congestion. At the same time an increased or decreased level of production at the other side of the congestion is ordered. This action ensures that the transmission through the congestion is lessened. The cost of this counter trading is covered by bottleneck revenues. The bottleneck revenue is the difference in price for consumers in a high priced region and consumers in a low priced region. This difference is multiplied with the volume of electricity being transferred between the regions. (Ibid.)

Svenska Kraftnät constructs the national grid following three long-term criteria. The first includes an accurate planning and construction of the grid. The second considers the day ahead planning of the grid and the third considers an effective real-time operation of the grid. (Ibid.)

### 3.5.5 Electricity Production and Withdrawal in each Electricity Region

Electricity regions were earlier described in section 3.5.4. This section describes the level of production and consumption of electricity in the different regions in Sweden. This provides a description behind the surplus and shortage of electricity in each region. Table 3.2 shows installed capacity in each bidding area. Hydro Power is frequent in the northern parts of Sweden while wind power and CHP plants together with DH is prevalent in the more populated south areas of Sweden. (Swedenergy, 2012)

<table>
<thead>
<tr>
<th>Installed capacity per bidding area [MW]</th>
<th>SE1</th>
<th>SE2</th>
<th>SE3</th>
<th>SE4</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro Power</td>
<td>5 255</td>
<td>8 015</td>
<td>2 587</td>
<td>341</td>
<td>16 197</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>9 363</td>
<td>9 363</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Power</td>
<td>198</td>
<td>487</td>
<td>1 294</td>
<td>920</td>
<td>2 899</td>
</tr>
<tr>
<td>CHP, DH system</td>
<td>160</td>
<td>260</td>
<td>2 244</td>
<td>887</td>
<td>3 551</td>
</tr>
<tr>
<td>CHP, Industry</td>
<td>122</td>
<td>260</td>
<td>522</td>
<td>335</td>
<td>1 240</td>
</tr>
<tr>
<td>Condensing Power</td>
<td></td>
<td></td>
<td>618</td>
<td>1 005</td>
<td>1 623</td>
</tr>
<tr>
<td>Gas Turbines</td>
<td></td>
<td></td>
<td>993</td>
<td>577</td>
<td>1 570</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>All</td>
<td>5 736</td>
<td>9 023</td>
<td>17 621</td>
<td>4 066</td>
<td>36 447</td>
</tr>
</tbody>
</table>

*Table 3.2 Installed capacity per bidding area in Sweden (Swedenergy, 2012).*

Table 3.3 shows the withdrawal of electricity is not proportional to how densely populated the bidding area is. There is a large electricity withdrawal from the industry in the north. The electricity use from the industry in SE1 and SE2 is about three times larger than that coming from residences of these two bidding areas. The columns displaying the percentages provide a good assessment around the difference between electricity production and electricity consumption in the bidding areas. The table shows that there is a surplus of electricity in the north region and a shortage of electricity in southern region of Sweden. (Thorstensson, 2012)
### Table 3.3 Withdrawal in the electricity regions, year 2007 (Thorstensson, 2012).

<table>
<thead>
<tr>
<th>Area</th>
<th>Total Residences</th>
<th>Industry Residences</th>
<th>Total</th>
<th>Industry</th>
<th>Residences</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1</td>
<td>186000</td>
<td>162000</td>
<td>-</td>
<td>5100</td>
<td>1600</td>
</tr>
<tr>
<td>SE2</td>
<td>437000</td>
<td>368000</td>
<td>-</td>
<td>9600</td>
<td>3200</td>
</tr>
<tr>
<td>SE3</td>
<td>3407000</td>
<td>2960000</td>
<td>-</td>
<td>32900</td>
<td>21300</td>
</tr>
<tr>
<td>SE4</td>
<td>1167000</td>
<td>985000</td>
<td>-</td>
<td>9000</td>
<td>7300</td>
</tr>
<tr>
<td>All</td>
<td>5197000</td>
<td>4470000</td>
<td>-</td>
<td>56700</td>
<td>33500</td>
</tr>
</tbody>
</table>

#### Percentage

<table>
<thead>
<tr>
<th>Area</th>
<th>Total</th>
<th>Industry</th>
<th>Residences</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1</td>
<td>4%</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td>SE2</td>
<td>8%</td>
<td>12%</td>
<td>17%</td>
</tr>
<tr>
<td>SE3</td>
<td>66%</td>
<td>63%</td>
<td>58%</td>
</tr>
<tr>
<td>SE4</td>
<td>22%</td>
<td>19%</td>
<td>16%</td>
</tr>
</tbody>
</table>

#### 3.5.6 Transmitting Electricity between the Electricity Regions in Sweden

A breakdown of the different bidding areas is given in order to provide a better explanation of the transfer capacity and thereby the scale of the bottlenecks.

Table 3.4 shows the difference between available production and consumption of electricity during a normal winter respective a 10-year winter representing an extremely cold winter. A 10 year winter results in a need for import. The table gives an indication of the amount assistance that a specific electricity region needs from another region. Certain bidding areas require export to others, while other require import from other regions. (Svenska Kraftnär, 2011)

### Table 3.4 Balance/need of net import for the electricity regions (Ibid.).

<table>
<thead>
<tr>
<th>Production and consumption [MWh\h]</th>
<th>Balance/need of net import [MWh/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Available production</td>
</tr>
<tr>
<td>SE1</td>
<td>4670</td>
</tr>
<tr>
<td>SE2</td>
<td>7188</td>
</tr>
<tr>
<td>SE3</td>
<td>13393</td>
</tr>
<tr>
<td>SE4</td>
<td>2525</td>
</tr>
<tr>
<td>All</td>
<td>27776</td>
</tr>
</tbody>
</table>
Table 3.5 shows the expected trade capacity between neighboring bidding areas during the winter in year 2011/2012 (Ibid.).

<table>
<thead>
<tr>
<th>From \ To</th>
<th>SE1</th>
<th>SE2</th>
<th>SE3</th>
<th>SE4</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1</td>
<td></td>
<td></td>
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Table 3.5 Maximum expected trade capacity from neighboring bidding areas. (Ibid.)

In order to better understand Table 3.5, Figure 3.8 is used as a visual aid. SE3 has few arrows and the level of transfer capacity is very large. This makes the risk for congestions and bottlenecks greater when alternative transfer routes are long and few. Comparatively the transfer capacity is much larger in Sweden than that of its neighboring countries. This makes the national electricity grid of Sweden more susceptible to changes compared to other surrounding countries. (Ibid.)

Figure 3.8 Detailed breakdown in trade capacity and bottlenecks within the different electricity regions in the Nordic electricity grid (Entso-E, 2011).
3.5.7 Electricity Certificates

Electricity certificates have been available since 2003 and are a financial support system for electricity producers. For each produced Megawatt-hour (MWh) of renewable electricity, the producer receives an electricity certificate from the state. The electricity producers can then in turn sell these electricity certificates on an open market where the price is determined between the buyer and seller. These electricity certificates thereby provide an additional income for renewable electricity production. Buyers are actors with a quota-obligation, usually this is an electricity supplier. (Swedish Energy Agency, 2012).

These actors are required to buy a certain share of electricity certificates relative to their sales of electricity or electricity usage. The size of the share is determined by a quotient. The quota is designed to create a demand of electricity certificates and renewable electricity each year until 2020. From 2002 to 2011, the renewable electricity production has increased by over 13 TWh, mainly though biomass power and wind power. 1500 new plants have been commissioned, most of which is wind power (Swedish Energy Agency, 2012).

If the quota-obliged is an electricity seller, the cost for buying the electricity certificates is debited the electricity consumer through the electricity bill. This means that it is the electricity customer that finances large parts of the electricity certificates. The amount that the customer is debited depends on the market price of the certificates and the quota of the present year. Since its inception in 2003, the price of electricity certificates has varied from 20 to 70 SEK for each MWh. (Swedish Energy Agency, 2012).

From January 2012, Sweden and Norway have a mutual electricity certificate market. Sweden has set an own target of 25 TWh of renewable electricity production for the year 2020. This means, that in order to achieve the Swedish target of 25 TWh in year 2020, an additional of 13.2 TWh of renewable energy is supposed to be produced, considering the level of renewable production Sweden has in year 2011. The mutual market makes it possible to trade with both Swedish and Norwegian certificates to meet the quota obligation. (Swedish Energy Agency, 2012).

Even though the market is common for both Sweden and Norway, each country has their respective national legislation governing the electricity certificate system. This means that there are some minor differences in the design of the electricity certificate system. (Swedish Energy Agency, 2012).

Actors that are subject to the electricity certificates quota requirement must submit an annual declaration to the Energy Agency. This declaration shows how many electricity certificates the actor need to buy. The electricity certificates are hold in an account, which is aimed for electricity certificates. Every year, 1st of April, the Energy Agency checks the balance of the account. Svenska Kraftnät performs a cancellation of the electricity certificates based on the submitted declarations. If there are electricity certificates missing in the account and the actors are unable to meet the quota requirement, they must pay a quota obligation fee. Actors with a quota obligation that have a surplus of electricity certificates can save them for next year’s needs or sell them. (Swedish Energy Agency, 2012)

Competition and technological development are long-term keys for reducing the cost of electricity generation from renewable sources. To achieve the goal of 25 TWh of renewable energy, the quota requirement will be raised until 2020 and at this point the electricity certificate system will have full effect.

The table in Attachment 3 shows the planned development of the quota-requirement until the final year in 2035. The table in Attachment 3 is visualized in Figure 3.9. The quota number indicates the share of electricity certificates that actors are required to buy relative to their sales of electricity or electricity usage. The figure indicates that there will be a slight decrease in the quota number in the next few years. The short-term reduction in the quota number is a way to stabilize the economic issues related to the supply/demand theory, which influences the price. A reduction of the excessive number of certificates that currently exists in the market is met by a reduction in the quota number. The quota will steadily increase from 2013 until as earlier mentioned 2020, when the forecasted goal of 25 TWh of renewable electricity production are supposed to be reached. In 2035, electricity certificates will no longer be available, this explains the reduction of the quota after 2020. (Swedish Energy Agency, 2011b).
Due to the financial subsidy the electricity certificates provide, it is important to look at what the future price of these certificates will be. The certificates have an influence on the electricity price, since a lower price than what was forecasted will result in less electricity production and thereby a higher electricity price for the consumer. The opposite will also be true, that a higher price on electricity certificates will stimulate more electricity production and in that way generate a lower price of electricity (Swedish Energy Agency, 2011a)
Figure 3.10 Total income over time for a electricity producer with a production which is warranted electricity certificates (Swedish Energy Agency, 2011b).

Figure 3.10 represents the future revenue structure for a producer with a production, which is warranted by electricity certificates. The figure represents different scenarios for the Swedish and Norwegian collaborative electricity certificate market. The base case scenario is based on the mutual level of ambition for Sweden and Norway regarding renewable energy sources, which is 26.4 TWh in the year 2020. The figure shows the future estimated changes in the revenue streams over the years, created by the changes in the electricity certificate system. There are four additional scenarios in the figure. The line named 7.5 TWh project refers to a scenario where the expansion of renewable energy sources is increased by additional 7.5 TWh, with reference from the base scenario. The line named 7,5 TWh certificates means the renewable energy sources are stimulated by a change in the quote number, 7,5 TWh more of the electricity production are involved in the electricity certificate system. The same principle applies to the other two scenarios with lines named 15 TWh. (Swedish Energy Agency, 2011b)

Figure 3.10 indicates that the electricity price will in a long-term perspective increase in all scenarios. For scenarios with a greater amount of additional expansion in renewable electricity, the electricity price will be lower than that of the base case scenario, since the amount of available electricity for these scenarios will be higher. However, the price of electricity certificates needs to stay high to be able to finance the additional expansion investments. (Swedish Energy Agency, 2011a)

Historical average quarterly prices of electricity certificates are found in Attachment 5. Buying and selling the electricity certificates can be done during the year, in order to have sufficient certificates in the account according to the declaration mentioned earlier. (Svenska Kraftnät, 2012b)

3.5.8 Wind Power Production and Spot Market Price of Electricity

In Denmark there are a relation between the spot market price and the electricity production from wind turbines. During periods of decreasing wind production the spot price increase. This is illustrated in Figure 3.11. The figure shows week 7 in 2007 in Denmark. On Monday afternoon, the wind production
decreased and the spot price increased close to the maximum of the week. This type of correlation can be seen on several times during the week.

![Diagram showing the correlation between normalized wind production and normalized spot price](image)

**Figure 3.11** The correlation between normalized wind production and normalized spot price (Blanke & Lund, 2007).

In 2006 the correlation between the spot price and the wind power production was in average around -0.30. This indicates that when the wind power production goes up and down the spot price takes the opposite direction. (Blanke & Lund, 2007)

### 3.6 Fees and Taxes

In Sweden, fees and taxes are charged in connection to the production of electricity and DH. A property tax is yearly obliged to the real estate where the production takes place. In year 2011, thermal power plants were charged a property tax between 1 and 5 SEK/MWh. Backup thermal power stations that are shutdown, are zero-taxed and do not pay property tax. Taxes and fees are also charged in connection to used fuels and emissions into the atmosphere. (Thorstensson, 2011) Below follows a more detailed description of taxes and fees in connection to production of electricity and DH.

#### 3.6.1 Carbon Dioxide and Energy Tax

Carbon dioxide and energy tax for electricity and heat production are distributed proportionally to the type of produced energy product. (Thorstensson, 2011).

Biofuels and peat used for DH production are not obliged to carbon dioxide or energy tax (Thorstensson, 2011). Fuels used for electricity production in CHP plants are not obliged to carbon dioxide or energy tax (Kylin, 2012).

Other fuels (not biofuels) connected to heat production, is benefited by a reduction of 85 % of the carbon dioxide tax for the year 2010 and 93 % for the year 2011. A full carbon dioxide tax level refers to 1.10 SEK/kg for the year 2011. The energy tax for fossil fuels (coal and oil) is 800 SEK/MWh. Industries has an energy tax 30 % lower than the general level. (Thorstensson, 2011) The Swedish government has in the spring proposition (for the year 2013) suggested to remove the carbon dioxide tax for all CHP plants. This means that CHP plants can compete on the same level as industrial cogeneration plants do (Svensk Fjärrvärme, 2012c).
3.6.2 Sulfur Tax

Emissions of sulfur lead to a tax of 30 SEK/kg. This is in situations where incineration of solid fuels takes place. For incineration of liquid fuels is the tax 27 SEK/m³ for every tenth percentage of the weight of sulfur in the fuel. The tax is not obliged if the sulfur content in the burned fuel is lower than 0.05 %. Sulfur concentrations between 0.05 to 0.2 % are approximated to a concentration of 0.2 % (Thorstensson, 2011).

3.6.3 Nitrogen Oxide Fee

The fee for mono-nitrogen oxides emissions is an efficient tool to lower the emissions of mono-nitrogen oxides from larger incineration plants. The mono-nitrogen oxide fee is obliged to incineration plants with boilers that produce more than 25 GWh/year. The fee is 50 SEK/kg and was introduced in 1992. (Thorstensson, 2011)

3.6.4 Carbon Credits

In year 2005, the European Union introduced a system with carbon credits. A certain volume of carbon credits gives the right to let a certain amount of carbon out in the atmosphere. Carbon credits are managed in a trading system. Since the introduction the price of carbon credits has varied between the initial price of 7 EUR/tonne to over 30 EUR/tonne. A rule of thumb can be used when considering the relationship between the carbon credit price and the spot price of electricity in the Nordic electricity market. The carbon credit price of 10 EUR/ton has resulted in an increase of the electricity price of 80 SEK/MWh. (Thorstensson, 2011)

3.7 Energy Systems using Variable Energy Sources

Hourly fluctuations in production patterns create a demand to efficiently plan the production from other units in order to avoid unbalances in the electricity system. The system reserves in Sweden have been increased to be able to handle deviations in the planned electricity generation. Considering the system mentioned above, it is important to evaluate if the generation capacity is available when it is needed. Every new electricity power generation unit, including that of renewable kind, contributes to an increase of total installed capacity. But a problem is to match the supply with the demand. (Widén, et al., 2010)

The term Capacity Credit has been coined to explain the ability of an electricity plant to generate energy during periods when the demand is high. In layman’s term it is defined as the amount of the conventional generation capacity that can be replaced by a certain amount of variable power, while still keeping the security of supply. (Giebel, 2005) Electricity generated from the sun has a low Capacity Credit. Especially in a high latitude country as Sweden where the solar insolation is relatively low. Generated electricity mismatches the peak loads during winter. In year 2010, energy from wind power had more than 1000 times higher production volume compared to the energy production from the sun. Wind power is more cost effective than solar power. (Widén, et al., 2010) Determining the Capacity Credit is primarily interesting for variable renewable energy sources. CHP plants are not directly included in this category. This implies that there is a lack of specific details regarding the Capacity Credit of CHP plants. (International Energy Agency, 2011)

No generator is available to produce energy 100 % of the time. This can depend on failures or a lack of the primary energy resource. A wind turbine does not work when there is no wind. (Hawkes & Leach, 2008) Wind power has a low correlation coefficient considering production and consumption. The correlation coefficient is 0.2. A correlation coefficient which equals to 1 means that the production is on the highest level when the demand is on the highest level. (Bollen, 2011) Electricity production from CHP plants is much more correlated with periods of high demand compared to wind and solar power (Bollen, 2011).
A study at Uppsala University (Widén, et al., 2010) has tried to show the future supply and demand of electricity in an energy system with a high amount of wind and solar power. He has studied two main cases beside the base case which represents the energy system of today. Diagrams showing the results are found in Attachment 1: Renewable Energy Systems. The electricity demand is showed in the diagram by the black solid staircase line and the production method is visualized as the area between two colored lines. The diagram representing case A shows the base case. Case B shows an increased production of electricity from solar and wind. The variable production is balanced with hydro power. This case is constructed in such a way that the increased electricity volumes are not compensated by a lower production. The excessive electricity from solar and wind are exported or used for heating. Case C shows an increased production of electricity from solar and wind, but this is compensated by a lower production in other units. The nuclear power is slowly phased-out. It is important to note that the diagrams in the attachment do not show the specific electricity demand coming from HPs.

3.8 Unleashing Capacity in the Electricity Grid

One way to respond to peak loads in the electricity grid is to increase the total installed power. Another way to respond to peak loads in the electricity grid is to release capacity. (Lovins, 1996). This possibility is already considered according to Svenska Kraftnät’s current way of handling the national electricity balance (Svenska Energii, 2012). This chapter describes how capacity can be released in the electricity grid.

3.8.1 Negawatts

Chairman Armory B. Lovins of the Rocky Mountain Institute, coined the phrase Negawatts. The expression symbolizes how power saved from one application can be released and become available for another application (Lovins, 1996). An example of Negawatt generation is showed through energy efficient light bulbs. The bulbs generate Negawatts when they use less energy compared to ordinary bulbs. This releases capacity, which becomes available for other applications.

Researchers believe that energy efficiency will have a big role in achieving the sustainability goals when tackling the global warming. Nicholas Stern devoted an entire chapter to energy efficiency in his paper around climate change for the British government (Stern, 2006). McKinsey Global Institute believe that energy efficiency could take the world halfway towards the goal of keeping a concentration of less than 550 parts per million in the atmosphere. McKinsey believes that energy-efficiency can be very profitable with existing technology. It is possible to achieve an average return of investment of 17 % (Farrell, et al., 2008).

Energy efficiency has not been implemented at a higher rate because of a series of market failures. The transitions costs are high as it is time-consuming to identify the best solution and get it installed. Therefore firms in the energy sector have focused more on generating additional incomes rather than cutting down the costs. (The Economist, 2008)

3.8.2 Disconnectable Electric Load

Disconnectable electric loads are objects that can be controlled and detached from the electricity grid. For example electric boilers (EB) or HPs. Through detachment the demand of electricity can be adjusted according to the prevailing market situation. (The demand of electricity is also affected by the price.) Ordinary consumption is not considered as disconnectable load even though it affects the withdrawal of power from the grid. Balance responsible actors are supposed to report to Svenska Kraftnät the part of the electricity load that is disconnectable. This is done in order to be able to analyze strained situations. (Svenska Energii, 2012)

Historically, EBs for steam and hot water production have been installed when the price of electricity has been low. Special contracts were signed with firms producing electricity. The contracts stated that EBs
can be detached from the electricity grid and be replaced by oil fueled boilers, when there is an increased power demand. Many of the installed EB:s are still left today and deployed depending on the relation between the oil- and electricity price. (Cronholm, et al., 2006)

If a grid owning actor has an agreement with an equipment owner that the equipment can be detached, this has to be reported as disconnectable load to Svenska Kraftnät. This also applies to another situation. An electricity trading firm or another balance responsible actor can have an agreement with an equipment owner, that equipment is detached when the spot price of electricity reaches a certain level. A prerequisite is that the load has an hourly metering of the consumption. (Svensk Energi, 2012).

3.9 More Intermittent Energy Resources Demands more Flexible Energy Systems

The night between 31 December 2006 and 1 January 2007 strong winds in Denmark resulted in serious problem. For the first time Energinet.dk, the electricity grid operator in Denmark, executed an emergency plan in order to avoid excess electricity production. The strong winds resulted in a production, which was 400 MW above the national demand and the export market. Initially the productions in large scale CHP plants were reduced according to the down-regulation bids in the market. Then small-scale CHP plants were requested to stop the production. The messages were sent to operators by SMS. After these two actions there were still excessive productions. This led to that Energinet.dk forced 200 MW of wind turbines to stand still for about 10 hours. A plan for situations like this, an excessive electricity production, where developed many years before but had not been executed before. This event shows that an energy system with more flexibility is required. (Blarke & Lund, 2007)

3.9.1 The Heat Immersion Law

In year 2009, Denmark launched a project aimed to purchase excessive electricity generated from wind power. This project lead to “The heat immersion law”, ensures that locally produced wind power are used in the home district instead of sold abroad at giveaway prices. This situation can occur during periods with a high wind power production and a low demand of electricity. Immersion heaters at DH plants are used to heat water in tanks. The heated water is used for DH. Electricity used under these situations is bought at Nord Pool at a price of € 200/MWh. (Vattenfall, 2009) (Sun and Wind Energy, 2009)

3.10 More Flexible Energy Systems

A situation like the one described in section 3.9, an excessive electricity production, shows that the demand of more flexible energy systems are increasing. This chapter will present some known theories and practical approaches around how the energy system can be developed for more flexibility.

3.10.1 Generation Perspective of Flexible Energy Systems

Blarke and Lund at Aalborg University, present theories how to deal with a high level of intermittent energy sources. Technical and economical researches show that combining wind power, CHP plants and large scale HPs is a feasible strategy. Blarke and Lund presents theories around energy systems. The results are underpinned by a mathematical coefficient related to the electricity supply and demand. The findings results in a discussion around future generations of renewable energy systems, where large scale HPs are integrated with CHP plants. These new generations of renewable energy systems will be showed and explained below. (Blarke & Lund, 2007)

A pre-sustainability energy system is characterized by a separation of the fuel-based production of heat and electricity. The first generation (1G) of renewable energy system is characterized by intermittent resources and a combined generation of heat and electricity. This kind of energy system is shown in Figure 3.12.
In a 1G system, intermittent sources and CHP sources are initially identified with a small capacity factor. This means that the available capacity the operator has to balance the system with intermittent sources and CHP plants is very limited or zero. Grid authorities are well prepared to handle the balancing issue and usually no practical problem occurs when the previous mentioned capacity is low. The fundamental problem in a 1G system is that the wind production and CHP production is not synchronized with the electricity demand and the other way around. (Blarke & Lund, 2007)

By integrating bridging technologies between the energy carriers (the electricity and DHC grids) more flexibility is created and a possibility adapting the system to the current situation. An EB create a simple relocation of electricity to heat and an electric-driven compression HP can create relocation from electricity to both heat and cooling. (Mathiesen & Lund, 2005) The system in Figure 3.12 extended with bridging technologies, is shown in Figure 3.13. A new category of components, relocation components is introduced. This kind of system is named the second generation (2G) of renewable energy system. In situations where the production of intermittent energy (wind turbines) is high, the electricity price on the spot market drops. This is described in section 3.5.8.

During these periods of low spot prices on the electricity market, the production from CHP plants are replaced with production of heat and/or cooling with HP:s. Storing this heat can be a possibility.

In situations where the intermittent electricity production is on a medium level, CHP plants and HP:s can run at the same time. In situations where the intermittent energy production is low and the electricity price in the spot market rise, CHP plants are optimized to produce as much electricity as possible and HP:s are not used. This means the production of heat will decrease but may be compensated by heat from a thermal storage. A challenge in the system is to maintain a high efficiency of conversion between the energy carriers. The system is showed in Figure 3.13. (Blarke & Lund, 2007)
The energy system can be constructed even more flexible if the demand of mobility is integrated. Fuels storages are introduced which improves the possibility to use fuel where it is most needed. Electricity storages also improve the flexibility. In connection to in CHP plants, more generation options in terms of generation of secondary fuels are introduced. These fuels can be hydrogen or ethanol from primary fuels, mainly electricity or waste. This means the CHP plants will be a kind of quad generation plant. (Blarke & Lund, 2007)

3.10.2 New Project for Storing Renewable Energy

A unique project has been launched in Hamburg. The project creates a possibility to feed heat from renewable energy sources into the public DH grid. The project makes is possible for private house owners who generate heat though solar-thermal systems, to feed heat into the DH grid, owned by E. ON Hanse Wärme. A customer feeding heat into the grid continues to own it. Heat from the summer months can be withdrawn during colder periods.
During this condition customers do not need to buy their own storage units and the complex devices needed to control the storage units. In order to support the project, an existing storage system of 4000 m\(^3\) in the Hamburg district was converted into a multi-functional storage system and integrated into E. ON:s DH system. (E.ON, 2011)

### 3.11 Fortum Heat Scandinavia

This chapter presents information from Fortum Heat Scandinavia. Most of the information is collected from interviews.

#### 3.11.1 Planning the Heat and Electricity Production

Fortum Heat is mainly a DH and DC firm. This means that the production of electricity is a secondary planning issue. The production plan is determined with respect to the demand of heat. (Blomgren, 2012) Heat is generated in CHP plants, mentioned in section 3.3.2, or in heat water centrals (HOB:s). The heat production is optimized according to the current situation. Fortum Heat has several CHP plants and HOB:s located at different positions in the DH grid. (Fortum, 2012e) The demand of heat is estimated with respect to weather forecasts. An algorithm with parameters for temperature, wind and how much clouds there are in the sky are used to estimate the demand of heat. The historical demand of heat the last 3 years is also considered. A production plan is built with respect to current prices of the fuels, which are used in the plants. Used fuels are coal, olive stones, waste, wooden chips and pellet. There are also HP:s and EB:s where the production cost is tied to the electricity price. When the production plan is determined, the planning with HP:s and EB:s are done with estimated electricity prices on the spot market. Electricity needed for the production is bought on the spot market and electricity produced in CHP plants is sold on the spot market. (Blomgren, 2012)

#### 3.11.2 Buying and Selling in the Electricity Market

Electricity produced in CHP plants is sold on the electricity market. Electricity needed for the HP:s for producing DH or DC is bought on the electricity market. This means there is no direct physical connection within Fortum Heat between the electricity production (from CHP plants) and the electricity consumption (HP:s or EB:s). If the production equals the consumption, a financial transaction in the electricity market is always included. Any kind of internal paring regarding Fortum Heats production and consumption does not take place. (Sundlöf, 2012) The buying and selling in the electricity market is done in line with the description of the electricity market in section 3.5.2, bids regarding the production and consumption are placed. The volumes of the bids are calculated with respect to the heat demand. (Sundlöf, 2012)

Fortum Heat is considered as an actor responsible for electricity balance. How the national electricity balance is maintained is described in section 3.5.3. Fortum Heat does not have a direct contract regarding this towards Svenska Kraftnät. This contract is hold by Fortum Generation, the part of Fortum that handles the businesses around electricity. Fortum Generation act towards Fortum Heat as they were holding the contract for electricity balance against Svenska Kraftnät. Most of the electricity produced by Fortum Heat, around 90 – 95 %, is sold in the Nord Pool Spot market. Selling a bigger part of the produced electricity to the (intra-day) Elbas market, described in section 3.5.2, means a higher risk compared selling in the (day-ahead) spot market. This risk is connected to the variations in the Elbas market, regarding volume and price. (Sundlöf, 2012)

#### 3.11.3 Plants and Production

Figure 3.15 shows the plants in the south and central part of the DH system. There are two types of plants. CHP plants and HOB:s for producing just hot water for DH. To the right in the figure, a list of the plants and fuels are presented.
The diagram in the figure shows how many hours of the years each plant is used. The x-axis presents the hours of a year. The y-axis shows the total power and the diagram is vertically segmented according to the power of each plant. (Fortum, 2012e)

Figure 3.15 Plants in the south and central parts of the DH system at Fortum Heat. (Fortum, 2012e)

Figure 3.16 shows the plants in the west part of the DH system. The principle in the diagram is the same as the one explained for Figure 3.15 above.

Figure 3.16 Plants in the west part of the DH system at Fortum Heat.

A more detailed description of the plants in Figure 3.15 and Figure 3.16 are found in Attachment 2: Plants. The attachment shows the installed power of the CHP plants, HOBs and HPs. (Fortum, 2012e)

3.11.4 Combined Heat and Power Plants at Fortum Heat Scandinavia

Figure 3.17 below shows the principal of a CHP plant at Fortum Heat. Fuels are burned and steam is produced in the boiler. The stated power of a CHP plant is the capacity of producing steam. The steam can be used in two ways. It can be sent directly to a condenser for producing DH, way 1 in the figure. The most common way is sending the steam to a turbine for producing electricity and after this to a condenser for producing DH, way 2 in the figure, like the description around CHP plants in section 3.3.2.
This way of using the steam gives the system a high efficiency. Attachment 2: Plants, show Fortum Heats CHP plants. (Kylin, 2012)

3.11.5 Värtaverket and CHP plant KVV6 (CHP Plant 6)

Värtaverket’s CHP plant KVV6 uses coal and biofuels to generate DH and electricity. In a normal year KVV6 supplies about 50 % of the total heat at Värtaverket. (Fortum Heat AB, 2010) The fuel mixture is currently 87 % coal and 13 % biofuel, olive stones. Fortum Heat has done research on raising the part of olive stones to 32 %. This corresponds to a production of 13 MWh electricity and 26 MWh heat. This covers the demand for 10 000 normal houses. (Fortum, 2011a)

It is currently invested in expanded storages to introduce a higher part of olive stones in the fuel, between 25 – 35 %. This will make KVV6 to one of Sweden’s largest bio-boilers (Ytterberg, 2012). The aim is to raise the part of biofuels to 50 %. KVV6 uses a heat gas condenser which extracts heat from the chimney gas that emerges during incineration. Depending on the fuel, the chimney gases contain different amounts of vapor. Through a cooling of the chimney gases to a lower temperature than the dew point, the gases will condensate and condensation heat is released. This heat is used for DH. (Fortum Heat AB, 2010)

CHP plant KVV6 is supposed to run at full power from the middle of October until to the middle of May. If KVV6 not has been run in this way, it depends on different kinds of unavailability. (Larsson, 2012)

3.11.6 Variable Production Cost for the Combined Heat and Power Plant KVV6 (CHP Plant 6)

The variable production cost of heat, \( VPC \), with CHP plant KVV6 (see Attachment 1: Plants), can be calculated with Equation 3.1 below. The equation has three terms. The first term \( PC_{heat} \) is related to the production cost of heat. The second term \( PC_{electricity} \) is related to the production cost of electricity. The last term \( E \) is related to the revenues from produced electricity. The revenues from produced electricity in the CHP plant is regarded as cost reducing and is thereby deducted from the variable production cost. (Franzén, 2012)

\[
VPC = PC_{heat} + PC_{electricity} * \alpha - E * \alpha \quad \text{[SEK/MWh]}
\]

\( \alpha = \frac{P_{electricity}}{P_{heat}} \)

Equation 3.2: Electricity-to-heat ratio (Zetterqvist, 2012).

\( \alpha \) is a proportion between the power of electricity and power of heat in the CHP plant. (Zetterqvist, 2012)

\[
\text{Equation 3.2: Electricity-to-heat ratio (Zetterqvist, 2012).}
\]

-43-
The three equations below present the components in the three terms which shown in Equation 3.1.

The production cost of heat, \( PC_{\text{heat}} \), is described in Equation 3.3. \( P_{\text{coal}} \) is the coal price. \( CC \) is the carbon credit price. \( CT \) is the carbon tax. \( ET \) is the energy tax. \( ST \) is the sulfur tax. \( P_{\text{olives}} \) is the price of olive stones. \( OM_{\text{heat}} \) is the cost of operation and maintenance related to heat production. NOX is the mono-nitrogen tax. \( \beta \) is the part of coal in the fuel. \( n_{\text{heat}} \) is the efficiency of the plant for heat production. (Franzén, 2012)

\[
PC_{\text{heat}} = \frac{(P_{\text{coal}}+CC+CT+ET+ST) \times \beta + P_{\text{olives}} \times (1-\beta)}{n_{\text{heat}}} + OM_{\text{heat}} + NOX \quad \text{[SEK/MWh]}
\]

*Equation 3.3: Production cost of heat (Franzén, 2012).*

The production cost of electricity, \( PC_{\text{electricity}} \), is described in Equation 3.4. \( OM_{\text{electricity}} \) is the cost of operation and maintenance related to electricity production. \( n_{\text{electricity}} \) is the efficiency of the plant for electricity production. (Franzén, 2012)

\[
PC_{\text{electricity}} = \frac{(P_{\text{coal}}+CC+ST) \times \beta + P_{\text{olives}} \times (1-\beta)}{n_{\text{electricity}}} + OM_{\text{electricity}} + NOX \quad \text{[SEK/MWh]}
\]

*Equation 3.4: Production cost of electricity (Franzén, 2012).*

The taxes and fees in Equation 3.3 and Equation 3.4 are presented in the section 3.6. The part of olive stones in the fuel is presented in section 3.11.5. The operating and maintenance cost for heat and electricity production refers to costs that are related to the actual production. Costs such as waste and ash management, no cost such as service is included. (Franzén, 2012)

Revenues from produced electricity, \( E \), is described in Equation 3.5. \( E_{\text{price}} \) is the electricity price. \( E_{\text{electricity certificate}} \) is the price of electricity certificates. \( E_{\text{grid}} \) is a revenue from the electricity grid owner. (Franzén, 2012)

\[
E = E_{\text{price}} + E_{\text{electricity certificate}} \times (1-\beta) + E_{\text{grid}} \quad \text{[SEK/MWh]}
\]

*Equation 3.5: Revenues from produced electricity (Franzén, 2012).*

Electricity certificates are described in section 3.5.7. The revenue from the electricity grid owner is obtained due to a local production of electricity. Local produced electricity decreases the losses in the electricity grid for the grid owner and this leads to an economic compensation. (Zetterqvist, 2012)

Attachment 5 presents the price components, which are used in the equations in this section. Price components for fuels, taxes, fees and other above presented components are presented. Attachment 4 presents quarterly historical prices of electricity certificates.

### 3.11.7 Current and Future Production Plans

Figure 3.18 to Figure 3.20 shows production plans. Plants and used fuels are seen to the right in the figures. Figure 3.18 shows the current production plan. The system is characterized by a high level of HP:s, bio-oils, and fossil based CHP plants. The usage of coal has begun to decrease due to a use of olive stones in one of the CHP plants in Värtan, which earlier only used coal as fuel. (Ytterberg, 2012)
Figure 3.18 Current production plan at Fortum Heat (Ytterberg, 2012).

Figure 3.19 shows the production plan according to the production plan for year 2016. The plan involves a larger part of CHP plants in the production. The new CHP production is based on recycled and renewable fuels. This displaces use of coal, HP:s and bio-oils. A big part of the load is still covered by coal, bio-fuels and HP:s. (Ytterberg, 2012)

Figure 3.19 Production plan according to the plan for year 2016 at Fortum Heat (Ytterberg, 2012).
Figure 3.20 shows the production plan according to the plan after year 2020. This plan can be considered as a goal for the development after year 2020. Analyses around economic aspects and risks as a function of prognoses of fuel prices and available assets have led to this plan. A new CHP plant will be built, Värtan KVV8. Environmental permit was acquired in year 2008 for this plant. Decision regarding the investment is supposed to be taken under year 2012. The CHP plant is planned to be in operation in year 2015. The estimated total power is 380 MW and the fuel is bio fuel related to wood. (Ytterberg, 2012)

![Graph showing production plan according to the plan after 2020 at Fortum Heat (Ytterberg, 2012).](image1)

### 3.11.8 Current and Future Energy Demand of Buildings

According to the construction prescription in Sweden (Boverkets byggregler BBR19), houses built year 2015 have an energy demand for heating of 50 kWh/m² and year respectively an energy demand for hot water of 25 kWh/m² and year. This means a total energy demand of 75 kWh/m² and year. The heat demand over the hours of a year is shown in Figure 3.21. (Johansson, 2012)

![Graph showing heat demand over the hours of a year for houses built according to Boverkets byggregler BBR19 (Johansson, 2012).](image2)
Stockholm Royal Seaport around year 2015 is supposed to have an energy demand for heating of 15 kWh/m² and year respectively an energy demand for hot water demand of 25 kWh/m² and year. This means a total energy demand of 40 kWh/m² and year. The forecasted heat demand for houses built in Sweden around year 2030 is the same as for the houses mentioned above in Stockholm Royal Seaport, 40 kWh/m² and year. The heat demand over the hours of a year is shown in Figure 3.22.

Buildings in Stockholm Royal Seaport around year 2030 are estimated to not demand any energy for heating, only for hot water, estimated to 20 kWh/m² and year (Johansson, 2012).

3.11.9 District Cooling at Fortum Heat Scandinavia

Cold water from a lake or the sea can be used to generate DC. When DC is generated in this way, it is known as free cooling, which is mentioned in section 3.3. Fortum Heat exploits seawater from Värtan to generate free cooling. When the temperature of the water is too high to cool the fluid in the DC network cooling machines are used. The usage of cooling machines results in a need to reject surplus heat. Surplus heat is generated from the condensers of the cooling machines. (Dahlberg, 2012a)

Fortum Heat does not currently use absorptions chillers. Absorption chillers are described in section 3.3.7. According to investigations and economic calculations, it is currently not economically motivated with absorptions chillers. Too short of run time combined with to low amount of surplus heat are limiting factors to the use of this method for cooling. (Hill, 2009)

DC is distributed through the DC grid. Expanding this grid is tied to high costs and the process often takes long time. Expanding the DC grid involves burrowing in order to place pipes in the ground. Before it is possible to dig, all actors around the area need to be considered. This can slow down the expanding process of the DC grid. The same principle is correct regarding an expansion of the DH grid. (Zetterqvist, 2012)
3.11.10 Rejection of Surplus Heat

Fortum Heat has the possibility to reject surplus heat within its facilities. Another way of expressing surplus heat rejection is through condensing possibilities. In connection to the plants in Hässelby, the condensing possibility is 60 MWh/h. With close relation to the plants in Högudalen, the condensing possibility is 15 – 20 MWh/h. In connection to the plants in Hammarby, the condensing possibility is 20 – 25 MWh/h. (Kylin, 2012)

In connection to CHP plant KVV1, Värtan, the condensing possibilities are very big, compared to what is described above. In order to reject heat into water, an appropriate water-right judgment is required. Such a judgment is valid for rejecting heat into the water in connection to CHP plant KVV1. A part of this judgment is shown in Attachment 6. This judgment was obtained in year 1996 when the electricity market in Sweden was deregulated. (Ramström, 2012) The CHP plant KVV1 is currently not used many hours of the year depending on the high operating cost. (Mellström, 2012) This is seen in section 3.11.3 and Figure 3.15.

The 2 pages of the water-judgment in Attachment 6 describe under which conditions condensing is allowed. It states that a water flow of 4,5 m$^3$/second and a temperature raise of 15,5 ºC is allowed. In addition to this, water used for regenerating the ion exchange filter needs to be neutralized. This means maintaining a pH value between 6 and 8. (Ramström, 2012) An ion exchange filter prevents fragments of metals from the cooling water coming out in the sea (Enskog Broman, 2012).

In order to use the condensing possibility mentioned above, flow and temperature need to be logged. This is not done today. (Ramström, 2012)

3.11.11 Environmental Concerns

Fortum Heat has rigorous systems for measuring and reducing their impact on the environment. In connection to the generation of heat, electricity and cooling, several purification systems are involved. The systems involve filtering, separation, burning or reverse osmosis. Equipment has been installed that detects leakage of harmful substances into the water or the air. (Fortum, 2011b)

The Swedish government has set environmental quality norms. These indicate pollution or noise levels that people can be exposed to without danger. The pollution level in the air is measured at several places in Stockholm. There are many places in the inner city of Stockholm, which have exceeded the accepted pollution levels. The traffic has contributed to this. The environment around Värtaverket follows the environmental quality norms, which are set by the Swedish government. (ÅF, 2006)

The inner archipelago of Stockholm, Lilla Värtan, located between Stockholm, Lidingö and Nacka Strand, is highly exploited. It is affected by traffic on the water and land based activities. The quality of the water is influenced by the infusion of water from the lake Mälaren. Fishing takes place in the archipelago. Mostly sport fishing. Stockholm Water regularly performs research on the bottom fauna and the state of the water. The studies show a high degree of undisturbed water environments and a large improvement over the previous last decades. (ÅF, 2006)

During periods of normal operation at Fortum Heat, the increase of the water temperature in the archipelago that occurs from the usage of free cooling, is considered as negligible since water is such a large energy carrier. During shorter periods of time when CHP plant(s) is run in condensation mode (electricity production), a heating of the water surface temperature occurs. The water surface temperature is increased approximately 4 ºC and this increase occurs approximately 40 cm from the surface. (ÅF, 2006)

During condensation of chimney gases in CHP plant KVV6, wastewater known as precipitate emerges. The precipitate is processed in several steps. The initial step involves separation processes. After the separation process, a filtering takes place. The final step uses chemicals and ionization to purify the precipitate, after which it can be diverted into the coolant water passage and then finally let out in the archipelago, Lilla Värtan. The condensation of chimney gases is beneficial because it reduces the amount
of hydrochloric acids, dust and sulfur in the chimney gases, which is let out in the atmosphere. It also increases the efficiency, meaning that more energy can be exploited from fuels (Fortum, 2011b).

Emissions in the form of heavy metals are emerged when plants in Värtan are operated. Only one of the generated heavy metals, mercury, is embraced with emission limits. CHP plant KVV6 is annually not allowed to let out more than 8 kg mercury through the chimney gases. During year 2010, a year that relied heavily on fossil fuels, as a result of the cold weather and subsequent shortage of bio-oils, Värtaverket let 5.2 kg of mercury out. This is far below the limit and this value is before the chimney gas condensation, which decreases the amount of mercury which leaves the chimneys. (Fortum, 2011b)

3.11.12 Disconnectable Electric Load

Classification of immersion heaters as disconnectable electric load started in the 70s. This means that the heaters can be disconnected from the electricity grid. Fortum Heat has approximately 320 withdrawal points in the electricity grid. Around 20 of these points are interesting considering a classification as a disconnectable load. Electric loads that are not interruptible (not disconnectable) are named prime loads. The prime load has a prime rate related to an uninterruptable connection to the electricity grid. If a load is interruptible (disconnectable) the rate disappears or is near zero. A number of immersions heaters are used for preheating HP:s and these are classified as disconnectable load. Hässelby has a number of such immersion heaters. The operating cost for producing steam with immersion heaters is lower than using oil. (Zetterqvist, 2012)

It is important to optimize the size and classification of the grid connections as uninterruptable or interruptible. This is done in order to minimize the rate for the grid connection and the cost for Fortum Heat. When optimizing in the way mentioned above, the risk of disconnection of the electric load is considered. Svenska Kraftnät needs to warn the actor before they disconnect the load. (Zetterqvist, 2012)

The annual cost for Fortum Heat related to the connection to the electricity grid is approximately 70 million SEK. The revenue stream for Fortum Heat related to the electricity production and the grid is approximately 50 million SEK. This means the connections to electricity grid create an annual cost of 20 million SEK. An earlier suggestion, which meant reporting a bigger part of the immersion heaters as disconnectable load, would have reduced the earlier mentioned cost with approximately 4 million SEK. Doing in this way was considered to involve too much risk, when it comes to securing the delivery of the services. (Zetterqvist, 2012)

3.11.13 Pricing Policy and Principals for District Heating at Fortum Heat Scandinavia

At the same time as the Swedish electricity market was deregulated, the municipal principle of setting the price with respect to the production cost was stopped. The law (38 § fjärrvärmelagen (SFS 2008:263)), dictates that municipal firms within the DHC industry should have a commercial direction. This principle includes private DHC firms. The Swedish law of competition also controls the conditions in situations where a supplier has a dominating position, which could be the case on local markets where the DH grid is fully extended. (Fortum, 2009)

All decisions regarding the price, the allocation between fixed and variable costs or decisions regarding other price issues are balanced between external requirement/desires and internal requirements/desires. This means that the decisions are balancing between the outside-in and inside-out perspective. (Fortum, 2009)

The outside-in perspective includes the customer and the competitors. Regular customer contact gives information about the desire of the customer. Each available option for heating or cooling for each customer creates a competition situation, which Fortum needs to consider. The inside-out perspective includes the owners and the daily operations. The income must give the owner revenues and a risk level
according to their goals. The price must cover the costs for daily operations, improvements, risk management and administration. (Fortum, 2009)

To balance between the two mentioned perspectives mentioned above, the price is set according to three principles; the principle of alternatives, the principle of equal treatment and the principle of openness. (Fortum, 2009) The principles are described below.

The principle of alternatives – The price is set according to the costs of the alternatives. The alternatives for all kinds of customers, small private buildings to big real estate complexes, are annually revised. Technical performance, capital costs and variable prices are considered.

The principle of equal treatment – Customers of the same type are offered the same price.

The principle of openness – The way of setting the prices are done in an open and transparent way.

More detailed information about the price components for DH and DC is found in section 3.2. Fortum Heat has different price lists for different customer segments (Fortum, 2012a). The price components for the different customer segments are also described in section 0.

3.11.14 Pricing Principle for District Cooling at Fortum Heat Scandinavia

As a few but larger customers with a high demand of cooling primarily use DC, some actors have chosen to set the price by individual contracts. (Folkesson, 2009) Fortum sets the price of DC in this way. This way of setting the price is beneficial because it satisfies the need of every specific individual customer. (Dahlberg, 2012a) Other actors have general price models, which mean the same price level for all customers. Mälarenergi and Norrenergi set the price in this way. (Folkesson, 2009)

3.12 Business Model Generation by Alexander Osterwalder

Osterwalder has written a handbook directed to visionaries, game changers and challengers. The handbook is meant to be used as a guide to challenge business models and design tomorrow’s enterprises. (Osterwalder, 2010)

“Today countless innovative business models are emerging. Entirely new industries are forming as old ones crumble. Upstarts are challenging the old guard, some of whom are struggling feverishly to reinvent themselves. How do you imagine your organization’s business model might look two, five, or ten years from now? Will you be among the dominant players? Will you face competitors brandishing formidable new business models?” (Osterwalder, 2010)

Osterwalder has a number of angles and ways which can be considered as tools, which can be used in different situations in order to discussion and develop new business models. (Osterwalder, 2010) The handbook consists of the chapters visualized in Figure 3.23. The first chapter, introducing the canvas, which is the central foundation of the handbook, is described in the next section 3.12.1. After this section, a briefer summary of the following chapters in the handbook follows in section 3.12.2. The structure and chapters of the handbook is shown in Figure 3.23.
3.12.1 Canvas

The foundation of Osterwalder’s handbook in business model generation, the canvas, consists of nine areas. These areas are used for analyzes in different aspects and angles. The canvas and the nine areas are visualized in Figure 3.24.

The following list numbered from 1 to 9, according to Figure 3.24 above, explains the different parts of the canvas (Osterwalder, 2010).

1. **Value Propositions (VP)** – The offer that solves customer problems and satisfy customer needs.

2. **Customer Segments (CS)** – The segments of customers the organization serves. In order to serve the customers in best possible way, they are segmented. Different segments can be served through different channels (see below).

3. **Key Partnership (KP)** – The network of suppliers and partners that make the business model work. A distinction can be made between different types of partnership; strategic alliances between non-competitors, strategic partnership between competitors, joint ventures to develop new businesses or buyer-supplier relationship aimed to assure reliable supplies.
6 **Customers Relationship (CR)** – A relationship is established and maintained with each customer segment. The customer relationship can take place through automatic services or self-services where customers help themselves.

7 **Channels (CH)** – The value proposition are offered to the customer through communication, distribution and sales channels. Direct channels can be a sales force/Internet and indirect channels can be found through partners.

8 **Key Resources (KR)** – The most important assets which are required making the business model working.

9 **Key Activities (KA)** – The most important activities in the organization required to make the business model working. In a software company, this can be the development of new software.

4 **Revenue Streams (RS)** – Revenue streams from the value offer to the customer. The revenue streams come from a one-time transaction, recurring revenues from ongoing payment to deliver the VP or streams connected to after-purchase support. A variety of price mechanism can be used; fixed price lists, prices set according to the volume or market dependent price mechanisms.

5 **Cost Structure (CS)** – The structure of the business model, results in a cost structure. With respect to the KP, KR and KA these can be calculated relatively easily. Costs structures have different characteristics. Fixed costs remains at the same level independently of the volume produced. Variable costs are connected to the volume of goods or service which is sold. Economies of scale occur when a bigger industry benefits from lower bulk purchase rates. Economies of scope occur when a company can benefit from several operations.

### 3.12.2 Some of the Main Concepts

Osterwalder introduced his handbook with the aid of seven perspectives regarding business model generation. One perspective is the entrepreneurial angle. This angle addresses unsatisfied customer needs and is building new business models around them. Another perspective is the entrepreneur, in which the latest technological development is exploited with the right business model. (Osterwalder, 2010)

Known patterns around leading business thinkers are presented. One known business pattern is where the business model is built up from more than one canvas. More than one canvas means that two or more distinct but interdependent customers groups are brought together. The value for the customers groups is created when both groups exist at the same time. Another pattern of a business model is where one segment of customers is financed by another part in the business model. (Osterwalder, 2010)

The designing of a business model can be based on a view where the insights of the customer are used. An example of this is Apple’s insight that people are not interested primarily in a music player. A solution where it is possible to search, find and download music is of higher value. Customers are more willing to pay for that kind of solution compared to a music player per se. Another way of designing a model is when a certain scenario is considered. A future scenario including an understanding of how products or services are used. It can be connected to the insights of the customer as described above. Another way of using future scenarios is to understand in which environments a model will compete. Not based on a prediction of the future, more an understanding of concrete details in the future. (Osterwalder, 2010)

The strategy section of the handbook deals with the developing of a strategy with respect to the canvas. This includes evaluating the business model environment. Different aspects in the environment that influences different areas of the canvas are analyzed. This can also be done in the opposite direction, external forces are analyzed in an inside out perspective. The strategy section also includes analyzing how a change in one part of the model impacts other components and how to deal with multiple business models. (Osterwalder, 2010)
The process section of the handbook helps identifying different phases to make the development of business models structured. The last chapter, the outlook section, extends the building of business models to additional situations, exemplified with non-profit business models. (Osterwalder, 2010)

### 3.12.3 Triple Bottom Line

Triple bottom line (3BL), aims to highlight three ways for a company to conceptualize and measure its performance. The expression was coined by John Elkington and is referring to three pillars, economic prosperity (profit), environmental quality (planet) and social justice (people). The purpose is to show that the effectiveness of a company cannot be judged only through financial performance. (Orlitzky & Erakovic, 2007) Today it forms the framework for the reporting of business performance by the Global Reporting Initiative and is commonly used by multinational companies. The concept includes a variety of different stakeholders. Stakeholders with an interest in socially responsible investing. Employees that strive to work for a company with excellent performance across all three dimension. Customers that wish to purchase from companies that they identify as having social environmental conscience. (Vann, 2007).

One of the problems of the triple bottom line is that the separate dimensions cannot easily be summed together. It is difficult to quantify planet and people in the same terms as profit, because profit is generally associated in monetary terms. This can be exemplified with the full-cost of an oil-tanker spillage. It is almost an impossible task to identify all associated costs. (The Economist, 2009) Quantitative measures increases the transparency for managers, shareholders and other stakeholders regarding ethical business practice and social responsibility (Norman & MacDonald, 2004).

### 3.13 Causal Loop Diagram

Causal Loop Diagram (CLD) is a tool used to determine structures by visualizing how interrelated variables affect one another. It simplifies a complex reality but have the same behavioral characteristics as the reality. A CLD should be designed in such a manner that it is easy to discuss around. Some aspects around CLD are presented below. (Sterman, 2000)

- A CLD is good to capture a proposed hypothesis by looking into the cause of the dynamics in a system.
- Confining and defining mental images of individuals or teams can be done with a CLD.
- A CLD can identify important feedbacks that are believed to be responsible for a certain situation.

A CLD is constructed through variables that are connected by causal links, denoted as arrows. Each causal link has a polarity, either positive (+) or negative (-). The link shows how the dependent variable varies with a change in the independent variable. (Sterman, 2000)

Important key loops are highlighted through a loop identifier. A loop identifier is a circle with the letter B inside, if the loop has a balancing character. A balancing character can occur if an increase of one variable leads to a decrease of another variable, which in turn affect the initial variable in a decreasing way. If the loop identifier has the letter R inside, the loop has a reinforcing character. A reinforcing character occurs if an increase of one variable leads to an increase of another variable, which in turn affect the initial variable in an increasing way. The same principle is appropriate in a situation where all the affected variables are decreasing. (Sterman, 2000)

The polarities of the arrows do not show what is happening for the moment. The polarities show what happens if the variable connected to the arrow increases. (Sterman, 2000). An example of a causal loop diagram can be seen in Figure 3.25
Figure 3.25 Example of a Causal Loop Diagram illustrating positive (reinforcing) and negative (balancing) loops for market sales growth (Kirkwood, 1998)
4 Empirical Studies

This chapter contains an analysis and discussion in advance to the subsequent chapter 5, where the business model is built. A description on how the empirical study contributes to chapter 5 is presented below. The process of the empirical study is shown in Figure 4.1.

Business Model Generation and the business model canvas created by Alexander Osterwalder is a central concept in creating the business model in this study. This toolset by Osterwalder has been chosen as it provides a template that in a quick and efficient manner maps and categorizes different facets of a business model due to its visual nature, both for the investigator and the beholder. This in turn makes it easy to review an existing business model and make modifications to generate a new business model.

The canvas presented in section 3.12.1 is used to map current aspects at Fortum Heat. The mapping is done with three canvases because Fortum Heat has more than one value proposition (VP), namely electricity, DH and DC. A cross-sectional perspective of the canvases using all three VPs is then developed to highlight similarities and differences between the canvases. This will in turn lead to that aspects regarding the design and strategy of a business model in our case will be considered and analyzed.

The canvases mentioned above in combination with design and strategy aspects are used to construct a Casual Loop Diagram (CLD). The theory around CLDs is presented in section 3.13. A CLD is a good method for showing interrelationships between the different subgroups of a VP, as an adjustment in one subgroup or factor will create a change on a different subgroup. With help from the CLD and earlier empirical studies, five business opportunities (BOs) for Fortum Heat are identified.

One of the five BOs is finally chosen and further developed into a business model.

A mapping of aspects with Osterwalder’s canvases in a multisided perspective.

Developing a cross-sectional perspective of the canvases.

Developing a Casual Loop Diagram for capturing dynamic of Fortum Heat’s situation.

Identification of business opportunities and a discussion around these.

One business opportunity is picked for further modeling in chapter 5.

Figure 4.1 Workflow of the empirical studies.
4.1 Osterwalder’s Canvas with a Multisided Perspective

The canvas with its nine areas discussed in Osterwalder’s handbook, can be used for deliberations and analysis around a problem. The canvas is a useful tool because it helps break down the different aspects of a business model. This is beneficial in order to manage a discussion around separate aspects.

In order to solve the problem statement, developing a business model that stabilizes the national electricity system, the relationship between DH, DC and electricity need to be considered. This direction of the problem statement was described in the introductory chapter 1. Fortum Heat offers three energy products, DH, DC and electricity. Considering this situation, a single Osterwalder canvas may not be sufficient for a mapping all the aspects. It may be possible, but according to the complexity and the amount of aspects this would not be ideal. A more structured way of analyzing the current situation is to use one canvas for each energy product offering. This means three canvases are used resulting in three VPs.

Osterwalder discusses situations where multisided canvases (platforms) are relevant, mentioned in section 3.12.2. Osterwalder argues that multi sided platforms are relevant in situations where one VP is dependent on another VP. This is in line with the situation at Fortum Heat. Especially with respect to the production of electricity which in Fortum Heat’s current situation is directly tied to the demand of DH as mentioned in section 3.11.1.

The situation described above strongly encourages a use of multisided platforms. There are several aspects to consider when three energy products are offered and these energy products are dependent on each other.

4.2 Triple Bottom Line

The triple bottom line perspective described in section 3.12.3 known in terms of people, planet and profit, captures an extended view in business model generation. Social and environmental costs respectively benefits are considered. Today we have a situation where discussions regarding the climate change, carbon dioxide emissions and the impact that human activities have on our planet are considered central. This situation including the triple bottom line perspective encourages business model development, which is truer when regarding business model development in energy firms. We include the triple bottom line perspective by complementing our canvas with two additional areas, social and environmental benefits respectively social and environmental costs. These two areas are used to include and analyze social and environmental aspects.

The 3BL needs to be considered when developing a business model since modern corporations have to consider certain practices such as business ethics to be successful. Modern consumer patterns are now more diverse and it is not merely enough to cut costs and lower prices to attract consumers hard earned income. Also these same aspects factor in when attracting a skilled workforce. DHC firms close relationship of providing social and environmental benefits further augment this point.

4.3 Three Canvases

This section uses the earlier mentioned canvases to map the current situation at Fortum Heat. One canvas for electricity, one canvas for DH and one canvas for DC. The mapping is done with respect to the triple bottom line perspective, included by two extra areas in the canvases, social and environmental costs respectively social and environmental benefits. More descriptions around each area of the canvases are found in the upcoming section 4.4 where the canvases are considered in a cross-sectional perspective to highlight similarities and differences between the individual canvases.
4.3.1 Electricity

Figure 4.2 shows a mapping around the electricity in an Osterwalder’s canvas extended with two areas for the social and environmental aspects.

![Diagram](image)

**KP**
- DH customers
- Fuel suppliers

**KA**
- Calculating production volume from heat demand

**VP**
- Electricity

**CR**
- System based contacts
- Personal contact

**CS**
- Svenska Kraftnät
- Nord Pool

**KR**
- CHP plants

**CH**
- Electricity grid
- Nord Pool trading system

**C$**
- Investment in CHP plants
- Variable related to fuels, taxes, operations and maintenance
- Mains connection

**R$**
- Variable recurring from electricity, electricity certificates and decreased electricity grid losses

**Social and environmental costs**
- Emissions from using fuels

**Social and environmental benefits**
- Local production close to consumption
- Production has beneficial correlation to periods with peak demands
- Efficient usage of fuel energy when DH is generated simultaneous

*Figure 4.2 An Osterwalder canvas with the electricity as VP at Fortum Heat.*
### 4.3.2 District Heating

Figure 4.3 shows a mapping around the DH in an Osterwalder’s canvas extended with two areas for the social and environmental aspects.

<table>
<thead>
<tr>
<th>KP</th>
<th>KA</th>
<th>VP</th>
<th>CR</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fuel suppliers</td>
<td>• Determining production-volume from heat demand</td>
<td>• Hot water for heating</td>
<td>• System based contacts</td>
<td>• Commercial buildings and firms</td>
</tr>
<tr>
<td>• Electricity from SvK for operation</td>
<td>• Sales</td>
<td></td>
<td>• Personal contact</td>
<td>• Housing Cooperative</td>
</tr>
<tr>
<td>• Subcontractors for operation</td>
<td>• Customer service</td>
<td></td>
<td></td>
<td>• Real estate concern</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Private houses</td>
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<table>
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<th>VP</th>
<th>CH</th>
<th>CS</th>
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</thead>
<tbody>
<tr>
<td>• DH grid</td>
<td>• System based contacts</td>
<td>• DH grid</td>
<td>• Commercial buildings and firms</td>
</tr>
<tr>
<td>• CHP plants</td>
<td>• Personal contact</td>
<td>• Invoices</td>
<td>• Housing Cooperative</td>
</tr>
<tr>
<td>• HOB:s</td>
<td></td>
<td>• Internet</td>
<td>• Real estate concern</td>
</tr>
<tr>
<td>• HP:s</td>
<td></td>
<td>• Phone and personal contacts</td>
<td>• Private houses</td>
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<table>
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<tr>
<th>CS</th>
<th>R$</th>
<th>Social and environmental benefits</th>
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<tbody>
<tr>
<td>• Investments in CHP plants, HOB:s and HP:s</td>
<td>• Recurring variable, from sold heat energy</td>
<td></td>
</tr>
<tr>
<td>• Sales force</td>
<td>• Recurring fixed, related to power demand</td>
<td></td>
</tr>
<tr>
<td>• Variable related to fuels, taxes, operations and maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Network charge</td>
<td>• Local clean environment</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social and environmental costs</th>
<th>Social and environmental benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Emissions from used fuels</td>
<td>• Efficient usage of fuel energy compared to individual smaller boilers</td>
</tr>
</tbody>
</table>

Figure 4.3 An Osterwalder canvas with DH as VP at Fortum Heat.
### 4.3.3 District Cooling

Figure 4.4 shows a mapping around the DC in an Osterwalder’s canvas extended with two areas for the social and environmental aspects.

<table>
<thead>
<tr>
<th>KP</th>
<th>KA</th>
<th>VP</th>
<th>CR</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DH customers</strong></td>
<td><strong>Short- and long-term production planning</strong></td>
<td><strong>Cold water for cooling</strong></td>
<td><strong>System based contacts</strong></td>
<td><strong>Commercial buildings and firms</strong></td>
</tr>
<tr>
<td><strong>Electricity from SvK for operation</strong></td>
<td><strong>Sales</strong></td>
<td></td>
<td><strong>Personal contacts</strong></td>
<td></td>
</tr>
<tr>
<td><strong>KR</strong></td>
<td><strong>DC grid</strong></td>
<td><strong>Cold water for cooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Ability to use water for free cooling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Cooling machine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Permission to reject surplus heat into water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C$</strong></td>
<td></td>
<td></td>
<td><strong>R$</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Investment in free-cooling and cooling machines</strong></td>
<td></td>
<td></td>
<td><strong>Recurring variable from sold cooling energy</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Sales force</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>Recurring fixed from power demand</strong></td>
</tr>
<tr>
<td><strong>Variable related to operations, maintenance and electricity price</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Network charge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Social and environmental costs</strong></td>
<td></td>
<td></td>
<td><strong>Social and environmental benefits</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Emissions related to used electricity</strong></td>
<td></td>
<td></td>
<td><strong>Less local noise from cooling machines</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Ecological issues using cool water from the sea</strong></td>
<td></td>
<td></td>
<td><strong>Less local space required for cooling machines</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>If electricity is used for production, this occurs in summer when the demand of electricity is low</strong></td>
<td></td>
</tr>
</tbody>
</table>
### 4.4 Three Canvases in a Cross-sectional Perspective

A cross-sectional perspective of the three canvases is shown in Table 4.1.

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>DH</th>
<th>DC</th>
</tr>
</thead>
</table>
| KR  | • CHP plants | • DH grid  
• CHP plants  
• HOBs  
• HPs | • DC grid  
• Ability to use water for free-cooling  
• Cooling machines  
• Permission to reject surplus heat into water |
| KA  | • Calculating production volume from heat demand | • Determining production volume from heat demand  
• Sales  
• Customer service | • Short and long term production planning  
• Sales |
| KP  | • DH customers  
• Fuel suppliers | • Fuel suppliers  
• Electricity supply from SvK for operation  
• Subcontractors for operation | • DH customers  
• Electricity from SvK for operation |
| VP  | • Electricity | • Hot water for heating | • Cold water for cooling |
| CR  | • System based contacts  
• Personal contact | • System based contacts  
• Personal contacts | • System based contacts  
• Personal contacts |
| CH  | • Electricity grid  
• Nord Pool trading system | • DH grid  
• Invoices  
• Internet  
• Phone and personal contacts. | • DH grid  
• Invoices  
• Internet  
• Phone and personal contacts. |
| CS  | • Svenska Kraftnät | • Commercial buildings and firms  
• Housing cooperative  
• Real estate concern  
• Private houses | • Commercial buildings and firms |
| C$  | • Investments in CHP plants  
• Variable related to fuels, taxes, operations and maintenance  
• Mains connection | • Investments in CHP plants, HOBs and HPs  
• Sales force  
• Variable related to fuels, taxes, operations and maintenance  
• Network charge | • Investment in free-cooling and cooling machines  
• Sales force  
• Variable related to operations, maintenance and electricity price  
• Network charge |
<table>
<thead>
<tr>
<th>R$</th>
<th>Variable recurring from electricity, electricity certificates and decreased electricity grid losses</th>
<th>Recurring variable from sold heat energy</th>
<th>Recurring variable from sold cooling energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social and environmental costs</td>
<td>Emissions from used fuels</td>
<td>Emissions from used fuels</td>
<td>Ecological issues occurred when exploiting water for free-cooling</td>
</tr>
<tr>
<td>Social and environmental benefits</td>
<td>Local production close to consumption</td>
<td>Local clean environment</td>
<td>No local noise from cooling machines</td>
</tr>
<tr>
<td></td>
<td>Production has beneficial correlation to periods with peak demands</td>
<td>Efficient usage of fuel energy compared to individual smaller boilers</td>
<td>No local space required for cooling machines</td>
</tr>
<tr>
<td></td>
<td>Efficient usage of fuel energy when DH is generated simultaneously</td>
<td>Efficient usage of fuel energy when electricity is generated simultaneously</td>
<td>If electricity is used for production, this occurs in summer when the demand of electricity is low</td>
</tr>
</tbody>
</table>

Table 4.1 A cross-sectional perspective with the three canvases with electricity, DH and DC as VP.

Below is a description and discussion around cross-sectional parts. Certain cross-sectional areas have a stronger discussion potential compared to others when considering the problem statement.

**Key Resources**

Fortum Heat primarily provides space heating for its customers and as a consequence the principal function, becomes to serve these same customers. DH customers therefore become a key resource when producing electricity because the demand in heat determines how much electricity that will be generated, since heat is the target market. If the DH grid is expanded, the demand of heat increases when new customers are connected. This can require an expansion in the production capacity from CHP plants. Expanding the production capacity from CHP plants leads to higher production capacity of both electricity and DH. A decrease in the demand of heat according to more energy efficient buildings can compensate the need for more production capacity if new customers are connected to the DH grid.

The decision to phase out HPs within Fortum is not final but according to the future production plan in section 3.11.7, the production capacity with HPs being phased out, results in increased production capacity. Therefore the procedure of HPs to use more electricity for generating DH when the supply of electricity is high, is contradictory to the future production plan if HPs are to be phased-out.

Cooling machines are a key resource for generating DC in situations where free-cooling cannot be used. Due to currently short run times and low access to surplus heat according to section 3.11.9, absorptions chillers for generating DC is not economically preferable and is therefore neglected. This means cooling machines will not be phased out.

**Key Activities**

As mentioned in the above section the production volume is determined by the heat demand. If there is room to produce more heat than currently needed for DH, example through heat rejection electricity can be generated more independent of the DH demand.
Key Partnerships
The partnership with DH customers needs to be maintained in order to have a demand for heat, which establishes the generation of electricity mentioned earlier regarding the key resources. Electricity from SvK and subcontractors involved in the production are important partnerships in order to provide smooth operation. Appropriate fuel suppliers are key partnership for generating both electricity and DH in CHP plants.

DH customers can be a key partnership for selling DC, because openings for signing contracts regarding DC are often generated through a DH customer.

Value Propositions
Three individual markets create three distinct value propositions. Electricity offered to Svenska Kraftnät, hot water offered for heating different customers segments and cold water that is offered for cooling different customers segments.

Customer Relationships
The relationship towards the customers are maintained by system based contacts and personal contacts in all three markets, but to a varying degree in each individual market. The customer relationship for electricity is mainly system based. The customer relationships towards DH and DC customers are compared to that of the relationship in electricity, more personal oriented.

Customer Channels
The customer is reached through the grid connected to each respective VP. Other channels for reaching the customer are through invoices, Internet, phone and personal contacts.

Customers Segments
The electricity only has one customers segment which is Svenska Kraftnät. DH and DC have several customers segments, namely commercial buildings and firms, housing cooperatives, real estate concerned and private houses.

Cost Structures
All three VP:s are connected to fixed investments which creates production capacity. All VP:s are connected to variable production costs related to fuels, taxes, operations and maintenance. DH and DC have a need for an active sales force, compared to the electricity.

The production of electricity leads to revenues. Theses revenues are considered as cost reducing components when internally calculating the production cost of DH at Fortum Heat. However, the mapping of the cost structure does not consider this.

Revenues Streams
Revenue streams from electricity are recurring and variable. They are generated from sold electricity, electricity certificates and decreased losses in the grid due to local production.

Revenue streams from DH and DC are recurring. They are generated from fixed and variable components from demanded volume and power. Price components are described in section 3.2.

Social and environmental costs
Emissions from used fuels contribute to pollutions when generating electricity and DH. Exploiting water for free-cooling can lead to changes in the water environment. Environmental aspects are described in section 3.11.11.
Social and environmental benefits

Local production is a strong benefit with DH and generation of electricity in CHP plants. Production of electricity in areas where the consumption is high, means low transmission losses. Electricity from CHP plants also correlates with periods of high demand in a positive way as described in section 3.7.

Central production of DH means local clean environment. Emissions from central boilers are lower compared to emissions from smaller individual ones.

The energy in the fuel is also used at a higher level in central boilers compared to small individual ones. In additions to this, the efficiency of a CHP plant system is high when heat and electricity are generated simultaneously.

DC cooling means no local noise or occupied space for cooling machines. In addition to this, electricity is used in cooling machines when the probability of a low electricity demand is present.
4.5 The Design of the Business Model

According to Osterwalder and design around business models, one design aspect when generating a business model is to understand the environment in which the model operates in. This setting is described in section 3.12.2. The understanding of the environment a business model operates in does not have to be based on a complete prediction of the future, rather an understanding of a specific detail of the future. As stated in our problem statement a stabilization of the national energy system according to variable electricity production is the aim of our model. This means that the future detail we consider is a variable production of electricity. It is under these conditions our model will operate and is designed to be competitive in. An all-out explanation of the future will add more uncertainty and make the future business model less pragmatic. By focusing on a specific detail a scenario based solution will be achieved, creating an answer for this specific future.

4.6 The Strategy of the Business Model

This section considers the strategic direction appropriate for a business model, contributing to a stabilization of the national electricity system. We are developing the strategy through a consideration in how the environment around the business model is behaving. This strategy is described in Osterwalder’s theories around strategies and business model generation described in section 3.12.2.

Svenska Kraftnät is responsible for maintaining the electricity balance in the national electricity grid. This is described in section 3.5. When maintaining the balance, different scenarios occur. Scenarios and strategies on how to support Svenska Kraftnät’s maintenance of the electricity balance are described in the following section. This means the strategy of the business model includes a consideration of how the environment is acting and how the business model can operate according to situation. The strategy is developed with an outside-in consideration which means the business model is adapting its operations to the current state of the environment.

4.6.1 Scenarios of Unbalance in the National Electricity System

Unbalances can occur in the Swedish national electricity system. A future high variation in the production of electricity due to renewable energy sources described in attachment 8 combined with variations in the demand, results in different scenarios. We have two sides of supply and demand. Two cases where stabilization of the national electricity system is appealing are showed in Figure 4.5.

![Figure 4.5 Cases where stabilization of the national electricity system is appealing.](image)

Case A is unbalanced due to a high demand and a low supply. This case can be solved by decreasing the demand or increasing the supply. Case B is unbalanced due to a high supply and low demand. This case can be solved by decreasing the demand or increasing the supply. This means we have four scenarios where stabilization of the national electricity is done in different ways. The scenarios are numbered 1 through 4 and shown in Table 4.2 below. The table shows what causes the unbalance and how the unbalance is settled.
### Handling the Scenarios with Unbalance

A business model that can handle all the described scenarios in the last section would be ideal. Such a high level of flexibility would be desirable. The probability of how often the scenarios occur, are to be considered but not detailed when making a decision regarding which of the scenarios the business model is supposed to handle. The aim of this thesis is not to make a deep consideration of how often a scenario occurs but more so providing an efficient business model. The current situation at Fortum Heat is considered and how they should be handled in each scenario when determining the business model.

Below is a brief description on Fortum Heat’s opportunities, in order to handle the earlier mentioned scenarios. The earlier studies and canvases have led to an identification of some possibilities described below.

In Scenario 1, lowering the demand of electricity stabilizes the national electricity system. An extended use of DH and DC decreases the demand of electricity. Load is moved from one part of the energy system to another. An increased use of DH moves load from the electricity system to the DH system during periods when the probability of too high demand of electricity is likely, which is more prevalent during the winter. Peak loads related to heating occur in the winter. An increased use of DC moves load from the electricity system to the DC system. This is common during periods when the probability of high demand of electricity is less likely, more prevalent during summer time. Peak loads related to cooling occur in the summer. This means that an increase in the use of DH compared to an increased use of DC is more beneficial when, it comes to stabilizing the national electricity system in this scenario.

In Scenario 2, increasing the supply of electricity stabilizes the national electricity grid. Fortum Heat has a number of CHP plants where heat and electricity is produced at the same time. A new CHP plant is planned. This is shown in the future production plan, which is presented in section 3.11.7. A larger production capacity with CHP plants increases the possibility to produce electricity. Currently the production of electricity is tied to the demand of DH. This is described in section 3.11.1. Producing electricity more independently may create a possibility to increase the supply of electricity.

In Scenario 3, increasing the demand of electricity is important. This can be done by using HP:s for generating DH or DC. Fortum Heat generates DH in this way according to the current production plan in section 3.11.3. Immersion heaters are used for preheating HP:s, described in section 3.11.12. An extended use of HP:s for generating DH and DC would extend the possibility to handle this scenario. But this is not in line with the future production plan, which is seen in 3.11.7. This plan shows that the usage of HP:s will be phased out. Another alternative would be to pump up water to increase the water level in hydro dams.

In Scenario 4, decreasing the supply of electricity can be done by producing less electricity in CHP plants. This can be done by not sending the steam from the boiler, through the turbine for electricity production according to the description of CHP plants in section 3.11.4. Revenues from electricity production are lost and the energy in the fuel is not used in the best way.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Unbalance caused by</th>
<th>Solved by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 (part of case A)</td>
<td>Demand to high</td>
<td>Decreasing the demand</td>
</tr>
<tr>
<td>Scenario 2 (part of case A)</td>
<td>Supply to low</td>
<td>Increasing the supply</td>
</tr>
<tr>
<td>Scenario 3 (part of case B)</td>
<td>Demand to low</td>
<td>Increasing the demand</td>
</tr>
<tr>
<td>Scenario 4 (part of case B)</td>
<td>Supply to high</td>
<td>Decreasing the supply</td>
</tr>
</tbody>
</table>

*Table 4.2 Scenarios where stabilization of the national electricity system is appealing.*

-65-
4.7 Casual Loop Diagram

This section presents a CLD, which is a method to map and understand the complexity and relationships between different aspects at Fortum Heat as well as the national energy system. The CLD is used to show how interrelated aspects affect one another, instead of the case with the business model canvas where all the aspects are clearly divided making it somewhat unclear how a modification in one facet changes a different facet in the canvas. These issues in the Business model canvas are now negated with the introduction of the CLD.

The CLD is found in Attachment 7.

4.8 Identified Business Opportunities

In order to solve the problem statement, tools to identify different perspectives have been used and are presented in the earlier chapters. The multi-sided platforms, the way of designing the business model and the strategy including different scenarios combined with the CLD, have created an identification of business opportunities (BOs).

The BOs are presented in Figure 4.6. Each BO is described in detail in the upcoming sections. A BO that is considered to require a low effort to further develop or implement with respect to Fortum Heat’s current situation, is presented at a low level in the figure. A BO that is considered to require a great amount of work to further develop or implement is presented at a higher level. A high quantity of work in order to further develop or implement does also mean the BO has a longer time perspective. These two mentioned aspects are showed in the Y-axis to the right in the figure. Each BO can handle one or more of the stabilization scenarios in section 4.6.2. Which stabilization scenario each BO can handle is shown to the right in the figure.

<table>
<thead>
<tr>
<th>Level of work to develop or implement / Time aspect</th>
<th>Handle Scenario</th>
<th>Business Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related to: A new integrated solution regarding the DH grid.</td>
<td>1 and 3</td>
<td>5</td>
</tr>
<tr>
<td>Increased number of DH and DC customers.</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Disconnectable electric load at Fortum Heat.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Electricity production in CHP plants.</td>
<td>2 and 4</td>
<td>2</td>
</tr>
<tr>
<td>Optimizing the use of electricity for DH and DC.</td>
<td>1 and 3</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 4.6 Identified business opportunities at Fortum Heat.*
4.8.1 Business Opportunity Number One

HP:s are used to generate DH at Fortum Heat. The amount of hours each year HP:s are used for generating DH is connected to the electricity price. Section 3.11.3 includes an overview how HP:s are used. The production plan for DH is determined with respect to the lowest cost, mentioned in section 3.11.4. The price in the electricity market is set according to the bids at Nord Pool, described in section 3.5.2. When the supply is high and the demand is low, the price is lower compared to situations where the supply is low and the demand is high. This means Fortum Heat is for the moment planning their DH production in a way which already stabilizes the electricity system. We refer to the stabilization scenarios in section 4.6.1. In scenario 1, stabilization is created by a decreasing the demand. High electricity demand implies a high electricity price which leads to less use of HP:s, according to Fortum Heat’s optimization strategy. The same principle in the contrary situation, scenario 3. Stabilization is created by increasing the demand. A low demand implies low electricity price which leads to an extended use of HP:s, according to the optimization strategy.

As mentioned in section 3.11.9, cooling machines are used for producing DC when the possibility to use free cooling not is sufficient. The demand for DC is at the highest point during the warm part of the year. During this part of the year it is appropriate to say that the demand of electricity is low, because the need for electricity for heating is low. If Fortum Heat uses cooling machines to generate DC, which is likely to occur in the mentioned situation, stabilization like the one needed in scenario 3 takes place, referring to section 4.6.1 again.

This BO is already strongly implemented and used at Fortum Heat. With respect to this, deeper analysis around this BO will not be interesting. A possible area for further analysis around this BO is the share of total production power that should be dedicated to HP:s. This can be optimized in order to meet variations in the electricity price and stabilize the electricity grid in the best way. But according to the future production plan in section 3.11.7 the production capacity from HP:s will be phased-out.

4.8.2 Business Opportunity Number Two

If the amount of electricity production from a CHP plant can be increased, this will stabilize the electricity grid in scenario 2.

Offering Svenska Kraftnät primary or secondary regulating power, described in section 3.5.3 is hard to do. CHP plants are too slow for this. Primary regulating capacity need be handled in a time perspective of seconds. The secondary regulation need to be commenced 30 seconds after the unbalance occurs and need to be in full operation after 15 minutes. Regulating the production capacity of a CHP plant, which is running on a certain level, takes approximately 2 hours. Starting a CHP plant from zero takes around 12 hours. A start from zero is also connected to a relative high starting cost. The interview with Mellström is presented in section 3.3.2, provided this information. The slowness of CHP plants makes it hard to offer electricity to the primary or secondary regulating market.

Referring back to section 3.11.4, possibilities to generate more heat than is required for DH leads to that more electricity can be produced in CHP plants. This is an interesting BO for Fortum Heat considering there may be a shortage of electricity during periods when the demand of heat is on a level which will not allocate all heat producing capacity in CHP plants. There need to be free production capacity in CHP plants combined with a possibility to reject the excessive heat. The excessive heat can be rejected as surplus heat or loaded into a thermal storage.

A future production plan is described in section 3.11.7. The new CHP plant KVV8 with a total estimated power of 380 MW leads to that capacity in the production system will be released. Especially when considering that a plant with a power of 380 MW can cover a (not small) part of the demand of power. Referring to section 3.11.3 and a consideration of the y-axis in the diagram showing the production in the central part of the DH network.
Capacity will be released in CHP plant KVV6. This is shown in section 3.11.7. It is appropriate to appreciate the change in run time in the figures which is shown in this section (Sandberg, 2012). The run time for CHP plant KVV6 will decrease with approximately 1500 hours every year if the current production plan is compared to the one for year 2015. KVV6 has coal and olive smash as fuel and the reduction of the run time will decrease emissions from coal. Communicating this creates a positive image against the public. Using the free capacity in CHP plant KVV6 to generate electricity in the way mentioned above is therefore a bad idea.

The future demand of heat for buildings will decrease and this leads to that more and more free capacity in CHP plants occurs. The peak load for heating and the buildings around year 2015 in Stockholm Royal Seaport is approximated to 7 W/m². This level compared to the peak load for heating and normal houses built around year 2015, 22.5 W/m² shows a strong decrease. The buildings in Stockholm Royal Seaport are supposed to show how much energy, buildings in the future will demand. This is described in section 3.11.8. On the other hand, an expansion of the DH grid and connections of new customers can use the free heat capacity. But this requires a geographical aggressive expansion of the DH grid. Approximately 90 % of the buildings in the central part of Stockholm are currently connected to DH (Blomgren, 2012). Considering the figures above, future buildings will only require approximately a third of the peak demand of energy, compared to what traditional houses require and will be built around year 2015. Covering this strong decrease with new DH customers is not realistic. Expanding the DH grid is a slow process and opinions from several involved actors need to be handled. Free capacity in CHP plants will occur occurring to what is mentioned above, both regarding the demand of peak power and the run time over a year.

If surplus heat can be handled from a CHP plant, electricity can be produced more independently. Ways to reject surplus heat is described in section 3.4. In Fortum Heat’s case rejection of heat into water is the easiest way to get rid of surplus heat. CHP plants are situated near water. Allocating space for cooling towers is not appropriate.

The possibility to reject heat into water at Fortum Heat varies as mentioned in section 3.11.10. The heat rejection possibilities in connection to KVV1 are big compared to other heat rejection possibilities. There are possibilities to connect the internal DH grid from CHP plant KVV1 to reject heat from other plants. Heat exchangers, pipes and pumps are needed to do this. If this is done to reject heat from CHP plant KVV6 the total cost can be approximated to 50 million SEK (Mellström, 2012). This situation means that a heat rejection possibility in one place can be used in a flexible way. This is beneficial for this BO because existing heat rejection possibilities can be exploited in a flexible way.

A water-judgment is required to reject heat into water. There is such a valid judgment in the case above. It is possible to assume that it is hard to change a water-judgment, but this does not mean it is appropriate to assume that the water-judgment cannot be used in the case above (Ramström, 2012). This is also beneficial for this BO if existing water-judgments can be exploited.

The maximum heat power which can be rejected into the water according to the conditions in section 3.11.10 is calculated with the general known Equation 4.1.

\[
P_{\text{max, rejection heat}} = \dot{m} \cdot c_p \cdot \Delta T \quad \text{[MWh/h]}
\]

*Equation 4.1 Maximum heat rejection capacity at CHP plant KVV1, Värtan.*

Calculations with the conditions in section 3.11.10, \(P_{\text{max, rejection heat}} \approx 292\) MWh/h.

There are disagreements regarding heat rejection to produce electricity. It is it not always considered the best method of generating energy from fuels, as it contributes to increased emissions if non-renewable fuels are used. Using renewable fuels can be considered a prerequisite. When there is low demand of DH, the excess heat can be stored into a thermal storage.
The heat in the storage can later be used to reduce the demand of production capacity during periods with peak demand of DH. Currently there are accumulators present at Fortum used for short-term storage. These accumulators however have minor effect. Currently this production capacity is covered by plants with a high operating cost, referring back to section 3.11.3.

The principle of storing heat for future demand can be applied during the autumn when the coming months will lead to an increased demand of DH. Introducing a thermal storage in the energy system is in line with what is described around future generations of energy systems in section 3.10.1. More investigations regarding thermal storages for heat are not done in this study.

### 4.8.3 Business Opportunity Number Three

This BO stabilizes the national electricity in scenario 1, referring to section 4.6.1. The scenario involves stabilization through a decrease in the demand of electricity. If Svenska Kraftnät can disconnect a high number of electric loads it this gives them a flexibility that can be used in to maintain the balance of the system. When an electric load can be reported as disconnectable, is described in section 3.8.2.

At Fortum Heat there are immersion heaters that are classified as disconnectable load. As mentioned in section 3.11.12 Fortum Heat can reduce costs by using disconnectable connections to the electricity grid. Cost reduction can be seen as a BO. But as described in the earlier mentioned section this way of reducing costs was not successful. The increased risk of failure when delivering the energy products earlier stopped an extension of the disconnectable connections to the electricity grid.

If the production capacity at Fortum Heat increases, this creates an increased possibility reporting more connections to the electricity grid as disconnectable. More capacity in the production system will lead to better possibilities covering a gap in the production during a disconnection of HP:s or EB:s. According to the future production plan mentioned in section 3.11.7 new production capacity will enter Fortum Heat’s production system. This can lead to extended possibilities to report electric load as disconnectable, referring to what is mentioned above. But it is also possible that extensions of the production capacity leads to other plants which not are related to the electricity are phased out. Plants with high operating costs are shown in the diagram in section 3.11.3. This can be the situation when the production is optimized according to the lowest cost. The price of electricity is a factor that influences this discussion.

### 4.8.4 Business Opportunity Number Four

This BO stabilizes the electricity grid through a decrease of the electricity demand. This is according to the stabilizing scenario 1.

Generally speaking and areas where DH and DC networks are established the alternatives regarding heating and cooling for customers not using DH and/or DC is limited. It is commonly known that using oil boilers are very expensive depending on the current oil price (year 2012). Burning wood, pellet or other fuels related to wood in small-scale boilers generates pollutions, which are not desirable in urban areas. It is also commonly known that the energy in the fuel is not used with the best efficiency, when condensation of chimney gases does not takes place in small boilers. During condensation of the chimney gases, energy which otherwise has been let out through the chimney is recovered. According to the discussion above, heating through electricity is a common alternative in certain urban areas, if DH is not used and where pellets or similar fuels. The heating is done by directly heated electricity radiators or via a water distribution system where the water is heated by EB:s. The other generally known alternative when using electricity for heating and producing warm water is through the usage of individual HP:s where the compressor is driven by electricity. When it comes to cooling and where an actor does not use DC for cooling, it is known that in most cases cooling machines are used with a compressor driven by electricity.

According to the general discussion above, it can be concluded that an actor which does not use DH/DC for cooling/heating use electricity for these needs. This implies that an increase in the number of DH and DC customers decreases the demand of electricity in urban areas.
Increasing the number of DH and DC customers may require an expansion of the distribution grid in geographical terms. This can be a slow process, as mentioned in section 3.11.9. Considering an expansion in the usage of DH and DC may also mean an internal fortifying of the grids to meet the capacity required when new customers are connected.

4.8.5 Business Opportunity Number Five

Referring to the stabilization scenarios in section 4.6.1, this BO increases the possibilities for Svenska Kraftnät to handle scenario 1 through a disconnection of electric load. This BO also handles scenario 3, which means increasing the demand of electricity when it is appropriate. The BO involves a new perspective of how the DH system is designed, an integrated solution similar to that of “open district heating”. The concept is showed in Figure 4.7 and is below explained in detail.

The production of heat by HPs are decentralized to a number of customers which have both a connection to the DH grid and a HP. There are also customers in the grid who only have a DH connection. The customers whom both have a DH connection and a HP can sell their surplus heat to Fortum Heat through the DH grid. Fortum Heat sells this surplus heat to customers who only have a DH connection. Fortum Heat also provides heat in situations where the heat from the HPs not is enough. Decentralized production of heat through HPs is appropriate in scenario 3 where a high electricity demand stabilize the national electricity system.

During periods where a decrease in the demand of electricity is appropriate, the decentralized production of heat through the customers’ HPs is stopped. Fortum Heat generates all the heat. Svenska Kraftnät can disconnect the HPs in the electricity grid. Fortum Heat has with support of their DH system, increased the level of disconnectable electric load. This gives Svenska Kraftnät a higher possibility to handle scenario 1, decreasing the demand of electricity.

Fortum Heat gets revenue streams related to the generation of disconnectable load, by support of DH. Revenue streams also come from a percentage of the reduced cost related to the connection to the electricity grid which is a cost reducing benefit for a customer with a load reported as disconnectable. Fortum Heat gets revenue streams from their central heat production and from the distribution of heat between the customers in the DH grid.

![Figure 4.7 The concept of BO 5 showing actors and revenue streams.](image-url)
This BO involves a lot of work to implement and further develop. Some customers need to have both a DH connection and a HP, which means increased investment costs. This cost can be financed by revenue streams from selling surplus heat and reduced costs, regarding the disconnectable electricity connection. This cost can also be supported by a decrease in the investment cost related to the lower dimensioning of the HP, when parts of the heat demand if covered by Fortum Heat.

It is commonly known at Fortum Heat, that customers today with their own HP is currently (year 2012) one of the biggest threats. This knowledge inspired this concept. An attraction of customers with individual owned HP:s to Fortum Heat can occur. Inspiration for this solution is also obtained from section 3.10.2. This section describes a project where energy from solar panels can be fed into the DH grid and later used when the demand is present. Inspiration has also been obtained from section 3.8.2 and 3.11.12, where disconnectable electric load is presented.
4.9 Svenska Kraftnät’s Perspective Regarding Balancing Production from Intermittent Renewable Energy Sources

Oskar Sämfors (2012) at Svenska Kraftnät believes Smart Grids will be an important future tool in setting the framework of counteracting intermittency from renewable energy. This technology will improve tracking and prevent system overloads. This will be important as the load connected to the electricity grid can vary significantly during different periods. Another important aspect is to have a geographical spread in the wind power expansion. If the wind power is concentrated to certain areas local variations will have more effect on the total amount of generated electricity from wind turbines.

Oskar Sämfors (2012) believes that in order to create secure and reliable electricity supply, there needs to be a variety of alternatives that are market oriented. A diverse amount of alternatives will make the entire energy system more flexible and relieve the pressure put on existing bottlenecks. One of the biggest future challenges Svenska Kraftnät identifies with a variable electricity production is the structural issues it brings. The fluctuations from wind and solar power will create imbalances leading to more up and down regulation. Wind power is difficult to prognosticate and the production from wind power is at the same time not matched to periods with high demand of electricity. It needs to be used when it is available. The load of nuclear power is difficult to adjust which means that there will always be a base production present. This emphasizes hydropower as the regulating power. In Sweden most of the electricity production lies in the northern regions while most of the consumption lies in the middle to southern regions. As a result, the excessive amounts of electricity in the northern regions will put a stress on the transmission of electricity from northern Sweden to southern Sweden. The middle region has to work as a transport hub between north and south while dealing with its own local transfer of electricity at the same time. The electricity regions and transmission between these are described in section 3.5.4 and 3.5.6.

CHP plants closeness to the consumption of electricity is a key factor, which makes CHP plants very interesting in order to balance the national electricity system in the situation mentioned above. DH networks are mostly present in populated areas aiding in more local electricity production from CHP plants.

Another aspect further strengthening CHP plants position, is Svenska Kraftnät’s future aim to phase-out the power reserve and make it commercialized. This creates an opportunity for CHP actors to establish themselves as actors for the power reserve. An issue however, is the slowness of the system in comparison to quicker alternatives such as gas turbines. Nevertheless, if its benefits outweigh its concerns and actors can present an attractive offer to Svenska Kraftnät, they will be all ears (Sämfors, 2012).

Another aspect regarding balancing the energy system is a disconnectable electric load. Svenska Kraftnät already cooperates with the industry to lower their consumption during times of electricity shortage by shutting down production, which is compensated in some way. This is however a costly action and is therefore further down on the list over alternatives Svenska Kraftnät wish to further develop. However, by maintaining this alternative, the flexibility of the system will increase which make the system easier to optimize and more efficient in a wide perspective (Sämfors, 2012).
4.10 Choosing a Business Opportunity to Further Develop

As stated in the introduction to the empirical studies, five BO:s have been identified with the intention of further developing one of these into a business model. This section examines and gives an attempt at justifying which one of these five that should be chosen.

A consideration has been given into the five BO:s and the time span needed for realization. The time perspective stated in our problem statement is the year 2020, which is believed to be a too ambitious outlook for integration and development of BO number five. This BO includes a totally new concept around the DH system and a completion in less than 8 years, is considered too optimistic. The BO involves new structures around a majority of the aspects. The production capacity needs to be reorganized and new contracts towards all included actors needs to be negotiated. Even though much work has been done in the field of “open district heating” within the last year, the concept lies too far ahead from Fortum Heat’s current situation to be considered fully developed. As a result BO number five is not further developed.

BO number four is related to an increase in the number of DHC customers. Fortum Heat is mainly a DHC firm. This means their core business area is providing DH and DC, as a consequence Fortum Heat is already considering this opportunity of increasing its customer base. An expansion and development of the DH and DC businesses is already in progress. With this reason, BO number four is discounted.

BO number one is already well integrated in Fortum Heat’s strategy. It is mentioned in several earlier sections how the firm deals with optimization. HP:s are used to generate heating when the electricity price is on an accurate level. BO number one is therefore disregarded.

Developing the strategy around disconnectable electric loads can be a good method for Svenska Kraftnät to decrease the electric load in strained situations. The use of HP:s driven by electricity, which this BO is tied to, are planned to decrease in Fortum Heats future production plan. In addition to this, Svenska Kraftnät does not prioritize a development of this aspect in order to stabilize the electricity system since it is an expensive alternative. Sämfors at Svenska Kraftnät highlights that efforts should be put in other areas than increasing the disconnectable load. These three factors supports that a development of this BO is not appropriate.

With four of the five BO:s disregarded, BO number two remains. This BO advocates an increased volume of electricity production from CHP plants. It leads to an increase of the revenue streams and has an appropriate time perspective considering our problem statement. Furthermore this BO exploits free production capacity. This occurs when the production assets is extended according to what is mentioned in the earlier description of BO number two. Production capacity also occurs when the demand of heat power decreases due to more and more energy efficient buildings.

BO number two is also highly supported by Svenska Kraftnät regarding a stabilization of the electricity system when a high level of variable electricity production enters the system. Sämfors at Svenska Kraftnät highlights that CHP plants produces electricity locally where the demand of electricity is situated. CHP plants are tied to DH grids and these are found in urban areas where the demand of heating and electricity is large. As mentioned in section *Fel! Hittar inte referenskälla.*, electricity production from CHP plants is more correlated to periods with high demand, compared to other energy sources. The situation means that CHP plants can complement hydropower when regulating unbalances in the national electricity system. These two factors, local production and good correlation to the peak demands of electricity, mean that electricity from CHP plants can act as local balancing power. Local balancing power can relieve the pressure on bottleneck in the electricity grid, which occurs when only hydro power is used as balancing power. Strained situations which occur in the electricity grid are earlier mentioned in section 4.9 and 3.5.4.

Furthermore, if electricity can be produced when there is no need for heat, Fortum Heat can be an actor in Svenska Kraftnät’s commercialization of the power reserve. Sämfors at Svenska Kraftnät highlights that if the barriers with CHP plants, such as the slowness in the system are outweighed by other benefits of CHP plants, this is a highly interesting opportunity.
Table 3.5 in section 3.5.6 shows the expected trade capacity between neighboring bidding areas. For example if there is electricity surplus in bidding area SE1 and electricity shortage in SE4, the transfer must first pass through SE2, then SE3 to finally land in SE4. Further adding complexity to the system is import and export from and to other Scandinavian countries, each with their own individual legislation and specific needs of the country. This in turn puts a stress at coordinating such a large and intricate system. The pricing varies between different bidding areas when each respective bidding area will try to fulfill its own needs while trying to cooperate on a common playing field. Each individual bidding area will have its own set of consumer needs and meteorological conditions which make the system to reacting almost instantaneous to immediate changes. With a future system consisting of increased volumes coming from variable electricity production methods such as wind and solar, the system will become even more delicate. It is concluded that CHP plants with its local production of electricity can reduce the stress in the complex electricity system mentioned above.

Table 3.2 in section 3.5.5 shows installed capacity per bidding area. The installed electric capacity CHP plant in relation to the total installed capacity in Sweden is approximately 10 %. For bidding area SE3 this relation is approximately 13 % and for bidding area SE4 approximately 22 %. It is here concluded that electricity from CHP plants is an important resource, which needs to be used as much as possible to stabilize the national electricity system.

A summary of the evaluation process of the different BO:s can be seen in Figure 4.8. It highlights the different BO:s from the perspective of Fortum Heat and from the perspective of Svenska Kraftnät. A green statement indicates a positive outlook, a blue a moderate outlook and red a negative outlook. Since BO number 2 is the only one with 2 positive outlooks it is chosen to be further developed into a business model. The earlier discussion above has created to foundation for Figure 4.8.

<table>
<thead>
<tr>
<th>BO</th>
<th>Fortum Heat</th>
<th>Svenska Kraftnät</th>
</tr>
</thead>
</table>
| 1  | • Already active today  
     • More HP:s against the future production plan at Fortum Heat | • Already active today  
| 2  | • Positive to exploit free capacity to generate electricity with bio-fuel  
     • Revenue increasing | • An outspread local electricity productions is beneficial for the electricity grid  
| 3  | • Earlier signs of unsuccessfulness due to high risk when increasing the disconnectable load | • Good opportunity, but a low priority to develop  
| 4  | • Increasing the number DH customers is already in focus | • Decreases peak loads in the electricity grid  
| 5  | • Too far ahead in time | • Too far ahead in time  

Figure 4.8 A summary of the evaluation process of the BO:s.
5 Business model

The business model will be based on the concept in BO number two. This BO means an increased electricity production with free capacity in CHP plants. The heat from the increased electricity production is loaded into a thermal storage or dumped as surplus heat into eater. This chapter develops the concept with help of an Osterwalder canvas (a new one, not one of the earlier ones in the empirical studies).

The first part of this chapter uses a canvas to identify aspects from the BO, which the business model is developed from. This leads to a qualitative model.

After the qualitative business model, an economical quantitative model is built. This quantitative model is used to evaluate economic aspects. It is a general exemplification with a CHP plant at Fortum Heat. A sensitivity analysis is developed in connection to this.

Finally, an integration discussion highlights what need to be considered when integrating this business model into Fortum Heat’s current situation. This is done through a reflection around the earlier investigated situation by empirical studies and canvases at Fortum Heat.
### 5.1 Qualitative Model

Figure 5.1 shows aspects of the business model. The business model is developed from BO number two. The next sections describe each area of the canvas.

<table>
<thead>
<tr>
<th>KP</th>
<th>KA</th>
<th>VP</th>
<th>CR</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DH customers</td>
<td>• Optimizing when to increase the electricity production</td>
<td>• Increased electricity production</td>
<td>• Mainly system based</td>
<td>• Svenska Kraftnät</td>
</tr>
<tr>
<td>• Renewable fuel suppliers</td>
<td>• Determining in which CHP plant the increased prod. takes place</td>
<td></td>
<td>• Personal contact at SvK</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KR</td>
<td>C$</td>
<td>R$</td>
<td>CH</td>
<td></td>
</tr>
<tr>
<td>• Free capacity in CHP plants</td>
<td>• Fixed for thermal storages</td>
<td>• Variable from electricity, electricity certificates and decreased electricity grid losses</td>
<td>• Electricity grid</td>
<td></td>
</tr>
<tr>
<td>• Thermal storages</td>
<td>• Fixed for capacity to reject surplus heat</td>
<td>• Reduced production costs for DH when heat in thermal storages covers peak demands of heat</td>
<td>• Nord Pool trading system</td>
<td></td>
</tr>
<tr>
<td>• Heat rejection capacity</td>
<td>• Variable related to fuels, taxes, operations and maintenance</td>
<td>• Recurring for providing SvK a power reserve</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Social and environmental costs
- Emissions from used fuels
- If heat is rejected into water instead of loaded into thermal storages, the energy in the fuel is not used in the best way, hard to communicate
- Rejecting heat into water influences the environment in the water

#### Social and environmental benefits
- Increased possibility for SvK to maintain a stable electricity grid in an energy system with renewable variable production
- Increased possibility for SvK to have local power reserves
- Local production close to consumption

*Figure 5.1 Canvas representing the business model.*
5.1.1 Value Proposition and Customer Segment

The VP is an increase in the volume of produced electricity. This is created by key resources, which make the electricity production more independent of the current demand of heat. The VP makes it easier for Svenska Kraftnät, the CS, to stabilize the national electricity grid when the electricity production from renewable sources varies.

Producing electricity independently of the demand for heat opens the opportunity to be an actor in the commercialization of the power reserve.

5.1.2 Customer Relationship and Channels

How the customer relationship is maintained through appropriate channels do not need a further description. The situation for these two areas in the canvas is the same as in section 4.3.1.

5.1.3 Key Resources

In order the offer the VP free capacity in CHP plants is exploited. Free capacity occurs when the capacity of the production system is extended with a new CHP plant and more energy efficient buildings lead to a decrease in the demand of heat.

The heat from CHP plants can be loaded into thermal storages, in addition to the existent accumulators at Fortum. We assume thermal storages for heat will be present in the future. Heat loaded into thermal storages can be used to cover future peak demands of heat and will reduce the cost for expensive production capacity which is used few hours during a year. This is principally interesting during autumn when the following months will have an increased demand of heat. Heat can also be rejected as surplus heat into water. This means capacity to reject surplus heat into water is a key resource for generating electricity.

When DC is produced in the summer through cooling machines surplus heat needs to be rejected. If the demand for cooling increases this implies an increased demand to reject surplus heat. This means a key resource in form of capacity to reject surplus heat can benefit both generation of electricity and DC.

5.1.4 Key Activities

Determining in which CHP plant the increased production of electricity will take place must be considered. This can depend on which fuel is used and if other required described key resources are available in connection to the current CHP plant.

Optimizing when to increase the electricity production by use of free capacity in CHP plants is the main key activity. This activity involves two aspects. The first aspect of the activity is to identify when free capacity occurs. The second aspect is to optimize when during the year this free production capacity is exploited., which is an area DHC firms today are actively working with. When it is appropriate to load heat into thermal storages also need to be optimized.

5.1.5 Key Partnership

The connections to the DH customers are a key partnership, which needs to be maintained. If unavailable, free production capacity in CHP plants will be undermined if the number of DH customers decreases.

Partnership to obtain renewable fuels is very important. Especially if heat is rejected as surplus heat during period of time when electricity is generated. Rejecting heat as surplus heat which not is generated from renewable fuels is very hard to communicate.
5.1.6 Cost Structure and Revenue Streams

The fixed cost structure is connected to investments in thermal storages and capacity to reject surplus heat. The variable costs are related to fuels, taxes, operations and maintenance.

Variable revenues are obtained from sold electricity, electricity certificates and decreased electricity grid losses. There are also recurring revenues streams for providing Svenska Kraftnät with a power reserve.

The business model does not only generate revenues from the electricity. Heat that is loaded into thermal storages is used to reduce the need of production capacity during peak demands of heat for DH. Reduction of the production capacity (reduction of HOB:s) for DH means a decrease of costs related to the DH production.

Some of these cost and revenues components are described in detail in the quantitative economical exemplification.

5.1.7 Social and Environmental Costs Respectively Benefits

Emissions from used fuels are the mainly environmental cost in the business model. If heat is rejected into water instead of loaded into thermal storages the energy in the fuel is not used in the best way. This may be hard to communicate, especially when emissions and environmental concerns are widely discussed today. This implies that use of renewable fuels is important. Partnership to obtain renewable fuels is described earlier. Rejecting heat into water can influence the environment in the water.

The business model has several environmental benefits. The possibility for Svenska Kraftnät to maintain a stable electricity grid in an energy system with renewable variable production is increased. There is an increased possibility for Svenska Kraftnät to have local power reserves. Local production of electricity close to consumption is important to decrease losses in the electricity grid. The electricity production has beneficial correlation to periods with peak demands.
5.2 Economical Quantitative Model

This chapter builds an economical quantitative model. The model shows the economic situation when heat from a CHP plant is rejected as surplus heat in order to generate electricity. The quantitative economical exemplification is done with renewable fuels. The exemplification is aimed to exemplify the revenues and costs in the business model tied to the operation above. It is not exemplified with a specific CHP plant but with a general situation where free production capacity in a CHP plant with renewable fuels is exploited.

It is important to highlight that the economical quantitative calculations do only consider revenues and cost from an increased electricity production. No revenues and costs for providing Svenska Kraftnät with a power reserve. The business model does also implicate lower production cost for DH if heat from electricity production it loaded into a thermal storage and used to cover coming peak demands of DH. This cost reducing benefit is not either considered in this economical quantitative model.

It is exemplified with year 2010. This year is close to the current year (2012) and relevant figures regarding the electricity market and fuels have been obtained. There are no other reasons to why it is exemplified with year 2010.

The revenues and costs for the operation vary during the year. Mainly the revenues from sold electricity. This implies that the following calculation is done with an hourly resolution. A discussion and sensitivity analysis follows.

5.2.1 Revenues

The cost reducing part from electricity in the variable production cost for heat in a CHP plant according to section 3.11.6, does in our case represent the revenues streams. Equation 5.1 shows how the revenue stream is built up of three components. These components are described in section 3.11.6. The hourly spot price of electricity for year 2010 is obtained from Nord Pool. Attachment 4 states historical quarterly prices of electricity certificates. Attachment 5 states the revenue from decreased losses in the electricity grid which occur due to local electricity production.

\[
E = E_{\text{price}} + E_{\text{electricity certificates}} + E_{\text{grid}} \quad \text{[SEK/MWh]}
\]

Equation 5.1 Revenues from electricity production with renewable fuel.

5.2.2 Costs

The variable production cost for electricity in a CHP plant described in section 3.11.6. The production of electricity with renewable fuels is tied to less tax compared to production of DH. We use the expression stating the cost for electricity production from the mentioned section and modify it.

The cost tied to the fuels in the expression is divided with the efficiency for pure electricity production instead of the efficiency when producing both DH and electricity. Operation and maintenance costs for DH are added to the expression because these occur even if generated heat is rejected as surplus heat.

The last term in the original expression, tax for mononitrogen-oxide, is neglected. This cost component is in Fortum Heat’s current situation positive. This means it reduces the production cost. It is small and is in our case neglected.
These modifications lead to a new expression which states the variable production cost for electricity. The expression is showed in Equation 5.2.

\[ VC_{electricity} = \frac{p_{fuel}}{n_{electricity}} + O M_{electricity} + O M_{heat} \quad [\text{SEK/MWh}] \]

*Equation 5.2 Variable cost when only generating electricity in CHP plant with renewable fuel.*

Attachment 5 states price components. The fuel is wooden chips. The costs for operations and maintenance for the CHP plant in Brista is representative in this general exemplification.

We assume that an existing possibility to reject the surplus heat into water can be exploited but leads to investment costs. Such a situation is described in section 4.8.2. Investments for heat exchangers, pumps and pipes to reject heat as surplus heat are assumed to be 50 million SEK. We use this amount in this exemplification. We assume this investment is depreciated during 25 years.

### 5.2.3 Run Time and Free Production Capacity

It is assumed that free capacity occurs in a CHP plant with renewable fuels. The free production capacity occurs in a similar way as earlier described for CHP plant KVV6. The run time is reduced with 1 500 hours every year, according to section 4.8.2. Free capacity in the spring and in the autumn, 750 hours respectively, are used to continuously produce electricity. Approximately from the middle of April to the middle of May and from the middle of October to the middle of November.

It is assumed that a boiler with a steam production capacity of approximately 200 MWh/h is used. With an assumed degree of efficiency around 40 % the rejection of the surplus heat may be done within the conditions described in section 4.8.2. The electricity production is 80 MWh/h.

### 5.2.4 Economic Result

An hourly calculation with revenues according to section 5.2.1, costs from section 5.2.2, run time and free capacity from section 5.2.3 combined with the figures from Attachment 5, Attachment 6 and electricity prices from Nord Pool gives the results in Table 5.1 Table 5.1 Economic result. The hourly calculation is exemplified with year 2010. The table is presented in million SEK.

<table>
<thead>
<tr>
<th>Revenues [E]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sold electricity</td>
<td>53,7</td>
</tr>
<tr>
<td>Electricity certificates</td>
<td>31,4</td>
</tr>
<tr>
<td>Grid profit</td>
<td>1,9</td>
</tr>
<tr>
<td><strong>Total Revenues</strong></td>
<td><strong>87,0</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs [VC_electricity]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel and operating cost</td>
<td>-75,7</td>
</tr>
<tr>
<td>Operating profit</td>
<td>+11,3</td>
</tr>
</tbody>
</table>

| Depreciations [D]                | -2    |
| Profit [P]                       | +9,3  |

*Table 5.1 Economic result.*
5.2.5 Economic Sensitivity Analysis

The earlier economical result in section 5.2.4 represents a general situation at Fortum Heat. A sensitivity analysis is relevant to show how a change in a specific aspect affects the economical result of the business model. The tables below with sensitivity analysis are presented in million SEK.

Table 5.2 presents the economic results when the degree of efficiency is varied. The costs decrease when the degree of efficiency decreases because the production cost has cost components directly related to produced volume, which decreases with lower degree of efficiency.

<table>
<thead>
<tr>
<th>n_{electricity}</th>
<th>E</th>
<th>VC_{electricity}</th>
<th>D</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 %</td>
<td>74,5</td>
<td>-73,9</td>
<td>-2</td>
<td>-2.5</td>
</tr>
<tr>
<td>36 %</td>
<td>74,9</td>
<td>-78,3</td>
<td>-2</td>
<td>1.4</td>
</tr>
<tr>
<td>38 %</td>
<td>82,7</td>
<td>-75,3</td>
<td>-2</td>
<td>5.4</td>
</tr>
<tr>
<td>40 %</td>
<td>87</td>
<td>-75,7</td>
<td>-2</td>
<td>9.3</td>
</tr>
<tr>
<td>42 %</td>
<td>91,4</td>
<td>-76,1</td>
<td>-2</td>
<td>13.3</td>
</tr>
<tr>
<td>44 %</td>
<td>95,7</td>
<td>-76,5</td>
<td>-2</td>
<td>17.2</td>
</tr>
</tbody>
</table>

*Table 5.2 Economic results when the degree of efficiency is varied.*

Table 5.3 presents the economic results when the operating and maintenance cost is varied. The cost level of this component is highly representable according to Attachment 6. This means only smaller variations of this cost component are motivated.

<table>
<thead>
<tr>
<th>Decrease/increase OM</th>
<th>E</th>
<th>VC_{electricity}</th>
<th>D</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15 %</td>
<td>87</td>
<td>-74,5</td>
<td>-2</td>
<td>10.5</td>
</tr>
<tr>
<td>-10 %</td>
<td>87</td>
<td>-74,9</td>
<td>-2</td>
<td>10.1</td>
</tr>
<tr>
<td>-5 %</td>
<td>87</td>
<td>-75,3</td>
<td>-2</td>
<td>9.7</td>
</tr>
<tr>
<td>0 %</td>
<td>87</td>
<td>-75,7</td>
<td>-2</td>
<td>9.3</td>
</tr>
<tr>
<td>+5 %</td>
<td>87</td>
<td>-76,1</td>
<td>-2</td>
<td>8.9</td>
</tr>
<tr>
<td>+10 %</td>
<td>87</td>
<td>-76,5</td>
<td>-2</td>
<td>8.5</td>
</tr>
<tr>
<td>+15 %</td>
<td>87</td>
<td>-76,9</td>
<td>-2</td>
<td>8.1</td>
</tr>
</tbody>
</table>

*Table 5.3 Economic results when the operating and maintenance cost is varied.*

Table 5.4 presents the economic results when the investment cost for heat rejection possibilities is increased.

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>E</th>
<th>VC_{electricity}</th>
<th>D</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>87</td>
<td>-75,7</td>
<td>-2</td>
<td>9.3</td>
</tr>
<tr>
<td>100</td>
<td>87</td>
<td>-75,7</td>
<td>-4</td>
<td>7.3</td>
</tr>
<tr>
<td>150</td>
<td>87</td>
<td>-75,7</td>
<td>-6</td>
<td>5.3</td>
</tr>
<tr>
<td>200</td>
<td>87</td>
<td>-75,7</td>
<td>-8</td>
<td>3.3</td>
</tr>
<tr>
<td>250</td>
<td>87</td>
<td>-75,7</td>
<td>-10</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Table 5.4 Economic results when investment cost for heat rejection possibilities is increased.*

Table 5.5 presents the economic results when the electricity price is varied.

<table>
<thead>
<tr>
<th>Decrease/increase electricity price</th>
<th>E</th>
<th>VC_{electricity}</th>
<th>D</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20 %</td>
<td>76,3</td>
<td>-75,7</td>
<td>-2</td>
<td>-1.4</td>
</tr>
<tr>
<td>-10 %</td>
<td>81,7</td>
<td>-75,7</td>
<td>-2</td>
<td>4</td>
</tr>
<tr>
<td>0 %</td>
<td>87</td>
<td>-75,7</td>
<td>-2</td>
<td>9.3</td>
</tr>
<tr>
<td>+10 %</td>
<td>92,4</td>
<td>-75,7</td>
<td>-2</td>
<td>14.7</td>
</tr>
<tr>
<td>+20 %</td>
<td>97,8</td>
<td>-75,7</td>
<td>-2</td>
<td>20.1</td>
</tr>
</tbody>
</table>

*Table 5.5 Economic results when the electricity price is varied.*
6 Integrating the Business Model at Fortum Heat

This section will discuss what is needed to further consider when implementing the business model into the current situation at Fortum Heat, earlier presented through the canvases in chapter 4. A discussion is held between the canvas representing the business model and the earlier canvases representing the current situation at Fortum Heat.

6.1.1 Customer Segment and Value Proposition

The customer segment for the increased electricity production is Svenska Kraftnät, the same customer segment as the current one for the produced electricity. Integrating the VP in the business model, an increased volume of produced electricity is not a big issue. Fortum Heat has well-established routines for selling electricity from CHP plants to the electricity market.

A part of the value proposition involves providing Svenska Kraftnät with a power reserve. This requires discussions and negotiations.

6.1.2 Key Resources

The business model exploit free capacity in CHP plants which occurs due to future more energy efficient buildings which demand less energy in combination with investments in new production capacity. The free capacity is exploited to produce electricity. When this KR occurs depends on the how fast the production capacity is extended and how fast buildings become more energy efficient. How fast buildings become more energy efficient is partly a political issue. It can also depend on available technical solutions. This KR does not need an active action, it occurs in the future.

Heat can be rejected as surplus heat or loaded into a thermal storage for use in the future. Possibilities with thermal storages need to be further investigated.

How to create an appropriate heat rejecting capacity for rejecting surplus heat need to be further investigated. Heat rejection possibilities are currently found in number of places within the DH network but these needs to be investigated if they can be used in the business model. A further investigation also needed to determine if current water-judgments are appropriate to use under the purpose of the business model, an increased production of electricity. A part of this also includes investigating how the water environment is affected.

6.1.3 Key Activities

A key activity is to optimize when to increase the electricity production with respect to the electricity demand and available free capacity in CHP plants. Currently optimizing takes place for the DH production. This means Fortum Heat is familiar with optimization issues and integrating one more optimization parameter should not be connected to bigger concerns. When the business model is implemented at Fortum Heat, the current KA for electricity production, calculating the electricity production from the demand of heat, is complemented with the KA above.

Other initial KA involves determining in which plant the increased electricity production will take place. This KA involves an identification of the KR mentioned above.

6.1.4 Key Partnership

It is very important to use renewable fuels for the increased electricity production. If not, the public image around Fortum Heat will not be maintained in a way which contributes to a positive attitude around the firm. Using renewable fuels is especially important if heat during certain periods is rejected as surplus heat (not loaded in a thermal storage).
Dumping heat from non-renewable fuel is not optional. Fortum Heat currently has KP to obtain renewable fuels. These partnerships need to be extended if the demand of renewable fuels at Fortum Heat increases when the business model is implemented.

As mentioned in the canvas which represents the current situation at Fortum Heat and the electricity, a KP is the DH customers. In this business model, this KP is also very important. If the DH customers not are present CHP plants will be undermined.

6.1.5 Customer Relationship and Customer Channel

The CS is reached through the same CH as earlier presented by the canvas for the electricity and current situation at Fortum Heat. The situation is the same regarding the CR with the customer. The CR and CH need no further investigations when the business model is implemented.

6.1.6 Cost Structure and Revenues Streams

When integrating the business model the C$ and R$ are important aspects which need to be evaluated. This is earlier done in the section with the economical quantitative model. It is showed that the business model generates positive economical result.

The economical quantitative sensitivity analysis shows that the degree of efficiency is one important aspect when integrating the business model at Fortum Heat. A low degree of efficiency for electricity production in a CHP plant results in lower economical profit.

A sensitivity analysis, which represents how changes in the electricity price influence the profit, is found in section 5.2.5. It is important to remember that variations in fuel prices can have a correlation with the variations in the electricity price. Today it is generally known that the price of coal influences the electricity price in Sweden. The fuel used in the economical exemplification is wooden chip. When integrating the business model at Fortum Heat it is important to investigate the correlation between the fuel and electricity price when doing a sensitivity analysis. This has not been done in the sensitivity analysis with the electricity price mentioned above.

6.1.7 Social and Environmental Costs and Benefits

Environmental concerns regarding heat rejection into water need to be further investigated because this is the mainly environmental cost of the business model. The high number of social and environment benefits needs to be communicated at the same time to show the entire situation around the model. If investigations around thermal storages show that a big part of the heat from the electricity production can be loaded into thermal storages, the environmental costs will be reduced. Both regarding the environment in the water when less heat is dumped and when the energy in the renewable fuels is used to a higher degree.

If Svenska Kraftnät states that they need the increased electricity production this business model is aimed to create, one more actor than Fortum Heat can communicate the positive social and environmental aspect towards the public. This is positive.
7 Conclusion

The empirical studies have identified a number of BO:s which have a stabilizing effect in a future national electricity system with a variable energy production. A stringent evaluation process of the identified BO:s and economic considerations indicates that BO number 2 has a high number of potential benefits. BO number 2 means an increased electricity production with future free capacity in CHP plants and has been developed into a business model. The potential benefits with the business model are described below.

- The business model increases the revenues by selling larger volumes of electricity when there is free production capacity available in CHP plants. Using free production capacity to produce electricity in CHP plants also means that DHC firms can use existing production assets to generate electricity when the demand of DH decreases due to more and more energy efficient building in the future.
- Increasing the volume of electricity generation in CHP plants is beneficial because CHP plants are tied to the DH grid where the electricity demand is proven to be high. CHP plants also have a beneficial correlation to peak demands in electricity and a potential ability to supplement regulating hydropower which is mostly located in northern Sweden. This can reduce strains in the national electricity grid during electricity transfer from north to south of Sweden.
- Bio-fuel can be used in CHP plants to generate electricity. Using bio-fuel is beneficial for the environment and an actor producing electricity with bio-fuels increases the possibility to have an advantageous position in the general known environmental discussion.
8 Closing Remarks

This chapter highlights possible future areas to investigate.

Investigating how to optimize the increased electricity production is interesting. CHP plants are slow to regulate and frequent starting and stopping is not preferable. The start operation is also tied to a start cost. Minimizing the number of start and stops of CHP plants when determining the production plan to stabilize a future national energy system with a variable production is a challenge.

Investigating how heat from the electricity production can be loaded into thermal storages and be used to cover future needs is interesting. Aspects regarding investment costs and how big area thermal storages occupy can be key factors when determining how big benefits a thermal storage can create.
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Attachment 1: Renewable Energy Systems

The diagrams below show duration curves for demand and supply of electricity. The electricity demand is showed by the black solid staircase line and the production method is visualized as the area between two colored lines. Case A represents the current situation. Case B shows a situation with an increased production from solar and wind power, not compensated by a lower production in other units. Case C shows a situation with an increased production from solar and wind power, compensated by a lower production in other units. (Widén, et al., 2010)
## Attachment 2: Plants

Description of Fortum Heat’s most important plants in the south and central parts of the DH grid, the plants are sorted from lowest to highest operating cost (Fortum, 2012e).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Fuel</th>
<th>Used since</th>
<th>Heat [MW]</th>
<th>Electricity [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Högdalen B1+B2</td>
<td>Household Waste</td>
<td>1970</td>
<td>17+17</td>
<td>6+6</td>
</tr>
<tr>
<td>Högdalen B3</td>
<td>Household Waste</td>
<td>1983</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Högdalen B4</td>
<td>Household Waste</td>
<td>2004</td>
<td>61</td>
<td>21</td>
</tr>
<tr>
<td>Högdalen B6</td>
<td>Return Fuel</td>
<td>2000</td>
<td>63</td>
<td>26</td>
</tr>
<tr>
<td>Högdalen FGC P1-6</td>
<td>Electricity/Chimney Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Värtan, CHP6</td>
<td>Carbon/Olive Smash</td>
<td>1989</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Nimrod HP</td>
<td>Electricity/DC</td>
<td>2001</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Hammarby HP 1</td>
<td>Electricity/Spill Water</td>
<td></td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Hammarby HP 2,5,6,7</td>
<td>Electricity/Spill Water</td>
<td></td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>Hammarby HP 3,4</td>
<td>Electricity/Spill Water</td>
<td></td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Ropsten 1,2</td>
<td>Electricity/Ocean Water</td>
<td>1985</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Ropsten 3</td>
<td>Electricity/Ocean Water</td>
<td>1986</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Hammarby BP1 + BP2</td>
<td>MFA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Årsta Heat Plant</td>
<td>MFA</td>
<td>1976-82</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Värtan HOBS 2, P14+P13</td>
<td>Pine Pitch/Eo5</td>
<td>1973</td>
<td>150/x</td>
<td></td>
</tr>
<tr>
<td>Högdalen P5</td>
<td>Fine-bio</td>
<td></td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Värtan CHP1</td>
<td>Fine-bio</td>
<td></td>
<td>1976</td>
<td></td>
</tr>
<tr>
<td>Värtan HOBS1, B11/ P12</td>
<td>Eo5/Eo5</td>
<td>1969</td>
<td>100/100</td>
<td></td>
</tr>
<tr>
<td>Värtan HOBS3, B15</td>
<td>Eo1, Eo5</td>
<td>1981</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

Description of Fortum Heat’s most important plants in the west part of the DH grid, the plants are sorted from lowest to highest operating cost (Fortum, 2012e).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Fuel</th>
<th>Used since</th>
<th>Heat [MW]</th>
<th>Electricity [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brista 1</td>
<td>Wooden Chips</td>
<td>1996</td>
<td>104</td>
<td>41</td>
</tr>
<tr>
<td>Hässelby</td>
<td>Pellet</td>
<td>1959</td>
<td>197</td>
<td>73</td>
</tr>
<tr>
<td>VP(FK) Akalla</td>
<td>Electricity/DC</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>VP Vilunda</td>
<td>Electricity/Ocean Water</td>
<td>1984</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Vilunda P1</td>
<td>Pellets/MFA</td>
<td>1978</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Akalla P3</td>
<td>Tall Pitch Oil</td>
<td>1973</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Akalla P1,P2</td>
<td>Fine-bio</td>
<td>1971</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>Vilunda P2-P4</td>
<td>Eo5</td>
<td>1978</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>
Attachment 3: Electricity Certificates Quota

The table shows the quotas for electricity certificate during the period 2003-2035. A forecast of the new renewable electricity production and the actual renewable electricity production is also presented for the years. (Swedish Energy Agency, 2011b)

<table>
<thead>
<tr>
<th>Year</th>
<th>Quota</th>
<th>Forecast, new renewable el. production (accumulated) [TWh]</th>
<th>Actual new renewable el. production (accumulated increase) [TWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>0,074</td>
<td>-</td>
<td>1,96</td>
</tr>
<tr>
<td>2004</td>
<td>0,081</td>
<td>-</td>
<td>4,55</td>
</tr>
<tr>
<td>2005</td>
<td>0,104</td>
<td>-</td>
<td>4,80</td>
</tr>
<tr>
<td>2006</td>
<td>0,126</td>
<td>-</td>
<td>5,66</td>
</tr>
<tr>
<td>2007</td>
<td>0,151</td>
<td>-</td>
<td>6,76</td>
</tr>
<tr>
<td>2008</td>
<td>0,163</td>
<td>-</td>
<td>8,54</td>
</tr>
<tr>
<td>2009</td>
<td>0,170</td>
<td>9,31</td>
<td>9,07</td>
</tr>
<tr>
<td>2010</td>
<td>0,179</td>
<td>10,81</td>
<td>11,55</td>
</tr>
<tr>
<td>2011</td>
<td>0,179</td>
<td>11,84</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>0,179</td>
<td>12,94</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>0,135</td>
<td>14,80</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>0,142</td>
<td>16,26</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>0,143</td>
<td>17,71</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>0,144</td>
<td>19,17</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>0,152</td>
<td>20,63</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>0,168</td>
<td>22,09</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>0,181</td>
<td>23,54</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>0,195</td>
<td>25,00</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>0,190</td>
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<td>2022</td>
<td>0,180</td>
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<td>2024</td>
<td>0,161</td>
<td>25,00</td>
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<tr>
<td>2025</td>
<td>0,149</td>
<td>25,00</td>
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<tr>
<td>2026</td>
<td>0,137</td>
<td>25,00</td>
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<td>2027</td>
<td>0,124</td>
<td>25,00</td>
<td></td>
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<td>2028</td>
<td>0,107</td>
<td>25,00</td>
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<td>2029</td>
<td>0,092</td>
<td>25,00</td>
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<td>2030</td>
<td>0,076</td>
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<td>2031</td>
<td>0,061</td>
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<td>2032</td>
<td>0,045</td>
<td>25,00</td>
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<td>2033</td>
<td>0,028</td>
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<td>2034</td>
<td>0,012</td>
<td>25,00</td>
<td></td>
</tr>
<tr>
<td>2035</td>
<td>0,008</td>
<td>25,00</td>
<td></td>
</tr>
</tbody>
</table>
Attachment 4: Quarterly Historical Prices of Electricity Certificates

The table below shows average quarterly historical prices of electricity certificates from year 2004 (the year after the introduction) to year 2010 (Svenska Kraftnät, 2012b).

<table>
<thead>
<tr>
<th>Year</th>
<th>Quarter</th>
<th>SEK/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>1</td>
<td>222</td>
</tr>
<tr>
<td>2004</td>
<td>2</td>
<td>232</td>
</tr>
<tr>
<td>2004</td>
<td>3</td>
<td>233</td>
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<tr>
<td>2004</td>
<td>4</td>
<td>241</td>
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<tr>
<td>2005</td>
<td>1</td>
<td>229</td>
</tr>
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<td>2005</td>
<td>2</td>
<td>207</td>
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<td>2005</td>
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<tr>
<td>2005</td>
<td>4</td>
<td>205</td>
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<tr>
<td>2006</td>
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<td>204</td>
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<td>2006</td>
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<td>2006</td>
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<td>155</td>
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<tr>
<td>2006</td>
<td>4</td>
<td>186</td>
</tr>
<tr>
<td>2007</td>
<td>1</td>
<td>191</td>
</tr>
<tr>
<td>2007</td>
<td>2</td>
<td>192</td>
</tr>
<tr>
<td>2007</td>
<td>3</td>
<td>199</td>
</tr>
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<td>2007</td>
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<td>208</td>
</tr>
<tr>
<td>2008</td>
<td>1</td>
<td>217</td>
</tr>
<tr>
<td>2008</td>
<td>2</td>
<td>288</td>
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<tr>
<td>2008</td>
<td>3</td>
<td>315</td>
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<td>2008</td>
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<td>2009</td>
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<td>2009</td>
<td>3</td>
<td>305</td>
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<td>2009</td>
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<td>309</td>
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<td>2010</td>
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<td>318</td>
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<td>2010</td>
<td>2</td>
<td>276</td>
</tr>
<tr>
<td>2010</td>
<td>3</td>
<td>238</td>
</tr>
<tr>
<td>2010</td>
<td>4</td>
<td>246</td>
</tr>
</tbody>
</table>
Attachment 5: Price Components

The table below shows monthly averages prices per MWh for coal, carbon credits, pellets and wooden chip for a number of months during year 2010. The prices are related to the energy in the fuel and include transportation to the CHP plant. (Larsson, 2012)

<table>
<thead>
<tr>
<th>Month</th>
<th>Coal</th>
<th>Carbon Credits</th>
<th>Pellets</th>
<th>Wooden chip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Värtan</td>
<td>Värtan</td>
<td>Hässelby</td>
<td>Brista</td>
</tr>
<tr>
<td>January</td>
<td>113</td>
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<td>106</td>
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<td>290</td>
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<tr>
<td>November</td>
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<tr>
<td>December</td>
<td>137</td>
<td>41</td>
<td>260</td>
<td>224</td>
</tr>
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</table>

The average price for olive stones during the first eight months of year 2012 is 256 SEK/MWh (Larsson, 2012).

The table below shows more components of the variable production cost for CHP plant KVV6 in Värtan and the CHP plant in Brista. The first two components operating and maintenance cost for heat and electricity cost are connected to sold units. The tax related to mononitrogen oxide is related the fuel. (Franzén, 2012) (Sandberg, 2012) The operating and maintenance cost for heat and electricity for the future new CHP plant KVV8 in Värtan is calculated to be the same as for the CHP plant in Brista (Sandberg, 2012).

<table>
<thead>
<tr>
<th>Component</th>
<th>Nomenclature</th>
<th>SEK/MWh</th>
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<tbody>
<tr>
<td>Operating and maintenance cost heat production</td>
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<tr>
<td>Operating and maintenance cost electricity production</td>
<td>OM_{electricity, Värtan}</td>
<td>48</td>
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<tr>
<td>Operating and maintenance cost heat production</td>
<td>OM_{heat, Brista}</td>
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<tr>
<td>Operating and maintenance cost electricity production</td>
<td>OM_{electricity, Brista}</td>
<td>34</td>
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<tr>
<td>Mononitrogen oxid tax</td>
<td>NOX</td>
<td>-5</td>
</tr>
</tbody>
</table>

Revenues from decreased losses in the electricity grid from local electricity production are 15 SEK/MWh (Franzén, 2012).
Attachment 6: Water-judgment for Heat Rejection

Part of the judgment which states conditions regarding possibilities to reject heat into the water in connection to the CHP plant KVV1, Värtan (Ramström, 2012)

...
dansdrift beräknas ökningen till enkäring 4,5 \( \frac{\text{C}}{\text{s}} \) med en temperatuurhöjning av 1,5\(^\circ\) C. Det planerade kraftvärmeverket innehåller ingen ökning i fråga en energitillskott, och tillsatte kylvattenvänster övar inte, såvitt känt, medfört några olägenheter. - Jaktet från kraftverkets vattenreningse- anläggning innehåller neutral saltlösning och vissa korrosionsprodukter samt jolyttermassa. Det ska leda ut i kylvattenkanalen. Koncentrationen av den neutrala saltlösningen kommer att underlåta 1 % och påvärdet ska justera till \( f = a \). Jolyttermassan består av inert polystyrematerial, d.v.s. att ämne som inte reagerar i någon form med andra ämnen och inte bryter genomsnittliga sänkningar av produkter. Sålunda ger materialet i vannfäste ej uppenbar påvirkning av någon typ av giftvänster. Materialiet är lättare än vatten. Det pulveriserade jolyttermaterialet kan, bortsett från densitet, närmast karakteriseras som finkornig sand. Den inliga undvikningsnärmaste uppdrift till 1,500 kg. - Saltvätska leds till en befintlig buffertbass- fång och släpper därefter ut i avloppsvatten. Oljefattigt avloppsvatten leds till en befintlig oljeavskiljande, var- ifrån det föras till buffertbassens försett. Driftvätska från tak och glasbruna skall ledas ut i kylvat- tenkanalen. Övrigt saltvatten leds till det kommunala dag- vattnetsmält och samtatt avloppsvatten till det kommunala spältvätersmältet. - Med hänsyn till den befintliga och för- vistade bakgrundslivnivån i området planeras också ljudläge på så vis att ljudintensiteten blir 45 dB (A) vid de närmsta verket belägna bostadsområden i Hjorthagen och 40 dB (A) vid bostadsområden närmare Lidingövägen. Den föreslagna utlekt- ningen kan variera innan en viss reposition av den totala inlektionsnivån i Hjorthagen, tämligen med nuvarande förbät- randen och det närmaste området av kraftvärmeverket. Korror- na av kylvattenmassa avvikelser starkt och tills med stimulerat störning och vanligtvis. - Det i buffertbassens avsiktiga stort störningar från befuk-
Attachment 7: Casual Loop Diagram

The time perspective for the dependency varies.
Renewable and Intermittent Energy Sources

Fossil fuels such as coal, gas and oil have a natural regeneration, but the time for the regeneration process varies a lot. Fossil fuel is considered to be a limited resource due to their slow regeneration process and is therefore considered as a non-renewable energy source. Renewable energy sources (RES) have a shorter regeneration time. (International Energy Agency, 2005).

An intermittent energy source has an output power, which varies with time and location due to exogenic factors. Renewable energy sources such as solar and wind has an output power that is determined by meteorological conditions, which makes it intermittent. Two main types of predictability can be considered, predictable related to the day-night cycle and seasonal differences. (Kanoria, et al., 2011).

The following two sections present two of the most common renewable intermittent energy sources, wind and solar.

Solar Power

Electricity from the sun is generated through the use of photovoltaic panels, which use the sunlight to generate electrical energy. The output power depends on the intensity of the sun and the angle the sunlight meets the photovoltaic panels. This means that electricity is generated during winter and also during cloudy days, but at a reduced rate compared to a perfectly clear and sunny day. Winter days are shorter while summer days longer, which means more sunlight for electricity production is available in the summer compared to the winter. The geographical location also affects the intensity of the solar radiation. Locations closer to the equator have a more constant radiation throughout the year. Finally, conditions such as clouds and rainfall influence the short-term fluctuation of the electricity production from photovoltaic panels. (Toothman & Aldous, 2011)

Wind Power

Electricity is generated through the use of wind turbines connected to a generator that produces electricity. The amount of produced electricity is dependent on the wind speed. The relationship between the electricity production and the wind speed can be expressed as the wind speed in cube. This means a small change in the wind speed influence the amount of produced electricity strongly. Wind turbines operates between wind speeds 2.5 to 25 m/s. Implying that during certain periods of times with low wind speeds, wind power is unavailable, but also during times with high wind speeds, as the turbines need to be shut down in order to avoid damage of the equipment. Wind power is considered intermittent as it varies with the seasonal variations in winter and summer, depending on the region. Forecasting the wind is important in order to determine future electricity production, both in time aspects of minutes and hours. (International Energy Agency, 2005)