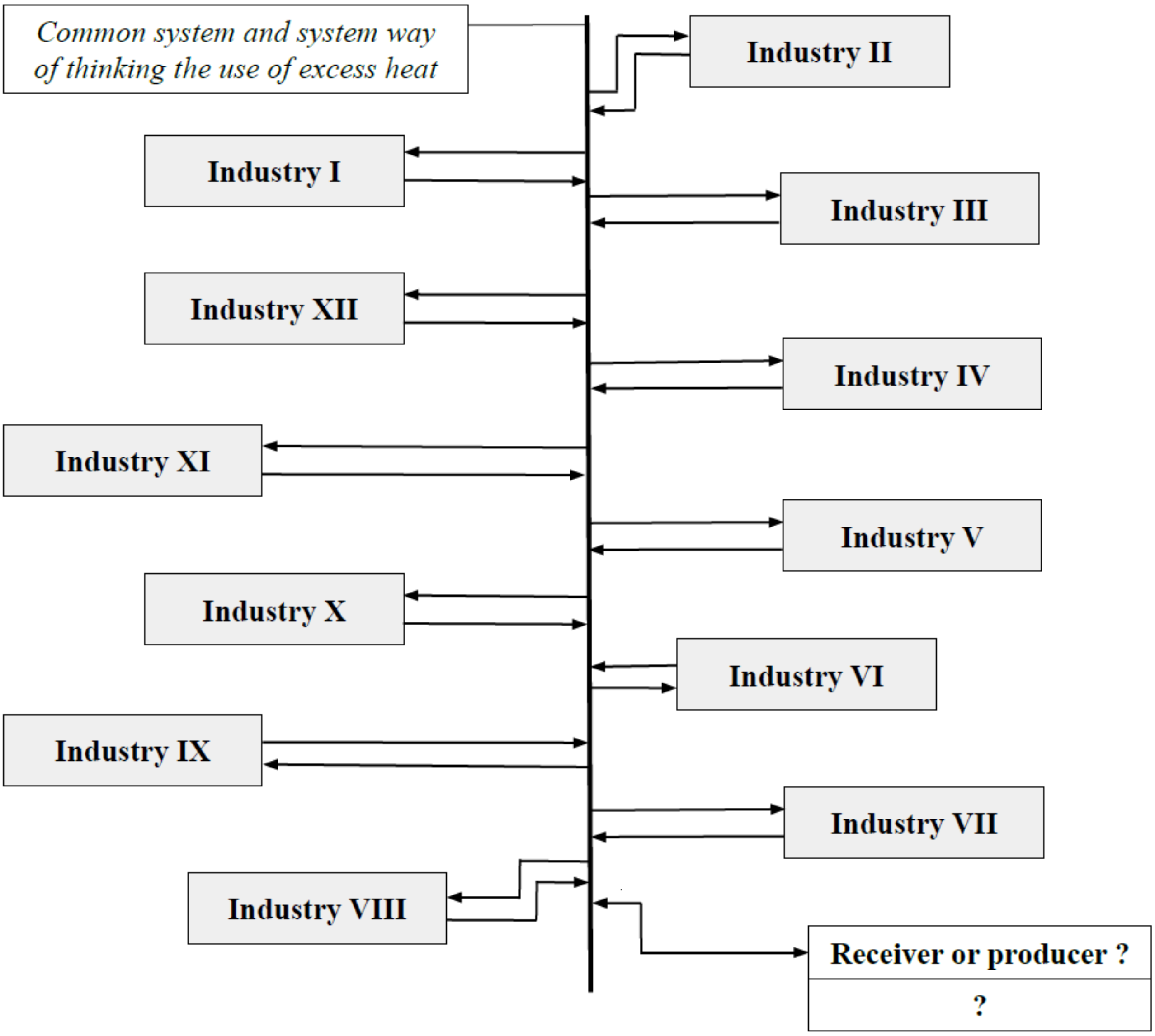
Exchange of Excess Heat between Industries at the Port of Aarhus



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June 4th, 2020

Master Thesis

Sustainable Energy Planning and Management

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Title:
Exchange of Excess Heat between industries at the port of Aarhus

Semester:
4th Semester - Sustainable Energy Planning and Management

Project:
Master Thesis

Project period:
1th of February to
4th of June (2020)

ECTS:
30

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Pages: 95
Pages, total: 134
Supplements: 2 audio files and 1 PDF

Synopsis:

The thesis has a starting point in a pilot project about excess heat at the port of Aarhus, and the pilot project is the case studied in the thesis. The focus of the pilot project is an additional approach to the utilisation of excess heat, which encompasses using excess heat in an exchange between industries in a common system at the port of Aarhus. The research question of the thesis is: *How can a common system of the exchange of excess heat between the industries at the port of Aarhus be designed, and how does regulatory and technical conditions as well as contractual conditions and agreements impact the system way of thinking the use of excess to be an additional approach in the utilisation of excess heat?* To answer the research question, the analysis of the thesis is concerned with establishing a design of the exchange of excess heat in a common system, and a sensitivity analysis is included to experiment with the design. The discussion elaborates and reflects on the design of the common system and discusses the regulatory and technical conditions as well as contractual conditions and agreements being present in the exchange of excess heat between the industries. The methodology of the thesis consists of e.g energyPRO as a modelling tool, meetings with external collaborating partners, interviews and literature study. The thesis concludes, that an additional approach to the utilisation of excess heat in a common system can be designed and function as an approach in the use of excess heat, but existing conditions can have an impact on the implementation of common system at the port of Aarhus.

By accepting the request from the fellow master student, who uploads the master thesis in the Digital Exam system, the student confirms that both master students have participated in the work related to the thesis, and thereby both master students are collectively liable for the contents of the project. Furthermore, the master students confirm that the report does not include plagiarism.

Preface

The master thesis is prepared and composed by two students from the master's programme: *Sustainable Energy Planning and Management at Aalborg University.*

The master thesis focuses on excess heat and as a part of preparing the thesis, the master students have been a part of an external collaboration with actors from Aarhus Municipality and the consulting firm PlanEnergi in relation to working with and analysing a pilot project about excess heat at the port of Aarhus. The pilot project at the port is concerned with an exchange of excess heat in a common system between industries located at the port.

Through the external collaboration, the master students have been a part of dialogues and discussions about the how to design and establish an exchange of excess heat between industries at the port of Aarhus. Based on these dialogues and discussions, the thesis entails analyses as well as discussions of and reflections on the design of the exchange of excess heat.

Although the thesis has been composed as a apart of a collaboration with external actors, the thesis has it own decided focus and take on the work with the exchange of excess heat the port of Aarhus. Furthermore, the thesis approaches the work with the exchange of excess heat between the industries at the port from a research perspective.

As a result of the external collaboration, the master students offer thanks to Uffe Kristensen from Aarhus Municipality, and do also thank Jakob Worm and Grethe Hjortbak from PlanEnergi.

The master students do also give thanks to Søren Djørup, who has been the supervisor, for the guidance and help in connection to the writing of the master thesis.

The thesis is typed and written in English, but Danish notation is applied in relation to dots and commas in connection to numbers.

Danish articles and reports are used in the thesis, and in situations where these are quoted, there can be deviations in the sentences quoted due to the translation from Danish to English. Translated quotes are denoted with [Translated from Danish to English].

The sources are entailed in the Bibliography, and the referencing method is the Harvard-method. The notation "n.d" in the Bibliography means, that no publishing date is informed in the source referenced to. If a source has more than one author, the term "et.al" can appear in the reference to describe this.

The figures and tables assigned no reference in the thesis are illustrations and tables made by the master students.

Attached files to the thesis in Digital Exam:

- Two audio files containing two separate interviews with Uffe Kristensen, development consultant from The Secretariat of Climate and Green Transition in the municipality of Aarhus, and Anne Zachariassen, chief operating officer at Aarhus Havn.
- energyPRO outputs from the sensitivity analysis

Nomenclature

Abbreviations

AVA	AffaldVarme Aarhus
MLP	Multi-level Perspective
O&M	Operation and maintenance
SNM	Strategic Niche Management

Terminology:

Energy Agreement: Energiaftale (2018)
Climate Act: Klimalov (2019)
The Danish Heat Supply Law: Varmeforsyningsloven
Danish Energy Agency: Energistyrelsen
The Danish Ministry of Climate, Energy and Utilities: Klima-, Energi- og Forsyningsministeriet
The Danish Climate Council: Klimarådet
Danish District Heating Association: Dansk Fjernvarme
The National Association of Local Authorities in Denmark: Kommunernes Landsforening (KL)
The Confederation of Danish Industry: Dansk Industri
The Danish Ministry of Taxation: Skatteministeriet
Aarhus Municipality: Aarhus Kommune

Contents

Introduction 1

The Danish energy system is going though a change process to comply with the long-term 2050-goal and the 2030-goal determined by the Danish Government. The general focus in the goals is on a replacement of fossil fuels as energy resources in the Danish energy system.

Excess heat can be viewed as an energy source, which can be utilised in the replacement of fossil fuels in the Danish energy system, and the thesis has a focus on excess heat.

Currently, excess heat is not used at the potential that it shows to have in the Danish energy system, and because of this, the thesis works with and analyses an additional approach to the utilisation of excess heat through a case study of a pilot project about excess heat at the port of Aarhus.

The pilot project about excess heat at the port of Aarhus originates from the project *Smart Energi Aarhus Havn*, and is based on a system way of thinking the use of excess heat. Because of the system way of thinking the use of excess heat in the pilot project, the project has a focus on designing and implementing an exchange of excess heat between industries located at the port in a common system.

The thesis analyses a design of the exchange of excess heat at the port of Aarhus. The design as well as other discussions and reflections included in the thesis in relation to the common system and the exchange of excess heat between the industries can function as inputs and can be used in the further work and development of an exchange of excess heat at the port of Aarhus.

Problem Analysis 2

The thesis has a focus on excess heat and works with a pilot project about excess heat at the port of Aarhus.

The Problem Analysis includes the energy policy goals defined by the Danish Government and describes the role of excess heat in the replacement of fossil fuels in the Danish energy system. In continuation of this, the Problem Analysis investigates the context around excess heat and describes the pilot project at the port of Aarhus, which functions as the case study of the thesis.

2.1 Danish Energy Policy Goals

Since 2011, a long-term goal has been guiding the transition and development of the Danish energy system. The long-term goal states, that Denmark must be independent of fossil fuels by 2050 and the goal is described in *Energistrategi 2050* [Energistyrelsen, n.d; Klima- og Energiministeriet, 2011]. The 2050-goal of Denmark becoming independent of fossil fuels was stated by the Danish Government at that time and has remained since 2011. As a result of an increasing political focus on contributing to and achieving the 2050-goal, supplementing goals have been formulated. As a part of an agreement on a new Climate Act published in 2019, the current Government presents the most recent national goal. The goal included in the Climate Act states that by 2030, a 70% reduction in CO_2-emissions[1] must be achieved [Klima-, Energi- og Forsyningsministeriet, 2019b]. The Climate Act from 2019 is a result of a settlement between the current Danish Government and other political parties from the Danish Parliament, and the agreement is binding to succeeding governments. To ensure the achievement of the 2030-goal, the Climate Act emphasises that climate action plans must be made and sub-goals are planned to be made every five years [Klima-, Energi- og Forsyningsministeriet, 2019b,a].

In addition to the formulations of supplementing goals in connection to the 2050-goal, following governments and political parties have also expressed and added other phrasings contributing to the long-term goal. In the Energy Agreement from 2018 it is described, that the agreement is made to achieve the ambition of having a *"low-carbon society"* in 2050, which can be considered to be an addition to the 2050-goal from 2011 [Energi-, Forsynings- og Klimaministeriet, 2018]. Besides containing the 2030-goal, the new Climate Act also defines, that the act will support achieving a long-term goal of *"climate neutrality"* in 2050 [Klima-, Energi- og Forsyningsministeriet, 2019b]. Although not specifically defined in the Climate Act, in the thesis, the term *"climate neutrality"* is understood to indicate that a balance between the level of emissions released and removed must be maintained in order to ensure *"climate neutrality"* in Denmark, which can be considered to add to the 2050-goal of Denmark becoming independent of fossil fuels.

[1]The 70% reduction in CO2-emission is in relation to the levels of emission in 1990 [Klima-, Energi- og Forsyningsministeriet, 2019b]

Considering the 2050-goal and the 2030-goal as well as the phrasings in the Energy Agreement and the new Climate Act, a political focus on the transition of the Danish energy system can be assumed to exist, and it can be stressed in this connection, that in order to achieve the national energy policy goals, changes in the Danish energy system have to be made.

As described above, the formulations of achieving a *"low-carbon society"* by 2050 stated in the Energy Agreement and achieving *"climate neutrality"* by 2050 mentioned in the Climate Act can be recognised as additions to the 2050-goal and contributes to the goal. In the thesis, the defined long-term 2050-goal and the 2030-goal can be emphasised to relate to the use of fossil fuels in the Danish energy system. This is stressed, as the 2050-goal includes independency from fossil fuels and the 2030-goal concerns a 70% reduction of CO_2-emissions, and as fossil fuels emit CO_2 when used in energy production [Europa Kommissionen, n.d]. It is possible to argue, that independence of fossil fuels is wanted by the Danish Government due to geopolitics and the fact that fossil fuels are scarce and depletable resources, and for that reason dependency on fossil fuels can be a challenge in relation to security of supply in the Danish energy system [Arler et al., 2015]. Reduction in CO_2-emissions from fossil fuels can be emphasised to be a goal by the government, because CO_2-emissions from burning fossil fuels in the Danish energy system contribute to climate changes [Europa Kommissionen, n.d].

This means, that in order to achieve the 2050-goal and the 2030-goal, the required changes in the Danish energy system can be argued to involve and deal with a replacement of fossil fuels. Figure 2.1 summarises the danish energy policy goals towards 2050 and 2030 together with the additional phrasings to the 2050-goal.

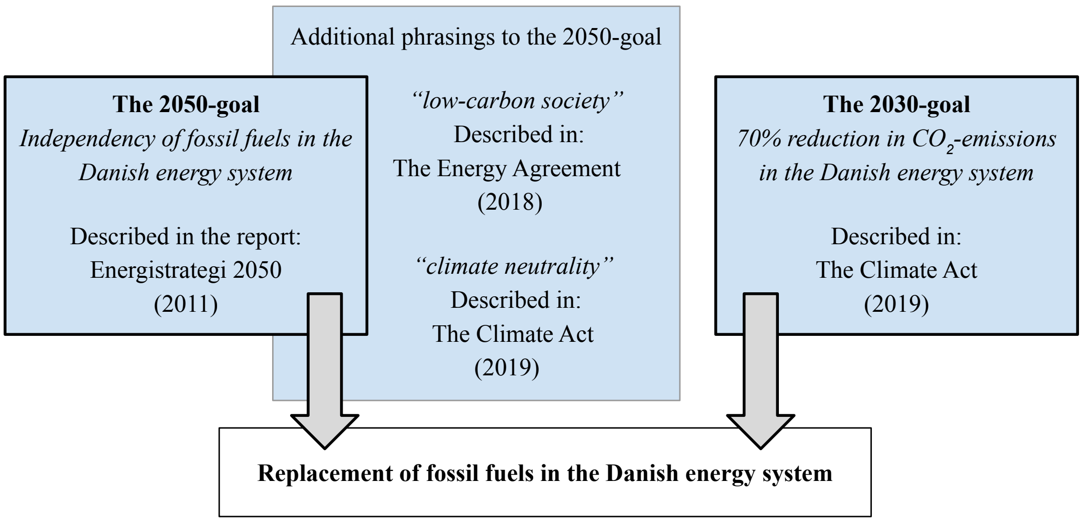

Figure 2.1: *Illustration of the 2050-goal and 2030-goal with the additional phrasings.*

2.2 Replacement of Fossil Fuels in the Danish Energy System

In the section above, the long-term 2050-goal and the 2030-goal are emphasised to evolve around replacing fossil fuels in the Danish energy system. It can be assumed, that different strategies exist for the replacement of fossil fuels in the energy system and in relation to this, The Danish Energy Agency, The Danish Climate Council, and Henrik Lund, who is a professor at Aalborg University [2], present and adhere to the following two strategies for the replacement of fossil fuels

[2]Henrik Lund is a professor at Aalborg University in the Department of Planning

in the Danish energy system: [Energistyrelsen, n.d; Klimarådet, 2020; Lund, 2014]

- Integration and implementation of renewable energy sources and related conversion units in the energy system.
- Implementation of energy efficiency initiatives in the production of energy and in the demand-side of energy in the energy system.

That these three different actors have the same perception of strategies in the replacement of fossil fuels can be argued to illustrate, that the replacement of fossil fuels both from a political point of view and a research perspective seems to include integration of renewable energy sources and conducting energy efficiency initiatives in the production of energy and in the demand-side in the Danish energy system.

In the Danish energy system, the replacement of fossil fuels and the integration of renewable energy sources and related conversion units have been a process going on in recent decades, and as a result, the current amount of renewable energy is around 38%[3] in the Danish energy system [Energistyrelsen, 2018b]. Energy efficiency initiatives are regarded to be carried out alongside the integration of renewable energy sources, because a focus on energy efficiency initiatives in the production of energy and in the demand-side can decrease the amount of fuels and energy sources used in the Danish energy system [Energistyrelsen, n.d; Klimarådet, 2020; Lund, 2014].

Figure 2.2 illustrates a simplified model of the Danish energy system, with the three overall energy sectors included: The electricity sector, the heat sector and the transport sector. The energy system on Figure 2.2 is made with inspiration from a set of reports describing the Danish energy system: [Energistyrelsen, 2018c; Mathiesen et al., 2015; Klimarådet, 2015].

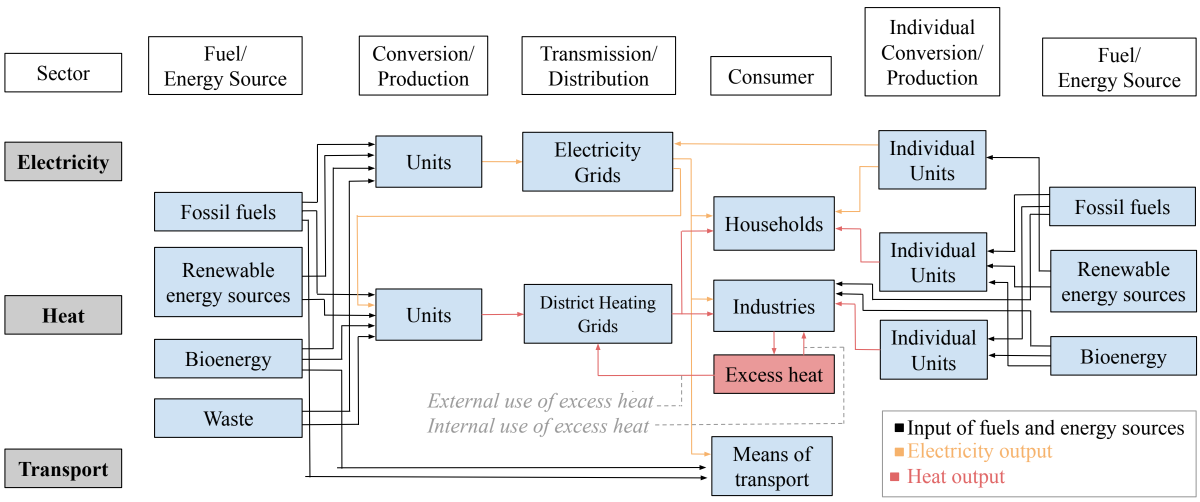

Figure 2.2: *Illustration of the Danish energy system.*

From Figure 2.2 it can be observed, that fossil fuels still are a part of the Danish energy system and are used in the production of electricity and heat as well as fuel in different means of transport. In the Danish energy system, the integration of renewable energy sources is an ongoing process and is included in the strategies to replace fossil fuels, which explains renewable energy sources being a part of the energy sources in Figure 2.2. In relation to the integration of renewable energy sources, bioenergy is often included in the characterisation of renewable energy, and bioenergy is a fuel in the Danish energy system as illustrated in Figure 2.2. With bioenergy often referred to as renewable energy and bioenergy being used in the energy system, it is in

[3] The 38% includes renewable energy sources, bioenergy and import of bioenergy [Energistyrelsen, 2018b]

the thesis assumed, that the integration of renewable energy sources to replace fossil fuels also covers bioenergy in the strategies mentioned above. Figure 2.2 shows, that renewable energy sources and bioenergy are used in conversion units to produce an output of electricity and heat and used as inputs in the transport sector. Looking at Figure 2.2, waste and excess heat are also a resource and an energy source included in the Danish energy system. Waste is a resource, that can be used as a fuel in the production of electricity and heat, whereas excess heat is an energy source connected to the heat sector. Going through different reports discussing the transition of the Danish energy system towards 2050 and the replacement of fossil fuels, waste and excess heat are also described and incorporated as a fuel and an energy source in the Danish energy system [Mathiesen et al., 2015; Energistyrelsen, 2014a,b; Klimarådet, 2020]. This can be argued to indicate, that waste and excess heat are also expected to be used in the transition of the energy system and the replacement of fossil fuels towards 2030 and 2050. For that reason, the thesis adds waste and excess heat as a fuel and an energy source to be included in the strategies described above in relation to the replacement of fossil fuels.

With excess heat being defined to be included in the strategies in the replacement of fossil fuels, the thesis focuses on excess heat as an energy source in the Danish energy system.

2.2.1 Excess Heat

In the thesis, excess heat is assigned the following definition: Excess heat is a heat output, which emerges from different types of industries and their production processes [Dansk Fjernvarme, n.d; Energi-, Forsynings- og Klimaministeriet, 2017].

Excess heat can occur as a result of a production of a certain product in an industry but also as a result of a cooling process [Dansk Fjernvarme, n.d; Energi-, Forsynings- og Klimaministeriet, 2017]. This means, that excess heat can be viewed as a bi-product and surplus from a process in an industry, where the main focus is not to produce an output of energy but manufacturing of a product or a demand for cooling. As excess heat from different processes in industries can be used as an energy input in the Danish energy system, excess heat is viewed as an energy source in the thesis, and not as a waste product from industries and their processes.

Figure 2.2 illustrates excess heat as a heat output from industries, and the figure also presents, how excess heat interacts within the heat sector of the Danish energy system. Within the heat sector, excess heat can be used internally by the industries, who have an output of excess heat, or excess heat can be allocated externally [Energi-, Forsynings- og Klimaministeriet, 2017; Skatteministeriet, 2018]. Internal use of excess heat means, that industries use excess heat for e.g. space heating or in other production processes in the industry [Energi-, Forsynings- og Klimaministeriet, 2017; SparEnergi.dk, 2019]. External use of excess heat can involve excess heat being used in and delivered to e.g district heating grids through bilateral connections to supply district heating consumers [Energi-, Forsynings- og Klimaministeriet, 2017; Grøn Energi, 2020]. The internal and external use of excess heat is also indicated in Figure 2.2.

The Confederation of Danish Industry argues, that with excess heat included as an energy source in the Danish energy system, excess heat can replace fossil fuels and by that remove an amount of the CO_2-emissions related to the use of fossil fuels in the heat sector [Dansk Industri, 2018]. Because of that, the Confederation of Danish Industry views the use of excess heat to be beneficial in relation to the 2050-goal and the 2030-goal [Dansk Industri, 2018]. However, viewing excess heat as an energy source with no CO_2-emissions can be discussed. Excess heat can occur from a production in an industry, where fossil fuels are used as fuel input in the production process.

In that situation, it can be stressed, that excess heat cannot be defined as having no CO_2-emissions. On the other hand, it can be argued, that industries have to change the fuel and energy sources used in their production processes towards 2050 to be a part of an energy system with an increasing amount of renewable energy sources and to comply with the national energy policy goals. In this case, excess heat can be considered to have no CO_2-emissions. Even though it can be discussed, if excess heat is an energy source with CO_2-emissions, the thesis takes the position, that it is beneficial to use excess heat from industries and their processes as a fuel in the Danish energy system instead of discharging the excess heat and letting an energy source go to waste. Furthermore, as previously mentioned, excess heat is an energy source included in plans and strategies for the transition of the Danish energy system, which argues for excess heat playing a role in the future Danish energy system [Mathiesen et al., 2015; Energistyrelsen, 2014a,b]. In addition to this, the Energy Agreement from 2018 includes regulative changes, that promotes the use of excess heat in the Danish energy system. This furthermore emphasises a political incentive to use excess heat as an energy source in the replacement of fossil fuels in the Danish energy system in relation to reaching the 2050-goal and the 2030-goal.

In 2018, the use of excess heat externally in district heating was about 4 PJ corresponding to about 3% of the total amount of district heating in the Danish energy system [Energistyrelsen, 2018b]. The Climate Partnership of energy-intensive industry states in the partnerships' final reporting that the potential of using external excess heat in the Danish energy system is about 12 PJ in total, where 8,5 PJ derive from energy-intensive industry [Partnerskab for energitung industri, 2020; Ingeniøren, 2020]. The Climate Partnership of energy-intensive industry is one of the 13 Climate Partnerships[4] made in collaboration with the current Danish Government[5].

As stated above, excess heat as an energy source is defined as a part of the replacement of fossil fuels in the Danish energy system and with that in mind, the current use of 4 PJ can seem puzzling when the potential for the use of excess heat shows to be about 3 times higher. Looking at this, the initial problem of the thesis appears as it can be questioned, why excess heat is not used to the potential that it shows to have?

2.3 Context of Excess Heat

With a point of departure in the initial problem of the thesis, the Problem Analysis includes an investigation of the context of excess heat, and the context of excess heat included in the thesis embraces debates about excess heat and comprises regulatory and technical conditions together with contractual conditions and agreements related to the utilisation of excess heat.

In recently published articles, the role of excess heat and the interaction of excess heat in an energy system with renewable energy sources are debated. In the article *"Klimaminister: Grøn energi fjerner klimaeffekten af energieffektiv overskudsvarme"*, the current Danish Minister of Climate, Energy and Utilities, Dan Jørgensen, states that due to the expected levels of renewable energy sources in the Danish energy system in 2030 *"[...] Increased use of excess heat will as a result primarily replace biomass and other renewable energy sources and has for that reason only a limited effect on the CO_2-emission in Denmark."* [Translated from Danish] [Ingeniøren, 2020]. The statement from the Minister shows, that the role of excess heat in the Danish energy system

[4]Translation of the Danish word: Klimapartnerskaber

[5]The focus of the Climate Partnerships is to collaborate on how the Danish business sector can contribute to the reduction of CO_2-emissions and as a result, the 13 Climate Partnerships give their view on the initiatives necessary to achieve this [Regeringen, 2019; Dansk Energi, n.d].

is discussed. In line with the statement from the Minister, it can be discussed, if excess heat will play a minor role in a future Danish energy system relying on renewable energy sources, which can lead to the question of the relevance of increasing the use of excess heat in the energy system. Participating in the debate about excess heat is also the current Danish Minister of Taxation, Morten Bødskov, having the same perspective on excess heat as the Minister of Climate, Energy and Utilities: *"The potential of excess heat replacing fossil fuels is decreasing over time. The effects on* CO_2*-emissions with an increased use of excess heat are thus minor towards 2030"* [Translated from Danish] [Skatteministeriet, 2020c].

However, as stated in Section 2.2 the strategy of the replacement of fossil fuels in the Danish energy system includes implementation of energy efficiency initiatives and in relation to this, it can be argued that an effective energy system is wanted. The Danish Ministry of Taxation points out in the report *Afgifts- og tilskudsanalysen på energiområdet - Delanalyse 5 - Nyttiggørelse af overskudsvarme*, that using excess heat is a "double use of energy" and that, *"this double use of energy will result in improved energy efficiency, as overall less energy will be utilised"* [Translated from Danish] [Skatteministeriet, 2018,p. 5]. Considering this, an effective energy system can be assumed to involve using excess heat and be of importance for an energy system to be energy effective. This shows another perspective on the role of excess heat in a future Danish energy system. In continuation of this, An opposing argument to the statements from the Ministers is also made by professor Henrik Lund from Aalborg University: *"It is true that we expect 100% renewable energy in 2030 but that is among other things due to the fact that we are making use of the excess heat from the industry including the data centres."* [6] [Translated from Danish] [Ingeniøren, 2020]. This statement argues for the use of excess heat as being a part of the strategies for the replacement of fossil fuels in the Danish energy system alongside the integration of renewable energy sources and energy efficiency initiatives.

The above-mentioned statements show, that different perceptions of the role of excess heat in the Danish energy system seem to exist and result in a debate, which can be assumed to maybe be one of the reasons for excess heat not being used at the potential that it shows to have. This debate about the role and relevance of excess heat in the Danish energy system can also be considered not to increase the focus on using excess heat, which might also be a reason for the difference in the amount of excess heat used and the potential of it.

Another factor often considered to impact the utilisation of excess heat is the regulatory condition of the tax on excess heat. The tax on excess heat is imposed on the excess heat produced at industries, however there are different circumstances under which the tax is applied: [Skatteministeriet, 2018]

- The tax on excess heat applies, when the excess heat from a production process in an industry is used for space heating.
- The tax on excess heat does not apply, when the excess heat from a production process in an industry is used for process heat.
- The tax on excess heat does not apply, when the excess heat from a space heating in an industry is used for process heat.
- The tax on excess heat does not apply, when the excess heat from a space heating in an industry is used for space heating.
- The tax on excess heat does not apply, when the excess heat is produced by renewable energy source or by the use of biomass.

[6] In the article, the 100% renewable energy in 2030 refers to the electricity sector and the district heating system [Ingeniøren, 2020].

The different circumstances, under which the tax is applied, are rooted in a difference in the energy taxes[7] paid in relation to the fuel used for production and whether the fuel is used to produce space heating or in a process. This is related to the fact that an allowance[8] of energy taxes paid for the use of fuels to process purposes exists, whereas fuels used for space heating are imposed to energy taxes [Skatteministeriet, 2018]. No tax on excess heat exists, when it is produced by renewable energy sources and biomass as these are exempted from tax payments [Skatteministeriet, 2018].

Recently, the tax on excess heat has been changed, and the change has resulted in a discussion. In March 2019, different political parties in the Danish Parliament settled on the *Agreement on increased use of excess heat*[9] with the purpose of increasing the use of excess heat by simplifying the regulations regarding the use of excess heat [Skatteministeriet, 2019]. As a part of this, the agreement proposes changes regarding the tax on excess heat and was in February 2020 enacted by law [Skatteministeriet, 2019; Folketinget, 2020]. Overall, the changes in the tax on excess heat involve going from a tax levied as a percentage of value to instead having a fixed tax on excess heat per produced amount of excess heat [Skatteministeriet, 2019]. In addition to this, a reduced tax for industries with a certification is also introduced [Skatteministeriet, 2019].
Below, Figure 2.3 illustrates the specifications of the newly enacted law on excess heat, where the new rates of the tax on excess heat are included.

Newly Enacted Law on Excess Heat: (will be evaluated after 2 years)

- Fixed tax on excess heat: 24,5 DKK/GJ (90 DKK/MWh)
- Tax on excess heat with a certification: 9,8 DKK/GJ = (36 DKK/MWh)
  (The terms for the certification are not determined, but the ISO-50001 standard about energy management is mentioned when referring to the certification of an industry)

- In the newly enacted law on excess heat, it is decided as possible to transfer the tax on excess heat to the receiver of the excess heat, if the excess heat is delivered for free from an industry.
- The possibility of a price regulation on excess heat is mentioned but not yet defined in the newly enacted law. The mentioned purposes of the price regulation are: To create an incentive at the industries to utilise excess heat, to avoid false excess heat and to ensure a cheap heat price for consumers.
- The newly enacted law on excess heat transfers the exemption from the tax on excess heat at production units implemented before 1995.
- In the newly enacted law on excess heat, it is determined, that existing projects with excess heat can continue on the former regulation related to excess heat in a period of maximum 15 years.
- The newly enacted law re-enacts the following payment of the tax on excess heat, when excess heat is produced on the basis of a cooling process:
  - The tax on excess heat is paid in relation to the amount of excess heat produced, that exceeds 3 times the electricity consumption related to the production of excess heat on the basis of a cooling demand.

Figure 2.3: *Illustration of the newly enacted law on excess heat. The information shown in the figure is from: [Skatteministeriet, 2019; Dansk Fjernvarme, 2019b].*

[7] Translation of the Danish word: energiafgifter
[8] Translation of the Danish word: godtgørelse
[9] Translation of the Danish name of the agreement: *Aftale om øget udnyttelse af overskudsvarme*

The agreement has since the settlement been object for a discussion regarding both the purpose of the agreement and the expected outcome of it. Opponents to the change in the tax count different actors such as the Danish District Heating Association, district heating companies, the National Association of Local Authorities in Denmark, and the Confederation of Danish Industry [Skatteministeriet, 2019]. As the purpose of the change of the tax is stated to be to simplify the regulation and to ease the tax burden for the use of excess heat, opponents of the change are of the opinion that the change of the tax will lead to the exact opposite [Ingeniøren, Gridtech, 2020; Altinget, 2019]. In addition to this, the opponents states, that the tax rate is too high and in connection to this, it is argued that the tax only exists to keep the state proceeds[10] of the tax, that there should be no tax on excess heat at all, and that the tax on excess heat is a barrier for the implementation of projects of excess heat. [Ingeniøren, Gridtech, 2020; Dansk Fjernvarme, n.d]. In relation to the opinion of no tax on excess heat, it is worth noting that the reasoning behind the tax on excess heat is to ensure an energy effective use of excess heat and a protection rule [11] against false excess heat.

False excess heat is one of two terms used in relation to excess heat. The term "real" excess heat describes excess heat, that occurs from an effective production process in an industry, whereas "false" excess heat covers excess heat, which is produced with the purpose of generating a surplus of heat by using extra fuel in a production process or excess heat that emerge by organising an inefficient process [Energi-, Forsynings- og Klimaministeriet, 2017; Skatteministeriet, 2018]. False excess heat is not preferred, as it can be argued to be an inefficient use of fuels and energy sources by producing heat through different types of industries and their production processes instead of using the fuels and energy sources directly to produce a heat output in the energy system [Energi-, Forsynings- og Klimaministeriet, 2017]. Relating this to the debate about the changes in the tax on excess heat, it can be argued that a tax on excess heat is necessary in order to ensure energy efficiency in the Danish energy system. On the other hand, it can be assumed that no industry will organise an inefficient process as this can be presumed to increase the costs of a production in an industry unnecessarily. Returning to the debate about the tax on excess heat, opponents to the tax are of the opinion, that false excess heat does not exist [Skatteministeriet, 2019].

It can be emphasised, that the tax on excess heat is subjected to a discussion as the tax results in expenses for the industries, when working with projects about the utilisation of excess heat, and for that reason, the tax rate is of importance.

Reflecting on the tax on excess heat and the discussion of the tax, the perception of false excess heat can be argued to create conditions, that makes it challenging to use excess heat in the Danish energy system, as the tax on excess heat is in place in order to avoid production of false excess heat, which leads to expenses in projects about excess heat.

The debate about the tax on excess heat can illustrate that the use of excess heat is challenged, as different opinions about the tax and its purpose are present. The discussion of the tax can be considered to strengthen the understanding that the tax is part of the reasons to why excess heat is not used at its full potential. Whether the tax is the reason for excess heat not being used at its full potential or not can be discussed, but other conditions in the context of excess heat having an impact on utilisation of excess heat have also shown to be present though maybe not discussed comparable to the debate about the tax on excess heat.

[10] Translation of the Danish word: provenu
[11] Translation of the Danish word: værnsregel

Different reports and actors suggest other conditions in the context of excess heat than the tax on excess heat as challenging in terms of the utilisation of excess heat.

The Ministry of Taxation finds in the report *Afgifts- og tilskudsanalysen på energiområdet - Delanalyse 5 - Nyttiggørelse af overskudsvarme* that the tax on electricity to heat, the electricity tariffs and PSO-tax can be considered barriers for the utilisation of excess heat and not specifically the tax on excess heat [Skatteministeriet, 2018; Klima, Energi- og Forsyningsministeriet, 2017]. Both the tax on electricity to heat, electricity tariffs and the PSO-tax are related to a use of electricity, which can be relevant in the utilisation of excess heat, when the excess heat emerges from a cooling process or a booster heat pump is required. On Figure 2.4, the tax on electricity to heat, electricity tariffs and the PSO-tax are included together with a description of these and the different tax rates.

Tax on Electricity to Heat:

The tax on electricity to heat applies, when electricity is used in a production of heat.

- Tax on electricity to heat: 210 DKK/MWh (tax rate in 2020)

In the newly enacted law on excess heat, a distribution of the tax on electricity to heat is defined between the production of cooling and the production of heat, when excess heat is produced on the basis of a cooling demand:

- The electricity consumption related to the production of excess heat is the produced excess heat divided by 3, but maximum the actual electricity consumption. This means, that the tax on electricity to heat is paid in relation to this amount. The rest of the electricity consumption for the tax payment is assigned to the production of cooling.

Electricity tariffs:

Electricity tariffs are paid in relation to a consumption of electricity, and the electricity tariffs are paid to Energinet and local electricity suppliers.
The electricity tariffs include:

- Transmission tariffs: 5,3 øre/kWh (53 DKK/MWh)
- System tariffs: 4,4 øre/kWh (44 DKK/MWh)
- Distribution tariffs: 6,745 øre/kWh (67,45 DKK/MWh)

PSO-tax:

The PSO-tax is paid, when using electricity and the tax is paid to support research and projects about renewable energy sources.

- The PSO-tax: 39,75 DKK/MWh (average tax rate in 2019)

Currently, the PSO-tax is subjected to a gradual phase out in order to become a permanent payment through the Act of Finance in 2022.

Figure 2.4: *Illustration of electricity costs with descriptions of these and their tax rates. The information shown in the figure is from: [Klima-, Energi- og Forsyningsministeriet, 2020a,b] [Skatteministeriet, 2020b] [Klima-, Energi- og Forsyningsministeriet, 2016] [Skat.dk, 2020] [Energinet, 2020] [Konstant, 2019a,b] [Energistyrelsen, 2018a, 2019a,b,c]*

With the findings of the tax on electricity to heat, the electricity tariffs and PSO-tax being possible barriers in projects about excess heat in the above-mentioned report, it can be indicated that taxes and tariffs in relation to electricity can be considered to influence the implementation of projects concerning excess heat.

The Danish District Heating Association describes technical conditions acting as possible barriers when looking at establishing projects about utilisation of excess heat [Dansk Fjernvarme, n.d]. The barriers are stated as conditions that can be present at the industry producing excess heat or the external receiver of excess heat such as district heating systems. This relates to factors such as the amount of and the temperature of the excess heat produced by an industry compared with the receiver's ability to use and capacity to receive the excess heat and the desired temperature of the excess heat at the receiver [Dansk Fjernvarme, n.d]. These conditions are barriers for implementing projects about excess heat, when they do not comply with each other [Dansk Fjernvarme, n.d].

Another technical condition outlined by the Danish District Heating Association, which can be a barrier and influence the implementation of projects about excess heat, is the location of an industry producing excess heat in relation to the location of the receiver of the excess heat [Dansk Fjernvarme, n.d]. Connecting excess heat from an industry to a receiver is attached with an implementation of technical installations such as e.g. transmission and distribution pipes. With the distance described as a barrier by the Danish District Heating Association, this can be assumed to be related to the laying out of pipe lines for the transmission of the excess heat, which is associated with expenses that will increase the further the distance between the industry producing excess heat and the receiver.

Additionally to the regulatory and technical barriers described above in connection to projects about excess heat, the Danish District Heating Association highlights in the report *Inspirationskatalog - 10 eksempler på samarbejde mellem fjernvarme og industri*, that challenges in relation to the utilisation of excess heat are also connected to contractual agreements needed to be obtained between an industry and district heating company. Below, types of contractual agreements, that can be made between industries and receivers are shown: [Grøn Energi, 2020]

- The industry producing the excess heat can own and pay the costs related to the utilisation of the excess heat and establishment of the project.
- The receiver has the ownership and pays the costs connected to the utilisation of the excess and the establishment of the project.
- The industry and receiver have a joint ownership and shares the payments of the costs for the utilisation of the excess heat and the establishment of the project.
- A third part can own and pay the costs in relation to the use of the excess heat and the establishment of the project.

It can be assumed, that the Danish District Heating Association mentions contractual agreements as challenges in projects about excess heat, because disagreements between the industry producing excess heat and the receiver in relation to costs and ownership structures can be perceived as barriers, as it can influence projects about excess heat being put aside.

In addition to the agreements on ownership and cost payments between the industry and receiver, agreements on a possible price for the excess heat also have to be made. In the report *Afgifts- og tilskudsanalysen på energiområdet - Delanalyse 5 - Nyttiggørelse af overskudsvarme*, the Ministry of Taxation describes, that when looking at a district heating company as a receiver of excess heat, the price regulation[12] defined in Danish Heat Supply Law can be a barrier, as it sets some boundaries for what the district heating company is able to pay for the excess heat from an industry [Skatteministeriet, 2018]. This is e.g. connected to the principle of substitution[13]

[12]Translation of the Danish word: Prisregulering

[13]Translation of the Danish word: Substitutionsprincippet.

related to the price regulation in the Danish Heat Supply Law. Furthermore, with district heating companies as receivers, the Danish District Heating Association describes, that disputes can appear in some cases as e.g. industries and district heating companies can be argued to have different positions towards depreciation of investments and perception of what can be considered feasible in terms of economy [Dansk Fjernvarme, 2019a].

Consequently, this shows that contractual conditions and agreements between the industry and the receiver of excess heat can be viewed as having an impact on the implementation of the utilisation of excess heat.

By looking at the context of excess heat, a debate about excess heat as an energy source in the Danish energy system is present and barriers and challenges can be understood to influence the utilisation of excess heat, which can be related to why excess heat is not used at the full potential that it shows to have. The barriers described are rooted in regulatory and technical conditions as well as contractual conditions and agreements. Reflecting on this, determining one main barrier for the utilisation of excess heat can seem difficult. The different barriers indicate that maybe the way to use the full potential of excess heat is not found in changing only one of the barriers. This leads to considerations of the necessity to change the overall way that excess heat is used currently. With that in mind, it can be argued that it can be a possibility to change the approach towards the utilisation of excess heat.

It can be stressed, that the current approach related to the use of excess heat is connected to a somehow traditional way of using excess heat which often equals to bilateral connections. Bilateral connections are, when an industry producing excess heat provides excess heat to one receiver of excess heat. This means that the industry and the receiver, often being district heating companies, enter specific agreements for this one connection to the utilisation of excess heat. With bilateral connections being the approach typically applied in the utilisation of excess heat, it can be assumed, that the above-mentioned barriers occur in relation to bilateral connections. For that reason, the thesis investigates an additional approach to the utilisation of excess heat.

The following section introduces the case study of the thesis, and the purpose of including the case is to investigate a different take and an additional approach on the utilisation of excess heat in the Danish energy system.

2.4 Case: Exchange of Excess Heat at the Port of Aarhus

The case study has a point of departure at the port of Aarhus, and the port of Aarhus is located in the town of Aarhus and is characterised as an industrial port.

Aarhus Municipality has a goal of achieving CO_2-neutrality in 2030 and the goal was defined already in 2007 by the City Council in the municipality of Aarhus [Kommune et al., 2018] [Aarhus Kommune, 2016a]. In the climate plan *Klimaplan 2016-2020* and the report *På vejen mod fossilfrihed - Klimastrategi for Aarhus*, Aarhus Municipality appoints a set of work areas for the industries in the municipality. These work areas include e.g. a focus on phasing out fossil fuels and establishing an efficient use of resources related to the industries [Aarhus Kommune, 2016a,b]. Based on that, it can be argued, that Aarhus Municipality recognises industries to be of importance in relation to reaching the goal of CO_2-neutrality in 2030 in the municipality. With the case study of the thesis being connected to the port of Aarhus, it is worth noting, that Aarhus Municipality is interested in the port to become a non-regulatory zone[14] [Meeting1, 2020].

[14]Translation of the Danish word: Regulatorisk frizone

Non-regulatory zones are mentioned in the Energy Agreement from 2018, and non-regulatory zones are emphasised as zones, where new solutions related to the transition of the energy sector can be tested [Energi-, Forsynings- og Klimaministeriet, 2018; Vækstteam for grøn energi- og miljøteknologi, 2019]. The fact that Aarhus Municipality wants the port of Aarhus to become a non-regulatory zone can be argued to indicate an initiative to make the port a place, where it is possible to ease some of the currently defined regulatory conditions in order to experiment with and develop projects, that can support the achievement of CO_2-neutrality in 2030 in the municipality.

Aarhus Havn[15] describes in the report *Reportagen - Port of Aarhus*, that Aarhus Havn wishes to establish a "sustainable port" at the port of Aarhus and contribute to reaching the goal of CO_2-neutrality in 2030 defined by Aarhus Municipality [Aarhus Havn, 2019]. This indicates, that Aarhus Havn is aware of the fact that the industries placed at the port have a role to play in relation to achieving CO_2-neutrality in 2030 in the municipality of Aarhus.

The focus on industries by Aarhus Municipality and Aarhus Havn in relation to reaching the goal of CO_2-neutrality in 2030 can be argued to have been a facilitating factor in the establishment of the project *Smart Energi Aarhus Havn*. The project *Smart Energi Aarhus Havn* is a project with an interdisciplinary collaboration between Aarhus Municipality, Aarhus Havn, Aarhus Vand[16] and the industries at the port of Aarhus, and the project was initiated in 2019 [ErhvervPlus, 2019; Sekretariat for Klima og Grøn Omstilling (Aarhus Kommune), 2019, 2020]. The project focuses on the industries placed at the port of Aarhus, and the aim of the project is to create an efficient use of energy and other resources by arranging and organising flows of resources and exchanges of energy between the industries at the port [ErhvervPlus, 2019; Transition, 2019].

Work has already carried out in connection to the project *Smart Energi Aarhus Havn* and the work has evolved around mobilising the industries at the port and attract their interest to participate in the project [Meeting3, 2020]. The energy consulting firm Transition has been the main actor in the mobilisation of the industries, and has conducted interviews with industries at the port of Aarhus to determine the motivating and demotivating factors for the industries to participate in the project *Smart Energy Aarhus Havn* [Transition, 2019]. Furthermore, Transition has also identified potential resource and energy exchanges between industries placed at the port [Transition, 2019; Meeting3, 2020].

On the basis of the project *Smart Energi Aarhus Havn*, a pilot project about an exchange of excess heat between the industries at the port has emerged. The focus on excess heat in the pilot project has developed as excess heat is an energy exchange, that can be established between industries at the port. Furthermore, the pilot project focuses on excess heat to address a possible exchange between the industries at the port to make a resource flow and an energy exchange tangible and more specific for the industries placed at the port [Meeting1, 2020].

In the project *Smart Energi Aarhus Havn*, Aarhus Municipality is represented by Uffe Kristensen, who works at The Secretariat of Climate and Green Transition, and in an interview carried out as a part of the thesis, Uffe Kristensen points out the thoughts behind working with the pilot project about excess heat at the port of Aarhus. Uffe Kristensen describes in the interview, that excess heat is available at the port, and until now, utilising the excess heat from the industries at the port has been connected with challenges when looking at the use of the excess heat from the

[15] Aarhus Havn is a company owned by Aarhus Municipality but the company is self-governing [Aarhus Havn, n.d]. Note: There is a difference between Aarhus Havn as a company and the area/location of the port of Aarhus

[16] Aarhus Vand is the water company in Aarhus Municipality [Aarhus Vand, n.da,n]

perspective of bilateral connections between the individual industries and the district heating company in Aarhus [Interview with Uffe Kristensen, 2020]. Uffe Kristensen states, that this has resulted in the fact that the potential of excess heat at the port of Aarhus is not utilised, currently. Anne Zachariassen, Chief Operating Officer at Aarhus Havn, highlights in an interview conducted as a part of the thesis, that projects about the utilisation of excess heat from industries at the port have been investigated before, but failed due to high costs and complex legislation on the area concerning excess heat [Interview with Anne Zachariassen, 2020]. Because of the challenges related to the use of excess heat from the industries at the port, Uffe Kristensen in the interview talks about rethinking the approach associated with the use of excess heat and bilateral connections. In this connection, Uffe Kristensen mentions, that the pilot project about excess heat emerging from the project *Smart Energi Aarhus Havn* rethinks the utilisation of excess heat by organising the use of excess heat based on an exchange of excess heat between the industries at the port [Interview with Uffe Kristensen, 2020]. This approach is different from the individual bilateral connections to the district heating company in the use of excess heat from the industries at the port, as it focuses on utilising the excess heat from the industries on the basis of a collaboration between the industries and an establishment of a common system and exchange of excess heat between the industries [Interview with Uffe Kristensen, 2020]. By that, it can be argued, that the pilot project experiments with a system way of thinking the use of excess heat compared to the approach about bilateral connections.

As a part of the pilot project, 12 industries at the port of Aarhus have shown an interest in participating in the exchange of excess heat. This means, that the thesis works with and analyses the pilot project about excess heat by designing a common system for the exchange of excess heat among the 12 industries at the port.

Figure 2.5 presents an illustration of different potential models of the exchange of excess heat at the port of Aarhus. The black highlighted line describes, that the exchange of excess heat exists in a common system, where the excess heat from the industries producing excess heat is fed into this common system and from which the excess heat also is taken to meet the heat demands at the industries. The input of excess heat to the common system and utilisation of excess heat from the exchange is marked by the directions of the black arrows on Figure 2.5.

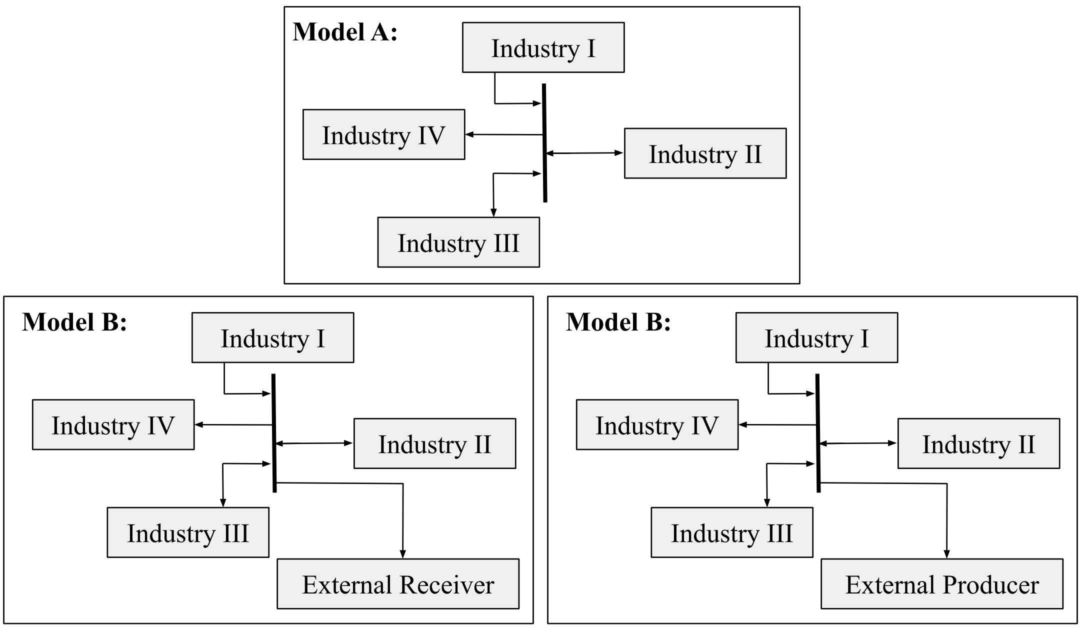

Figure 2.5: *Illustration of different potential models of the exchange of excess heat at the port of Aarhus. The number of industries illustrated at the figure is an example.*

Model A shows a design of an exchange between the industries at the port of Aarhus, where the excess heat is delivered by and used by the industries participating in the exchange. Model B illustrates a design of the exchange of excess heat, where an exchange of excess heat occurs between the industries participating in the exchange but also contains an allocation of excess heat to an external receiver, due to a surplus of excess heat being present after the exchange among the industries. Model C presents a design of the exchange of excess heat at the port, where not enough excess heat is available from the industries producing excess heat in the exchange to meet the heat demands at the participating industries, and because of that, it is necessary to organise the exchange with an input of heat from an external producer to be able to meet the heat demands at the industries.

Looking at the models included in Figure 2.5 and the descriptions of these, the design of the exchange of excess heat between the industries at the port depends on the amount of excess heat being produced by the industries in the exchange.

The models illustrate the system way of thinking the use of excess heat by having a focus on using excess heat between the industries and/or arranging an allocation of excess heat or a reception of heat jointly.

By including Figure 2.6, which shows an illustration of a bilateral connection between an industry and a district heating company, it can be observed how the system way of thinking the use of excess heat in the pilot project deviates from bilateral connections.

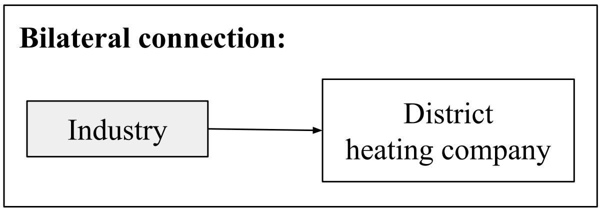

Figure 2.6: *Illustration of a design of a bilateral connection between an industry and a district heating company.*

In the thesis, the focus is put on the pilot project and the exchange of excess heat between the 12 industries interested in being a part of the exchange to analyse and experiment with a common system and a system way of thinking the use of excess as an additional approach to the use of excess heat.

Summary

Based on the Problem Analysis, the thesis views excess heat as an energy source, that can be used in the replacement of fossil fuels in the Danish energy system and by that being an energy source that can support the achievement of the 2050-goal and 2030-goal. The Problem Analysis outlines, that excess heat is not used at its full potential in the Danish energy system currently. In relation to this, the Problem Analysis has investigated the context of excess heat and presented regulatory and technical conditions together with contractual conditions and agreements, which are described to have an impact on project concerning excess heat and are perceived as barriers for the use of excess heat. Because of the difference in the conditions perceived as barriers, it can be assumed to be difficult to determine one main barrier for excess heat not being used to the potential that it shows to have. In the thesis, bilateral connections are viewed as the traditional approach connected to the use of excess heat and can be attached with the barriers understood to be present in project about the utilisation of excess heat. For that reason, the thesis has a focus on an additional approach related to the use of excess heat through the pilot project about excess heat at the port of Aarhus.

The thesis focuses on and works with the pilot project at the port of Aarhus to analyse, if a common system and a system way of thinking the use of excess heat between the industries at the port can be designed and function as an additional approach to the utilisation of excess heat.

3 Problem Formulation

On the basis of the Problem Analysis, the thesis analyses an additional approach in relation to the utilisation of excess heat through the case study of the pilot project about excess heat at the port of Aarhus. The pilot project concerns an exchange of excess heat between 12 industries placed at the port and working with the pilot projects entails designing a common system for the exchange of excess heat and experimenting with a system way of thinking the use of excess heat between industries.

3.1 Research Question

How can a common system of the exchange of excess heat between the industries at the port of Aarhus be designed, and how does regulatory and technical conditions as well as contractual conditions and agreements impact the system way of thinking the use of excess to be an additional approach in the utilisation of excess heat?

In the thesis, the design of the exchange of excess heat at the port of Aarhus is modelled in energyPRO, and the design is constructed by a set of choices and assumptions, which are further elaborated on in the analysis of the thesis. The design of the exchange of excess heat in energyPRO is technical, but the design of the exchange has a point of departure in the context of excess heat with the regulatory and technical conditions together with contractual conditions and agreements, and therefore the model of the design in energyPRO also entails e.g. taxes and tariffs connected to the utilisation of excess heat, which are also analysed through the model of the exchange of excess heat.

The regulatory and technical conditions as well as contractual conditions and agreements referred to in the research question leads back to the different conditions described in the Problem Analysis in the context of excess heat in relation to the utilisation of excess heat, as these are perceived to influence and challenge the implementation of projects about excess heat.

Sub questions

1. What is a possible design for the exchange of excess heat between the industries at the port of Aarhus?
2. How robust and sensitive is the design of the exchange of excess heat?
3. What regulatory and technical conditions as well as contractual conditions and agreements exist for the implementation of the exchange of excess heat at the port of Aarhus and in relation to these conditions, which changes are needed?

3.2 Scope and Delimitation

The scope of the thesis is excess heat, as excess heat is viewed as an energy source in the thesis, that can be used to replace fossil fuels in the Danish energy system and support reaching the 2050-goal and 2030-goal. Excess heat is not considered as an alternative to the integration of renewable energy sources in the replacement of fossil fuels in the Danish energy system. But the thesis puts weight on the fact that excess heat can interact in collaboration with renewable energy sources in the energy system by arguing, that excess heat is an available energy source that just as well can be used. For that reason through the pilot project about excess heat at the port of Aarhus, the thesis analyses an additional approach to the utilisation of excess heat with the purpose of assessing, if a common system and system way of thinking the use of excess heat can be viewed and function as an additional approach in the utilisation of excess heat.

The case study of the thesis emerges from the project *Smart Energi Aarhus Havn*, and the project *Smart Energi Aarhus Havn* involves working with different kinds of resource flows and energy exchanges at the port of Aarhus. With the scope of excess heat in the thesis, the thesis is delimited from other resource exchanges between the industries at the port and focuses on the pilot project concerning the exchange of excess heat between the 12 industries at the port of Aarhus.

As the work with and development of the common system and exchange of excess heat at the port of Aarhus is presented as an additional approach to the use of excess heat in the thesis, the thesis deals with how to design the exchange of excess heat between the industries at the port. In relation to designing and analysing the exchange of excess heat among the 12 industries at the port, it has not been possible to obtain actual data and information about e.g. heat demands and production of excess heat from the industries. This can be assumed to have had an impact on the scope and delimitation of the thesis, as it can be presumed that the actual data and information could have provided information, that could be a part of shaping the scope of the thesis.

In the analysis of the design of the exchange of excess heat, the thesis considers the regulatory and technical conditions as well as contractual conditions and agreements described in the Problem Analysis. However, in relation to the technical conditions, the thesis does not entail a detailed examination of the grid and pipe lines for the transport and distribution of the excess heat between the industries, but the transport and distribution of the excess heat can be argued to be relevant for the design. The transport and distribution of the excess heat between the industries is included in the thesis by assuming, that it is possible to use the district heating grid already implemented at the port by the district heating company in Aarhus, AffaldVarme Aarhus (AVA). An illustration of the district heating grid at the port is shown in Appendix C. Related to the use of the implemented grid at the port, the thesis is delimited from further considerations in relation to a potential purchase of the grid and possible implementations of more service pipes.

In the analysis of the robustness and sensitivity of the design of the exchange of excess heat at the port, many changes can be performed in order to describe the sensitivity of the model designed of the exchange. The thesis incorporates many changes and the focus of carrying out these changes in the design is to assess some general changes and their impact on the design, which means that variations in the changes are not included.

The analysis of the exchange of excess heat at the port of Aarhus is carried out from the perspective of establishing, if it is possible to design and arrange an exchange of excess between industries. This means, that the thesis does not analyse the design of the exchange of excess heat and common system from the perspective of the industries and because of that, the thesis does not e.g. include concrete calculations of business economy at the industries in relation to the use of excess heat from their production processes. The thesis does not analyse the exchange of excess heat from the perspective of the industries, as the focus in the thesis is oriented about utilising an available energy source in terms of excess heat, which means that a focus is rather put on a system way of thinking the utilisation of excess heat.

Research Design 4

The Research Design of the thesis is illustrated in Figure 4.1.

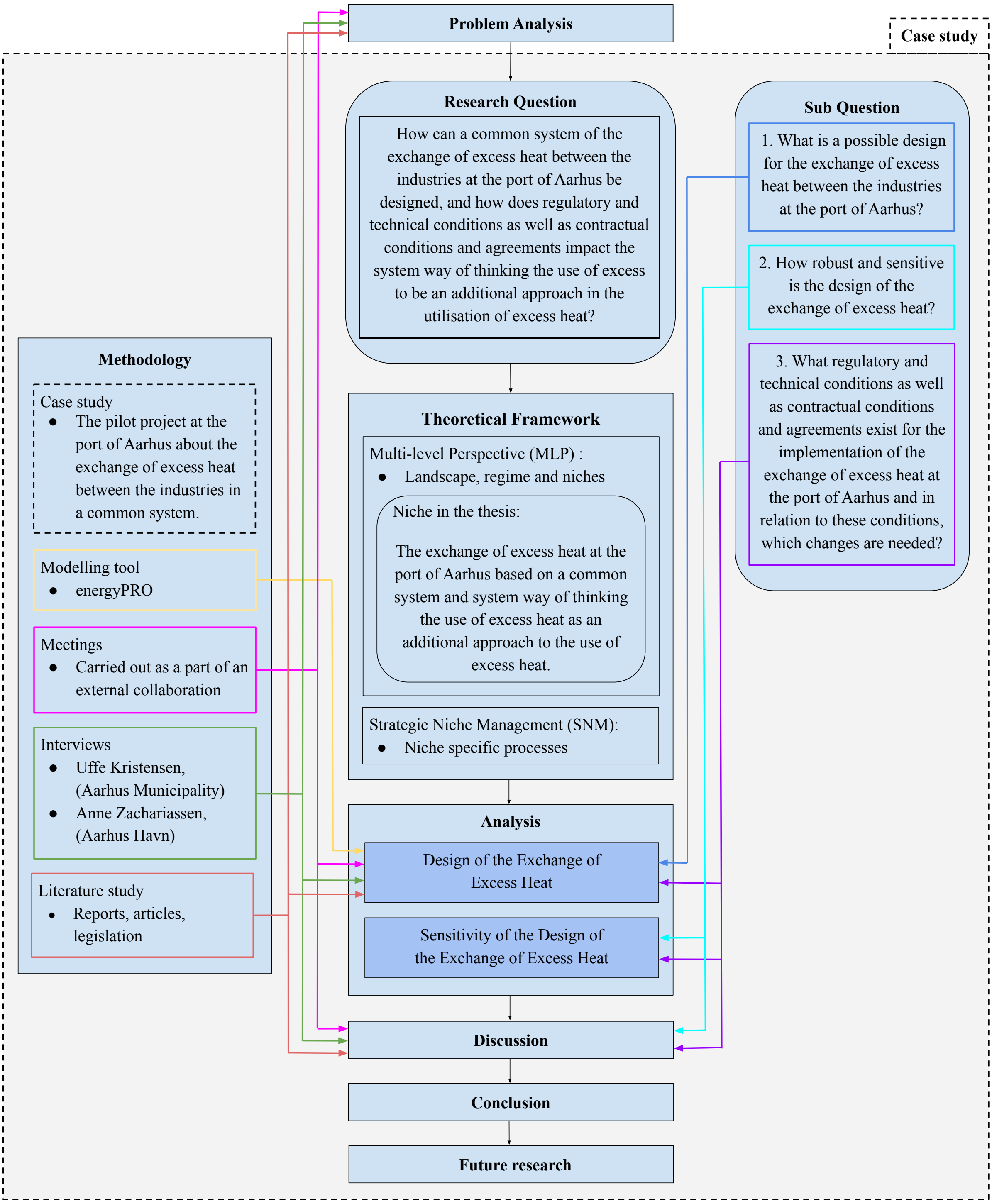

Figure 4.1: *Illustration of the Research Design.*

Figure 4.1 shows the interactions of the different elements in the thesis and gives an impression of the content and structure of the thesis. The Problem Analysis describes the problem of the thesis and is for that reason followed by the research question to which the sub questions are formulated and prepared. The sub question are listed next to the research question in the figure, and the function of the sub question are to guide the answering of the research question. On Figure 4.1, the use of the sub questions in the thesis is also illustrated. A Theoretical Framework is constructed in the thesis and provides a theoretical description and understanding of the problem defined in the research question. The Theoretical Framework results in considerations to be included in the analysis and discussion of the thesis, and therefore the Theoretical Framework is constructed before the analysis and discussion. The Methodology of the thesis is also presented in Figure 4.1 and arrows indicate where the different methods are applied. A dotted line surrounding the elements in the figure shows that the thesis is conducted as a case study. The results of the analysis in the thesis lead to the discussion and conclusion of the thesis. As also included in the research design on Figure 4.1, the thesis also entails reflections on future research connected to the thesis.

Theoretical Framework 5

In the thesis, the Theoretical Framework is formed in relation to the research question, and by including the Multi-level Perspective and Strategic Niche Management, the Theoretical Framework of the thesis is created.

When working with a defined problem, it can be argued necessary to establish knowledge and understanding of the settings around the research question to carry out an analysis of the defined problem [Hvelplund, 2001]. The Multi-level Perspective (MLP) is included in the Theoretical Framework to conceptualise the settings in society in which the additional approach in the utilisation of excess defined in the research question interacts. MLP can be used to conceptualise the settings of the defined problem as MLP entails a set of structures, which describes interactions in society.

5.1 Multi-level Perspective (MLP)

The Multi-level Perspective (MLP) can be used as a theoretical viewpoint for analyses of the development and changes in society through socio-technical structures defined as: Landscape, regime and niches [Geels, 2011]. Figure 5.1 illustrates the socio-technical structures in MLP.

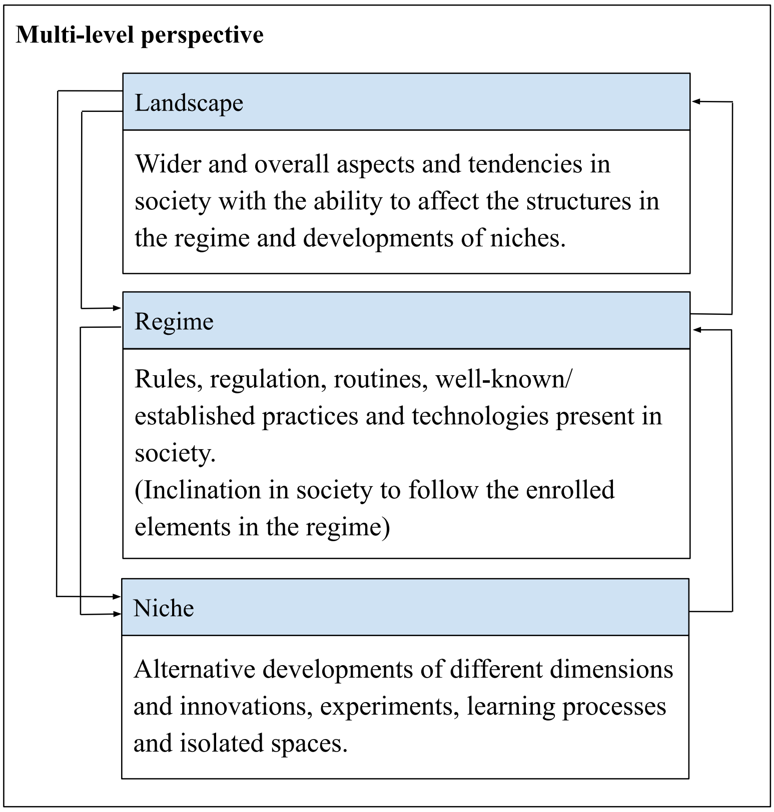

Figure 5.1: *Illustration of the Multi-level Perspective.*

In MLP, landscape is described as "wider exogenous" aspects, that have the ability to affect different kinds of developments in society [Geels, 2006]. By that, landscape can be understood to cover wider and overall tendencies in society. MLP highlights, that aspects and overall tendencies included in the defined landscape can impact the regime and the appearance of niches [Geels, 2006]. The ability of the landscape to influence the regime and developments of niches is marked on Figure 5.1 by the arrows going from landscape to regime and niche.

In MLP, the regime is defined as the socio-technical structure existing of e.g. the rules and determined regulation, inherent routines, well-known and established practices, perceptions and debates as well as technologies present in the society [Geels, 2011]. The elements included in the regime are in MLP considered stable and there is an inclination in society to follow the enrolled elements in the regime [Geels, 2006]. The enrolled elements in the regime can be disturbed and affected by the development of niches and it can lead to the regime having the opportunity to influence the landscape. On the other hand, the regime is also able to affect niches, as the regime can be argued to set limitations for the development of niches [Geels, 2006]. In Figure 5.1, arrows going from the regime to the landscape and niche illustrates this.

In MLP, niches are structures that present as alternatives and are as a result not a part of the regime. In MLP, niches are presented as structures of innovation, that are characterised as being experiments, learning processes, and development in different dimensions [Geels, 2006]. As niches are not a part of the regime, niches represent experiments and innovations, which are not present and accepted in relation to the enrolled structures in the current regime. With niches representing experiments and innovations, it can be understood, that niches are the drivers for transitions in society in MLP. For niches to provide a transition, niches have to become a part of the regime or influence the enrolled elements in the regime to the extent, that the niches either create a new regime replacing the existing one or the niches are accepted into the existing regime [Geels, 2006]. By that, it can be interpreted, that the focus of niches is to become a part of the regime in MLP. The entrance of a niche into the regime is illustrated by the arrow from niche to regime in Figure 5.1.

5.1.1 Landscape, Regime and Niche in the Thesis

In relation to the thesis, the description of the landscape, regime and niche is carried out on the basis of the focus on excess heat. This means, that the elements highlighted in the different socio-technical structures are related to excess heat and the research question containing the pilot project at the port of Aarhus.

With the landscape describing wider aspects in society, which can affect and steer developments, it can be argued, that with the focus on excess heat in the thesis, the landscape can be described to consist of broader tendencies such as climate changes, which affect developments in the energy system such as the replacement of fossil fuels. It can be emphasised, that these broader tendencies are expressed through the energy policy goals defined by the Danish Government; the 2050-goal and 2030-goal. Because of that, the national energy policy goals are defined to be a part of the landscape in the thesis. In addition to this, locally defined energy policy goals can also be stressed to reflect the broader tendencies in society in relation to climate change. For that reason, the 2030-goal of CO_2-neutrality in Aarhus Municipality and the vision of Aarhus Havn about making the port of Aarhus a sustainable port are determined as included in the landscape in the thesis. The national energy policy goals and the 2030-goal of Aarhus Municipality as well as the vision of a sustainable port in Aarhus are determined to constitute the landscape in the thesis, as the goals set a direction for developments both nationally and locally in society. In relation to this, it can be emphasised that the aspects defined to be a part of the landscape in the thesis has been the facilitating goals and visions for the development of the exchange of excess heat at the port of Aarhus, which further below, is determined as the niche in the thesis.

As the regime consists of elements such as regulation, inherent routines, debates and well-known practices, the regime can in the thesis be outlined to include the unfolding debates about excess heat and the described regulatory and technical conditions together with the contractual conditions and agreements connected to the use of excess heat. The well-known practice for the utilisation of excess heat inherent in the regime can be emphasised to be bilateral connections. Bilateral connections are entailed as the inherent approach for the use of excess heat in the regime, as bilateral connections are viewed as the traditional approach for the utilisation of excess heat in the thesis. As elements contained in the regime can impact activities of actors, and by identifying bilateral connections as the approach for the use of excess heat in the regime, it can be assumed, that actors involved with the use of excess heat such as industries and receivers of the heat as a routine will analyse the external use of excess heat with a mindset focusing on bilateral connections. Considering the description of the regime in the thesis, it can be argued, that the conditions described in the Problem Analysis which can influence projects about excess heat together with bilateral connections act within the structures of the regime.

In the thesis, the niche is defined as the pilot project about excess heat at the port of Aarhus. This is argued, as the pilot project includes an analysis of an exchange of excess heat between industries located at the port based a common system and system way of thinking the use of excess heat. Based on that, the exchange of excess heat at the port of Aarhus can be considered a niche as the system way of thinking the use of excess heat presents an additional approach to the utilisation of excess heat, and as exchanging excess heat in a common system is not a well-known practice in relation to the utilisation of excess heat in the regime. Considering this, the thesis views the exchange of excess heat between industries in a common system as an additional approach to the use of excess heat, which is outside the regime, currently. With the exchange of excess heat being outside the regime, the niche has to enter the regime to be recognised and accepted as an approach and become a practice in the use of excess heat. As the niche is about an additional approach to the use of excess heat, the purpose of the niche is not to overrule bilateral connections as an approach in the utilisation of excess heat but adding another approach to the use of excess heat from industries.

By using MLP to conceptualise the context of excess heat, the approach about using excess heat in a common system at the port of Aarhus is defined as a niche and through that, MLP is used to illustrate, that the additional approach to the utilisation of excess heat as a niche has to be accepted in the regime to be developed and considered as an additional approach in the utilisation of excess heat.

As the exchange of excess heat at the port of Aarhus is viewed as a niche in the thesis, Strategic Niche Management (SNM) is introduced, as it is concerned with how niches can be managed to become a part of the regime.

5.2 Strategic Niche Management (SNM)

In Strategic Niche Management, niches are understood to *"act as building blocks for broader societal changes"* [Schot and Geels, 2008,p. 537], and SNM deals with processes for niches to become a part of the regime [Schot and Geels, 2008]. This means, that SNM focuses on niches and is based on MLP with the three structures: Landscape, regime, and niche [Schot and Geels, 2008]. Due to this, the description and understanding of niches in SNM is equal to the one in MLP. This means, that in the thesis, the niche to be considered in relation to SNM is the pilot project about developing a common system and exchange of excess heat between industries at the port of Aarhus.

In SNM, it is central to deal with: *"how and under what circumstances is the successful emergence of a technological niche possible?"* [Schot and Geels, 2008,p. 540]. In the thesis, the emerging niche is not defined as a "technological niche" but instead a niche that experiments with an additional approach in relation to the use of excess heat, which is an already known energy source.

To establish a "successful" emergence and entrance of a niche in the regime, SNM includes niche specific processes. Among other things, a niche specific process mentioned in SNM involves articulation and expression of the visions behind the development of the niche, as it sets some expectations and a direction for the establishment of the niche. Articulation of the vision can also be stressed to function as a driver for the work related to the development of the niche and create an interest in the niche [Schot and Geels, 2008]. In addition to this, it is also emphasised as a part of the niche specific processes in SNM, that it can be considered a necessity to create a network/networks in order to ensure support from actors that are essential for the development of the niche [Schot and Geels, 2008]. Furthermore, a niche specific process in SNM evolves around learning processes and experiments which are viewed as crucial for the establishment of a robust niche, that is able to enter the regime [Schot and Geels, 2008]. In SNM, the learning processes and experiments are carried out through different analyses of the niche, which e.g. can be related to an analysis of the design specifications of the niche. Learning processes are highlighted as a part of SNM, as niches do not exist in the regime and therefore, it is necessary to experiment with and adapt e.g. the design of the niche a couple of times. This also means, that working with niches in SNM creates iterative processes in the development of niches. The learning process does also consist of projecting niches to outer circumstances such as the regime and landscape [Schot and Geels, 2008]. Relating the niche to outer circumstances is emphasised to be included in the learning processes in SNM, as it e.g helps to clarify limitations in the regime concerning the development and implementation of the niche, and by that an understanding and reflection on what structures in the regime that needs to be changed for the niche being accepted in the regime.

The niche specific processes can be different relative to the concrete niche, which means that it can be assumed that not all of the above-mentioned niche specific processes always occur when managing niches or that the processes can have a different role in relation to the concrete niche being developed.

In Figure 5.2, bullet points showing the niches specific processes in SNM are illustrated together with the interaction between MLP and SNM.

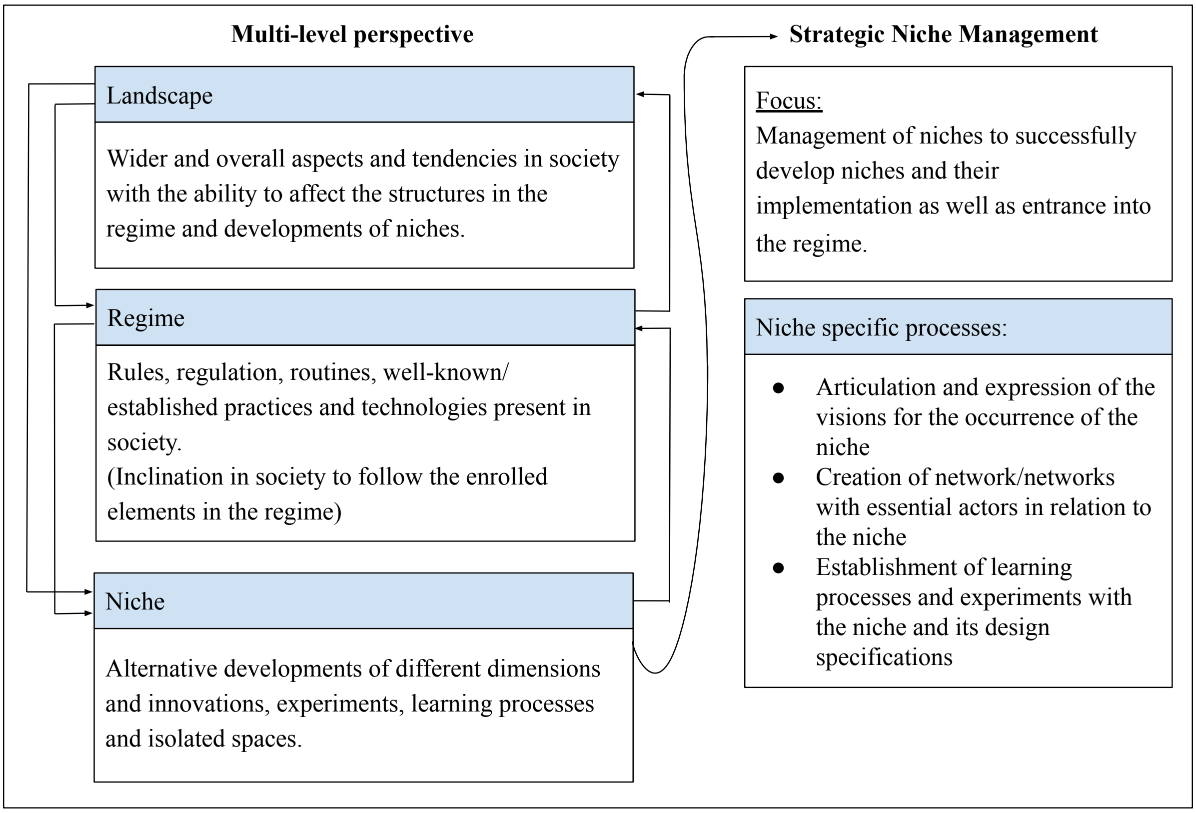

Figure 5.2: *Illustration of Strategic Niche Management together with Multi-level Perspective.*

Relating the management of niches and the niche specific processes to the niche defined in the thesis, it can be argued, that the exchange of excess heat between industries at the port of Aarhus has occurred based on the goals and visions set forward by Aarhus Municipality and Aarhus Havn. This shows, that a goal and vision exist behind the niche, which creates both expectations and sets a direction for the implementation of the niche. Furthermore, it can be assumed, that the goal and vision behind the occurrence of the niche have attracted interest to the development of the niche, as industries placed at the port have expressed interest in participating in the common system and the exchange of excess heat. In addition to this, it can also be highlighted, that a network is created in relation to the niche including: Aarhus Municipality, Aarhus Havn, Aarhus Vand, industries placed at the port, consulting firms and master students. This is a range of actors, that can be relevant for the development of the niche, as the network includes actors, which are facilitating and able to work with and analyse the niche, and furthermore includes actors that are necessary for the niche to exist, such as the industries.

Based on that, it can be emphasised, that the niche about the pilot project and exchange of excess heat at the port of Aarhus is at the stage about establishing learning processes through experiments with the niche in relation to the described niche specific processes in SNM. As a result of that, the analysis and discussion of the thesis include a design of the exchange of excess heat in a common system as well as experiments with and considerations of the design specifications in relation to the niche.

Figure 5.3 illustrates that the first part of the analysis concerns the design of the exchange of excess heat in a common system, where after a sensitivity analysis is carried out as a part of developing learning processes and to experiment with the design specifications of the niche in the thesis. The discussion of the thesis reflects further upon the niche and the design of the exchange of excess heat in the analysis, and considers changes for the implementation of the niche as an additional approach in the utilisation of excess heat and the entrance of the approach in the regime.

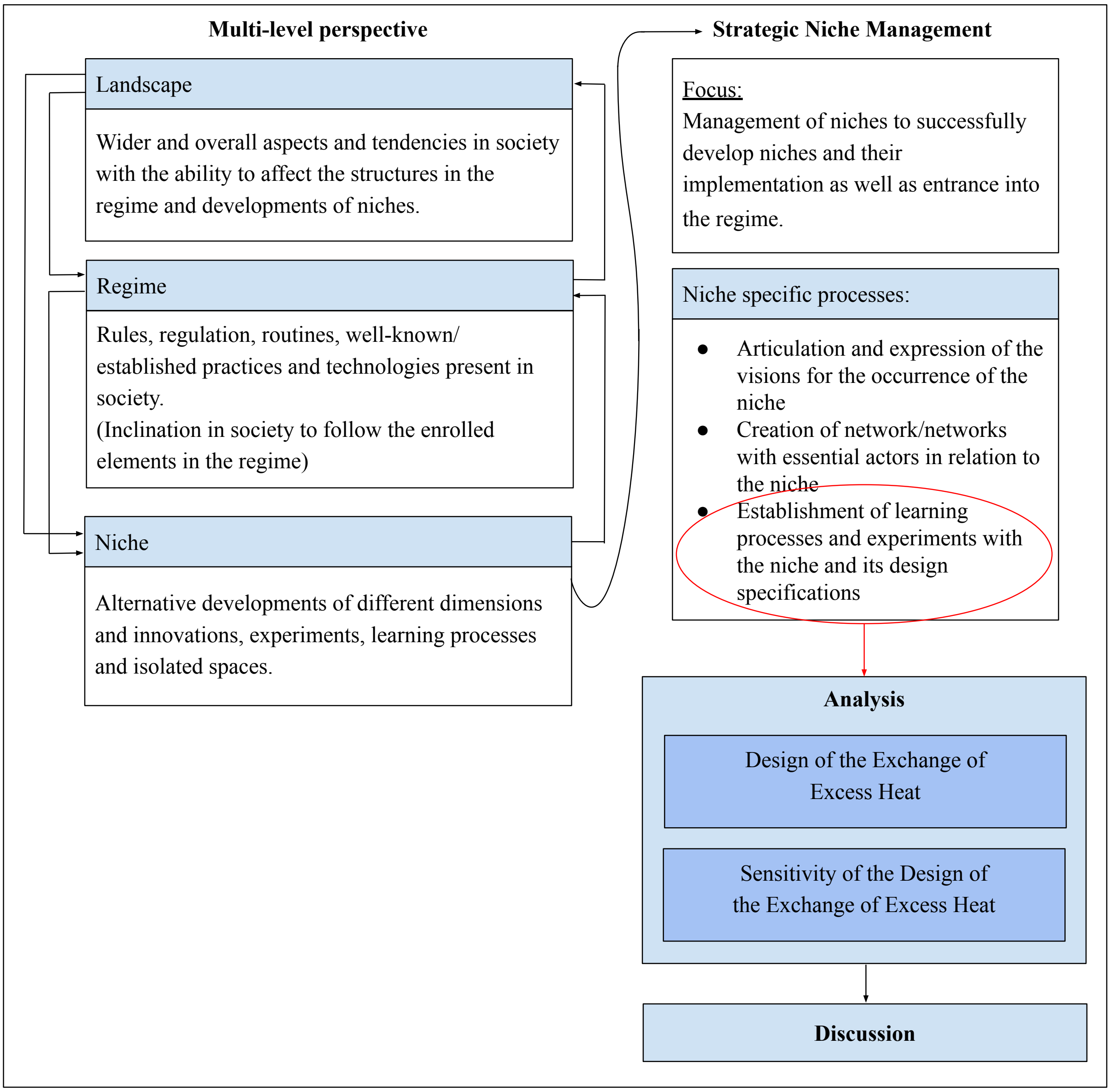

Figure 5.3: *Illustration of the use of niche specific processes in the thesis.*

Methodology 6

The Methodology includes a description of the methods applied in the thesis to form and answer the defined problem in the research question.

6.1 Case Study

A case study is used and act as a research method in the thesis, and the case study concerns the pilot project at the port of Aarhus about the exchange of excess heat between industries at the port. The case study of the pilot project at the port of Aarhus also functions as the defined niche in the thesis, and the niche focuses on the exchange of excess heat at the port based on a common system and system way of thinking the use of excess heat as an additional approach in the utilisation of excess heat.

The book *Social Research Methods* outlines, that when performing a case study, the case in question is investigated thoroughly by the researcher with the purpose of analysing the nature as well as the "unique features", difficulties and complexities of the case included in the research [Bryman, 2016]. This means, that with the nature of a case being analysed in a case study, it can be assumed that the context of the case is investigated when conducting case studies. Relating this to the case study of the thesis, it influences, that the context in which the case interacts is relevant for the study of the case and also implies, that the specific location of the exchange of excess heat at the port of Aarhus plays a role in the study of the case. Furthermore, the fact that a case study also can include an analysis of the uniqueness of a case can be connected to the pilot project at the port of Aarhus being an investigation of an additional approach to the use of excess heat based on a common and system way of thinking the use of excess heat between industries. The analysis of difficulties and/or complexities of a certain case in a case study can be related to the analysis of the design of the exchange of excess heat and the experiment with the design in the sensitivity analysis and the discussions included in relation to the design in the thesis.

Different strategies and selection types behind the choice of a case exist, and Bent Flyvbjerg highlights different selection types in relation to choosing a case [Flyvbjerg, 2013]. From the descriptions of the selection types by Flyvbjerg, it can be interpreted, that an impression of why a case study is conducted can be found in the strategy behind the choice of a case. Therefore, the strategies and selection types related to the choice of a case can be concerned with the expected information output of the case study after conducting the research in which the case study is entailed [Flyvbjerg, 2013]. The selection types defined by Flyvbjerg involve choosing e.g. an extreme/atypical case, a critical case or a paradigmatic case [Flyvbjerg, 2013]. Among these, the choice of the case at the port of Aarhus can be emphasised to be connected to the case selection type denoted paradigmatic cases. The argumentation given by Flyvbjerg for choosing and working with paradigmatic cases is: *"To develop a model example, a prototype or a metaphor within the area, that the case is concerned with"* [Translated from Danish] [Flyvbjerg, 2013,p.

475]. With the pilot project at the port of Aarhus involving the experiment with developing and analysing an exchange of excess heat between the 12 industries at the port, it can be argued to appear as this "model example", which can be used as a basis and to accumulate knowledge for further work and development of the common system of the exchange of excess heat between industries at the port of Aarhus. In addition to this, paradigmatic cases are by Flyvbjerg mentioned as deviating from traditional norms, which can be associated with the definition of the exchange of excess heat in a common system as an additional approach and niche in the thesis, which deviates from bilateral connections in the utilisation of excess heat [Flyvbjerg, 2013].

Case study as a research method is by opponents of cases studies appointed with critique, especially in relation to the ability to generalise the results from a case study into a broader context [Flyvbjerg, 2013; Bryman, 2016]. Opponents of case studies stress, that general conclusions can not be established based on an analysis of one single case and its associated results [Flyvbjerg, 2013]. In relation to this, the generalisation and scalability of the exchange of excess heat in a common system can be discussed and reflected on. It can be assumed, that the idea and approach about working with an exchange of excess heat in a common system and the system way of thinking the use of excess heat can be generalised and experimented with elsewhere. Furthermore, thinking in alternatives to the utilisation of excess heat can also be applied and act as inspiration for other alternatives to emerge elsewhere in relation to the use of excess heat, which perhaps can support, that excess heat can be utilised to the potential that it shows to have. However, the case of the exchange of excess heat at the port of Aarhus is based on many industries participating and the fact that the industries are placed near by each other in the common system. This can influence, that the success of experimenting with and implementing the exchange of excess heat between industries elsewhere can depend on a similar situation. In connection to this, it can be argued that, the area in which another exchange of excess heat is investigated does not have to be a port area, but it can be stressed, that it might have to be an area including the location of a number of industries.

6.2 Modelling

EnergyPRO is used in the analysis of the thesis to model the design of the exchange of excess heat at the port of Aarhus.

The choice of energyPRO as the modelling tool is based on a set of requirements determined for the modelling tool applied in the thesis. The modelling tool e.g. has to be able to model energy projects at a locale scale, as the exchange of excess heat in the common system at the port of Aarhus is viewed as a locally isolated "energy system". Furthermore, the modelling tool has to have the ability of modelling a production of heat in order to be able to simulate the production of excess heat from the industries. Additionally, a requirement for the modelling tool is also e.g. the capability to present the energy conversion as well as expenses and revenues connected to an energy project on a yearly basis, which also means that the modelling tool has to have the means of including e.g. taxes and tariffs.

EnergyPRO is consistent with the examples of requirements stated above, which means that energyPRO is chosen as the modelling tool for the analysis of the exchange of excess heat in the thesis. An example of another modelling tool is EnergyPLAN, which is not chosen in the thesis, as it usually is used to simulate energy systems on a national or regional scale and contains many different energy sectors [Connolly et al., 2010]. The modelling of the exchange of excess heat at the port of Aarhus is viewed as a locally oriented project and the main sector, that the tool has to be able to analyse, is the heat sector. The design of the exchange of excess heat could also have been modelled in Excel. Excel could have been used as a modelling tool, as Excel enables the user to develop a model of an energy project from scratch. This means, that specific elements relevant for the modelling of the exchange of excess heat could have been incorporated into Excel. With both Excel and energyPRO as possible tools for the design the exchange of excess heat, it is in the thesis decided to use energyPRO. This is chosen as a part of the external collaboration with Aarhus Municipality and PlanEnergi, where energyPRO is a known modelling tool, and by using energyPRO in the thesis, it is possible to have an easy transfer of the results of the analysis of the design to the cooperating partners. However, if Excel had been applied as the modelling tool, it can be argued that control and awareness of all steps included in the model would have been present.

When using energyPRO as a modelling tool, a module has to be selected. The module selected in energyPRO has an impact on, what is included in the simulation. In the thesis, the module DESIGN is used [EMD International A/S, 2014]. The module DESIGN puts weight on energy conversion and the payments for operating the system simulated in energyPRO [EMD International A/S, 2014]. The module DESIGN in selected, as the model of the exchange of excess heat is focused on the energy conversion in terms of the energy balance in the exchange of excess heat together with knowledge of the total annual costs connected to the model of the exchange.

EnergyPRO is used to design a model of the exchange of excess heat between industries at the port of Aarhus. The model represents an experiment and proposal of a design of the common system. The design of the model is based on choices and assumptions and the analysis of the exchange of excess heat contains as a result changes in the choices made in the design. This means, that one model is made of the exchange of excess heat and separate changes are carried out within this model. These changes are carried out as a part of niche specific processes described in SNM and to assess the robustness and sensitivity of the design of the model of the exchange of excess heat.

In relation to designing the exchange of excess heat at the port of Aarhus in energyPRO, it has not been possible to obtain actual data about the 12 industries included in the exchange. It has not been possible to obtain the actual data, as the process of collecting the data has been a part of the external collaboration. As described in the Problem Analysis, the energy consulting firm Transition has as a part of the project *Smart Energi Aarhus Havn* worked with the industries at the port of Aarhus. As a result of this, it was decided in the collaboration together with the external cooperating partners at Aarhus Municipality and PlanEnergi in a meeting (denoted Meeting 3 in appendix), that Transition should continue being the contact and driver for the communication with the industries. This was decided to prevent the mobilisation of the industries by Transition to fall a part, if the industries suddenly had to collaborate with other actors connected to the work about the exchange of excess heat at the port. But the process of getting the data and approval to use the data has been a process of inertia. As a result of this, it was decided to perform the analysis of the design of the exchange of excess heat in energyPRO by the means of assumptions. These assumptions have been discussed with PlanEnergi and working with assumptions can be argued to have presented a degree of freedom in the design of the exchange of excess heat in the thesis, which has given the possibility to include industries with different characteristics in the analysis of the design, and investigate the effect of the different characteristics in the exchange of excess heat and common system.

The 12 industries included in the modelling in energyPRO are denoted as Industry 1, Industry 2, Industry 3 etc., which means that the names of the industries are not included or used in the thesis. The reason for this lies in the thesis being composed as a part of the collaboration with Aarhus Municipality and PlanEnergi about the pilot project. The pilot project is meant to be presented for the included industries and naming the industries can in this connection be assumed to disturb the industries in understanding the system way of thinking the use of excess heat in the common system.

6.2.1 Parameters

The model of the design of the exchange of excess heat in energyPRO is evaluated based on two defined parameters:

- The energy balance in the design of the exchange of excess heat at the port
- The total annual costs of the design of the exchange of excess heat at the port in terms of expenses and revenue

The energy balance is determined as a parameter, as analysing the energy balance in the design of the exchange is viewed necessary in order to establish whether the heat demands at the industries participating the exchange of excess heat are met and to examine the productions of excess heat. Furthermore, the energy balance as a parameter can also be used to illustrate, if there is a balance between heat demands at the industries and the production of excess heat in the common system or if an external receiver of excess heat or producer of heat needs to be a part of the design (These different situations are illustrated in Figure 2.5 containing Model A, B, and C).

The total annual costs are defined as a parameter in order to establish the costs of the design of the common system and the exchange of excess heat between the industries. In relation to the the total annual cost, a bar chart with a cost break down is included to describe the distribution of expenses and revenue in the design.

6.3 Meetings

In the thesis, meetings have served as one of the methods carried out as a part of the collaboration with Aarhus Municipality and consultants from PlanEnergi. The meetings have served different purposes as the meetings have been conducted in different phases of the thesis. As a result, the subjects of and the agendas for the meetings have also been of different characters.

Three meetings have been carried out:

- A meeting with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus.
- A meeting with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus and consultants from the energy consulting firm PlanEnergi.
- A meeting with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus, consultants from the energy consulting firm PlanEnergi, and consultants from the energy consulting firm Transition.

The overall subject dealt with in the meetings is the pilot project about the exchange of excess heat at the port of Aarhus. The first meeting was set in place to share and discuss initial thoughts on the pilot project about the exchange of excess heat at the port of Aarhus. The second meeting had a focus on discussing potential ways to organise the exchange of excess heat between the industries at the port, whereas the third meeting was mainly focused on knowledge sharing, where findings from the projects *Smart Energi Aarhus Havn* were presented by Transition.

In addition to the three meetings listed above, 4 minor meetings have been carried out with consultants from PlanEnergi. These meetings have been a part of the collaboration with PlanEnergi in the thesis, and have been concerned with the design of the exchange of excess heat between the industries at the port of Aarhus. The modelling of the design of the exchange of excess heat in energyPRO and the data and information used for the modelling have been the focus of the discussions at these meetings. In addition to the meetings, consecutive e-mail correspondences have also been a part of the collaboration with PlanEnergi. As a part of the discussions about the modelling of the exchange of excess heat in energyPRO, the consultants from PlanEnergi have shared reflections on possible assumptions to make regarding the modelling in energyPRO. These reflections and considerations have been helpful in the thesis as the actual data from the industries at the port of Aarhus has not been available and as a result not possible to include in the model and design of the exchange of excess heat.

In the thesis, the meetings can be viewed as a method that is used to gather information and share thoughts about the design of the exchange of excess heat, as the meetings have been forums for discussions and dialogue, which have supported the modelling and design of the exchange of excess heat included in the thesis. Additionally, the meetings have made it possible to incorporate the reflections from the actors working with the exchange of excess heat in a real-life context, but in this process awareness of not neglecting own ideas and thoughts has been present in the thesis.

Descriptions of the meetings including notes are attached in appendix A in page 105.

6.4 Interviews

Two interviews have been conducted as a part of the thesis, and the interview respondents are:

- Uffe Kristensen, development consultant in The Secretariat of Climate and Green Transition in the municipality of Aarhus.
- Anne Zachariassen, Chief Operating Officer, at Aarhus Havn

The two interviews are providing information and knowledge collected directly at the sources, which in these cases are from the two above-mentioned respondents. The interviews are semi-structured, which means that the interviews follow the structure of an interview guide but with room for and the possibility of dissenting from the questions listed in the interview guide [Bryman, 2016]. As a result, the interviews are open for impulsive questions appearing in the interviews or for an elaboration on questions in the interview guide. The interviews are also carried out as semi-structured to give the respondent the possibility of adding knowledge and points that are beyond the scope of the interview guide and maybe not included in the questions asked [Bryman, 2016]. The semi-structured interview is chosen in the thesis, as this form of interviewing makes it possible to obtain the desired knowledge from the interview, but also gives the interview a character of being more of a dialogue with room for the respondents to add further knowledge and their own reflections and opinions.

An interview has been carried out with Uffe Kristensen from Aarhus Municipality, as Uffe Kristensen is the facilitating actor at the municipality in relation to the project *Smart Energi Aarhus Havn* and the pilot project about excess heat at the port of Aarhus. The interview with Uffe Kristensen was composed to get an insight in and an impression of the background for working with a project about excess heat at the port and the common system and system way of thinking the utilisation of excess. Based on that, the interview with Uffe Kristensen is used in the thesis to understand, how the case analysed in the thesis has emerged. Furthermore, the interview was also conducted to deduce the interest at the municipality in establishing an exchange of excess heat at the port and which possibilities and hindrances the municipality associated with an implementation of the exchange of excess heat between the industries at the port of Aarhus.

The purpose of the interview with Anne Zachariassen from Aarhus Havn was made to include an actor connected to the port and the industries placed at the port. Aarhus Havn cannot "force" the industries at the port to participate in the exchange of excess heat, but Anne Zachariassen explains in the interview, that Aarhus Havn has in interest in initiatives at the port, that furthers reaching the vision of a sustainable port defined by Aarhus Havn. Aarhus Havn has knowledge of the industries located at the port, and due to this, the interview with Anne Zachariassen was also performed to get the opinion from Aarhus Havn about, what they think could prevent and attract the interest of the industries at the port to participate in the common system and exchange of excess heat.

It can be argued, that conducting interviews with the industries at the port of Aarhus could have strengthened the thesis instead of getting an impression of the interest at the industries at the meetings and through the interview with Uffe Kristensen and Anne Zachariassen. It can be assumed, that interviews with the industries could have given insight in whether the industries have an interest in the exchange of excess heat at the port of Aarhus or not, and in connection to this perhaps what their interest is. As a result of this, interviews with the industries can be assumed to could have given an understanding of, what could prevent or attract the industries from participating in the exchange of excess heat at the port. The reason for not conducting interviews with the industries in the thesis is due to the fact that the energy consulting firm Transition has made interviews with the industries at the port of Aarhus as a part of the project *Smart Energi Aarhus Havn* and has advised, that the industries should not be contacted again in relation to the pilot project and the exchange of excess heat at the port. The argument for this, stated by Transition, has been that the industries should not be disturbed or bothered further, as Transition by that fears that the industries will back out from the collaboration in connection to the project *Smart Energi Aarhus Havn*. In the project *Smart Energi Aarhus Havn*, Transition has worked with mobilising the industries at the port of Aarhus and is in connection to this not interested in seeing this mobilisation disappear again [Meeting3, 2020].

The fact that no interviews with the industries have been carried out means, that it is assumed that the industries are both interested in and willing to participate in the exchange of excess heat. This can perhaps be viewed as an important issue to investigate further on, as it can be argued to be decisive that the industries are interested in participating and collaborating with other industries at the port for the pilot project about the exchange of excess heat in a common system to happen.

The two interviews are attached to the thesis as audio files and the interview guides can be viewed in Appendix B in page 109. Both interviews have been carried out during the corona-period, which affects that the interviews have been carried out online and due to this, disturbances can occur in the audio files.

6.5 Literature study

Literature study is applied as a method in the thesis. In a research process, a literature study can support the creation of background knowledge on the topic of interest in the research and also help the researcher form an impression of, what debates and discussions are unfolding in relation to the topic of interest [Bryman, 2016]. In the thesis, the topic of interest is excess heat and as a part of composing the Problem Analysis of the thesis, a literature study has been conducted by going through different reports, articles and current legislation. The literature study has helped define excess heat and has contributed to an understanding of the context of excess heat as well as regulatory and technical conditions together with contractual conditions and agreements influencing the use of excess heat. As the literature study has been used to describe the context of excess heat and the conditions for the utilisation of excess heat, the literature study entailed in the Problem Analysis has also provided inputs to the analysis of the design of the exchange of excess heat at the port of Aarhus and elements to be included in the discussion of the thesis.

When doing literature studies, it is important to assess the literature and its content from a critical perspective in order to evaluate the credibility and validity of the knowledge, facts and information provided by and extracted from the literature being studied [Bryman, 2016]. To ensure the credibility and validity, many of the reports, which have been studied, are published by mainly actors such as the Danish Energy Agency, The Danish Ministry of Climate, Energy and Utilities and The Danish Ministry of Taxation. These actors are in the thesis viewed as being reliable in the information that they provide, but using literature from these actors has in the thesis been carried out with having in mind, that there is a possibility of the literature containing hidden political agendas. In the thesis, the articles used in the description of the context of excess heat are from news agencies such as Ingeniøren and Altinget, who can be argued to produce articles of a technical, academic or scientific character. This means that as a part of evaluating the credibility in these articles, they have been selected to avoid using articles having an orientation of sensation-telling from other news agencies. The current legislation used in the literature study has been found at Retsinformation.dk, which is the data base of the publicly available legislation in Denmark.

Design of the Exchange of Excess Heat 7

In the thesis, the pilot project at the port of Aarhus concerning the exchange of excess heat between the 12 industries at the port is viewed as a niche based on the exchange being argued to illustrate an additional approach to the utilisation of excess heat. SNM describes niche specific processes, that relates to the management of niches and their development and entrance into the regime. In relation to the niche specific processes described in SNM, the pilot project is at the stage about development of learning processes as described in the Theoretical Framework. In SNM, the learning processes evolve around analyses and experiments with the niche and its design specifications as well as relating the niche to outer circumstances in the regime and landscape. For that reason, the analysis of the thesis contains a proposed design of the exchange of excess heat at the port of Aarhus, and a sensitivity analysis of the design to experiment with and develop learning processes in relation to the design of the common system, which can be considered in relation to the system way of thinking the use of excess heat to enter the regime as an additional approach in the utilisation of excess heat.

This chapter contains a description of how the exchange of excess heat between the industries at the port of Aarhus is designed in the thesis, and presents the results of the design of the common system.

The sensitivity analysis of the design of the exchange of excess heat and common system is entailed in the following chapter of the analysis.

7.1 Model of the Design

The design of the exchange of excess heat and common system between the 12 industries at the port of Aarhus is made in energyPRO. In connection to the design of the exchange of excess heat and the modelling of the exchange in energyPRO, the thesis entails some overall choices and assumptions in relation to the design of the exchange of excess heat. The choices and assumptions are made to define a set of general circumstances for the exchange of excess heat, and these can be viewed in the list below:

- The industries producing excess heat to the exchange of excess heat at the port of Aarhus do not receive any payment for the delivery of excess heat to the industries participating in the exchange.
- The industries have shared ownership in the common system and shares the payment of expenses connected to the exchange of excess heat at the port.
- The industries share the revenues from the exchange of excess heat at the port.
- In the situation of an external receiver of excess heat or an external producer of heat being necessary to connect to the common system, AVA, which is the district heating company

in Aarhus, is determined as the receiver of the excess heat or the producer of heat to the common system.
- The temperature of the excess heat being exchanged at the port of Aarhus is determined to have a required temperature of 75^{o}C.
- In relation to the transport and distribution of the excess heat between the industries, it is assumed to be possible to use the district heating grid already implemented at the port. The grid is owned by AVA, and it is assumed, that AVA will continue to administrate, operate and be in charge of the maintenance of the grid.

The choice concerning no payment for the excess heat exchanged between the industries at the port is made for the exchange of excess heat to become a common system for the industries participating in the exchange. The choice is also made in order to simplify the modelling of the exchange of excess heat in energyPRO.

With the exchange of excess heat at the port of Aarhus emerging from a common and system way of thinking the utilisation of excess heat, the choice about shared ownership as well as shared payment of expenses and revenue is made, as the exchange of excess heat can be emphasised to be viewed as a creation of a common system, which involves and relies on a collaboration between the industries.

AVA is determined to be the external receiver of a surplus of excess heat and the external producer for heat to the common system in a situation of a shortage of excess heat in the exchange, because AVA as a district heating company is assumed to have an interest in the surplus of excess heat and to have the ability of delivering heat to the industries included in the exchange of excess heat at the port.

The thesis defines the required temperature of the excess heat being exchanged between the industries to have a temperature at 75°C. This temperature is defined as it corresponds with the supply temperature in the district heating grid in Aarhus [Varmeplan Aarhus, 2020]. With a temperature at 75°C, it is possible to have AVA as a potential receiver of a surplus of excess heat, or the producer of heat in a shortage of excess heat in the exchange between the industries. Furthermore, the 75°C can also be argued as a sufficient temperature in relation to covering the space heating demands at the industries participating in the exchange of excess heat at the port. To this it can be added, that there can be an uncertainty in relation to the defined temperature of the excess heat at 75°C in connection to the process heat demands at the industries. But with limited knowledge of the temperature needed for the process heat demands at the industries, an assumption and definition of a required temperature of the excess heat in the exchange is made in the thesis.

Based on conversations and dialogues about the design of the exchange of excess heat at the port of Aarhus with PlanEnergi, it is decided and assumed feasible to use the district heating grid already laid out and administrated by AVA at the port. A map illustrating the implemented grid at the port of Aarhus is included in Appendix C. The utilisation of the grid can be presumed to depend on establishing an agreement with AVA about this, which can involve e.g. clarification about expenses in connection to the use of the grid in the exchange of excess heat. But as included in the delimitation of the thesis, considerations in relation to the grid and establishment of pipe lines are not further elaborated on in the thesis.

7.1.1 Data and Information about the Industries

As described in Methodology in Section 6.2, it has not been possible to obtain actual data for the 12 industries interested in participating in the exchange of excess heat at the port of Aarhus, and for that reason the design and modelling of the exchange in energyPRO is simulated and based on inspiration from information and data about the industries presumed and provided by the consulting firm PlanEnergi. To this, additional assumptions are made and added in relation to the industries in the thesis, and these additional assumptions have also been discussed at meetings with PlanEnergi. This results in the fact, that different industries with different characteristics are included in the design of the exchange of excess heat at the port of Aarhus and in the modelling of the exchange in energyPRO.

Table 7.1 gives an overview of the data and information from PlanEnergi (marked with green) and furthermore shows where additional assumptions are made relation to the 12 industries in the thesis (marked with yellow). Table 7.1 is included on the following page, and from the table the industries incorporated into energyPRO can be observed together with their different characteristics. The table illustrates e.g. a variation in the demand for space heating and process heat at the industries and furthermore presents, that some of the industries have an excess heat production while others do not. Table 7.1 does also show, that it is assumed, that the excess heat from some of the industries at the port occurs based on a demand for cooling. In relation to this, it is in the thesis presumed, that the cooling processes at the industries require a heat pump, which is located at the property of industries. Additionally, it can also be seen in Table 7.1, that the temperature of the excess heat produced at some of the industries is assumed to be lower than the required temperature of the excess heat exchanged between the industries in the common system. In connection to these industries, it is assumed in the thesis, that booster heat pumps are needed to increase the temperature of the excess heat to be able to utilise the excess heat in the exchange. Which industries, that require a booster heat pump, are also indicated in Table 7.1.

In Table 7.1, COP-factors are presented for the heat pumps used in the cooling processes at the industries with a cooling demand and for the booster heat pumps. The COP-factors are assumed and determined by calculating the theoretical Lorentz COP-factors of the heat pumps. In these calculations, the presumed temperatures of the cooling demands and the excess heat produced at the industries shown in Table 7.1 are included. To get the COP-factors of the heat pumps, the calculated theoretical COP-factors are multiplied with a typical efficiency of a heat pump [EMD International A/S, 2019; Grøn Energi et al., 2017]. In Appendix D section D.1, the calculations and determination of the COP-factors are illustrated.

	Space heating demand [MWh/year]	**Process Heat Demand** [MWh/year]	**Even Process Heat Demand**	**Cooling demand** (meet by a heat pump)	**Excess Heat Production** [MWh/year]	**Even Production of Excess Heat**	**Excess Heat Produced by Cooling**	**Booster heat pump**
Industry 1	No demand for space heating	4.000	Yes	No cooling demand	3.000 Temperature: 75ºC	Yes	-	No Direct use of excess heat
Industry 2	30	No demand for process heat	-	No cooling demand	No production of excess heat	-	-	-
Industry 3	50	56.000 Temperature: 100-140 ºC	-	Yes Temperature: 2ºC COP: 2,5	28.000 Temperature: 75ºC	Yes	Yes	No Direct use of excess heat
Industry 4	30	4.000	Yes	Yes Temperature: 5ºC COP: 5,2	3.000 Temperature: 75ºC	Yes	Yes	No Direct use of excess heat
Industry 5	50	No demand for process heat	-	Yes Temperature: 30ºC COP: 11,9	9.636 Temperature: 60ºC	Yes	Yes	Yes COP: 9,3
Industry 6	50	No demand for process heat	-	No cooling demand	No production of excess heat	-	-	-
Industry 7	30	2.000	Yes	Yes Temperature: 2ºC COP: 4	1.000 Temperature: 75ºC	Yes	Yes	No Direct use of excess heat
Industry 8	25	No demand for process heat	-	No cooling demand	No production of excess heat	-	-	-
Industry 9 (100 MW heat and power unit, Fuel oil)	No demand for space heating	400.000	-	No cooling demand	40.000 Temperature: 75ºC	Yes	-	No Direct use of excess heat
Industry 10	No demand for space heating	8.000	Yes	No cooling demand	6.000 Temperature: 40ºC	Yes	-	Yes COP: 9,2
Industry 11	No demand for space heating	50.000	Yes	No cooling demand	32.000 Temperature: 75ºC	Yes	-	No Direct use of excess heat
Industry 12	30	No demand for process heat	-	Yes Temperature: 6ºC COP: 17,9	8.000 Temperature: 24ºC	Yes	Yes	Yes COP: 4,9

Figure 7.1: *Overview of the data, information, and assumptions regarding the 12 industries at the port of Aarhus. Marked with green are the data and information provided by PlanEnergi and marked with yellow are the additional assumptions made in the thesis.*

7.1.2 Data and Information Processing in energyPRO

The following sections entail a description of the processing of the information and data shown in Table 7.1 in energyPRO, which leads to a presentation of the design of the exchange of excess heat between the 12 industries at the port of Aarhus.

Heat Demand for Space Heating

In energyPRO, the heat demand for space heating at Industry 2, 3, 4, 5, 6, 7, 8, and 12 is inserted and graduated in relation to the ambient temperature to obtain an annual distribution of the total heat demand for space heating. This influences, that no heat demand for space heating exists in the summer months at the industries in energyPRO. The graduation of the space heating demands is made in energyPRO by using time series of external conditions contained in energyPRO [EMD International A/S, 2014].

Table 7.1 highlights the total demand for space heating included in the exchange of excess heat at the port of Aarhus:

Table 7.1: *Total demand for space heating in the design of the exchange of excess heat.*

Total Demand for Space Heating:	295 MWh/year

Heat Demand for Process Heat

The process heat demand at Industry 1, 4, 7, 10, and 11 is included in energyPRO by adding the demands as time series based on the total annual demand for process heat at the industries. In the time series, the process heat demands are distributed on an hourly basis and it is assumed, that the industries have an even demand for process heat throughout a year (This assumption can also be seen in Table 7.1). Outages [1] are implemented in the process heat demands at Industry 1, 4, 7, 10, and 11. The outages are implemented in the summer holidays[2] and in the Christmas break[3] as it is assumed, that industries usually close down in these periods, and for that reason, the industries at the port of Aarhus are presumed not to have a demand for process heat at these periods.

Table 7.1 shows, that Industry 3 is expected to have a process heat demand at 56.000 MWh/year and the needed temperature of the process heat is illustrated to be 100-140 ^{o}C. In the thesis, it is chosen not to incorporate the process heat demand for Industry 3 in energyPRO as well as in the design of the exchange of excess heat at the port of Aarhus. This is chosen as the industry requests process heat in a high temperature, which does not comply with the defined temperature at 75^{o}C in the exchange of excess heat.

From Table 7.1, it can be observed, that Industry 9 has a process heat demand at 400.000 MWh/year and in the thesis, this process heat demand is de-selected to be a part of the modelling in energyPRO and the design of the exchange and common system at the port. The choice of not including the process heat demand at Industry 9 is related to the assumption about the industry having a 100 MW heat and power unit located at its property (This is assumption is

[1] Translation of the Danish word: udetider

[2] The summer holidays (2019): 8^{th} of July to 28^{th} of July

[3] Christmas break (2019): 20^{th} of December to 2^{nd} of January

put forward by PlanEnergi and is also included in Table 7.1). The heat and power unit produces in combination both the heat and electricity needed at the industry and because of that, it is in the thesis assumed, that Industry 9 will not replace the heat produced by the production unit with excess heat from the exchange at the port. This is presumed, as Industry 9 would still need the electricity produced by the heat and power unit. With that in mind, it can be argued not to be economically beneficial in relation to the purchase of fuel at Industry 9 not to use the heat output from the combined heat and power production at the industry.

In Table 7.1, the choice of not including Industry 3 and 9 in energyPRO and the design of the exchange of excess heat at the port of Aarhus is shown with a yellow X.

The table below presents the total demand for process heat included in the exchange of excess heat at the port:

Table 7.2: *Total demand for process heat in the design of the exchange of excess heat.*

Total Demand for Process Heat:	68.000 MWh/year

Production of Excess heat

As it can be viewed in Table 7.1, Industry 1, 3, 4, 5, 7, 9, 10, 11, and 12 are expected to have a production of excess heat, that can be used in the exchange of excess heat between the industries at the port of Aarhus. This means, that Industry 2, 6, and 8 are a part of the exchange of excess heat and the common system, but without delivering excess heat and only having a heat demand for space heating.

In the modelling of the exchange of excess heat in energyPRO, it is assumed, that the excess heat is not used internally by the industries and based on that assumption, the total amount of excess heat assumed to be produced at the industries is utilised in the exchange between the industries.

From Table 7.1, it can be observed, that PlanEnergi has presumed an even production of excess heat throughout a year for some of the industries placed at the port. With no actual information regarding the production of excess heat from the 12 industries, an even production of excess heat at all of the industries is assumed in the thesis.

In energyPRO, the excess heat produced by Industry 1, 9, and 11 is simulated as a heat production from a set of boilers with no defined fuel, but a production of heat based on time series consisting of the total annual amount of excess heat with an even production throughout the year and an hourly distribution. The boilers are set to have outages in the summer holidays and Christmas break, as described earlier, because industries are usually closed down in these periods, and therefore it can be assumed, that no excess heat production is present in these times.

The production of excess heat at Industry 3, 4, and 7 is based on a cooling demand, and the excess heat emerging from these industries are simulated as user defined units[4] in energyPRO. Industry 5 and 12 do also have a production of excess heat from a cooling process, but the simulation of the use of excess heat from Industry 5 and 12 is elaborated in the following section.

[4]Translation of the the Danish word: Brugerdefinerede enheder

In energyPRO, the user defined units simulating the production of excess heat from Industry 3, 4, and 7 are based on time series containing the excess heat production from the industries with an even production and hourly distribution over the year. As the excess heat at Industry 3, 4, and 7 emerges from cooling processes by heat pumps, the electricity consumption by the heat pumps located at Industry 3, 4, and 7 are included in energyPRO and defined by dividing the total production of excess heat with the assumed COP-factors of the heat pumps at the industries. Outages are also implemented in connection to the user defined units simulating the production of excess heat at Industry 3, 4, and 7 in the summer holidays and Christmas break due to the assumption about industries usually closing down in these periods.

In Table 7.1, Industry 1, 3, 4, 7, 9, and 11 are marked with an assumption about a direct use of excess heat. This means, that it is presumed in the thesis, that these industries produce excess heat at a temperature around 75^{o}C, which is the required temperature of the excess heat exchanged between the industries at the port in the common system. However, as also indicated in Table 7.1, Industry 5, 10, and 12 are presumed to produce excess heat at temperatures around 60^{o}C, 40^{o}C and 24^{o}C, respectively. This influences, that booster heat pumps are needed for the utilisation of the excess heat from Industry 5, 10, and 12 in order to meet the defined temperature at 75^{o}C. For that reason, the production of excess heat from Industry 5, 10, and 12 is simulated as a fuel connected to user defined units, where the user defined units simulate the booster heat pumps. The electricity consumption related to the booster heat pumps is determined based on the assumed COP-factors for the booster heat pumps and the total excess heat production from Industry 5, 10, and 12. Outages are also scheduled in the summer holidays and Christmas break in relation the user defined units simulating the booster heat pumps. In Table 7.1, the total production of excess heat is noted as 28.000 MWh/year, 9.636 MWh/year, and 8.000 MWh/year for Industry 5, 10, and 12 but by connecting the excess heat production from Industry 5, 10, and 12 to the booster heat pumps in energyPRO, a higher amount of excess heat occurs in connection to Industry 5, 10, and 12 due to the electricity used in the booster heat pumps.

In energyPRO, the boilers and user defined units simulating the production of excess heat at Industry 1, 3, 4, 5, 7, 9, 10, 11, and 12 are set to produce excess heat at full load at all times. The units are set to produce at full load as it can be emphasised, that the production of excess heat at the industries does not depend on a heat demand but rather the production in the industries and for that reason, the industries are set to produce excess heat at full load at all times.

Table 7.3 shows the total production of excess heat included in the exchange of excess heat between the industries at the port of Aarhus:

Table 7.3: *Total production of excess heat in the design of the exchange of excess heat.*

Total Production of Excess Heat:	134.565 MWh/year

Receiver and buyer (AVA)

With the total demand for space heating and the total demand for process heat inserted in energyPRO together with the total production of excess heat, a surplus of excess heat at 66.270 MWh/year appears. This influences, that after the exchange of excess heat between the 12 industries at the port an additional amount of excess heat around 66.270 MWh/year exists, which can be utilised.

As described in Section 7.1, it is chosen to add AVA as the receiver of a surplus of excess heat. AVA is added to utilise the excess heat produced by the industries at the port and not to discharge the excess heat, instead. Furthermore, adding AVA as a receiver and buyer of the surplus of excess heat in the model also helps to create an energy balance in the design of the exchange in relation to the amount of excess heat produced by the industries and the excess heat being utilised.

In energyPRO, AVA is included as an additional heat demand, and the heat demand defined in relation to AVA is 67.000 MWh/year. AVA's heat demand is defined as higher than the aforementioned surplus of excess heat, because it makes it possible for the industries with a production of excess heat to produce at full load at all times in energyPRO. However, this results in the fact that the heat demand is not met in energyPRO, but this is accepted in the thesis to incorporate the entire excess heat production in the modelling of the exchange of excess heat at the port of Aarhus. In a real-life context, AVA will only be able to receive and buy 66.270 MWh/year.

Electricity market

The booster heat pumps added to utilise excess heat from Industry 5, 10, and 12 result in a use of electricity. The expenses connected to the use of electricity are included by putting in an electricity market in energyPRO and the electricity prices embedded in the electricity market are based on spot market prices from 2019. The prices have an hourly distribution and relates to the price area denoted DK1, which includes Western Denmark. The electricity spot marked prices are obtained from: [Energi Data Service, 2019].

As the booster heat pumps are needed for the use of excess heat from Industry 5, 10 and 12 in the exchange of excess heat at the port, the expenses related to the purchase of electricity to the booster heat pumps are viewed as common and shared expenses to be paid by all of the industries involved in the exchange. Sharing the expenses between the industries is determined based on the common and system way of thinking the use of excess heat at the port as described in Section 7.1.

In energyPRO, an electricity consumption is also attached to the heat pumps used in the cooling processes at Industry 3, 4, 5, 7, and 12. The purchase of the electricity consumed by the heat pumps in the cooling processes is paid by Industry 3, 4, 5, 7, and 12 and is therefore not an expense in the exchange of excess heat and common system, as this electricity consumption is related to the production processes within the industries. With the electricity consumption connected to the spot market in the energyPRO-model, the purchase of electricity related to the heat pumps in the cooling processes is subtracted as expenses in energyPRO.

Taxes and tariffs

Taxes and tariffs are expenses connected to the design of the exchange of excess heat at the port of Aarhus. The taxes and tariffs put in energyPRO are viewed as shared expenses paid by all of the 12 industries participating in the exchange. The shared payment of the taxes and tariffs is connected to the common and system way of thinking the utilisation of excess heat at the port and the creation of a collaboration between the industries as described in Section 7.1.

Tax on Excess heat

As described in the Problem Analysis, a tax on excess heat exists and the tax on excess heat is incorporated into the energyPRO-model of the exchange of excess heat. The rate of the tax on excess heat included in energyPRO is 90 DKK/MWh. This means, that it is assumed, that none of the industries with a production of excess heat at the port of Aarhus have achieved a certification, and by that having the reduced tax of 36 DKK/MWh as the tax on excess heat to pay.

For Industry 1, 9, 10, and 11, a tax on excess heat is paid in relation to the total amount of excess heat produced by the industries. In energyPRO, this influences, that the tax at 90 DKK/MWh is included in relation to the production of excess heat at these industries.

Industry 3, 4, 5, 7, and 12 do also have to pay a tax in relation to the excess heat produced at the industries, but the tax on excess heat is determined in a different manner than at Industry 1, 9, 10, and 11. In Table 7.1, the excess heat from Industry 3, 4, 5, 7, and 12 is marked as expected to be produced by cooling processes in the industries and in the thesis, the cooling processes at the industries are assumed to require a heat pump. As described in the Problem Analysis in Figure 2.3, regulation defines that in situations where excess heat is produced from a cooling process by a heat pump, the charge and payment of the tax on excess heat is only imposed on the amount of excess heat produced, which is 3 times higher than the electricity consumption of the heat pump [Skatteministeriet, 2020a]. Based on this regulatory condition, the payment of the tax on excess heat is included and paid in energyPRO in relation to the amount of excess heat produced at Industry 3, 4, 5, 7, and 12, which exceeds 3 times the electricity consumption of the heat pumps placed at the industries. In Appendix D Section D.1, the formula behind this calculation is shown.

In the Problem Analysis, it is described in which situations the tax on excess heat is paid, and from this it can be deduced, that e.g. no tax on excess heat exists, when excess heat from a production process is used as heat in another production process. Reflecting on this in relation to the design of the exchange of excess heat between the industries at the port of Aarhus, it can be argued, that the process heat demands at Industry 1, 4, 7, 10, and 11 are being covered by excess heat from other production processes in the industries participating in the exchange and common system. This means, that in the thesis, it is emphasised as possible to characterise this use of excess heat to cover the process heat demands as a process-to-process utilisation of excess heat, which is not subjected to the tax on excess heat. As the industries deliver excess heat to the common system at the port, it is not possible to determine specifically what excess heat is allocated and used to met the process heat demands. This means, that it cannot be defined which industries that cover the process heat demands and by that, where the tax on excess heat should not be paid. For that reason, a revenue corresponding to a repayment of the tax on excess heat in relation to the excess heat used to meet the process heat demands at Industry 1, 4, 7, 10, and 11 is included in energyPRO to account for the tax expenses already paid.

In energyPRO, the revenue is put in as earnings of 90 DKK/MWh in relation to the process heat demands at Industry 1, 4, 7, 10, and 11.

As a result of the categorisation of process-to-process use of excess heat in the exchange, the tax on excess heat is only paid in relation to the space heating demands and in connection to the amount of excess heat allocated to AVA in the design and common system of the exchange of excess heat at the port of Aarhus.

Tax on Electricity to Heat

A tax on electricity to heat is paid, when electricity is used in a production of heat, and because of that, a tax on electricity to heat is imposed in relation to the booster heat pumps needed for the use of excess heat from Industry 5, 10, and 12 [Skatteministeriet, 2020b]. In energyPRO, the tax on electricity to heat is inserted in connection to the electricity consumption of the booster heat pumps and put in with a tax rate at 210 DKK/MWh (included in Figure 2.4).

The tax on electricity to heat does also apply in relation to Industry 3, 4, 5, 7, and 12, where the excess heat is produced on the basis of a cooling demand. As included in Figure 2.4 in the Problem Analysis, a distribution of the electricity consumption between the production of excess heat and cooling has to be made, when a heat pump produces both excess heat and cooling [Skatteministeriet, 2020a]. In relation to the production of excess heat, regulation defines, that the electricity consumption for the excess heat production is 1/3 of the heat produced by the heat pump - yet the electricity consumption divided to the production of heat cannot be defined as higher than the actual electricity consumption of the heat pump [Skatteministeriet, 2020a]. The cooling production is assigned the rest of the electricity consumption of the heat pump. Due to this regulatory condition, the payment of the tax on electricity to heat is paid in energyPRO in relation to the heat production from Industry 3, 4, 5, 7, and 12, which corresponds to 1/3 of the excess heat produced by the heat pumps in the cooling processes at the industries or the actual electricity consumption of the heat pumps. The formula used for the calculations of this is included in Appendix D Section D.1.

Electricity tariffs

In connection to the booster heat pumps needed for the utilisation of excess heat from Industry 5, 10, and 12, electricity tariffs must be paid in connection to the consumption of electricity of the heat pumps [Klima-, Energi- og Forsyningsministeriet, 2020a,b].

The electricity tariffs included in energyPRO involve transmission, distribution and system tariffs, and the tariffs are included as one aggregated price, 164,45 DKK/MWh. The aggregated price is based on the electricity tariffs shown in Figure 2.4 in page 11 in the Problem Analysis.

PSO-tax

A PSO-tax is paid in relation to a consumption of electricity [Klima-, Energi- og Forsyningsministeriet, 2020a]. Due to the electricity consumption associated with the booster heat pumps needed for the use of excess heat from Industry 5, 10, and 12, the PSO-tax is a part of the design of the exchange of excess heat at the port of Aarhus. The PSO-tax has been determined based on an average of the prices of the tax in 2019 which gives a tax rate of 39,75 DKK/MWh [Energistyrelsen, 2018a, 2019a,b,c]. The rate of the PSO-tax is also shown in Figure 2.4 in the Problem Analysis. In energyPRO, the tax is inserted as an expense relative to the electricity consumption by the booster heat pumps.

Investments

In energyPRO, investment costs are put in for the booster heat pumps needed in the utilisation of excess heat from Industry 5, 10, and 12. The investment costs are determined by calculating the capacities of the heat pumps and using information about investments costs of heat pumps provided in the technology catalogue from the Danish Energy Agency: Technology Data - Generation of Electricity and District heating [Energistyrelsen, 2020]. The calculations of the capacities and investment costs of the booster heat pumps are included in Appendix D Section D.1 and D.1.

In energyPRO, the investment costs connected to the booster heat pumps are included with a depreciation period of 5 years. A depreciation period of 5 years is chosen, as the industries are assumed to want a relatively short depreciation period, because they are assumed to be exposed to competition [Skatteministeriet, 2018].

The technology catalogue does also provide information about operation and maintenance costs (O&M) of heat pumps, and these are also included in relation to the booster heat pumps in energyPRO.

The investment costs and costs related to O&M are also shared expenses for the industries participating in the exchange at the port, due to the perception of the exchange at the port as a common and system way of thinking the use of excess heat as described in Section 7.1.

Revenues

As defined in section 7.1, no payment for the delivery of excess heat among the industries is presumed in the design of the exchange of excess heat at the port of Aarhus. But with AVA defined as the receiver and buyer of the surplus of excess heat from the exchange of excess heat between the industries, AVA buys the surplus of excess heat from the common system and this purchase is included as a revenue in energyPRO.

As explained in the Problem Analysis, a price regulation is defined in relation to district heating companies and the heat price, that district heating companies can charge district heating consumers in the Danish Heat Supply Law [Klima-, Energi- og Forsyningsministeriet, 2020c; Skatteministeriet, 2018]. The price regulation describes, that district heating companies must only include "necessary expenses" in the heat price paid by district heating consumers. The price for the purchase of excess heat from an industry is determined as being a part of the "necessary expenses" according to the Danish Heat Supply Law [Klima-, Energi- og Forsyningsministeriet, 2020c]. In addition to this, §20b in the Danish Heat Supply Law highlights, that industries with a production of excess heat may incorporate a revenue in the price for the excess heat agreed upon with a district heating company [Klima-, Energi- og Forsyningsministeriet, 2020c]. However, a district heating company must not pay a price for the excess heat from an industry, which exceeds the price of an alternative heat production at the district heating company. This is related to the principle of substitution and the alternative heat price is also denoted the substitution price[5][Skatteministeriet, 2018]. With that in mind, the maximum revenue that the industries at the port of Aarhus can achieve pr. MWh of excess heat by allocating and selling the surplus of excess heat to AVA is the substitution price. For that reason, a time series consisting of hourly substitution prices at AVA is included in energyPRO and is connected to the heat demand defined as AVA in the design of the exchange of excess heat in energyPRO. The time series entailing the substitution prices is provided by AVA and the prices are from 2019. The substitution prices from AVA have an hourly variation, because the price varies in relation to which production units are used by AVA in the production of district heating.

7.1.3 Presentation of the Design of the Exchange of Excess Heat

Figure 7.2 presents an illustration of the proposed design of the exchange of excess heat between the 12 industries at the port of Aarhus and the design of the exchange of excess heat in a common system.

[5]Translation of the Danish word: substitutionspris

An illustration of the energyPRO-model of the design of the exchange can be viewed in Appendix E in Section E.1.

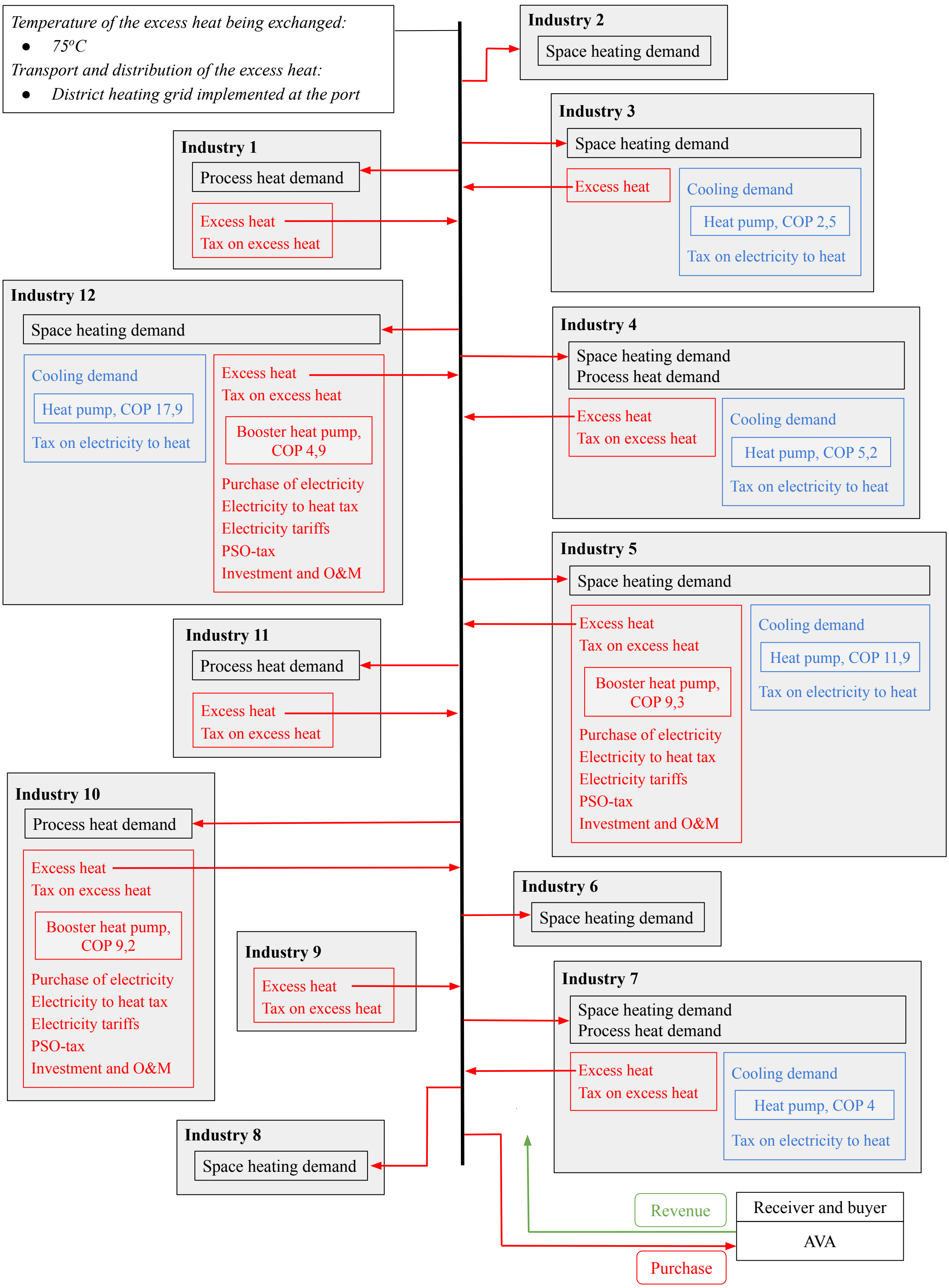

Figure 7.2: *Illustration of the exchange of excess heat at the port of Aarhus.*

In Figure 7.2 the 12 industries included in the exchange of excess heat are presented. The placement of the heat demands and the production of excess heat at the industries can be observed. In relation to this, the figure also illustrates at which industries the excess heat is produced based on a cooling demand and to which industries booster heat pumps are needed for the utilisation of the excess heat in the exchange. As also illustrated on Figure 7.2, the exchange of excess heat modelled in energyPRO is designed as a common system and based on the system way of thinking the use of excess heat, and this can be viewed from the figure as the excess heat produced by the industries at the port of Aarhus is used to cover the heat demands among them. In relation to this, it can be mentioned to create a form of dependency between the industries in the common system, as they depend on each other to deliver excess heat to the exchange. The black line indicates the common system of the exchange and the grid at the port of Aarhus in which the excess heat is exchanged.

AVA is included in the design of the exchange to use and buy the surplus of excess heat existing after the excess heat has been distributed between the 12 industries. The revenue from allocating the surplus of excess heat to AVA is shared between the industries and the revenue is marked on Figure 7.2 by the green arrow going back into the common system. The revenue from AVA is the only revenue obtained by the industries in the exchange of excess heat, as no payment is charged for the excess heat exchange between in industries in the common system at the port.

In addition to this, Figure 7.2 does also indicate at which industries the expenses in relation to taxes and tariffs, purchase of electricity and investment costs exist. As described in Section 7.1, the expenses connected to the exchange of excess heat at the port are shared by the 12 industries included in the exchange, but in energyPRO and in the Figure 7.2, the expenses are assigned to the different industries to illustrate and get an impression of where expenses emerge in the design of the exchange. From this it can be seen, that different taxes and other expenses varies in relation to, whether the excess heat can be used directly in the exchange and common system or the excess heat is produced based on a cooling demand and require a booster heat to be utilised.

In relation to the transport and distribution of the excess heat in the common system, AVA owns, operates and carries out the maintenance of the grid. This means, that the 12 industries in the common system have a shared ownership of the booster heat pumps and operates everything but the grid in the design of the common system.

7.1.4 Results of the Design of the Exchange of Excess Heat

In the following, the results of the design of the exchange of excess heat are presented. As described in the Methodology in Section 6.2, a set of parameters are defined involving the energy balance and the total annual costs. The parameters are use to present the result of the design of the exchange of excess heat modelled in energyPRO.

Results

In Table 7.4, the energy balance of the exchange of excess heat in the model is shown.

In Appendix E an output from energyPRO is included presenting the energy balance in the design and model by the energy conversion on a yearly basis.

Table 7.4: The energy balance in the design and model of the exchange of excess heat.

Energy Balance in the Model

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270

The energy balance in Table 7.4 shows, that roughly around half of the excess heat produced by the industries is utilised and exchanged between the industries at the port to cover the space heating demands and process heat demands at the industries included in the exchange. This also results in the fact, that around half of the excess heat produced by the industries at the port is allocated to AVA.

In Table 7.5, the total annual expenses of the exchange of excess heat are shown together with the total revenue from AVA. Below the table, a bar chart of a cost break down of the total annual costs is shown.

In Appendix E an output from energyPRO is included showing the total annual costs in terms of expenses and revenues.

Table 7.5: The total annual expenses and total annual revenue from AVA

Total Annual Expenses and Revenue together with Costs/Profit in the Model

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330

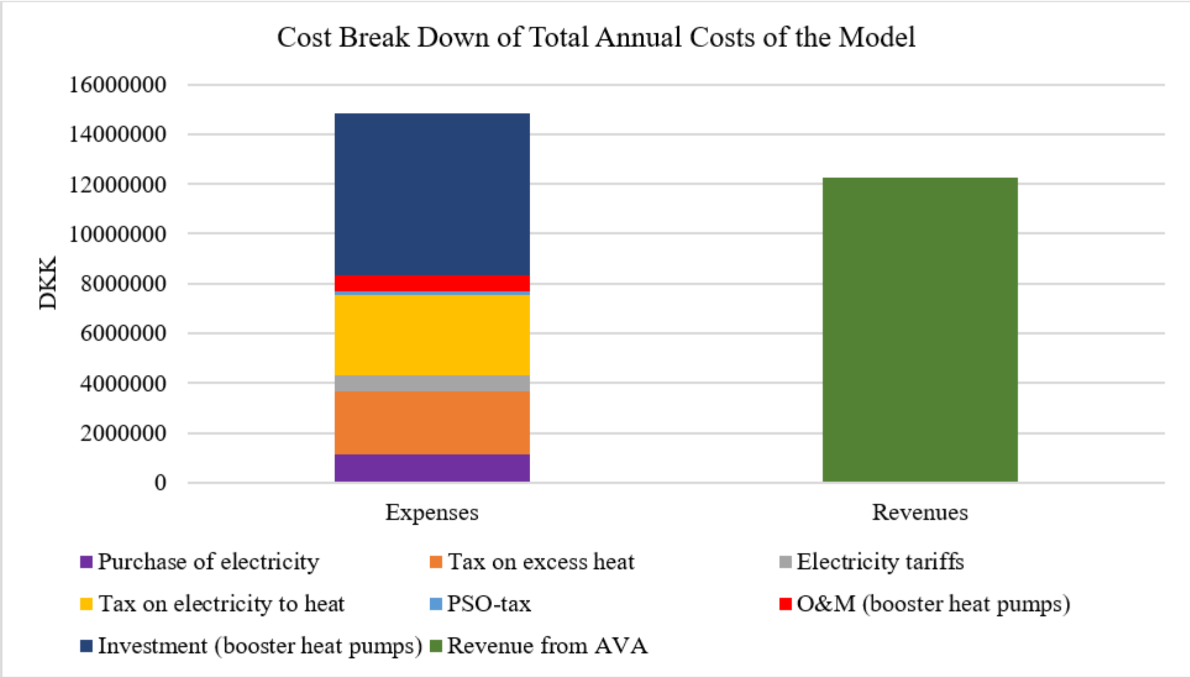

Figure 7.3: *Bar chart showing a cost break down of the total annual costs of the model.*

Table 7.5 shows that the total annual expenses included in the exchange exceeds the total annual revenue from AVA, which means that in the model of the exchange of excess heat, a deficit exists. This means, that with choices and assumptions made and the current design for exchange of excess heat, the common system does not profit from the exchange of excess heat. From Table 7.5 it can seen that each industry included in the common system has annual costs of 216.330 DKK. As no actual data has been obtained in relation to the 12 industries included in the common system, it is not possible to compare the annual costs in the common system to the costs connected to fulfilling the heat demands currently. But the costs for each industry are still presented, as it gives an impression of the costs connected to participating in the common system and the costs related to the proposed design of the exchange of excess heat at the port of Aarhus.

The cost break down of the total annual costs in the bar chart in Figure 7.3 illustrates, that the tax on excess heat is present in the total annual costs. However, it can also be viewed, that all other costs contained in the total annual costs are related to electricity costs and aggregated the electricity costs make up a greater deal of the expenses in the common system than the tax on excess heat. From this is can be deduced, that costs related to electricity are larger expenses than the tax on excess heat in the proposed design of the exchange of excess heat at the port of Aarhus with the choices and assumptions made in the thesis. Looking at the cost break down in more detail, the majority of the expenses in the total annual costs are the investment in booster heat pumps, the tax on electricity to heat, and the tax on excess heat. It can be argued that the investment in booster heat pumps and the tax on electricity to heat primarily relates to the use of booster heat pumps in the exchange of excess heat. This can be interpreted to indicate that expenses are connected to the use of booster heat pumps and the use of excess heat with a low temperatures from Industry 5, 10, and 12 in the common system. In addition to this, the tax on excess heat also seems to be a dominant expense for the common system with the choices and assumptions made in the model of the exchange.

Considering the above, the expenses can be argued to be a result of conditions included in the proposed design of the common system. This means, that the regulatory and technical conditions incorporated in the design have an impact on the total annual costs of the common system as these conditions can be argued to be reflected in the majority of the expenses being the tax on excess heat, the tax on electricity to heat, and the expenses related to using low temperature excess heat.

Summary

In this chapter of the analysis, a proposed design of the exchange of excess heat and common system is outlined. The design of the exchange of excess heat between the 12 industries at the port of Aarhus is based on a set of choices and assumptions, which are a part of the modelling of the design in energyPRO.

The results of the design shows, that an energy balance exists in the common system by having an exchange of excess heat between the industries included in the exchange at the port and adding AVA as the receiver and buyer of the surplus of excess heat.

The total annual costs of the design of the common system presents, that the regulatory and technical conditions incorporated into the design of the exchange of excess heat are reflected in the expenses in the design.

As SNM describes learning processes as a part of the management of niches into the regime, in the following chapter the thesis experiments with the choices and assumptions in the design and in the included regulatory and technical conditions to further develop the niche of the common and system way of thinking the use of excess heat as an additional approach in the utilisation of excess heat.

8 Sensitivity of the Design of the Exchange of Excess Heat

The model of the design of the exchange of excess heat is based on specific choices and assumptions. In order to see how sensitive the design of the exchange of excess heat is, it is necessary to make changes in the choices and assumptions as well as the regulatory and technical conditions in the design and model. Included in SNM as important in the establishment of a successful niche and the entrance of the niche into the regime is experimenting with and developing the niche through learning processes. This means, that the analysis of the sensitivity of the design is also carried out based on the management of niches in SNM.

In energyPRO and the design of the exchange of excess heat, the energy balance between the heat demand and production of excess heat is created by having an exchange of excess heat between the industries at the port and adding AVA as a receiver and buyer of the surplus of excess heat. It can be emphasised, that the defined energy balance in the exchange of excess heat at the port of Aarhus has to be robust against potential changes, that can affect the energy balance for the pilot project to be carried out. To analyse the sensitivity and robustness of the energy balance, changes are experimented with in relation to:

- Reduction of the production of excess heat
- Increase in the production of excess heat
- Increase in the connections to the exchange of excess heat

In energyPRO different regulatory and technical conditions are incorporated, and the results of the proposed design of the exchange of excess heat showed, that theses have an impact on the total annual costs in the common system. To analyse the how sensitive the design of the exchange of excess heat is in relation to the different regulatory and technical conditions included in the model of the design, changes are experimented with in relation to:

- Tax on excess heat
  - Process-to-process use of excess heat
  - Certifications in the industries
  - No tax on excess heat
- Tax on electricity to heat
- Low temperature excess heat
- Change of the required temperature for excess heat

When a change is carried out, the results of the change are related to the results of model of the proposed design of the exchange of excess heat and common system presented in Section 7.1.4. This means, that in the tables and figures, the results from the different changes are illustrated next to the results from the model of the design in energyPRO.

Outputs from energyPRO showing the energy balance and the total annual costs in terms of expenses and revenue for the changes entailed in the sensitivity analysis are attached to the thesis in Digital Exam.

8.1 Energy balance

8.1.1 Reduction of the Production of Excess Heat

A possible situation, that can unfold at the 12 industries participating in the exchange of excess heat, is the implementation of energy efficiency initiatives in the production processes of the industries. In the Problem Analysis, excess heat is mentioned as a "double use of energy" which is argued to be related to an efficient use of energy. However, energy efficiency initiatives can be done in the production process at an industry, which results in a reduction in the production of excess heat or in no production of excess heat.

Another situation, which can reduce the production of excess heat from the 12 industries in the exchange, is the possibility of an industry closing, which removes a production of excess heat from the exchange at the port. In addition to this, many of the industries located at the port of Aarhus have rental agreements with Aarhus Havn about the placing of the industry at the port-area, and at the end of a rental agreement, it is possible that an industry wants to move to another location [Interview with Anne Zachariassen, 2020]. If this is the case for an industry included in the exchange of excess heat, a production of excess heat is removed from the exchange between the industries.

In energyPRO, the reduction in the production of excess heat is simulated by turning off the production of excess heat from Industry 9 in the exchange. It is chosen to remove the production of excess heat from Industry 9 as the industry provides the largest volume of excess heat (40.000 MWh/year) to the common system and by removing it, it shows a "worst case" situation of reduction of the production of excess heat in the current design of the exchange.

Results
Table 8.1 includes the energy balance in the design and model of the exchange of excess heat with the reduction in the production of excess heat.

Table 8.1: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with a Reduction of the Production of Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	94.565	295	68.000	26.270

The table shows the reduced production of excess heat in the exchange and by looking at Table 8.1, the reduction in the production of excess heat results in a lower allocation of excess heat to AVA. This means, that by removing the production of excess heat from Industry 9, it is still possible to exchange excess heat between the 12 industries and meet the heat demands at the industries. This means, that the energy balance of the exchange of excess heat is affected in the way, that AVA receives and buys a lower amount of excess heat from the common system.

The removal of the production of excess heat from Industry 9 shows as an example of a reduction in the production of excess heat. In relation to this, it is worth noting that the result of removing the production from another industry or from a combination of industries will probably be different from the results of removing the production of excess heat from Industry 9. But the general tendency in the situation of a reduction in the excess heat production can be emphasised to be a reduction in the amount of excess heat allocated to AVA. The exchange of excess heat among the industries will be affected, when no excess heat can be allocated to AVA and not enough excess heat is present to meet the heat demands in the exchange.

Table 8.2 shows the total annual expenses and revenue of the exchange of excess heat with the reduction in the production of excess heat, and below the table, a bar chart with a cost break down of the total annual costs is illustrated:

Table 8.2: *The total annual expenses and total annual revenue from AVA.*

Total Annual Expenses and Revenue together with Costs/Profit
with a Reduction of the Production of Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	11.234.187	4.931.834	-6.302.353	-525.196

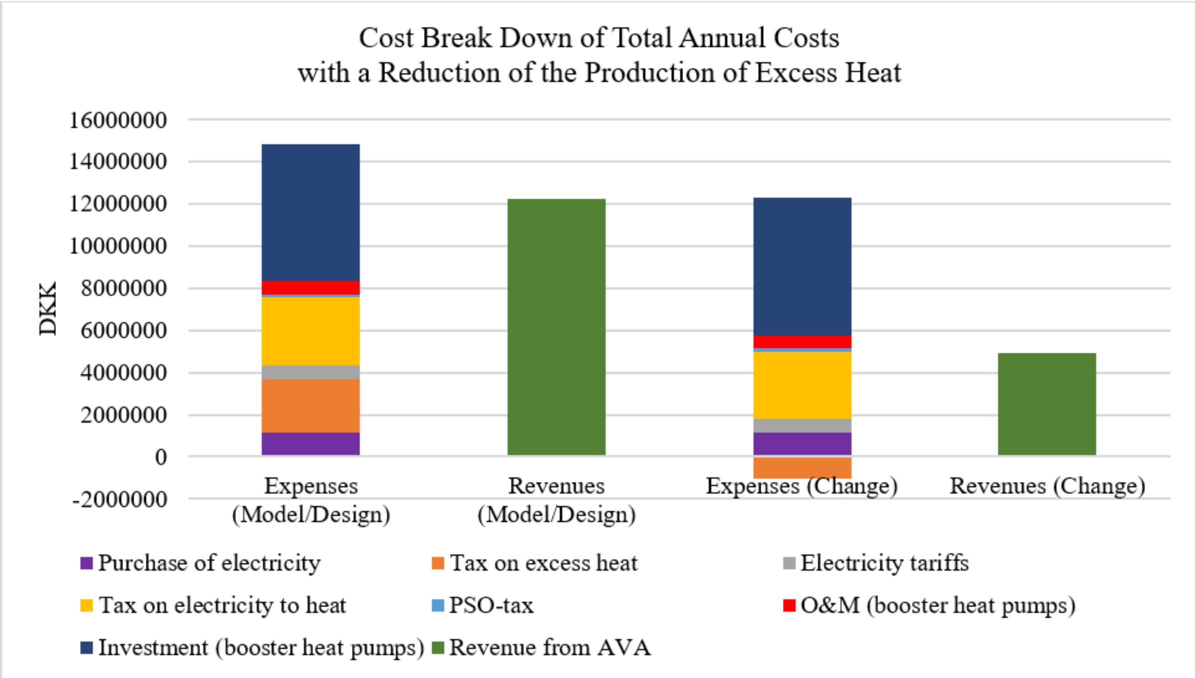

Figure 8.1: *Bar chart showing a cost break down of the total annual costs with a reduction of the production of excess heat.*

From the table and bar chart of the cost break down, a reduction in the annual expenses and revenue from AVA can be observed. The reduction in the revenue from AVA is a result of the lower amount of excess heat allocated to AVA due to the reduction in the production of excess heat by removing the excess heat produced at Industry 9. In Table 8.2, it can be observed that the reduction in the production of excess heat in the common system results in an increase in the expenses related to each industry in the exchange, which can be associated with the decrease in the revenue from AVA. In Figure 8.1, the tax on excess heat shows as an expense in minus, and this is related to the repayment in connection to the process heat demands becoming larger than the payment of the tax on excess heat, when the reduction in the production of excess heat is carried out. The expense in minus figures in the cost break down as en expense to be subtracted from the total annual expenses. But in a real-life context, it can be assumed that the repayment concerning the tax on excess heat in relation to the process heat demand only will be repaid equal to the amount of expenses paid for the tax.

In relation to the total annual costs with a reduction in the production of excess heat, the general tendency can be argued to be a change in the expenses and result in a reduced revenue from AVA, which indicates that the model of the exchange of excess heat is sensitive to a change involving a reduction of the production of excess heat.

8.1.2 Increase in the Production of Excess Heat

The model and the design of the exchange of excess heat containing the 12 industries is a pilot project, and because of that, it is possible, that the pilot project can attract interest of other industries placed at the port to participate in the exchange of excess heat. With a potential for additional industries connecting to the exchange, a possible situation can be that the total amount of excess heat included in the exchange at the port can increase. Besides the pilot project attracting an interest at other industries placed at the port, it can also be assumed that industries at the port can arouse an interest in being a part of the exchange because of the national energy policy goals and as steps in supporting the 2030-goal of CO_2-neutrality in Aarhus Municipality and the vision of the port of Aarhus becoming a "sustainable port". Being a part of the exchange can also be emphasised to maybe have a positive effect on the image of the industries, which can be assumed to be a driver for more industries at the port wanting to participate the exchange of excess heat.

In energyPRO, the increase in the production of excess heat is simulated by adding an industry producing excess heat to the exchange. A production of excess heat of 14.500 MWh/year is chosen as this is an average of the productions of excess heat in the model. An average is used in order to simulate the increase in the production of excess heat, as it makes it possible to define the increase in production on the basis of the kind of industries already included in the exchange and placed at the port of Aarhus.

The increased production of excess heat inserted in energyPRO is assumed not to be based on a cooling demand and presumed to have a temperature at 75°C, which means that no booster heat pump is needed for the utilisation of this excess heat.

Results

In Table 8.3, the energy balance in the design and model of the exchange of excess heat with the increase in the production of excess heat is presented.

Table 8.3: *The energy balance in the design of the exchange of excess heat*

Energy Balance with an Increase of the Production of Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	149.065	295	68.000	80.770

The table shows that the total production of excess heat is increased and that more excess heat is received and bought by AVA. This illustrates, that with an increase in the production of excess heat, the heat demands at the industries in the common system are met and this results in a larger amount of excess heat allocated to AVA. With an increase in the production of excess heat, the energy balance in the design of the exchange is created by delivering a larger amount of excess heat to AVA. Based on this, an increase in the production of excess heat without an increase in the heat demand in the exchange at the port can be argued to lead to an increase in the allocation of excess heat to AVA.

The table below includes the total annual expenses and revenue of the exchange of excess heat with the increase in the production of excess heat. After the table, a bar chart is shown with a cost break down of the total annual costs.

Table 8.4: *The total annual expenses and total annual revenue from AVA*

Total Annual Expenses and Revenue together with Costs/Profit
with an Increase in the Production of Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	16.139.216	14.886.832	-1.252.384	-104.365

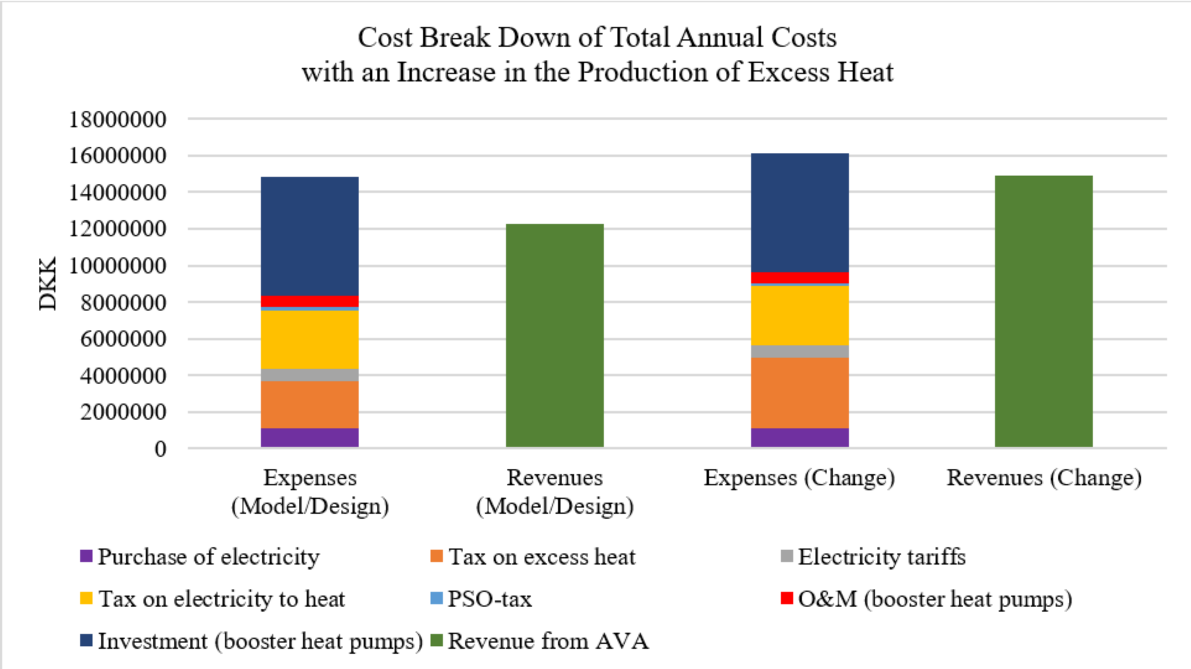

Figure 8.2: *Bar chart showing a cost break down of the total annual costs with an increase in the production of excess heat.*

The total annual expenses and revenue show, that both the expenses and revenue are increased as a result of increasing the production of excess heat in the exchange. Looking at Figure 8.2, the increase in total annual expenses seems to be related to an increase in the payment of the tax on excess heat, which is connected to the increase in the production of excess heat in the exchange being subjected to the tax. The increase in the revenue can be explained by more excess heat being received and bought by AVA from the exchange at the port. Table 8.4 shows that for each industry costs exist, but the costs are reduced with the increase in the production of excess heat in the common system compared to the proposed design of the exchange.

As the increase in the excess heat production is simulated as excess heat being delivered with a temperature of 75°C, it is assumed that a booster heat pump is not required for the utilisation of the excess heat. It can be presumed, that simulating the increase in the excess heat production with the need of a booster heat pump will have another impact on the total annual costs. Furthermore, it is chosen that the increased production of excess heat is not produced on the basis of a cooling demand, which can also be assumed to have an impact on the total annual costs related to an increase in the production of excess heat. This means, that in relation to an increase in the excess heat production to the exchange at the port, the temperature of the increase in excess heat and how the excess heat emerges can be assumed to have an impact on the total annual costs. The results of increasing the production of excess heat in the exchange of excess heat show, that the model is sensitive towards this change.

8.1.3 Increase in the Connection to the Exchange of Excess Heat

In relation to the description above of additional industries potentially connecting to the exchange of excess heat at the port of Aarhus, a possible situation is also, that more industries with only demands for space heating and process heat (and no production of excess heat) want to be included in the exchange at the port to use the excess heat to cover their demands. It can be assumed, that the same reasoning exists at these industries for wanting to connect to the exchange as highlighted in the section above related to the increased production of excess heat.

In energyPRO, adding industries to the exchange with a demand for space heating or process heat are simulated as two separate changes in the model. The added space heating demand and demand for process heat are based on an average of the space heating demands and process heat demands already implemented in the model, which means that a space heating demand of 37 MWh/year and a process heat demand of 13.600 MWh/year are added. With the increase of a process heat demand, a repayment of the tax on excess heat is also added to the model due to the characterisation of this being a process-to-process use of excess heat in the thesis.

Results

In Table 8.5, the energy balance of the exchange of excess heat with an increase in connection to the exchange is illustrated.

Table 8.5: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with an Increase in Space Heating Demand

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	134.565	332	68.000	66.963

Energy Balance with an Increase in Process Heat Demand

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	134.565	295	81.600	52.670

The table shows that with an increase in either the space heating demand or the process heat demand, the amount of excess heat allocated to AVA is reduced. This means, that with an increase in the space heating demand or process heat demand of these magnitudes, the energy balance in the design of the exchange of excess heat shows that the heat demands within the exchange are still met, but AVA is as a result receiving and buying less excess heat from the common system.

Below, a table shows the total annual expenses and revenue of the exchange of excess heat with an increase in the connection to the exchange of excess heat. Two bar charts are presenting cost break downs of the total annual costs connected to an added space heating demand and an added process heat demand to the exchange of excess heat.

Table 8.6: *The total annual expenses and total annual revenue from AVA*

Total Annual Expenses and Revenue together with Costs/Profit
with an Increase in Space Heating Demand

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	14.834.220	12.231.496	-2.602.724	-216.894

Total Annual Expenses and Revenue together with Costs/Profit
with an Increase in Process Heat Demand

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	13.610.216	9.754.072	-3.856.144	-321.345

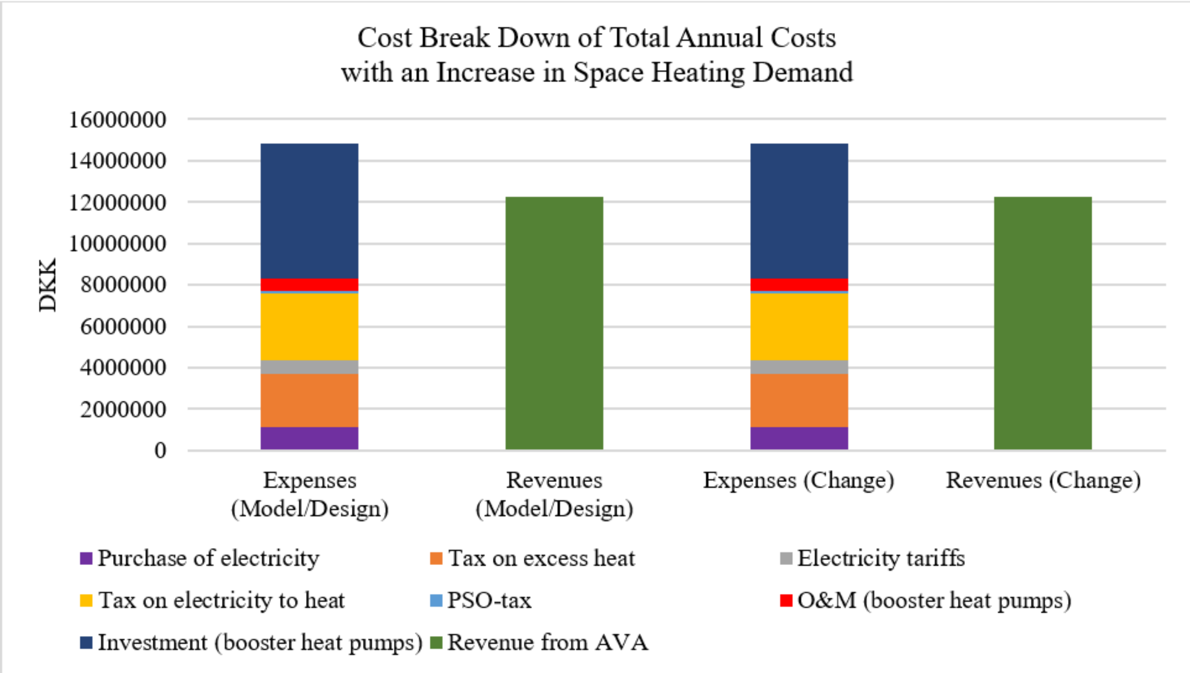

Figure 8.3: *Bar chart showing a cost break down of the total annual costs with an increase in space heating demand.*

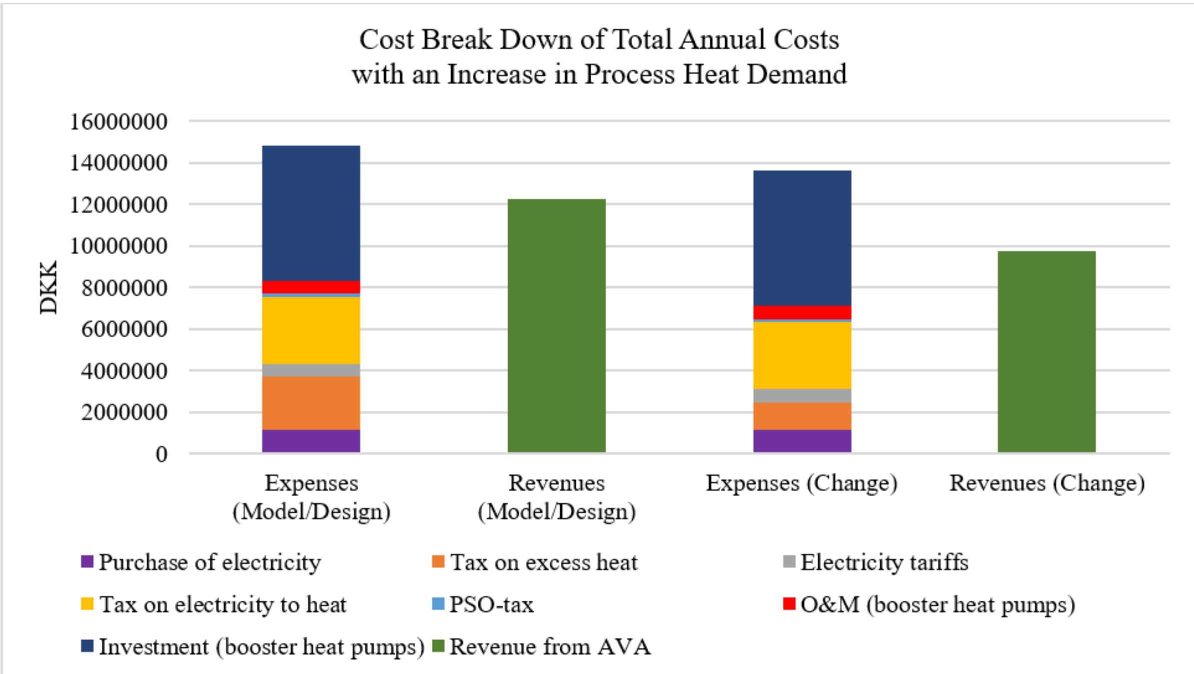

Figure 8.4: *Bar chart showing a cost break down of the total annual costs with an increase in process heat demand.*

Looking at the total annual expenses and revenue, the increase in space heating demand at 37 MWh/year gives approximately the same total annual expenses and a decrease in the total annual revenue. The decrease in the revenue can be explained by adding a demand to the exchange between the industries leading to a lower amount of excess heat to be allocated to AVA and thus a lower revenue.

Increasing the process heat demand with 13.600 MWh/year reduces the total annual expenses and relating this to the bar chart of the cost break down, the reduction in the expenses can be connected to the tax on excess heat. The total expenses related to the tax on excess heat are reduced when adding a process heat demand, because of the process-to-process characterisation of the use of excess from the exchange to cover the process heat demands. This reduces the expenses related to the tax on excess heat, as process-to-process utilisation of excess heat is not subjected to the tax. This also explains, why a reduction in the expenses does not occur when adding a space heating demand. The revenue from AVA decreases with the increase in the process heat demand, and this can be explained by more of the excess heat produced by the industries being used in the exchange to cover the added process heat demand. The decrease in the revenue from AVA is larger than the decrease appearing when adding a space heating demand, due to the different magnitudes of the demands.

Table 8.6 shows that the increase in space heating demand at 37 MWh/year result is around the same expenses at each industry as in the proposed design of the model, whereas the expenses for each industry increase by connecting an additional process heat demand at 13.600 MWh/year to the common system.

The results of the increasing connection to the exchange of excess heat presented by adding a space heating demand and a process heat demand show that the model of the exchange of excess heat is sensitive towards this. However, the energy balance and total annual costs show that there is a difference in increasing the connection to the exchange of excess heat by a space heating demand or a process heat demand.

8.2 Total annual costs

8.2.1 Tax on Excess Heat

Process-to-process Use of Excess Heat

In the model and the design of the exchange of excess heat, the use of excess heat from the exchange to cover the process heat demands at Industry 1, 4, 7, 10, and 11 is defined as a process-to-process use of excess heat, which is not imposed to the tax on excess heat. If it is not possible to use the process-to-process categorisation, it can be assumed, that this will have an impact on the total annual costs associated with the exchange of excess heat the port of Aarhus. Due to this, the categorisation of the process-to-process utilisation is experimented with in energyPRO by removing the repayment of the tax on excess heat related to the process heat demands in the exchange of excess heat. This means, that the tax on excess heat is paid for both the space heating demands and the process heat demands in the common system.

Results

In Table 8.7, the energy balance is shown for the exchange of excess heat with a change in the categorisation of the process-to-process use of excess heat.

Table 8.7: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with a Change in Process-to-Process Use of Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	134.565	295	68.000	66.270

Table 8.7 illustrates, that no changes occur in the energy balance with a change in the categorisation of the process-to-process use of excess heat.

The total annual expenses and revenue are shown in Table 8.7, and below the table, a bar chart is included containing a cost break down of the total annual costs.

Table 8.8: *The total annual expenses and total annual revenue from AVA*

Total Annual Expenses and Revenue together with Costs/Profit with a Change in Process-to-Process Use of Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	20.954.216	12.238.255	-8.715.961	-726.330

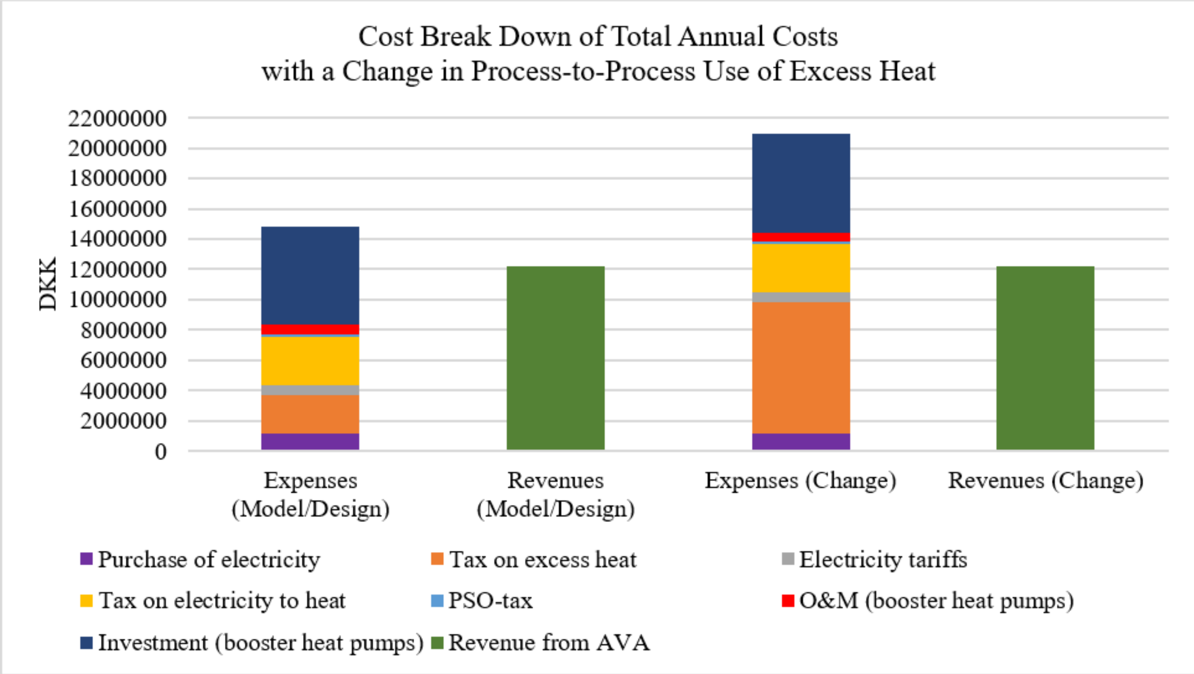

Figure 8.5: *Bar chart showing a cost break down of the total annual costs with a change in process-to-process use of excess heat.*

By not using the categorisation of the process-to-process use of excess heat in the exchange of excess heat at the port, it can be viewed in Table 8.7, that the total annual expenses increase whereas the revenue from AVA does not change. It can be argued, that the increase in the expenses is a significant increase compared to the expenses present in the model of the proposed design of the exchange of excess heat. The significant increase in the expenses is also reflected in the expenses for each industry in the common system. The bar chart shows, that when the categorisation of the process-to-process utilisation of excess heat in the design of the exchange is not used, the tax on excess heat increases and can be argued to make up around half of the total expenses. Looking at this, it seems, that the model and design of the exchange of excess heat is sensitive to a change in the categorisation of the use of excess heat as process-to-process in relation to covering the process heat demands at the industries in the exchange. Additionally, is can also be argued, that it appears that the categorisation of the process-to-process use of excess heat in the exchange can be important for an implementation of the exchange of excess heat between the industries at the port of Aarhus, as it seems that otherwise the total annual expenses increases.

Certification of the Industries

As part of the recent legislative change of the tax on excess heat, it is possible to obtain a reduced tax on excess heat if an industry is certified, and the reduced tax rate is 36 DKK/MWh. It is possible to assume, that some of the 12 industries included in the exchange of excess heat at the port of Aarhus will be certified in the future. This can be presumed, as achieving a certification also can be viewed as a part of a strategy at the industries in relation to implementing initiatives within the industries, that complies with the 2050-goal and 2030-goal as well as the defined goal of Aarhus Municipality and the vision about the port of Aarhus becoming a sustainable port. Achieving a certification can also have an impact on the image of an industry, which can be assumed to be a motivating factor for some of the industries participating in the exchange to obtain a certification.

In energyPRO, the tax rate on excess heat is changed from 90 DKK/MWh to 36 DKK/MWh.

Results
In Table 8.9, the energy balance of the exchange of excess heat with a certification of the industries is illustrated.

Table 8.9: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with Certification of the Industries

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	134.565	295	68.000	66.270

The table shows, that no changes occur in the energy balance with the industries having a certification.

Table 8.9 includes the total annual expenses and the total annual revenue from AVA. Below the table, a bar chart is presented with a cost break down of the total annual costs.

Table 8.10: *The total annual expenses and total annual revenue from AVA.*

Total Annual Expenses and Revenue together with Costs/Profit
with Certification of the Industries

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	13.301.984	12.238.255	-1.063.729	-88.644

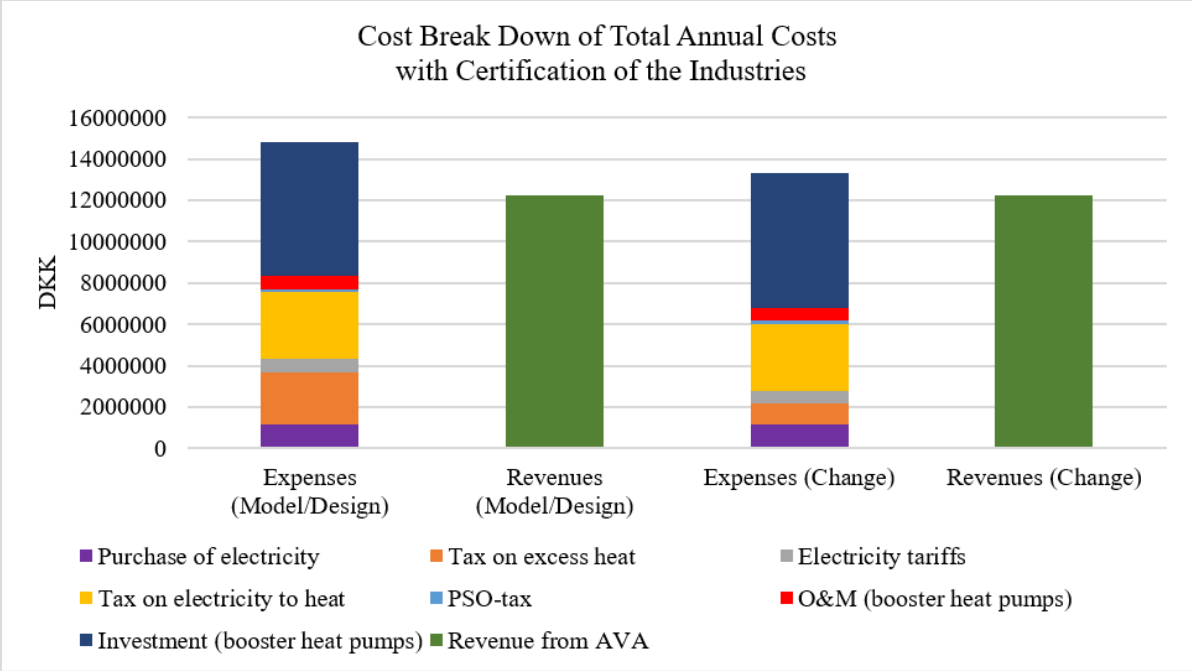

Figure 8.6: *Bar chart showing a cost break down of the total annual costs with certification of the industries.*

Looking at the total annual costs with a certification of the industries, the expenses decrease and the revenue from AVA is not changed. Simulating the exchange of excess heat with a certification of the industries gives a reduction in the costs for each industry in the common system. The decrease in the total annual expenses can be explained by the lower tax rate on excess heat, which is also shown in Figure 8.6, where a reduction in the payment of the tax on excess heat in the common system can be observed. As the expenses in relation to the tax on excess heat are reduced with a certification of the industries, it can be argued to indicate, that the design and model of the exchange of excess heat is sensitive in relation to the tax rate on excess heat and by that showing, that the tax on excess heat influences the expenses in the exchange. This can be argued to relate back to the description of the tax on excess heat as a regulatory condition which can be challenging for the utilisation of excess heat as mentioned in the Problem Analysis.

The experiment with a certification of the industries participating in the exchange shows that a certification of the industries can reduce the impact of the tax on excess heat, as the certification and the lower tax rate have an impact on the annual expenses connected to the payment of the tax on excess heat in the common system. Considering this, a certification of the industries can also be determined as a premise for the industries to be part of the exchange of excess heat as it gives the opportunity of a reduced tax on excess heat for the common system.

No Tax on Excess Heat

In the Problem Analysis, arguments are put forward by a set of actors highlighting that there should be no tax on excess heat. The arguments for this are rooted in e.g. the opinion of false excess heat not existing and that a state proceeds not should be obtained by the tax on excess heat.

In energyPRO, the model of the exchange of excess heat at the port of Aarhus is simulated without a tax on excess heat by removing the tax.

Results

In Table, the energy balance of the exchange of excess heat is shown with no tax on excess heat.

Table 8.11: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with no Tax on Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	134.565	295	68.000	66.270

Based on the table of the energy balance, having no tax on excess heat does not change the energy balance in the design and model of the exchange of excess heat.

Table 8.12 includes the total annual expenses and the revenue from AVA. A bar chart showing a cost break down of the total annual costs is shown below the table.

Table 8.12: *The total annual expenses and total annual revenue from AVA.*

Total Annual Expenses and Revenue together with Costs/Profit
with no Tax on Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	12.280.496	12.238.255	-42.241	-3.520

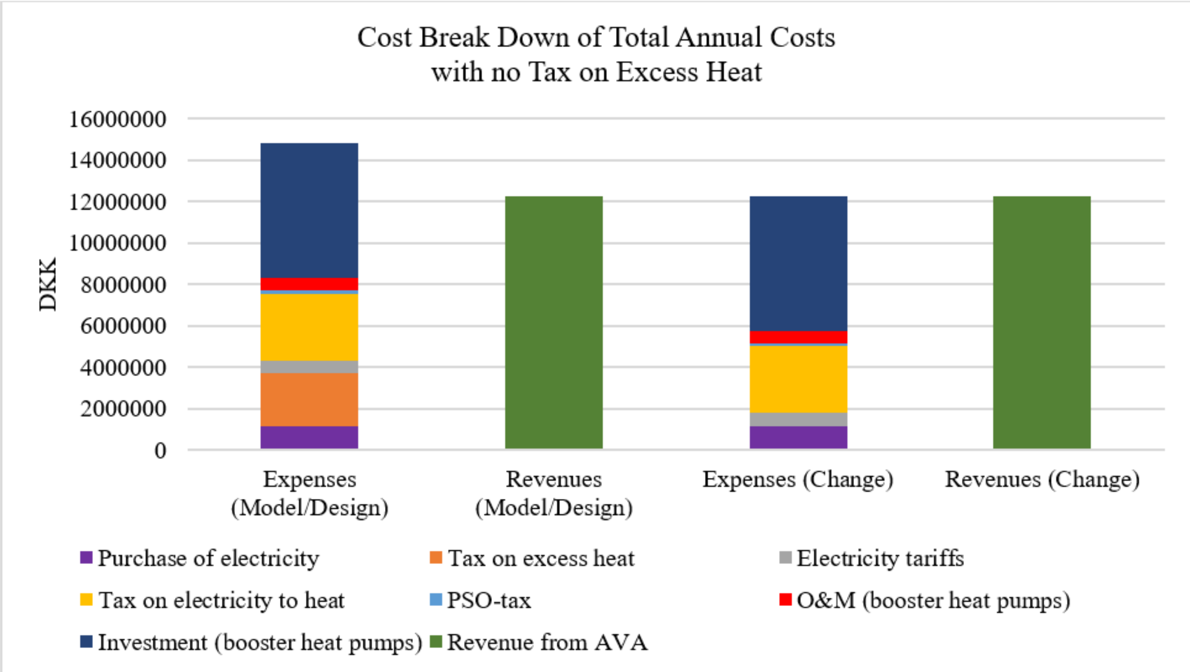

Figure 8.7: *Bar chart showing a cost break down of the total annual costs with no tax on excess heat.*

Table 8.12 describes the total annual costs and shows, that the total annual expenses are decreased with no tax on excess heat whereas the total annual revenue remains the same compared to the model of the exchange of excess heat. With the decrease in the total annual expenses, the expenses and revenue in the common system is approximately at the same level. As a result of this, the costs of each industry participating in the exchange of excess heat is significantly reduced. The bar chart in Figure 8.7 shows, that this decrease in the total annual expenses is related to the tax on excess heat as the tax is removed in the model. This indicates that by experimenting with no tax on excess heat, the impacts and challenges presented in the tax disappears.

8.2.2 Tax on Electricity to Heat

In Section 7.1.4, the tax on electricity to heat is shown as a part of the majority of the expenses in the design and model of the exchange of excess heat and due to this, an experiment with the tax on electricity to heat is included.

The experiment with the tax on electricity to heat is based on the two changes listed below, as these are argued in the thesis to be changes that could be considered in relation to the use of excess heat:

- Exemption from the tax on electricity to heat in relation to booster heat pumps needed for the utilisation of low temperature excess heat, as the purpose of booster heat pumps is not a production of heat but making it possible to use excess heat with a low temperature.
- Exemption from the tax on electricity to heat in relation to the use of excess heat from a cooling process at an industry, because the purpose is a production of cooling at the industry and therefore, the output of excess heat can be viewed as a bi-product from the production of cooling.

In energyPRO, the exemptions are simulated by removing the tax on electricity to heat in relation to the booster heat pumps at Industry 5, 10, and 12 and the tax paid in relation to the excess heat produced on the basis of a cooling process within Industry 3, 4, 5, 7, and 12.

Results

The table below entails energy balance of the exchange of excess heat with the removal of the tax on electricity to heat.

Table 8.13: *The energy balance in the design of the exchange of excess heat.*

Total production of excess heat	**Total space heating demand**	**Total process heat demand**	**Total amount of excess heat allocated to AVA**
134.565 MWh/year	295 MWh/year	68.000 MWh/year	66.270 MWh/year

From Table 8.13, it can be seen, that no changes in the energy balance happen with the removal of the tax on electricity to heat.

In Table 8.14, the total annual expenses are presented together with the annual revenue from AVA. Below that table, a bar chart illustrating a cost break down of the total annual costs is shown.

Table 8.14: *The total annual expenses and total annual revenue from AVA.*

Total Annual Expenses and Revenue together with Costs/Profit with no Tax on Electricity to Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	11.610.828	12.238.255	627.427	52.286

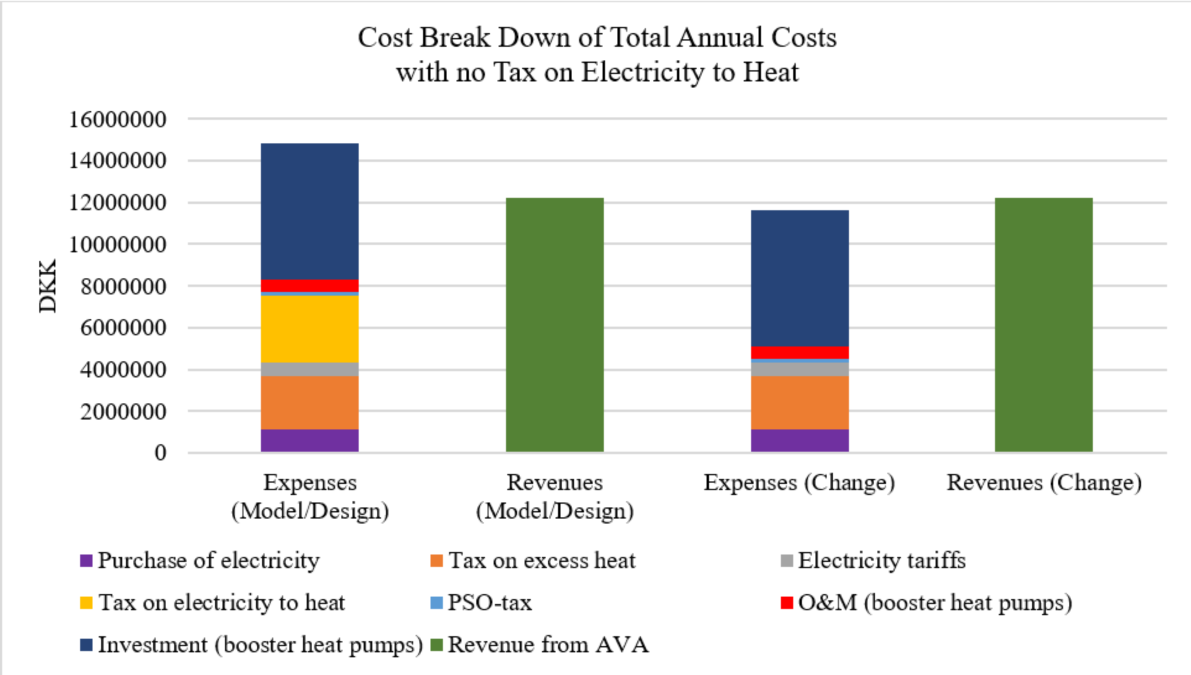

Figure 8.8: *Bar chart showing a cost break down of the total annual costs with no tax on electricity to heat.*

The total annual costs presented in Table 8.14 show that with the removal of the tax on electricity to heat, the total annual expenses decrease and the total annual revenue from AVA is the same. However, both the table and Figure 8.8 illustrate that the expenses are lower than the revenue with the removal of the tax on electricity to heat, which means that the common system has a profit in the exchange of excess heat. The profit in the common system is also shown in the profit of each industry with no tax on electricity to heat. With the decrease in the annual expenses, it can be argued, that the design and model of the exchange of excess heat at the port is sensitive towards changes in relation to the tax on electricity to heat, which also indicates, that costs associated with electricity have an impact on the expenses in the exchange of excess heat between the industries. This also correlates to the description of the electricity costs as a regulatory condition in the Problem Analysis as influencing projects about excess heat.

8.2.3 Low Temperature Excess Heat

In Section 7.1.4, the investment in the booster heat pumps is highlighted as a part of the majority of the expenses in the proposed design of the common system. With the booster heat pumps implemented to utilise excess heat with a low temperature from Industry 5, 10, and 12, the low temperature excess heat is a technical condition incorporated in to the model, which influences the total annual expenses in the exchange of excess heat at the port of Aarhus. For that reason, an experiment is carried out in relation to the use of low temperature excess heat in the common system.

To experiment with the use of low temperature excess heat in the design, the excess heat with a low temperature is removed from the common system. This means, that the desired temperature of the excess heat at 75^{o}C becomes a requirement for the excess heat being used in the common system.

In energyPRO, the booster heat pumps used for the utilisation of the excess heat produced at Industry 5, 10, and 12 are removed. The booster heat pumps are removed as they simulate the use of low temperature excess heat in the design and model of the exchange of excess heat.

Results

In Table 8.15, the energy balance of the design of the exchange of excess heat with no low temperature excess heat is presented.

Table 8.15: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with no Low Temperature Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	107.000	295	68.000	38.705

Table 8.15 shows that a decrease of the total production of excess heat is present in the exchange with no low temperature excess heat. Furthermore, the table shows that the amount of excess heat allocated to AVA is also decreased.

Below, Table 8.16 presents the total annual expenses and the total annual revenue, and a bar chart shows a cost break down of the total annual costs.

Table 8.16: *The total annual expenses and total annual revenue from AVA*

Total Annual Expenses and Revenue together with Costs/Profit
with no Low Temperature Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	2.900.368	7.203.236	4.302.868	358.572

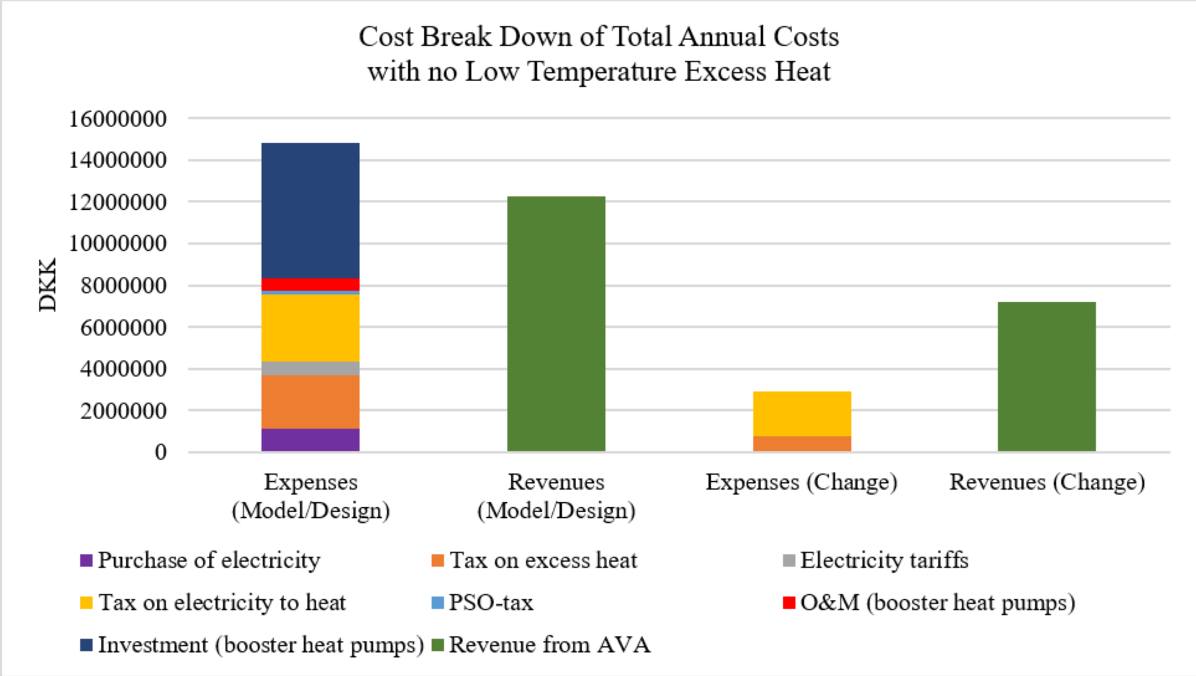

Figure 8.9: *Bar chart showing a cost break down of the total annual costs with no low temperature excess heat.*

Looking at the total annual expenses with no low temperature excess heat in the common system, a significant decrease can be seen. This can also be seen in relation to the annual revenue from AVA, where a reduction in the revenue also appears. However, the revenue from AVA is larger than the expenses, which means that the common system earns a profit when excess heat with low temperatures is not included in the exchange of excess heat between the industries at the port. The profit in the common system also results in the fact that each of the industries in the exchange of excess heat earns a profit.

Figure 8.9 indicates that the only expenses present in the exchange of excess heat with no low temperature excess heat are the tax on excess heat and the tax on electricity to heat. The tax on electricity to heat is still present in the expenses because of the excess heat produced on the basis of a cooling demand. This means that all other expenses included in the model such as the purchase of electricity, electricity tariffs, PSO-tax and the tax on electricity to heat in relation to the booster heat pumps are not a part of the total annual costs. These expenses can be argued to be connected to the use of the booster heat pumps in the common system and by that to the utilisation of excess heat with low temperatures.

Based on this, it can be outlined, that the design and model of the exchange of excess heat is sensitive towards changes related to the use of excess heat with low temperatures, as many of the expenses incorporated in the model are connected to the use of booster heat pumps. This also shows that the technical condition in relation to using low temperature excess heat in the common system has a consequence for the total annual costs in the common system and can be assumed to have an impact on the implementation of the exchange of excess heat.

8.2.4 Change of the Required Temperature for Excess Heat

Defined as part of the choices and assumptions for the design of the exchange of excess heat is the required temperature of the excess heat being 75^{o}C. In relation to this, the results of the model show, that expenses connected to the use of booster heat pumps are a part of the majority of the total annual costs of the proposed design of the exchange of excess heat. As the use of the booster heat pumps in the design of the exchange of excess heat can be argued to be related to the required temperature of 75^{o}C, experimenting with changing the required temperature for excess heat is carried out.

By changing the required temperature of 75^{o}C to 60^{o}C instead, it is in relation to this assumed, that AVA as a receiver and buyer of the surplus of excess heat is able and willing to receive the excess heat being 60^{o}C. For AVA to be able to receive excess heat at 60^{o}C, initiatives will have to be carried out in the district heating system in Aarhus Municipality which relates to having low temperature district heating.

In energyPRO, the change of the required temperature to 60^{o}C is conducted by removing the booster heat pump related to the production of excess heat from Industry 5. As shown in Table 7.1, the excess heat from Industry 5 is assumed to have a temperature of 60^{o}C, which means that when the required temperature of the excess heat in the common system is set to 60^{o}C, it is not necessary to use a booster heat pump to utilise the excess heat from Industry 5 in the exchange. In addition to this, the COP-factors of the booster heat pumps connected to the production of excess heat from Industry 10 and Industry 12 are re-calculated with the change in the temperature. This is done as changing the temperature to 60^{o}C has an impact on the use of the booster heat pumps as the temperature, that the booster heat pumps is boosting the excess heat to, is changed.

Results
Table 8.17 shows the energy balance of the design of the exchange of excess heat with 60^{o}C as the required temperature of the excess heat.

Table 8.17: *The energy balance in the design of the exchange of excess heat.*

Energy Balance with 60℃ as the Required Temperature for Excess Heat

	Total production of excess heat [MWh/year]	**Total space heating demand** [MWh/year]	**Total process heat demand** [MWh/year]	**Total amount of excess heat allocated to AVA** [MWh/year]
Model/Design	134.565	295	68.000	66.270
Change	132.683	295	68.000	64.388

In Table 8.17, a decrease in the total production of excess heat is shown with the change of the required temperature to be 60^{o}C instead of 75^{o}C. In addition to this, the table also shows that there is a decrease in the amount of excess heat, that is allocated to AVA. The decrease in the total production of excess heat can be explained by the fact that the booster heat pump connected to Industry 5 is removed. This is due to the fact, that the use of a booster heat pump in the model in relation to Industry 5 results in a production of excess heat higher than the excess heat produced by Industry 5, as the electricity consumption of the booster heat pump also becomes a part of the output of heat from the booster heat pump. This means that with the change of the temperature to 60^{o}C, the excess heat related Industry 5 is "only" the production of excess heat from the industry.

Table 8.18 presents the total annual expenses and the total annual revenue. Below the table, a bar chart showing a cost break down of the total annual costs is illustrated.

Table 8.18: *The total annual expenses and total annual revenue from AVA*

Total Annual Expenses and Revenue together with Costs/Profit
with 60℃ as the Required Temperature for Excess Heat

	Total annual expenses [DKK/year]	**Total annual revenue from AVA** [DKK/year]	**Costs or profit** [DKK/year]	**Costs or profit (each industry)** [DKK/year]
Model/Design	14.834.216	12.238.255	-2.595.961	-216.330
Change	10.818.551	11.894.469	1.075.918	89.660

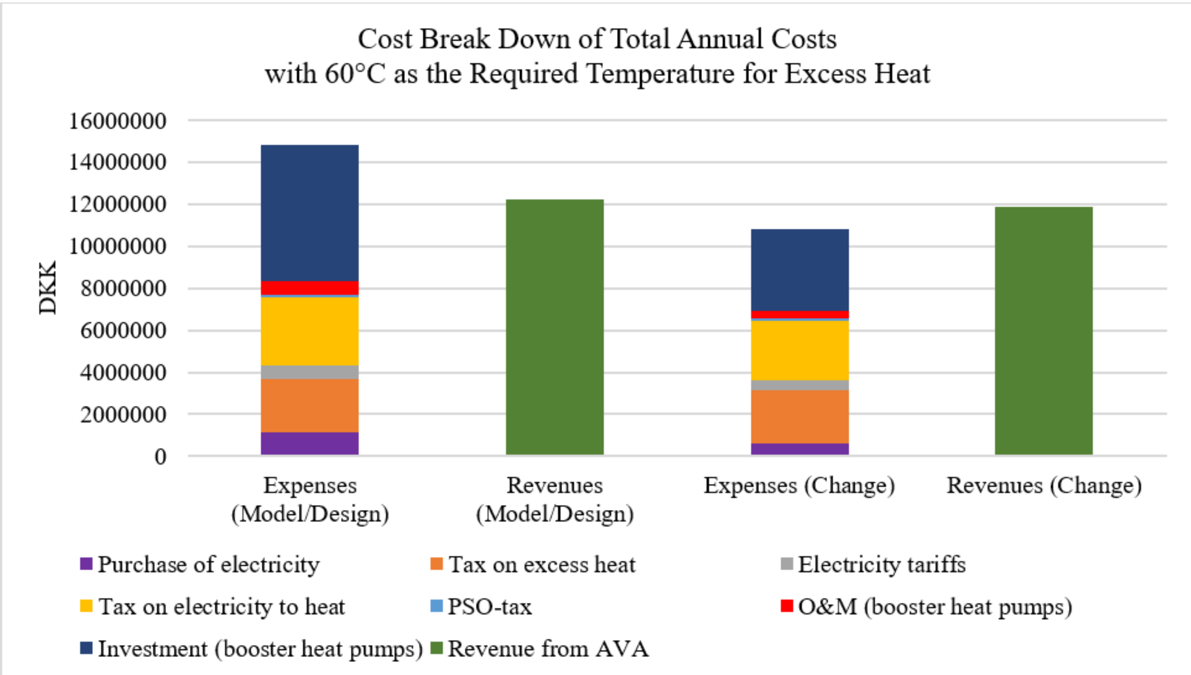

Figure 8.10: *Bar chart showing a cost break down of the total annual costs with 60^{o}C as the required temperature for excess heat.*

Table 8.18 shows, that the total annual expenses are decreased with the change of the required temperature in the exchange of excess heat. In addition to this, a decrease in the total annual revenue from AVA compared to the model and design is also present. Looking at Table 8.18, a profit for the common system is showing, as the revenue is larger than the expenses when the required temperature is changed in the system. This means, that the common system earns a profit when the temperature is changed to being 60^{o}C. The profit also shows at each of the industries included in the exchange of excess heat.

Figure 8.10 shows the cost break down of the total annual costs with 60^{o}C as the required temperature for excess heat. The figure shows, that the expenses connected to the change are to some extent similar in the composition compared to the expenses in the model of the exchange of excess heat at the port. As the expenses are lower than the expenses in the model, Figure 8.10 shows that this reduction in the expenses are related to the removal of the booster heat pump connected to Industry 5. The reduction in the expenses can also be argued to be related to the re-calculated COP-factors of the booster heat pumps connected to the production of excess heat from Industry 10 and Industry 12, as the re-calculated COP-factors result in a higher efficiency of the booster heat pumps, which reduces the expenses connected to the use of the booster heat pumps.

Looking at the results from changing the required temperature to be 60^{o}C in the common system, it can be argued that the design and model of the exchange of excess heat is sensitive in regards to the required temperature in the common system. This means, that the required temperature in the common system can be argued to have an impact on the design and model of exchange of excess heat and also to be of importance in relation to the implementation of the exchange.

Summary

In this chapter of the analysis, experiments are carried out in the choices and assumptions as well as the regulatory and technical conditions included in the design and model of the common system and exchange of excess heat between industries at the port of Aarhus. The experiments have been carried to analyse how sensitive the design of the exchange of excess heat is in relation to the choices, assumptions and conditions as a part of developing learning processes described in relation to the management of niche in SNM.

The sensitivity analysis and experiment with the changes affecting the energy balance in the common system shows, that the energy balance in the design and model to some extent is robust in relation to reduction and increase in the production of excess heat as well as an increase in connections of additional heat demands. The main impact in the energy balance based on these changes is the amount of excess heat allocated to AVA and by that, the revenue from AVA to the common system.

In addition to this, the sensitivity analysis and the experiment with the changes in the total annual costs presents, that the common system is sensitive towards changes in the regulatory and technical conditions included in the proposed design of the exchange of excess heat. In relation to the tax on excess heat, the experiment with removing the process-to-process categorisation shows that the use of this categorisation can be a necessity for the common system and the exchange of excess heat to be implemented, as without the categorisation the tax on excess heat makes up a greater part of the expenses in the common system, which can be assumed to influence an establishment of the pilot project about excess heat at the port of Aarhus. The changes regarding a certification of the industries and no tax on excess heat shows a reduction in the expenses entailed in the common system. A reduction in the expenses in the common system does also occur in the experiments with the removal of the tax on electricity to heat, having no low temperature excess heat in the exchange and reduction of the required temperature of the excess heat to 60^{o}C. Based on this, it can be deduced that the use of low temperature excess heat in the exchange and the required temperature can be experimented with and reflected further upon in the development of the exchange of excess heat between the industries at the port of Aarhus. However, the tax on excess heat and the tax on electricity to heat are regulatory conditions existing the regime, which can influence the implementation of the exchange of excess heat. In relation to this, these regulatory conditions can be argued to set some limitations for the development of the system way of thinking the use of excess heat as an additional approach in the utilisation of excess heat and the acceptance of the approach in the regime.

9 Discussion

The discussion of the thesis reflects and discusses further upon the choice and assumptions as well as regulatory and technical conditions incorporated in the design of the common system and exchange of excess heat at the port of Aarhus. In addition to this, the discussion also reflects and considers other conditions such as contractual conditions and agreements that are related to the implementation of a common system and exchange of excess heat between the industries at the port. This means, that the reflections and discussions entailed in the discussion of the thesis also are related to the niche specific process in SNM about developing learning processes in relation to the management of niches and their entrance in the regime. By that, the discussion of the thesis also includes reflections, that can be considered in the development of the system way of thinking the use of excess heat as an additional approach in the utilisation of excess heat and the entrance of the approach in the regime.

9.1 Choices and Assumptions

In the analysis of the thesis as a part of the data and information processing and design of the exchange of excess heat at the port of Aarhus in energyPRO, the thesis includes a set of choices and assumptions to set some general circumstances for the exchange of excess heat and these are discussed and reflected on in this section.

Even Distribution of the Production of Excess Heat and Process Heat Demands

In relation to the production of excess heat from Industry 1, 3, 4, 5, 7, 9, 10, 11, and 12 an assumption is made, being that the excess heat from the industries is produced with an even distribution throughout the year. Furthermore, for the industries with a process heat demand, it is also assumed in the modelling of the exchange in energyPRO, that the demand for process heat at the industries is evenly distributed over the year. In the thesis, these assumptions are made, as no information is obtained about the production patterns at the industries. It can be assumed, that an even production of excess heat and an even demand for process heat over at year exist at some of the industries included in the exchange, but it is also possible that some of the industries at the port have variations in their production of excess heat and demand for process heat. In a situation of variations in the production of excess heat as well as process heat demand, it can be argued that this would have an effect on the design of the exchange of excess heat. However, with around half of the excess heat produced in the exchange of excess heat in the model of the design being allocated to AVA, it can be argued that despite possible variations in the production of excess heat together with variations in the process heat demand at Industry 1, 4, 7, 10, and 11, it is assumed to be possible to meet the space heating demands and process heat demands included in the common system. It can be argued, that the variations have to be very significant to create a disturbance big enough in the exchange of excess heat not to make it possible to fulfil the demands at the industries included in the common system at the port of Aarhus.

However, it can be assumed, that the variations in the production of excess heat and the process heat demands can affect the allocation of excess heat to AVA. The total amount of excess heat allocated to AVA on a yearly basis might not change, but it can be assumed, that AVA will experience diversity/fluctuations in the amount of excess heat received e.g. on a daily basis. This means, that in order to have AVA as the receiver and buyer of the surplus of excess heat in the design of the common system and exchange of excess heat at the port, AVA has to be willing to and able to potentially receive excess heat in varying amounts. In relation to this, a way to deal with the possible variations in the production of excess heat and process heat demands in the common system and with the allocation to AVA could be an implementation of a storage in connection to the common system.

No Payment for the Excess Heat Exchanged between the Industries

In the design of the exchange of excess heat modelled in energyPRO, it is chosen not to include a payment for the excess heat exchanged between the industries. This is chosen, as the exchange of excess heat at the port of Aarhus is viewed as an organisation of a common system with a collaboration between the industries. Relating this choice to the different industries participating in the exchange (the industries can be seen in Figure 7.2), it can be argued that the choice of no payment for the excess heat among the industries in the exchange creates varying advantages and disadvantages between the industries. To exemplify this, it can be highlighted, that Industry 2, 6, and 8 only have space heating demands compared to Industry 9, which only delivers excess heat to the exchange. Between these industries, it can be emphasised, that Industry 2, 6, and 8 can have a greater advantage from having no payment for utilising the excess heat from the common system compared to Industry 9, which does not receive any payment for the production of excess heat.

However, it is a possibility, that a payment of using the excess heat from the exchange can be organised at the port. In this situation, it can be argued to be a necessity to make a contractual agreement between the industries with a production of excess heat and the industries with heat demands in connection to determining a price for the excess heat. Nevertheless, the exchange of excess heat in the common system can be argued to make it difficult to allocate from which industries the excess heat is produced, and at which industry the heat is received and use to meet the heat demands. As a result of this, it can be stressed that all of the industries participating in the common system should agree on a price for the excess heat. In relation to form a contract with a fair payment for the excess heat among the industries in the common system, the agreement on the price for the excess heat can be determined with inspiration from the determination of the substitution price described in The Danish Heat Supply Law in connection to the principle of substitution [Klima-, Energi- og Forsyningsministeriet, 2020c]. This principle can be transferred to the determination and agreement on the price for the excess heat to be paid between the industries in the exchange, as it makes sure, that the industries with heat demands in the common system does not pay a price for the excess heat, which is higher than the price of an alternative way to cover the heat demands at the industries. But, as the industries are different, it can be assumed that the substitution price of each industry is different from the others', and as a result it might be challenging to determine one price, that fits all.

The production of the excess heat in the industries is also coming about in different ways (e.g. on the basis of a cooling demand or as a heat output from another process), which can be argued to have an impact on the value of the excess heat and by that what the industries can be paid for the excess heat by the other industries. The value of the excess heat can be assumed to be connected to e.g. the temperature of the excess heat, as it can be argued that excess heat having the required temperature has a higher value for the common system than low temperature excess heat as the low temperature excess heat can be presumed to require further initiatives (such as a booster heat pump) to be utilised in the common system, whereas the excess heat having the required temperature can be used directly in the exchange. Reflecting on this, setting up prices for the excess heat will have to reflect these differences which can be argued to pose as challenges in relation to this, but it can also be argued, that it is possible as it will probably rely on the industries collaborating on finding a solution in connection to this.

Shared Expenses and Revenue between the Industries

In continuation of the choice of having no payment for the excess heat among the industries participating in the exchange of excess heat, it is also assumed in the thesis and as a part of designing the exchange in energyPRO, that the 12 industries included in the common system at the port of Aarhus share the expenses and revenue connected to utilising the excess heat in the common system. Again, this assumption is made on the basis of the exchange of excess heat being a common system with a collaboration between the industries, and therefore the industries being jointly responsible for the expenses related to the exchange and together in dividing the revenue. Similar to the choice of having no payment for the excess heat among the industries included in the common system, sharing the expenses and revenue between the industries at the port can be assumed to have different advantages and disadvantages for the industries. Figure 7.2 shows, that the expenses in the common system emerge differently at the 12 industries. Because of that, it is possible, that e.g. Industry 1, 9, and 11, where the excess heat is used directly in the exchange, are paying for expenses that are not related to their own production of excess heat, as e.g. no booster heat pump is required for the utilisation of excess heat at these industries. Booster heat pumps are required to utilise the excess heat from Industry 5, 10, and 12. The expenses connected to using the booster heat pumps at Industry 5, 10, and 12 are shared by all of the industries, which can be argued to be a disadvantage for the industries not inflicting this kind of expense to the common system.

On the other hand, it can also be discussed if sharing the expenses and revenue can have a positive impact in relation to the utilisation of the excess heat available at the port of Aarhus. It is emphasised in the interviews with Uffe Kristensen and Anne Zachariassen, that projects about excess at the port have been investigated but the projects have been subjected to challenges and have stranded due to the costs [Interview with Uffe Kristensen, 2020; Interview with Anne Zachariassen, 2020]. With that in mind, it can be argued, that the assumption about having shared expenses and revenue in the common system provides a basis for the use of excess heat from the 12 industries as these in collaboration pay the associated expenses related to the use of excess heat from each individual industry.

AVA as the Receiver and Buyer

In the design of the exchange of excess heat, it is in the thesis chosen to add AVA as the receiver and buyer of the surplus of excess heat from the common system. In relation to this, how the excess heat from the exchange can interact with the fuels and energy sources already used in the production of district heating at AVA can be reflected upon.

The greater part of the district heating production at AVA is produced with use of biomass and waste resources, and it can be emphasised, that the biomass and waste make up the majority of the base load and middle load in the production of district heating in the municipality of Aarhus [Kommune et al., 2018]. In relation to district heating systems, excess heat is an energy source, which is used, when the excess heat is available and present, which also means, that excess heat typically is used together with other fuels and energy sources in the base load in a district heating production [Dansk Fjernvarme, 2020]. Considering this, it can be presumed, that the surplus of excess heat from the exchange between the industries at the port will be a part of the base load at AVA along side heat produced from biomass and waste. In this matter, it can be assumed, that the excess heat will reduce some of the biomass used in the base load in the district heating production at AVA.

The use of biomass as an energy source is a current subject for discussion, where both the role of biomass in the energy system in the transition towards achieving the 2050-goal and 2030-goal and the categorisation of biomass as being CO_2-neutral are subjects being debated [Klimarådet, 2018; Danmarks Naturfredningsforening, n.d; Information, 2018]. Relating this to the assumption of the excess heat from the industries at the port of Aarhus replacing biomass used in the base load in the district heating production at AVA, it can be argued that the discussions of biomass can be relevant to include in the considerations of having excess heat replace biomass. Worth noting in this connection is, that comparing excess heat and biomass in relation to e.g. CO_2-neutrality or CO_2-emissions can be difficult, as also excess heat can be viewed as subject to a discussion regarding this. As stated in the Problem Analysis, the thesis takes the position that excess heat from industries should rather be used as an energy source than just discharged and not used, but viewing excess heat as an energy source and defining excess heat as having no CO_2-emissions can be discussed. This is related to the fact that the fuels used in the industries producing excess heat and the processes within the industries have an impact on, if the production of excess heat includes releasing CO_2-emissions. This means, that excess heat replacing biomass in the district heating production at AVA can also be discussed when looking at the goal in Aarhus Municipality of becoming CO_2-neutral by 2030, where using both biomass and excess heat can be discussed in relation to achieving the municipal goal.

The revenue from AVA included in energyPRO is determined based on the hourly substitution price at AVA. The substitution price is used in the design of the exchange, as the substitution price is the maximum price on an hourly basis, which the industries at the port can expect to be paid for the excess heat allocated to AVA. However, receiving a payment for the excess heat at a price around the level of the substitution price depends on AVA agreeing upon paying this price for the excess heat in a contractual agreement with the industries in the common system. Perhaps, AVA will be interested in paying a lower price on an hourly basis than the substitution price, as a lower payment for the excess heat can make it possible for AVA to reduce the district heating price paid by the district heating consumers. With the price regulation in The Danish Heat Supply Law determining, that a district heating company must not pay a price for the excess heat, that is higher than the substitution price, and the fact that AVA has a great amount of biomass in the district heating production, can impact the revenue from AVA in the common system [Klima-, Energi- og Forsyningsministeriet, 2020c; Kommune et al., 2018]. The substitution price can be affected by the great amount of biomass in the district heating production at AVA, because biomass is not subjected to a tax. In connection to this, it can be discussed, if a tax on biomass would result in an increased substitution price at AVA and by that, the possibility of an increased revenue from AVA to the common system. The lack of a tax on biomass is highlighted in relation to the revenue in the common system of the exchange of excess heat at the port of Aarhus, because it can be assumed, that the revenue in the common system can have an affect on the industries and their interest in participating in the exchange.

As presented in the Problem Analysis in Figure 2.3 9, the newly enacted law on excess heat also suggest a price regulation specifically on excess heat [Skatteministeriet, 2019]. The price regulation on excess heat is e.g. suggested to ensure a low heat price at district heating consumers, when excess heat is used externally in district heating system [Skatteministeriet, 2019; Dansk Industri, 2019b]. However, The Confederation of Danish Industry highlights, that an implementation of the suggested price regulation on excess heat will act as a price ceiling[1] on the revenue, that industries with excess heat can obtain from allocating excess heat externally [Dansk Industri, 2019a]. Furthermore, the Confederation of Danish Industry also points out, that a price regulation on excess heat is unnecessary, as the district heating consumers already are protected in relation to paying a "fair" price for district heating by the price regulation entailed in The Danish Heat Supply Law, which e.g can be argued to be related to the regulation about the substitution price [Dansk Industri, 2019a; Klima-, Energi- og Forsyningsministeriet, 2020c]. Considering the argumentation from the Confederation of Danish Industry in relation to the price regulation on excess heat, implementing a price regulation on excess heat can be discussed. But with no further descriptions of the price regulation on excess heat presented yet, the influence of a price regulation on excess heat relative to the exchange of excess heat cannot be determined more concrete at this moment. However, it can be stressed, that the use of excess heat from the industries at the port and an allocation of it to AVA will be exposed to a triple regulation with an enactment of a price regulation on excess heat together with the price regulation in The Danish Heat Supply Law and the tax on excess heat. This can be argued not to further the incentive at the industries to engage in the utilisation on excess heat and an external allocation and sale of the excess heat to district heating companies and also to some extent challenge the simplification of the law on excess heat, which is mentioned in the Problem Analysis as a part of the argumentation for changing the taxes on excess heat.

Other Receivers and Buyers

In a meeting with Uffe Kristensen from Aarhus Municipality, the possibility of having other receivers and buyers of the surplus of excess heat than AVA was presented and was also further discussed in an interview with Uffe Kristensen [Meeting1, 2020; Interview with Uffe Kristensen, 2020]. In the interview, Uffe Kristensen explains, that even tough Aarhus Municipality owns AVA, the project about excess heat at the port of Aarhus does not have a focus on AVA, but a focus on establishing the exchange of excess heat at the port, and other actors that have an interest in being a receiver and buyer of the surplus of excess heat are also viewed as a possibility and relevant to investigate. An example of other receivers could be an industry not located at the port [Interview with Uffe Kristensen, 2020]. In a situation of another receiver and buyer than AVA, a contractual agreement does also have to be made e.g involving a determination of the price on excess heat.

Ownership and Operator

Besides the opportunity of designing the exchange of excess heat with another receiver and buyer of the surplus of excess heat than AVA, it can be argued also to be possible to design and organise the exchange of excess heat in the common system with a different ownership structure and another operator of the grid than AVA. The ownership structure in the proposed design

[1]Translation of the Danish word: prisloft

is a shared ownership by the 12 industries of e.g. the booster heat pumps and AVA owning the grid for the transport and distribution of the excess heat. Another possible organisation of the ownership structure and operator can be carried out with an externally imposed operator. Having an externally imposed operator can be assumed to have the opportunity of resulting in different ownership structures and organisations of the operation of the exchange of excess heat, where one option could be, that an externally imposed operator invests in the common system of the exchange and becomes the owner of the system in that way. This can be viewed as an ownership structure, where the industries being a part of the exchange can be argued to have reduced risks connected to the exchange compared to when the industries have investments in the common system as shared expenses and ownership. This is connected to the fact that if an externally imposed operator invests in the common system by carrying the investments for e.g. booster heat pumps needed in the exchange, the operator in this situation is carrying the investments and by that the risks, but maybe also the majority of the responsibility for implementing the exchange of excess heat in the common system. Looking at this, it can be discussed if including an externally imposed operator carrying both investments and some of the responsibility for establishing the exchange of excess heat can perhaps make it attractive for the industries to participate in the exchange due to the assumed lower level of risk and responsibility for the industries. In addition to the reflections above, it can be highlighted that in an ownership structure like this, the system way of thinking the exchange of excess heat is still present and the exchange can be argued to still have the character of a common system even though an externally imposed operator has the ownership and operation of the exchange, as the industries are still producing and receiving excess heat in a system between them. To organise the common system with an externally imposed operator, it can be assumed to be necessary to compose contractual agreements between the industries at the port and the externally imposed operator in relation to agreeing on terms of ownership and the operation of the common system and the exchange of excess heat.

Another ownership structure and organisation of operation of the exchange of excess heat in connection to an externally imposed operator could be to construct a kind of market within the exchange of excess heat. Constructing a kind of market or platform could bring about the possibility for the industries to do business and trade with the excess heat produced in the industries on the conditions of a market, which can be argued to maybe attract the industries to participate in the market of excess heat as it could be argued to present as a direct possibility for the industries to see an opportunity for profit. A possible organisation of this could still involve an externally imposed operator, who could be the organiser and trader of the excess heat. In practical terms, the market could be constructed as a market, where the industries producing excess heat could offer their production of excess heat (at a given price) and the industries having demands for space heating and/or process could buy the excess heat from the market. The externally imposed operator could thus act as the linking element or trader of the market, and as a result a local energy market of excess heat could be formed at the port. It can be argued, that setting up a local energy market at the port could be viewed as an attractive solution for the industries to utilise the production of excess heat within the industries and doing so on market conditions. However, it can be discussed, if setting up a market would change the exchange of excess heat to not be a common system, as the industries could act as individual actors participating in a market and not having a collaboration regarding the exchange of excess heat at the port. Reflecting on this, it can be argued, that the industries would not be as dependent on each other in a market of the excess heat, which could perhaps actually motivate the industries to participate. Furthermore, it can be highlighted, that setting up a market for the exchange would make it possible to differentiate the prices for the excess heat in relation to the value of the excess heat, which was elaborated on further above in the discussion. It can be argued, that a market platform for the exchange of excess heat is also a different approach from the bilateral connections like the common system is, which means that it could also be a possible approach in order to utilise the excess heat at the port.

The required Temperature at 75^{o}C

As a part of the choices and assumptions made in the modelling of the design of the exchange of excess heat is the required temperature at 75^{o}C. The sensitivity analysis showed, that lowering the required temperature of the excess heat to 60^{o}C reduced the expenses in the common system and by that increased the opportunity to utilise excess heat with a low temperature in the exchange of excess heat at the port. However, looking at the defined temperature at 75^{o}C in the common system in relation to the process heat demands at the industries, it can be discussed, if the 75^{o}C is too low a temperature level of the excess heat being exchanged between the industries. This is stressed, as the determination of the temperature at 75^{o}C maybe is too low in relation to the process heat demands existing at the industries in the exchange. The temperature is reflected upon in relation to the process heat demands, as Industry 3 was deselected to be a part of the exchange in the model of the design in energyPRO, because Industry 3 has a presumed process heat demand at a temperature level around 100-140^{o}C. This indicates, that process heat demands can have high temperature levels and therefore also, that the temperatures of the process heat demands at Industry 1, 4, 7, 10 and 11 included in the common system can be higher than the 75^{o}C defined in relation to the excess heat in the exchange.

A solution, which can be implemented to deal with the potential of high temperature process heat demands in the common system, could be the installation of a heat pump in connection to industries, where the temperature level for the process heat demands exceeds 75^{o}C. The heat pumps can utilise the excess heat from the exchange and boost the temperature of the excess heat to meet the required temperature of the process heat demands in the industries. By installing the heat pumps in connection to the industries with process heat demands at temperatures over 75^{o}C, it is possible to still include the process heat demands in the common system. However, it can lead to a discussion of whether these heats pumps should be invested in and paid by the common system or by the industries with process heat demands requiring high temperatures. The distribution of where the investment in heat pumps are placed plays a role in relation to the expenses in the common system. This is highlighted, as the investment in and use of the booster heat pumps in the model and design in energyPRO showed to be the reason for many of the expenses in the common system. Another point is, if the industries with the high temperature process heat demands are assigned the investments, O&M, purchase of electricity etc. themselves, it is possible that the industries lose interest in being a part of the common system. The discussions of and reflections upon the required temperature at the 75^{o}C and the temperature of the process heat demands at the industries illustrates, that it can be considered and questioned which types of industries are able to utilise excess heat to cover process heat demands?

9.2 Regulatory conditions

In the analysis of the thesis, regulatory conditions are incorporated in the design and model of the common system and theses are discussed and reflected on in this section.

Tax on Excess Heat

Process-to-process Use of Excess Heat

In the design of the exchange of excess heat, the excess heat from the exchange used to cover the process heat demands at Industry 1, 4, 7, 10, and 11 is categorised as process-to-process use of excess heat, which is not imposed to the tax on excess heat. The sensitivity analysis presented in Section 8.2.1 shows, that not being able to use the categorisation of process-to-process use of excess heat in relation to the process heat demands in the common system results in additional expenses in terms of the tax on excess heat. It can be discussed, if the implementation of the exchange of excess heat between the industries at the port of Aarhus is dependent on the opportunity to use the categorisation of process-to-process use of excess heat as it reduces the expenses. As a part of the results of the proposed design of the exchange of excess heat it is described, that the electricity costs aggregated accounts for a greater deal of the expenses in the design compared to the tax on excess heat. Relating this to the sensitivity analysis and experiment with the process-to-process categorisation, the noting of the electricity costs aggregated making up a greater part of the expenses than the tax on excess heat change. The tax on excess heat constitute around the same level in the expenses as the electricity costs in the common system, when the categorisation of the process-to-process use of excess heat is not applied in the exchange of excess heat. This means, that the tax on excess heat has the same influence on the expenses in the design and common system as the electricity costs, when not using the process-to-process categorisation. This again shows, that the categorisation is of relevance for the expenses present in the common system, which can be assumed to have an impact on the establishment of the exchange of excess heat.

Furthermore, reflecting on the process-to-process categorisation used in the design of the common system shows, that the possibility of categorising and having a process-to-process use of excess heat is an element that distinguishes the use of excess heat in the exchange between the industries at the port from the utilisation of excess heat through bilateral connections. This is emphasised, as the excess heat in bilateral connections is often used for space heating demands in district heating systems, and the use of excess heat to cover space heating demands is subjected to the tax on excess heat.

Certification

The sensitivity analysis shows, that a certification of the 12 industries included in the common system results in reduced expenses in the common system in relation to the tax on excess heat due to the lower tax rate assigned, when an industry is certified. Because of this, at suggestion is put forward in the analysis concerning making a certification a premise for the industries to participate in the exchange of excess heat at the port of Aarhus. However, in the debate about the newly enacted law on excess heat, the requirement of a certification is highlighted to inflict an administrative burden on the industries [Skatteministeriet, 2019]. This means, that determining a certification as a premise for the industries at the port to participate in the exchange can be discussed. It can be questioned, if all of the 12 industries will put aside the resources to become certified due to the administrative work and resources connected to getting a certification. But seen from another perspective, getting a certification in terms of e.g. ISO-50001 can also be assumed to have other benefits for the industries than a reduced tax on excess heat. A certification can also be presumed to support an implementation of energy efficient initiatives in the industries, strengthen the image, and be something that the industries can use in marketing strategies. These can be argued as elements, that the industries at the port can have an interest in, as they can have financial benefits for the industries. This means, that setting a certification as a premise for the industries to be included in the common system is a possibility, if the industries at the port can see the potentials in being certified.

No Tax on Excess Heat

In the Analysis of the thesis, no tax on excess heat is experimented with in the design of the common system. When simulating the exchange of excess heat with no tax on excess heat, the expenses are reduced and a profit occurs in the common system. Because of this, removing the tax on excess heat can be discussed. First and foremost, to remove the tax on excess heat it can be argued, that the perception about false excess heat has to be challenged and made up with. In addition to this, as a state proceeds exits in the tax on excess heat, it can be argued to challenge removing the tax on excess heat. In relation to this, it can be discussed, if the energy taxes on fossil fuels should be increased and a tax should be put on biomass to remove the tax on excess heat and still ensure state proceeds.

If it is not possible to remove the tax on excess heat completely, ways to reduce the expenses related to the tax on excess heat can be discussed.

Obtaining a certification at an industry can be argued and stressed to ensure, that a production of false excess heat is not taking place in the production process of an industry [Klimarådet, 2019]. This is assumed, as steps in achieving a certification are presumed to include initiatives within an industry, that optimises the production [Klimarådet, 2019]. With production of false excess heat being the overall reasoning behind the tax on excess heat, it can be argued, that a certification removes the possibility of false excess heat being produced in an industry and by that the incentive for the tax on excess heat being present [Skatteministeriet, 2019]. For that reason, it can be argued, that no tax on excess heat should be present, when an industry is certified.

In the newly enacted law on excess heat, a free delivery of excess heat from an industry to a receiver makes it possible to transfer the tax on excess heat to the receiver of the heat [Skatteministeriet, 2019]. Applying this regulatory condition in the design of the exchange of excess heat at the port would remove the expenses related to the tax on excess heat paid for the surplus of excess heat delivered to AVA. However, this would also mean, that no revenue from AVA is obtained in the common system, and it also requires AVA to agree upon paying the tax on excess heat for the heat received from the common system. Considering the free delivery of excess heat from industries in more details, it can be highlighted, that a free delivery of excess heat from an industry should not result in a tax on excess at any time, as a free delivery of excess heat from industries counterbalances the perception and possibility of an industry earning a profit from producing false excess heat and selling it externally [Skatteministeriet, 2018].

Tax on Electricity to Heat

The electricity costs included in the design of the exchange of excess heat are related to the use of excess heat from cooling processes at Industry 3, 4, 5, 7, and 12 and the need of booster heat pumps at Industry 5, 10, and 12. Reflecting on that, it can be considered, that using excess heat from cooling processes and excess heat with a low temperature have an affect on the expenses in the common system. When utilising the excess heat from Industry 3, 4, 5, 7, 10, and 12, it can be discussed in relation to reducing the costs in the common system, if these industries should pay the electricity costs themselves instead of having these expenses shared between all the industries in the exchange. Implementing this decision in the design of the exchange will remove expenses present in the common system related to the electricity costs, but also result in Industry 3, 4, 5, 7, 10, and 12 individually having to pay these costs. Transferring the electricity costs to the industries can perhaps affect their interest in delivering excess heat to the exchange, and it can also be argued to contradict with the system way of thinking the use of excess heat in a common system at the port of Aarhus. Therefore, the discussion instead focuses on which changes can be made in relation to the electricity costs, and as a result provide a reduction in the electricity costs present in the common system.

Changes in the expenses in relation to the purchase of electricity, electricity tariffs, and the PSO-tax are not discussed, but instead the discussion of the electricity costs is oriented about the tax on electricity to heat.

In the Energy Agreement from 2018, a modification in the tax on electricity to heat is presented, and the argumentation for this was among other things to create better conditions for the use of excess heat. The modification entailed in the Energy Agreement can be stressed to show a political initiative to create better conditions for the utilisation of excess heat [Energi-, Forsynings- og Klimaministeriet, 2018]. However, with the tax on electricity to heat being a dominant expense in the common system as shown in Figure 7.3, it can be discussed, if modifications in the tax are enough. In the sensitivity analysis, two suggestions are experimented with, which results in a removal of the tax on electricity to heat in the common system. The suggestions are described and analysed in Section 8.2.2, and concerns an exemption from the tax on electricity to heat at the booster heat pumps and in relation to the excess heat emerging from the cooling processes. In the model and design of the exchange of excess heat, having no tax on electricity to heat results in the expenses in the common system being lower than the total revenue from AVA. This argues for, that a removal of the tax on electricity to heat eliminates the impact from the tax on electricity to heat in relation to an implementation of the exchange at the port of Aarhus. However, it can be discussed, if exemptions from the tax on electricity to heat can be achieved. Is this not possible, reflections on the possibility to define the use of electricity at the booster heat pumps connected to Industry 5, 10, and 12 as a use of electricity in a process in the common system can be made. By defining the use of electricity at the booster heat pumps as a use of electricity in a process, a process allowance is enabled. With a process allowance for the electricity used in the booster heat pumps, a reduction in the payment of the tax on electricity to heat can be obtained in the common system.

In addition to enabling a process allowance, another way of reducing the expenses related to the tax on electricity to heat in the common system is to change the distribution between the heat production and the cooling production of the electricity consumption in relation to the production of excess heat on the basis of a cooling demand [Dansk Fjernvarme, 2019a]. Currently, the distribution of the electricity consumption states that the heat production accounts for the electricity consumption equal to the amount of excess heat divided by 3 (but maximum the total electricity consumption). The distribution of the electricity consumption results in the fact, that the tax on electricity to heat is paid in relation to this. With this distribution, productions of excess heat on the basis of a cooling demand with an efficiency of more than 3 expressed by e.g. a COP-factor end up accounting for the total electricity consumption related to the cooling process, which also means that the production of heat is imposed the tax on electricity to heat on the total electricity consumption. With this in mind, it can be argued that the distribution leads to the fact that in efficient cooling processes, the production of heat ends up accounting for the total electricity consumption. As a result, it can be argued that perhaps the distribution should be changed in such a manner that a more "equal" distribution of the electricity consumption between the production of cooling and production of heat. In this connection, it can be argued that the change of the distribution should be to find another level for dividing the electricity consumption, which should be more than 3 [Dansk Fjernvarme, 2019a]. Changing the distribution of the electricity consumption can be argued to be another way that results in reducing the expenses related to the tax on electricity to heat in the common system.

9.3 Technical conditions

In the analysis of the thesis, technical conditions are included in the design and model of the common system and in this section, the technical condition related to the use of low temperature excess heat in the common system is discussed and reflected upon.

Low Temperature Excess Heat

As a part of the sensitivity analysis of the design of the common system, a simulation of the design is done without including the excess heat with an assumed temperature lower than 75^oC. This reduces the expenses in the common system significantly as the majority of the expenses in the design are shown to be related to the booster heat pumps installed to utilise the low temperature excess heat from Industry 5, 10, and 12 in the common system. Because of this, it can be questioned, if the use of low temperature excess heat should be avoided in the common system. Reflecting on this from the perspective of reducing expenses, it can be said, that low temperature excess heat should not be included in the exchange. However, this also results in the fact, that excess heat from Industry 5, 10, and 12 is not utilised, and this can be argued not to be beneficial, as it means that an available energy source is not made use of, and that the excess heat is discharged, instead.

Taking the position to include excess heat with a low temperature in the exchange between the industries in the common system, it can be discussed, if maybe the industries, where the booster heat pumps are needed, should pay the investment costs in the booster heat pumps themselves. This is stressed, as the investment costs related to the booster heat pumps are a part of the majority of the expenses in the common system as shown in Figure 7.3. An argumentation for Industry 5, 10, and 12 to pay for the booster heat pumps is, that it is the industries, who needs booster heat pumps to meet the 75^o in the exchange. However, if the common system is interested in using the excess heat from Industry 5, 10, and 12, it can also be emphasised as fair, that all of the industries in the exchange share the costs related to the investments in the booster heat pumps. Moreover, a possible consequence that can occur, if the investment costs for the booster heat pumps are assigned to Industry 5, 10, and 12, is the possibility of the industries not being interested in participating in the exchange of excess heat at the port due to the high investment costs associated with the booster heat pumps. It can be argued, that the expenses connected to the booster heat pumps influence the incentive of Industry 5, 10, and 12 to make use of the excess heat from their production processes. As reflected on further above in the discussion, it is also possible that an operator can be in charge of and responsible for the expenses in the common system. Having an operator would remove the investment costs in the booster heat pumps from the common system as well as Industry 5, 10, and 12. Yet in this context, Uffe Kristensen mentions in the interview, that industries at the port might be reluctant towards having e.g. a heat pump located at the property of the industry, which is owned by and driven by an operator not attached to the industry [Interview with Uffe Kristensen, 2020]. This implies, that if an operator is chosen in relation to the common system, reflections on the physical placement of the booster heat pumps also need to be carried out.

9.4 Creation of Interest and Collaboration between the Industries

The discussions and reflections above have an orientation towards the choices and assumptions as well as regulatory and technical conditions together with contractual conditions and agreements related to the design of the exchange of excess heat. But besides having considerations about these elements, an establishment and implementation of the pilot project and the common system at the port of Aarhus also rely on the industries and their interest in being a part of the common system and their willingness to collaborate about the utilisation of excess heat in the exchange.

In one of the meetings carried out as a part of the thesis, it was stressed, that the industries at the port only share the location at the port-area currently, and do not have any further communication and collaboration across the industries [Meeting3, 2020]. This indicates, that in order to organise the exchange of excess heat among the industries and apply the system way of thinking the use of excess heat at the port of Aarhus, it can be argued, that a dialogue and collaboration between the industries have to be built. Creating a collaboration and communication between the 12 industries included in the exchange can be considered of importance as the industries in the design of the common system depend on excess heat from one another and share the expenses and revenue related to the exchange.

In the interview, Uffe Kristensen considers the motivation at the industries and their interest for being a part of the exchange of excess heat. Uffe Kristensen mentions, that the industries realising, that they can participate in a project together and collaborate about something to "make a difference", is a factor, that can awake an interest in the exchange of excess heat at the industries [Interview with Uffe Kristensen, 2020]. Additionally, as participating in the exchange of excess heat also can influence the marketing strategies at the industries individually, Uffe Kristensen also describes this to be a motivating factor for the industries and their interest in the project about excess heat [Interview with Uffe Kristensen, 2020]. The fact, that the exchange of excess heat in the common system also presents as an alternative approach to the utilisation of excess heat from the industries, is also by Uffe Kristensen presented as reason for the industries wanting to be a part of the common system, as it can clear the way of using the excess heat from the industries [Interview with Uffe Kristensen, 2020]. Based on the considerations from Uffe Kristensen, interest in the exchange of excess heat can be argued to exist at the industries, however organising the exchange of excess heat at the port of Aarhus in a common system and creating a collaboration among the industries can also be emphasised to shape a dependency between the industries. In the interview with Anne Zachariassen, the dependency between the industries in the common system is discussed, and Anne Zachariassen outlines, that being dependent on other industries placed at the port might be a circumstance, which can influence that some of the industries might not want to be included in the common system [Interview with Anne Zachariassen, 2020].

From the discussions and reflections above, the industries at the port of Aarhus can have an interest in participating in the exchange of excess heat, but circumstances, that can influence the interest at the industries in relation to being a part of the common system and exchange of excess heat, do also exist. This shows, that in the process of working with the exchange of excess heat at the port of Aarhus communicating and presenting the project to the industries can be of importance to create and/or to keep the industries interested in being a part of the exchange of excess heat and collaboration related to this. It can therefore also be argued to be a good idea to have dialogues with the industries in the process of developing the design of the exchange of excess heat to include thoughts and inputs from the industries in the design. This is emphasised, as it can create a basis for designing a common system and exchange of excess heat in which the industries at the port can see themselves interact within.

In continuation to this, Uffe Kristensen during the interview put weight on the fact, that an implementation of the common system and the exchange of excess heat at the port of Aarhus is relying on the project being prepared and acted upon [Interview with Uffe Kristensen, 2020]. In the process of acting upon, the industries have a role to play, but by combining considerations from the interviews with Uffe Kristensen and Anne Zachariassen, a project facilitator can be argued to be necessary to appoint [Interview with Uffe Kristensen, 2020; Interview with Anne Zachariassen, 2020]. This is stressed, as the industries might have an interest in the project about excess heat at the port of Aarhus, but not an interest in or the resources and employees available to coordinate and carry out the work associated with the development and implementation of the exchange of excess heat. This relates to e.g. the industries perhaps not having the knowledge about the technical installations as well as understanding of and opportunity to create an overview of the regulatory conditions connected to the utilisation of excess heat [Interview with Anne Zachariassen, 2020]. The character of the project facilitator can be discussed, as the project facilitator e.g does not have to have any ownership in the common system or be an operator of the exchange, but to have the role of coordinating the work and draw on the needed resources and organise the development of the exchange of excess heat. It is possible that the project facilitator can be Aarhus Municipality or an actor with no party in the exchange of excess heat at the port of Aarhus.

Summary

The discussion of the thesis has shown, that different design specifications can be found and connected to the proposed design of the common system and exchange of excess heat at the port of Aarhus in energyPRO. This e.g. relates to the choices and assumptions of no payment for the excess heat between the industries in the exchange, having shared expenses and revenue as well as the defined required temperature of the excess heat in the common system, where the discussion has presented other perspectives in connection to these choices and assumptions. In relation to the niche specific processes in SNM, it illustrates that further experiments and analyses of these choices and assumptions in the design of the common system can be performed in order to further develop the niche of the system way of thinking the use of excess heat, which can be argued to be a possibility in relation to preparing the way for the entrance of the niche into the regime.

In the discussion, the choice of having AVA as the receiver and buyer of the surplus of excess heat from the common system is reflected upon, and it is discussed how contractual agreements can be constructed with AVA in relation to the allocation of the excess heat and the price for the excess heat. It can be assumed, that making contractual agreements with AVA is a central element for the proposed design of the common system to be implemented. Forming contractual agreements with a receiver of the surplus of excess heat from the common system can also be argued to have an effect on the entrance of the niche into the regime, as forming contractual conditions with the receiver also is a part of the development of the niche. Furthermore, the discussion also considers the opportunity of another receiver than AVA in the common system. In addition to this, the discussion also reflects on other ownership structures and operation of the common system compared to the ones in the proposed design by including an externally imposed operator. Investigating this opportunity can also be further developed in learning processes related the design of the common system as a part of the management of the niche and the acceptance of the additional approach and system way of thinking the utilisation of excess heat in the regime.

The technical condition in terms of the utilisation of low temperature excess heat in the common system is also discussed, and it is reflected on whether to use low temperature excess heat in the exchange at the port, and considerations of the distribution of expenses related to the booster heat pumps, which are necessary for the utilisation of the low temperature excess heat, are made. On the basis of this, determinations connected to the use of excess heat with a low temperature have to be carried out for implementing the exchange of excess heat at the port. This shows, that handling technical conditions in the common system can be of relevance for the niche to be present in the regime.

The discussion does also contain discussions of the regulatory conditions incorporated into the design of the exchange of excess heat. The discussion as well as the analysis of the thesis shows, that the regulatory conditions can have an impact on the implementation of the common system, and by that also be assumed to influence the additional approach in the utilisation of excess heat to be included in the regime. In connection to this, the discussion has reflected on and considered argumentation for changes in the tax on excess heat and the tax on electricity to heat. The tax on excess heat and the tax on electricity to heat are defined as regulation related to the utilisation of excess heat within the regime and it can be argued, that changes in the taxes requires a political initiative and incentive to implement the changes in the tax on excess heat and the tax on electricity to heat in relation to projects about excess heat. As mentioned in the Problem Analysis in Section 2.4 in page 13, Aarhus Municipality is interested in the port of Aarhus becoming at non-regulatory zone. If this is achieved, it can be put forward as a possibility to experiment with the changes in the tax on excess heat and the changes regarding the tax on electricity to heat reflected on in the discussion.

In the discussion, considerations of the interest of the industries and the creation of a collaboration between the industries in the common system have shown, that the implementation of the exchange of excess heat at the port of Aarhus also relies on this. This can be presumed to also illustrate, that implementing the system way of thinking the use of excess heat as an additional approach in the utilisation of excess heat in the regime also is affected by industries being interested in collaborating about the use of excess heat in a common system.

Conclusion 10

This chapter contains the conclusion of the thesis.

In the thesis, excess heat is perceived as an energy source, which can be applied in the transition of the Danish energy system to replace fossil fuels and comply with the 2050-goal and 2030-goal determined by the Danish Government.

The Problem Analysis of the thesis contains a description of excess heat showing that excess heat is not utilised at the potential that it shows to have. Due to this, the thesis works with an additional approach in the utilisation of excess heat through a pilot project at the port of Aarhus. The pilot project is concerned with developing an exchange of excess heat in a common system between industries located at the port and is based on a system way of thinking the use of excess heat, which leads to the research question of the thesis:

How can a common system of the exchange of excess heat between the industries at the port of Aarhus be designed, and how does regulatory and technical conditions as well as contractual conditions and agreements impact the system way of thinking the use of excess to be an additional approach in the utilisation of excess heat?

In the Theoretical Framework of the thesis, the pilot project at the port of Aarhus about an exchange of excess heat in a common system is as an additional approach in the utilisation of excess heat defined as a niche. Through the management of niches described in the SNM, niche specific processes are used to develop and experiment with the niche in the analysis of the design of the common system and in the sensitivity analysis and discussion of the thesis.

In the analysis of the design of the exchange of excess heat, a proposed design of the common system is presented. The results of the design show, that the common system of an exchange of excess heat between industries at the port of Aarhus can be designed with an external receiver of the surplus of the excess heat. In relation to the proposed design, it can be concluded, that regulatory and technical conditions have an impact on the implementation of the common system at the port of Aarhus.

The sensitivity analysis experiments with the choices and assumptions, that are included in the proposed design as well as regulatory and technical conditions present in the design of the common system. The results of the sensitivity analysis shows that the proposed design of the common system is sensitive to changes in relation to the choices and assumptions and the regulatory and technical conditions. On the basis of that, it can be concluded that the choices and assumptions made in relation to the design have an impact on the design and therefore also on a possible implementation of the exchange of excess heat in a common system. In addition to this, the thesis concludes that regulatory and technical conditions can have an influence on the implementation of the common system.

On the basis of the discussion it is concluded, that choices and assumptions included in the common system can be designed and organised differently than in the proposed design of the exchange of excess heat. Additionally, based on the discussion, it can be concluded, that considerations regarding the technical conditions related to the exchange of excess heat have to be made. Furthermore, the thesis concludes from the discussion that changes can be made in the regulatory conditions to reduce the influence of the regulatory conditions in the common system and on the implementation of the exchange of excess heat between the industries at the port. From the discussion it can also be concluded, that forming contractual agreements and creating an interest and collaboration at the industries are a necessity for implementing the common system and exchange of excess heat between the industries at the port.

Considering the conclusions from the analysis and the discussion entailed in the thesis, it is concluded that a common system of the exchange of excess heat between the industries at the port of Aarhus can be designed with an external receiver of the surplus of excess heat. This shows, that the common system and system way of thinking the use of excess heat presents as an additional approach to the utilisation of excess heat in the Danish energy system and can be a part of excess heat being used at the potential that it shows to have. Challenges imposed by regulatory and technical conditions as well as contractual conditions and agreements exist in the additional approach, which shows that the additional approach also is challenged by these conditions as well as bilateral connections. This can be deduced to indicate, that the system way of thinking the use of excess heat perhaps not solely makes up with the influence from the regulatory and technical conditions as well as contractual conditions and agreements presented as challenges in connection to bilateral connections. The overall conclusion of the thesis is as a result, that the additional approach to the utilisation of excess heat in a common system can act in the regime together with bilateral connections to further the use of excess heat in the Danish energy system towards the potential that it shows to have.

11 Future Research

As a result of the thesis being composed as a part of an external collaboration with Aarhus Municipality and the consulting firm PlanEnergi, the work carried out in the thesis will be presented to the external cooperating partners, and the purpose of presenting the results of the thesis to the cooperating partners will be to present inputs from the thesis, that can possibly be used in the further development of the common system and exchange of excess heat at the port of Aarhus. Furthermore, the work with the common system and exchange of excess heat at the port of Aarhus aims to have a presentation for the industries at the port to show the industries a tangible and possible design as a part of initial steps in implementing the pilot project of the exchange of excess heat at the port.

Reflecting on the future work concerning the model and the design of the exchange in energyPRO, a possibility can be to obtain actual data from the industries and incorporate it into the model in energyPRO. Furthermore, additional experiments with the proposed design can be carried out to develop the design of common system. Further work with the design and model of the common can also include determinations of the possibility of using the district heating grid at the port and in connection to this, further investigations of alternatives for the transport and distribution of the excess heat, if it is not possible to use the grid at the port of Aarhus.

Additionally, the future research can involve a direct collaboration with the industries at the port. This can be viewed interesting, as it enables to include the perspective of the industries in relation to designing the common system at the port. As a result of this, it can be argued to also be possible in this process to assess the business economic potential of the industries in participating in the common system with a an establishment of a collaboration and dialogue with the industries.

Another point interesting to include in the future research with the common system at the port can be to enter a direct collaboration with AVA in relation to the allocation and purchase of the excess heat from the common system. In addition to this, an investigation of a potential other receiver and a potential externally imposed operator(s) can also be of relevance in the future work with the development of the exchange of excess heat at the port of Aarhus.

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A

A.1 Meetings

This appendix contains the notes from the three meetings carried out in the thesis.

Meeting 1

The meeting denoted Meeting 1 was carried out with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus. The meeting was conducted on the 17th of February 2020. The meeting was carried out in the beginning of the project period, and was as a result used to discuss initial thoughts on the pilot project of an exchange of excess heat at the port of Aarhus.
In the following, notes from the meeting are outlined. The notes are a combination of statements and opinions from the participants in the meeting, which means that the notes are not to be seen as a transcription of statements from Uffe Kristensen, but as a summary of the considerations expressed in the meeting.

- The pilot project must deal with the current situation of excess heat at the port of Aarhus:
  - What are the possibilities?
  - What are the barriers?
- A desired outcome of the pilot project is to increase the focus on energy efficiency at the industries at the port of Aarhus and to have transparency by bringing about a system way of thinking.
- A technical analysis can be conducted as a part of the pilot project e.g. in energyPRO, where a number of industries at the port can be part of the model as either producers, users of excess heat or by being both. The exchange of excess heat can be modelled as a heating plant with a storage or with different receivers.
  - One of the receivers of the excess heat can be the district heating system, but the main focus of the technical analysis is not to examine, how the excess heat at the port of Aarhus can be used in the district heating system in the municipality.
  - In relation to the district heating system, an interesting point of analysis can be to see what the excess heat replaces in terms of the production units and fuels used in the district heating system.
- A technical analysis can be viewed as important in relation to making the pilot project about excess heat tangible, relatable, and concrete for the industries at the port and to experiment with a different concept for the utilisation of excess heat.
- A scope and delimitation of the technical analysis is important:
  - Is the analysis and model dealing with the entire district heating system in the municipality of Aarhus or only a system isolated to the port of Aarhus?
- A possible scope for the pilot project about excess heat is also to investigate, if the use of excess heat can be changed into be used in conditions as a service.

  - This can perhaps challenge the system in terms of taxes and lead to the question of, how the excess heat should be classified.
  - This can also lead to an experiment of creating a new business model for the use of excess heat.
- Aarhus Municipality is interested in getting the port of Aarhus to become a non-regulatory zone[1].
- Aarhus Havn = a company owned by the municipality of Aarhus. The port of Aarhus = the specific area and location of the port.

Meeting 2

The meeting denoted Meeting 2 was conducted with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus and consultants from the energy consulting firm PlanEnergi. The meeting took place the 18th of February 2020. The general subject of the meeting was discussing possible arrangements and organisations of the exchange of excess heat at the port, and a focus was also put on the collaboration between the participants of the meeting. As a result, the meeting had the form of a discussion and brainstorm of the approach towards the pilot project.
This meeting is not used as a direct reference in the thesis, but is a part of the working process in relation to the thesis.
Notes from the meeting are outlined, below:

- The pilot project shall contain a mapping of the potential and the proportions of excess heat available at the port of Aarhus. This means, that the energy balance at the port shall be clarified. In addition to this, it must be clarified what energy exchanges that can happen between the industries.
  - In connection to this, it should be clarified, what the technical barriers are.
- The mapping can be limited to the synergies at the port.
- An interesting point for the district heating company in the municipality of Aarhus (AVA) is, if the excess heat can be organised as being flexible in the sense of being dispatchable.
- Important questions to be answered:
  - Who owns the transmission/distribution grid at the port?
  - What is the value of the "residual heat"? (The heat, that is remaining after the heat demand at the industries is covered)
  - Can the district heating company in the municipality of Aarhus receive the excess heat in order to balance the system at the port?
- Aarhus Havn is interested in the pilot project, but are not necessarily interested in investing.
- The pilot project shall be presented at a meeting for the network at the port in June and the findings of the pilot project presented for Aarhus Havn and the industries at the port at a later date.
- Transition has:
  - Made mapping with a focus on initiatives for symbiosis between the industries at the port.
  - Collected data on the a year basis.
- Data from the industries must be collected (besides the data collected by Transition) to make yearly profiles.

[1] Translation of the Danish word: Regulatorisk frizone

- The focus of the pilot project is on potentials, economy, risks, regulation and in connection to this, it is also important to include the presupposed conditions of the pilot project and to make the system robust.

Meeting 3

The meeting denoted Meeting 3 was carried out with a number of different participants all working with the pilot project. The meeting was conducted with development consultant Uffe Kristensen from The Secretariat of Climate and Green Transition in the municipality of Aarhus, consultants from the energy consulting firm PlanEnergi, and consultants from the energy consulting firm Transition. The meeting took place the 16th of March 2020 and was carried out as an online meeting.
The general subject of the meeting was the work conducted by Transition as a part of the project *Smart Energi Aarhus Havn* and the purpose of the meeting was as a result for Transition to give information about the industries at the port of Aarhus with a focus on the pilot project about utilisation of excess heat at the port.
Notes from this meeting are outlined in the following. As the meeting was carried out with a number of participants, the notes are not showing a transcription of the meeting but rather a summary of the statements and opinions expressed during the meeting. This also means that the statements and opinions are not ascribed to specific participants in the meeting, but due to the fact that the consultants from Transition were handing over collected information, the statements are primarily from the consultants from Transition.

- Transition has interviewed 14 industries and the industries have shown an interest in the pilot project.
- Some of the industries at the port has had a dialogue with AVA regarding utilisation of excess heat, but has not been successful with conducting an agreement or establishing the utilisation of excess heat. Through the interviews, the industries have expressed interest in establishing an utilisation of excess heat between the industries at the port.
- Through the interviews made by Transition, it has been made clear that the industries at the port of Aarhus only share location and do not have any kind of community or cooperation with each other.
- Some of the industries have a cooling demand and produce as a result of this excess heat.
- The work carried out by Transition in the project *Smart Energi Aarhus Havn* has lead to an identification of potential energy and resource exchanges between the industries at the port, but a collection of detailed data has not been carried out.
- The industries have different temperatures and volumes of excess heat. As an example, one industry produces excess heat at low temperatures (about 25°C), but produces excess heat in great volumes.

Other meetings

In addition to the meetings mentioned above, 4 meetings with the consultants from PlanEnergi have been carried out as a part of the collaboration with the consultants. Together with e-mail correspondences, the meetings have been forum for discussions about the design of the exchange of excess heat between the industries at the port of Aarhus. This means that the focus of the correspondences with the consultants has been to discuss the modelling of the exchange of excess heat in energyPRO and the data used for this. In addition to this, the consultants have been sharing reflections on assumptions appropriate for the modelling in energyPRO as the actual data has not been available to be included in the thesis.

B

B.1 Interview Guides

This appendix contains interview guides for the two interviews carried out in the thesis.

Two interviews are conducted as a part of the thesis. In the following, the interview guides for the two interviews are listed. As the interviews are carried out in Danish, the two interview guides are written in Danish, too.

The two interviews are attached as audio files.

Interview with Uffe Kristensen

1. Hvordan er ideén omkring en systemtankegang omkring brugen af overskudsvarme opstået?
2. Hvorfor er det interessant at eksperimentere med udvekslingen af overskudsvarme på havnen i Aarhus?
3. Hvilke fordele/ulemper ser Aarhus Kommune ved at fremme brugen af overskudsvarme på havnen i Aarhus?
4. Hvad vurderer du, der skal til for at gennemføre projektet på Aarhus Havn? Tror du, projektet vil kunne udføres andre steder med virksomheder tæt placeret?
5. Hvorfor er det interessant at arbejde med et system vedrørende overskudsvarme, hvor AVA ikke er hovedaktør? Hvorfor er AVA ikke hovedaktør i projektet?

Interview with Anne Zachariassen

1. Hvad er Aarhus Havns rolle i forhold til havnen i Aarhus og virksomhederne placeret på havnen? Og hvordan er samarbejdet med Aarhus kommune, nu når Aarhus Havn er selvstyret men ejet af kommunen?
2. Har Aarhus Havn interesse i arbejdet med udveksling af overskudsvarme mellem virksomheder på havnen i Aarhus?
3. Ser Aarhus Havn fordele og ulemper ved at arbejde med en udveksling af overskudsvarme mellem virksomheder på havnen i Aarhus?
4. Har du indtryk af, hvad virksomhedernes interesse er i forhold til at deltage i projektet med udvekslingen af overskudsvarme på havnen?
5. Har du indtryk af, hvad der afholder virksomhederne på havnen i at deltage i projektet med udvekslingen af overskudsvarme?
6. Hvad er dine tanker vedrørende, at virksomhederne på havnen i udvekslingen af overskudsvarme vil skulle samarbejde om dette og tildeles være afhængige af hinanden?

C

C.1 Map of the District Heating Grid at the Port of Aarhus

This appendix contains a map of the district heating grid implemented at the port of Aarhus, and Figure C.1 presents the district heat grid.

On Figure C.1, the black pipe lines are transmission pipe lines whereas the distribution pipe lines are highlighted as purple and the service pipe lines[1] are marked as greenish-blue.

The map is received from PlanEnergi passed on by AVA as a part of working with exchange of excess heat at the port of Aarhus.

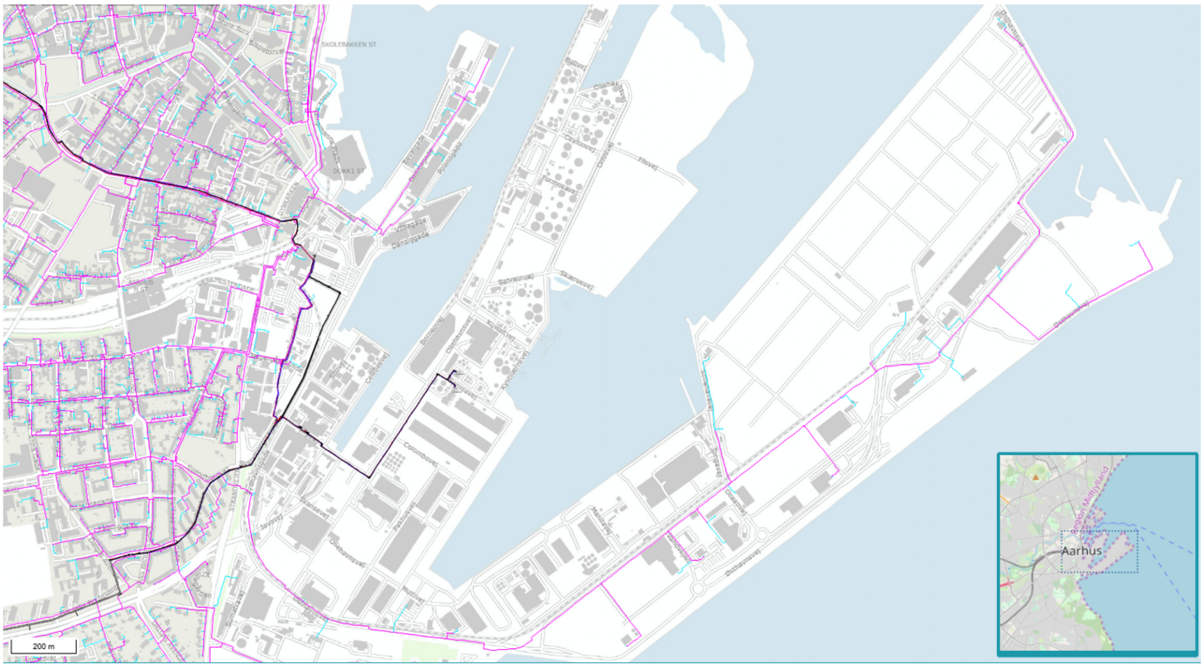


Figure C.1: *Illustration of the district heating grid at the port of Aarhus. The map is made by AVA.*

[1]Translation of the Danish work: stikledninger

D

D.1 Additional Explanation of the Data and Information Processing

This appendix contains additional explanations to the description of the data and information processing in energyPRO in relation to the design of the common system and exchange of excess heat at the port of Aarhus.

COP-factors

This section outlines the calculations and determination of the COP-factors assumed and assigned to the heat pumps used in the cooling processes at Industry 3, 4, 5, 7, and 12 and the booster heat pumps at Industry 5, 10, and 12

The COP-factors are determined based on calculating the theoretical Lorentz COP-factor. The calculation of the theoretical Lorentz COP-factor is described in [EMD International A/S, 2019] and determined by the following formula:

$$COP = \frac{T_{HighMean}}{T_{HighMean} - T_{LowMean}} \quad \text{where, } T_{HighMean} = \frac{T_{HighOutle} - T_{HighInlet}}{\ln\left(\frac{T_{HighOutlet} + 273{,}15\ K}{T_{HighInlet} + 273{,}15\ K}\right)} \quad \text{and } T_{LowMean} = \frac{T_{LowOutle} - T_{LowInlet}}{\ln\left(\frac{T_{LowOutlet} + 273{,}15\ K}{T_{LowInlet} + 273{,}15\ K}\right)}$$

Figure D.1: *Illustration of formula behind the calculation of the theoretical Lorentz COP-factor. The illustration is made based on the description of the formula in [EMD International A/S, 2019].*

To get the COP-factor of the heat pumps, the calculated theoretical Lorentz COP-factor is multiplied with a typical efficiency of a heat pump [EMD International A/S, 2019; Grøn Energi et al., 2017].

Heat pumps used in cooling processes

Table D.1 shows the expected cooling demands at Industry 3, 4, 5, 7, and 12 together with the assumed temperature of the excess heat produced from the industries.

Table D.1: *The assumed cooling demands and temperature of the excess heat produced at Industry 3, 4, 5, 7, and 12.*

	Industry 3	Industry 4	Industry 5	Industry 7	Industry 12
Temperature of the cooling demand [°C]	2	5	30	2	6
Excess heat temperature [°C]	75	75	60	75	24

By using the formula in Figure D.1, the theoretical Lorentz COP-factors of the heat pumps used in the cooling processes at Industry 3, 4, 5, 7, and 12 are calculated. The calculations are carried out in Excel, and the theoretical COP-factors are shown in Table D.2.

Table D.2: *Theoretical COP (Lorentz) - Heat pumps in cooling processes*

	Industry 3	**Industry 4**	**Industry 5**	**Industry 7**	**Industry 12**
$T_{HighOutlet}$	75ºC	75ºC	60ºC	75ºC	24ºC
$T_{HighInlet}$	35ºC	40ºC	45ºC	45ºC	15ºC
$T_{HighMean}$ =	328 K	330 K	326 K	333 K	293 K
$T_{LowOutlet}$	35ºC	40ºC	45ºC	45ºC	15ºC
$T_{LowInlet}$	2ºC	5ºC	30ºC	2ºC	6ºC
$T_{LowMean}$ =	291 K	295 K	311 K	296 K	284 K
Theoretical COP (Lorentz)	**9**	**9,4**	**21,7**	**9**	**32,5**

In relation to defining the COP-factors of the heat pumps used in the cooling processes at the industries, the calculated theoretical Lorentz COP-factors are multiplied with a typical efficiency of a heat pump, which is an efficiency around 55% [Grøn Energi et al., 2017]. However, it is assumed, that the production processes at Industry 3, 4, 5, 7, and 12 have different efficiencies, and for that reason, other efficiencies are used in the calculations of the COP-factors at Industry 3 and 7. The calculations are carried out in Excel, and the COP-factors of the heat pumps in the cooling processes at Industry 3, 4, 5, 7, and 12 are included in Table D.3.

Table D.3: *COP - Heat pumps in cooling processes*

	Industry 3	**Industry 4**	**Industry 5**	**Industry 7**	**Industry 12**
Theoretical COP (Lorentz)	9	9,4	21,7	9	32,5
Efficiency	28%	55%	55%	45%	55%
COP	**2,5**	**5,2**	**11,9**	**4**	**17,9**

Booster heat pumps

Table D.4 includes the assumed temperatures of the excess heat produced at Industry 5, 10, and 12 and shows the required temperature of the excess heat in the exchange of excess heat at the port of Aarhus.

Table D.4: *The assumed excess heat temperatures at Industry 5, 10, and 12 with the required excess heat temperature in the exchange at the port of Aarhus.*

	Industry 5	**Industry 10**	**Industry 12**
Temperature of the excess heat [ºC]	60	40	24
Required temperature of the excess heat in the exchange at the port [ºC]	75		

Based on the formula in Figure D.1, the calculations of the theoretical Lorentz COP-factors of the booster heat pumps at Industry 5, 10, and 12 are carried out. The calculations are done in Excel, and the theoretical COP-factors can be observed in Table D.5.

Table D.5: *Theoretical COP (Lorentz) - Booster heat pumps*

	Industry 5	**Industry 10**	**Industry 12**
$T_{HighOutlet}$	75ºC	75ºC	75ºC
$T_{HighInlet}$	60ºC	40ºC	24ºC
$T_{HighMean}$ =	341 K	330 K	322 K
$T_{LowOutlet}$	60ºC	40ºC	24ºC
$T_{LowInlet}$	35ºC	35ºC	2ºC
$T_{LowMean}$ =	320 K	310 K	286 K
Theoretical COP (Lorentz)	**16,9**	**16,8**	**8,95**

The calculated theoretical Lorentz COP-factors are multiplied with the typical efficiency of a heat pump at 55% [Grøn Energi et al., 2017]. The calculations are done in Excel, and the COP-factors of the booster heat pumps at Industry 5, 10, and 12 are illustrated in Table D.6.

Table D.6: *COP - Booster heat pumps*

	Industry 5	**Industry 10**	**Industry 12**
Theoretical COP (Lorentz)	16,9	16,8	8,95
Efficiency	55%	55%	55%
COP	9,3	9,2	4,9

Tax on Excess Heat

Industry 1, 3, 4, 5, 7, 9, 10, 11, and 12 produce excess heat, but for the industries the tax on excess heat is paid and incorporated differently into energyPRO.

For Industry 1, 9, 10, and 11, the tax on excess heat is paid in relation to the total amount of excess heat produced by the industries.

At industry 3, 4, 5, 7, and 12, the excess heat production is based on a cooling process by a heat pump, and according to regulation, when excess heat emerges from a cooling process by a heat pump, the tax on excess heat is also charged in relation to the amount of excess heat produced, that is 3 times higher the electricity consumption of the heat pump.

In the thesis, the amount of excess heat imposed to the tax on excess heat is determined and calculated by the formula shown in Figure D.2:

*Heat production at Industry X - (Electricity consumption at Industry X * 3)*
= Amount of excess heat imposed to the tax on excess heat

Figure D.2: *Formula*

The formula is inserted in energyPRO in relation to Industry 3, 4, and 7. For Industry 5 and 12, the formula is used to calculate the amount of excess heat imposed to the tax on excess heat in Excel. The calculated amount is multiplied with 90 DKK/MWh (the tax rate on excess heat). In energyPRO, the tax on excess heat related to Industry 5 and 12 is put in as an annual expense.

Tax on Electricity to Heat

For the booster heat pumps at Industry 5, 10, and 12, the tax on electricity to heat is paid of the entire electricity consumption by the heat pumps.

At industry 3, 4, 5, 7, and 12, where excess heat is produced from the cooling process, regulation defines a distribution of the tax on electricity to heat between the production of heat and cooling. For the production of excess heat, the electricity consumption is determined as 1/3 of the heat produced but not higher than the actual electricity consumption of the heat pump.

In the thesis, the accounted electricity consumption for the heat production is defined by the formula shown in the figure below:

IF(Heat production at Industry X / 3) > Electricity consumption at Industry X;
Electricity consumption at Industry X; (Heat production at Industry X / 3)
= Amount of electricity for the heat production imposed the tax on electricity to heat

Figure D.3: *Formula*

The formula is used and connected to Industry 3, 4, and 7 in energyPRO. In relation to Industry 5 and 12, the electricity consumption for the heat production is calculated in Excel and multiplied with 210 DKK/MWh (the tax rate on excess heat) and afterwards included in energyPRO as an annual expense.

Capacity of the booster heat pumps

In energyPRO, outages are implemented to simulate the industries at the port of Aarhus closing down in the summer holidays and Christmas break. This results in a production of excess heat in 7.944 hours in a year at Industry 5, 10, and 12.

The capacity of the booster heat pumps at Industry 5, 10, and 12 is determined by dividing the total production of excess heat from the industries with the hours of production of excess heat in a year.

The calculations are carried out in Excel and the defined capacities of the booster heat pumps can be viewed in Table D.7.

Table D.7: *Capacities of the booster heat pumps*

	Industry 5	**Industry 10**	**Industry 12**
Hours of excess heat production	7.944		
Total production of excess heat [MWh/year]	10.794	6.729	10.041
Capacity [MW]	1,4	0,8	1,3

Investment costs of the booster heat pumps

The investments cost of the booster heat pumps connected to Industry 5, 10, and 12 are determined based on the capacities of the booster heat pumps and information about investment costs of electric heat pumps found in the technology catalogue *Technology Data - Generation of Electricity and District heating* by the Danish Energy Agency [Energistyrelsen, 2020].

Based on the investment costs of the heat pumps found in the technology catalogue, the investment costs of the booster heats pumps are calculated. The calculations are done in Excel and the total investment costs of the booster heat pumps at Industry 5, 10, and 12 are presented in Table D.8.

Table D.8: *Investment costs of the booster heat pumps*

	Industry 5	**Industry 10**	**Industry 12**
Investment cost (Technology catalogue)	1,24 M€/MJ/s		
	1.240.000 €/MJ/s		
	9.300.000 DKK/MJ/s		
Capacity	1,3 MW	0,8 MW	1,4 MW
Investment	12.090.000 DKK	7.440.000 DKK	13.020.000 DKK

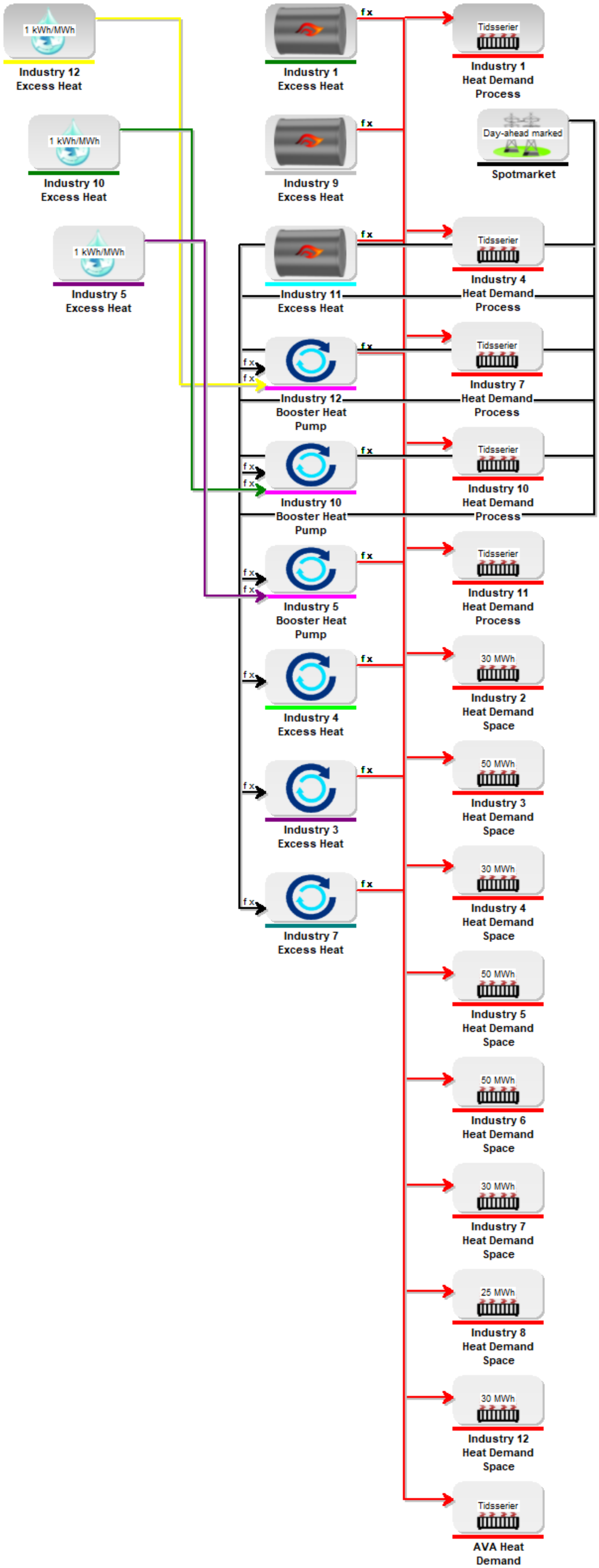
E

E.1 Outputs from energyPRO

This appendix contains outputs from energyPRO including an illustration of the design of the common system and the exchange of excess heat from energyPRO together with result outputs of the energy conversion and total annual costs in relation to the proposed design of the exchange of excess heat.

Outputs from energyPRO concerning energy conversion and total annual costs to the entailed changes in the sensitivity analysis are attached to the thesis in Digital Exam.

Illustration from energyPRO of the design of the exchange of excess heat at the port of Aarhus:



1 kWh/MWh
Industry 12
Excess Heat
1 kWh/MWh
Industry 10
Excess Heat
1 kWh/MWh
Industry 5
Excess Heat
Industry 1
Excess Heat
Industry 9
Excess Heat
Industry 11
Excess Heat
Industry 12
Booster Heat
Pump
Industry 10
Booster Heat
Pump
Industry 5
Booster Heat
Pump
Industry 4
Excess Heat
Industry 3
Excess Heat
Industry 7
Excess Heat
Tidsserier
Industry 1
Heat Demand
Process
Day-ahead marked
Spotmarket
Tidsserier
Industry 4
Heat Demand
Process
Tidsserier
Industry 7
Heat Demand
Process
Tidsserier
Industry 10
Heat Demand
Process
Tidsserier
Industry 11
Heat Demand
Process
30 MWh
Industry 2
Heat Demand
Space
50 MWh
Industry 3
Heat Demand
Space
30 MWh
Industry 4
Heat Demand
Space
50 MWh
Industry 5
Heat Demand
Space
50 MWh
Industry 6
Heat Demand
Space
30 MWh
Industry 7
Heat Demand
Space
25 MWh
Industry 8
Heat Demand
Space
30 MWh
Industry 12
Heat Demand
Space
Tidsserier
AVA Heat
Demand

Results output:

Base - Design modul - 3.epp

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License period January 1, 2020 to September 1, 2020
SPRING 2020
6305

Energiomsætning, Årlig

Beregnet periode: 01-2019 - 12-2019

Varmebehov:

Industry 1 Heat Demand Process	4.000,0 MWh
Industry 4 Heat Demand Process	4.000,0 MWh
Industry 7 Heat Demand Process	2.000,0 MWh
Industry 10 Heat Demand Process	8.000,0 MWh
Industry 11 Heat Demand Process	50.000,0 MWh
Industry 2 Heat Demand Space	30,0 MWh
Industry 3 Heat Demand Space	50,0 MWh
Industry 4 Heat Demand Space	30,0 MWh
Industry 5 Heat Demand Space	50,0 MWh
Industry 6 Heat Demand Space	50,0 MWh
Industry 7 Heat Demand Space	30,0 MWh
Industry 8 Heat Demand Space	25,0 MWh
Industry 12 Heat Demand Space	30,0 MWh
AVA Heat Demand	67.000,0 MWh
Total	135.295,0 MWh

Max varmebehov 17,1 MW

Varmeproduktioner:

Industry 1 Excess Heat	3.000,0 MWh/år	2,2%
Industry 9 Excess Heat	40.000,3 MWh/år	29,7%
Industry 11 Excess Heat	32.000,0 MWh/år	23,8%
Industry 12 Booster Heat Pump	10.040,8 MWh/år	7,5%
Industry 10 Booster Heat Pump	6.729,9 MWh/år	5,0%
Industry 5 Booster Heat Pump	10.794,2 MWh/år	8,0%
Industry 4 Excess Heat	3.000,0 MWh/år	2,2%
Industry 3 Excess Heat	28.000,0 MWh/år	20,8%
Industry 7 Excess Heat	1.000,0 MWh/år	0,7%
Total	134.565,2 MWh/år	100,0%

Elektricitet forbrugt af energianlæg:
Spotmarket:

	Af årlig [MWh/år]
Industry 12 Booster Heat Pump	2.040,8
Industry 10 Booster Heat Pump	729,9
Industry 5 Booster Heat Pump	1.158,2
Industry 4 Excess Heat	578,0
Industry 3 Excess Heat	11.200,0
Industry 7 Excess Heat	250,0
Total	15.957,0

Driftstimer:
Spotmarket:

	Total [t/År]	Af årlig timer
Industry 12 Booster Heat Pump	7.944,0	90,7%
Industry 10 Booster Heat Pump	7.944,0	90,7%
Industry 5 Booster Heat Pump	7.944,0	90,7%
Industry 4 Excess Heat	7.944,0	90,7%
Industry 3 Excess Heat	7.944,0	90,7%
Industry 7 Excess Heat	7.944,0	90,7%
Ud af hele perioden	8.760,0	

Base - Design modul - 3.epp

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Energiomsætning, Årlig

Produktionsenhed(er) ikke forbundet til elmarked:

	Total [t/År]	Af årlig timer
Industry 1 Excess Heat	7.944,0	90,7%
Industry 9 Excess Heat	7.968,0	91,0%
Industry 11 Excess Heat	7.944,0	90,7%
Ud af hele perioden	8.760,0	

Starter:

Industry 1 Excess Heat	2
Industry 9 Excess Heat	2
Industry 11 Excess Heat	2
Industry 12 Booster Heat Pump	2
Industry 10 Booster Heat Pump	2
Industry 5 Booster Heat Pump	2
Industry 4 Excess Heat	2
Industry 3 Excess Heat	2
Industry 7 Excess Heat	2

Fuldlastsdriftstimer:

Industry 1 Excess Heat	7.944
Industry 9 Excess Heat	7.944
Industry 11 Excess Heat	7.944
Industry 12 Booster Heat Pump	7.944
Industry 10 Booster Heat Pump	7.944
Industry 5 Booster Heat Pump	7.944
Industry 4 Excess Heat	7.944
Industry 3 Excess Heat	7.944
Industry 7 Excess Heat	7.944

Brændsler:

Som brændsler

	Brændselsforbrug	Brændselsproduktion	Tilbudt brændsel	Ikke brugt brændsel
Industry 12 Excess Heat	7.999.999,6 MWh	0,00 MWh	8.821.751,84 MWh	821.752,23 MWh
Industry 10 Excess Heat	5.999.999,7 MWh	0,00 MWh	6.616.313,88 MWh	616.314,17 MWh
Industry 5 Excess Heat	9.635.999,5 MWh	0,00 MWh	10.625.800,10 MWh	989.800,56 MWh

Som energianlæg

Industry 1 Excess Heat	0,0 MWh	=0,0	----
Industry 9 Excess Heat	0,0 MWh	=0,0	----
Industry 11 Excess Heat	0,0 MWh	=0,0	----
Industry 12 Booster Heat Pump	8.000,0 MWh	=7.999.999,6	MWh
Industry 10 Booster Heat Pump	6.000,0 MWh	=5.999.999,7	MWh
Industry 5 Booster Heat Pump	9.636,0 MWh	=9.635.999,5	MWh
Industry 4 Excess Heat	0,0 MWh	=0,0	----
Industry 3 Excess Heat	0,0 MWh	=0,0	----
Industry 7 Excess Heat	0,0 MWh	=0,0	----
Total	23.636,0 MWh		

Base - Design modul - 3.epp

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Resultat af ordinær drift fra 01-01-2019 00:00 til 31-12-2019 23:59

(Alle beløb i kr.)

Driftsindtægter							
Revenue from AVA	:	12.238.254,7	á	1,0	=	12.238.255	
Industry 1 repayment process hea	:	4.000,0 MWh	á	90,0	=	360.000	
Industry 4 repayment process hea	:	4.000,0 MWh	á	90,0	=	360.000	
Industry 7 repayment process hea	:	2.000,0 MWh	á	90,0	=	180.000	
Industry 10 repayment process he	:	8.000,0 MWh	á	90,0	=	720.000	
Industry 11 repayment process he	:	50.000,0 MWh	á	90,0	=	4.500.000	
Subtraction electricity purchase In	:				=	3.471.967	
Ialt Driftsindtægter							**21.830.222**
Driftsudgifter							
Purchase of electricity	:				=	4.606.101	
Tax on excess heat Industry 1	:	3.000,0 MWh	á	90,0	=	270.000	
Tax on excess heat Industry 3	:				=	0	
Tax on excess heat Industry 4	:	1.265,9 MWh	á	90,0	=	113.931	
Tax on excess heat Industry 5	:				=	648.608	
Tax on excess heat Industry 7	:	250,0 MWh	á	90,0	=	22.500	
Tax on excess heat Industry 9	:	40.000,3 MWh	á	90,0	=	3.600.029	
Tax on excess heat Industry 10	:	6.000,0	á	90,0	=	540.000	
Tax on excess heat Industry 11	:	32.000,0 MWh	á	90,0	=	2.880.000	
Tax on excess heat Industry 12	:				=	598.652	
Electricity tariffs	:	3.928,9 MWh	á	164,45	=	646.110	
Tax electricity to heat Industry 3	:	9.333,3 MWh	á	210,0	=	1.960.000	
Tax electricity to heat Industry 4	:	578,0 MWh	á	210,0	=	121.387	
Tax electricity to heat Industry 5	:				=	170.047	
Tax electricity to heat Industry 7	:	250,0 MWh	á	210,0	=	52.500	
Tax electricity to heat Industry 12	:				=	94.382	
PSO Tax	:	3.928,9	á	39,75	=	156.174	
Tax electricity to heat Industry 12	:	2.040,8	á	210,0	=	428.571	
Tax electricity to heat Industry 10	:	729,9	á	210,0	=	153.285	
OM Fixed Industry 12 Booster He	:				=	19.500	
OM Fixed Industry 10 Booster He	:				=	12.000	
OM Variable Industry 10 Booster	:	6.729,9	á	20,25	=	136.281	
OM Variable Industry 12 Booster	:	10.040,8	á	20,25	=	203.327	
Tax electricity to heat Industry 5 B	:	1.158,2	á	210,0	=	243.216	
OM Variable Industry 5 Booster H	:	10.794,2	á	20,25	=	218.582	
OM Fixed Industry 5 Booster Heat	:				=	21.000	
Investment Industry 12 Booster H	:				=	2.418.000	
Investment Industry 10 Booster H	:				=	1.488.000	
Investment Industry 5 Booster He	:				=	2.604.000	
Ialt Driftsudgifter							**24.426.184**
Resultat af ordinær drift							**-2.595.962**