Aalborg University, Copenhagen

Identifying the valuation of co-produced district heating and cooling

A case study of the socio-technical network of a new co-producing thermal technology in Taarnby, Copenhagen.

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Front picture: (Ramboll, 2018a)

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Abbreviations

CTR	Central Municipalities Transmission Company
VEKS	Vestegnens Combined Heat and Power Company
DH	District Heating
DC	District Cooling
DHC	District Heating and Cooling
CHP	Combined Heat and Power
DEA	Danish Energy Agency
HSA	Heat Supply Act
STS	Science and Technology Studies
DCA	District Cooling Act
O&M	Operation & Maintenance
IEA	International Energy Agency
DST	Statistics Denmark
CEU MINISTRY	Climate, Energy and Utility Ministry
ATES	Aqua Thermal Energy Storage
PV	Solar Photovoltaic

Preface

This report is the product of Frederik Palshøj Bigum's master thesis of the Master of Science in Engineering in Sustainable Cities at Aalborg University Copenhagen. The work has been supervised by Iva Ridjan Skov and Nis Bertelsen. The report is written in the period from September 1st, 2019 to January 10th, 2020.

For referencing, the Harvard style is used, thus references in the text include the author's surname and year of publication e.g. (Bigum, 2020). The bibliography is available in the end of the report, ordered alphabetically in accordance to surname.

Multiple people have been essential for this thesis to come into being, first and foremost my beloved wife Louise and my son Louie, who have supported me through rough times.
Secondly, people providing valuable inputs to the making of this report, I would like to express my sincerest gratitude towards. The topic came to my attention during my third semester internship at Ramboll with several interesting projects and colleagues. I would like to thank all the interviewees, providing me with valuable information and insights.
Finally, I would like to thank my supervisors Iva Ridjan Skov and Nis Bertelsen for supervision and guidance throughout the entire semester.

Dansk Resumé

Historisk ser er køling overset i det videnskabelige felt omkring energisystemer. Stigende globalt fokus på bæredygtighed har bidraget til anerkendelsen af, at køling repræsenterer en af de største udfordringer for fremtidigt energiforbrug. Det stigende problem omkring køling opstår grundet udvidelsen af ineffektive individuelle kølekompressorer, hvilket udgør en udfordring for elektricitetsnettet.

Fælles kølesystemer der forbinder flere kølekunder i et netværk, er identificeret som en mulighed for at øge effektiviteten i den progressive kølesektor. Sådanne netværk kaldes for fjernkøling. Navnet er tæt relateret til fjernvarme, da det praktisk talt har samme formål; at distribuere termisk energi. Synergier mellem fjernvarme og fjernkøling har længe været teoretisk kendt, men der mangler en undersøgelse af implementeringen af sådanne systemer. Tårnby Forsyning bygger i øjeblikket et kombineret fjernvarme- og fjernkølesystem, som anvender en fælles varmepumpe til at udnytte synergierne. Med mulighed for at undersøge et materialiseret system, ønsker dette speciale at studere, hvordan et kombineret fjernvarme- og kølesystem skaber værdi fremfor flere individuelle kølemaskiner.

Med en interdisciplinær fremgangsmåde er et casestudie af det kombinerede system i Tårnby blevet udført. Dette er tilstræbt for forstå den kontekstbestemte viden omkring forskelligartede opfattelser og værdiansættelser blandt de involverede aktører. De otte udførte interviews, identificerede to værdiansættelsestemaer; *økonomi* og *teknisk design.* Adskillige egenskaber i det kombinerede system var værdsat; *storskala fordele, udlicitering af drift og vedligehold, fleksibel energiproduktion, forsyningssikkerhed* og *det at være miljøvenlig* var identificeret som værende de mest signifikante.
I skabelsen af en ny forretningsmulighed er konflikter uundgåelige. Undersøgelse af, hvordan "closure mechanisms" kan anvendes i konfliktsituationer, demonstrerer en mulig måde at håndtere konflikt.

Kombineret produktion af varme og køl i en varmepumpe skaber påviseligt både en økonomisk og forståelsesmæssig værdi for de involverede aktører. Grundlaget for værdiskabelsen er forretningsplanen, der har skabt troværdige forhold, som tillader aktørerne at interagere og engagere sig i projektet. Derudover vil kombineret produktion af varme og køling i en varmepumpe sandsynligvis bidrage til forsat elektrificering af fjernvarmesektoren, samt udbredelsen af effektive fjernkølesystemer.

Abstract

Retrospectively cooling has been neglected in the scientific field of energy systems. Increasingly global focus on sustainability has identified cooling as one of the greatest challenges for further energy consumption. The major problem with cooling occurs in the expansion of ineffective individual cooling units posing a great challenge to the electricity grid.

Collective systems of cooling, connecting multiple cooling consumers in a network, has been identified as one possible way of increasing efficiency in the progressive sector of cooling. Such networks are called district cooling. The name is closely related to the notion of district heating, as it practically serves the same purpose, distributing thermal energy. Synergies between district cooling and district heating has been known on a theorical level, however implementation is poorly explored. Taarnby Utility currently constructs a combined district heating and cooling system operating from a collective large-scale heat pump utilising the synergies between the two supplies. Having a materialised system at hand, this thesis desires to examine how a combined district heating and cooling system creates value over multiple individual chillers.

With an interdisciplinary approach a case study of the combined district heating and cooling system in Taarnby has been conducted. Aiming at understanding the context depended knowledge of the heterogenous perceptions and valuations among the involved actors. Eight interviews have been performed identifying two themes of valuations; e*conomy* and *technical design.* Various properties of a combined system were valued; *economy of scale, outsourcing operation and maintenance, flexible energy production, supply security* and *being environmentally friendly* was highlighted as the most significant.
Creating a novel business opportunity implies controversies. Examining how closure mechanisms can be applied in a situation of conflict demonstrated possible closure of controversies.

Combining heat and cold production in a heat pump proves to create both economical and perceptual value for all actors involved. The foundation of the value created is the business plan establishing trustworthy conditions, allowing the actors to interact and engage in the project.
Furthermore, evidently combining production of heating and cooling in a heat pump, can benefit the continued electrification of the district heating sector and promote the expansion of efficient district cooling systems.

1 Introduction

Globally cooling is the fastest growing end-use energy demand, and simultaneously one of the biggest challenges in global energy consumption. (IEA, 2018) This calls for immediate implementation of cooling systems that limit the emission of greenhouse gasses, utilise the fluctuating electricity and optimises the use of available energy sources. In the scientific body of literature there are few examples of empirical research investigating the implementation of cooling systems. Preliminary work in this field focus primarily on the technical and theoretical development and understanding of smart energy systems, with a significant focus on heating over cooling. (Lund et al., 2018; Werner, 2017) This leaves room for empirical research of implementing cooling systems from the perspective of the actors involved rather than the conventional system perspective. Understanding how different perceptions and valuations of a common energy system differ or aligns, allowing an innovative technology to be implemented, is the main concern of this thesis.

One example of such a cooling system can be found in Taarnby. A heat pump providing combined district heating and cooling (DHC) is currently under construction in Taarnby. This thesis analyses the complex assembly of actor networks with various valuations of the system. The aim is to identify the value created by a collective system over the conventional solution of multiple individual cooling units.

1.1 Cooling: A blind spot in today's energy debate

The International Energy Agency, IEA, is pointing at cooling as one of most critical energy issues in modern time in their report "*The Future of Cooling – Opportunities for energy-efficient air condition*" (IEA, 2018). Fathi Birol, IEA Executive Director, states that "*Growing demand for air conditioners is one of the most critical blind spots in today's energy debate*" (IEA, 2018) The referred analysis finds that cooling is the fastest growing use of energy in buildings and if no action is taken, the energy demand for cooling will triple by 2050. Today space cooling already accounts for approximately 10% of the global electricity consumption. One of the major problems identified in the IEA report is that today's consumers buy inefficient individual cooling technologies increasing the demand for electricity. Inefficient and inflexible cooling units increases the peak demand for electricity and accelerate the need for new power plants. (IEA, 2018)

In 2015 the Birmingham Energy Institute issued a report called "*Doing Cold Smarter*" aiming to raise awareness of cooling in the political agenda. They, similar to IEA, find cooling being much neglected in the energy debate both politically and academically, even though it represents a growing issue in the global energy consumption. Cooling is essential for modern living standards and are expected to increase significantly in coming years – especially in developing countries. The researchers of the report argue that a system level approach to the problem of cooling is preferable, as it allows synergies and increase efficiency significantly, compared to the conventional cooling. (Teverson et al., 2015)

Even though the demand for cooling primarily is expected to increase in developing countries and in warmer climates, cooling demand is also found to be increasing in colder regions, such as Denmark. In 2016 "*Cooling Plan Denmark*" was published to establish district cooling in the context of thermal planning in Denmark for politicians, authorities and district heating companies. (Aalborg University, Ramboll & Dansk Fjernvarme, 2016) The total cooling demand in Denmark were estimated to 9.5 TWh whereas 4.2 TWh could be supplied by district cooling (Aalborg University, Ramboll & Dansk Fjernvarme, 2016). District cooling (DC) distributes cold water through pipes from a central production unit into buildings. Having a central unit has several advantages for the collective energy system compared to having an individual cooling unit, i.e. increased flexibility and efficiency. These aspects are of increasing importance in the future energy system with higher levels of fluctuating energy. Having a heat pump co-producing district heating and cooling optimise the energy efficiency and allow for integration of storage units and flexible electricity consumption in interruptible heat pumps, increasing the overall energy system efficiency as well. (Aalborg University, Ramboll & Dansk Fjernvarme, 2016).

One of the clear advantages in the colder climates is the well-established district heating (DH) networks. DC and DH are fairly similar in technology and have several synergies among them, as referred. In colder climates the cooling demand for space cooling is primarily for tertiary industry and in the summer period, however process cooling is needed for industry purposes all year. Residential cooling is not commonly used in colder climates. (Aalborg University, Ramboll & Dansk Fjernvarme, 2016).

1.2 Knowledge gap of district cooling implementation

The smart energy system concept has created an area for scientists to analyse and develop synergies in different energy sectors. Several scientific articles have been published on this matter. Since the introduction of the smart energy system concept in 2012 (Lund et al., 2012), and more significant with the definition from Henrik Lund in the book "*Renewable Energy Systems"* in 2014 (Lund, 2014) an increasing number of articles have been published concerning smart energy systems with different scientific scopes. (Lund et al., 2017) Preliminary research in

this field has been on the technical solutions, technical operations and synergies. (Lund et al., 2017; Lund et al., 2018)
A literature review by Lund et al. (2018) finds that there is a great scientific understanding of the technical aspects of the smart energy system concept, however implementation of systems in local contexts and legal frameworks is lacking attention in the scientific body of literature. (Lund et al., 2018)
Sven Werner (2017), a Swedish professor in district energy, did an international review of DHC markets, technologies, supply, institutions and future context in 2017. Werner emphasises that there is a heavy unbalance found between scientific knowledge of DH and DC, as DC is in the early phase of development, publications concerning cooling are rare. (Werner, 2017) Werner, similar to Lund et al. (2018), finds the technical potential for DHC to be substantial, however efforts to identify the implementation of such systems are essential to reach the potential. (Werner, 2017)
Examining the body of literature few researchers have addressed implementation of smart energy systems, leaving room for further research of this subject matter. Studies in this field establish the lack of *empirical validation* (Lammers and Arentsen, 2017; van der Werff and Steg, 2016), and *implementation of combined heating and cooling technologies* (Pieper et al., 2018; Sayegh et al., 2017).

The literature review on implementation of smart energy systems find that empirical analyses of implementation of district cooling system constitute a research area with room for more research. To the best of the author's knowledge, no scientific articles were identified concerning the implementation of district cooling in the perspective of the value created for the actors involved. This justifies an empirical analysis of the valuations and perceptions of a materialised DHC system in complex network of actors.

1.3 The case of Taarnby

The aim of this thesis is to identify the value created by a collective cooling system over a conventional solution of multiple individual cooling units. To determine the valuation, the case of Taarnby DHC is selected to illustrate the complexity of building a collective energy system, when different sectors, demands and actors with different interpretations of technology meet in one cross sectoral solution that suits all actors involved. A further description of the case will be provided in chapter 6. By investigating a specific case, the valuation of a DHC system co-producing heating and cooling in Denmark, can be identified and analysed.

1.4 Research question

Based on the previous sections, presenting the problems of cooling systems and justifying the subject in question, the following research question is posed:

How was value created in the case of Taarnby by materialising a single district heating and cooling (DHC) technology rather than multiple individual cooling units?

With the following sub-questions explicating the subject matter:

- *Which different perceptions and valuations of the properties of a DHC system can be identified among the actors in the network?*
- *How can closure mechanisms resolve controversies among actors with different perceptions and valuations?*

1.5 Report structure

This thesis consists of 11 chapters plus the bibliography and appendices. Figure 1 illustrates the report structure.

Chapter 2 develops the methodological considerations for designing the research process. Furthermore, it establishes the scientific foundation for the research.

Chapter 3 elaborates the theoretical framework applied to the subject matter in question. Whereas, chapter 4 presents the methods used generating the empirical data.

Chapter 5 presents a general description of the differences between the DH and DC market, as this is found to be one of the complications of materialising a collective system.

Chapter 6 provides a case specific description of the DHC system in Taarnby in terms of technical composition, market architecture and involved actors.

Chapter 7 aim to answer the first sub-question by analysing the involved actors' perceptions and valuation of the properties in the DHC system in Taarnby.

Chapter 8 analyses how closure mechanisms can resolve controversies caused by different perceptions and valuations, thus answering the second sub-question.

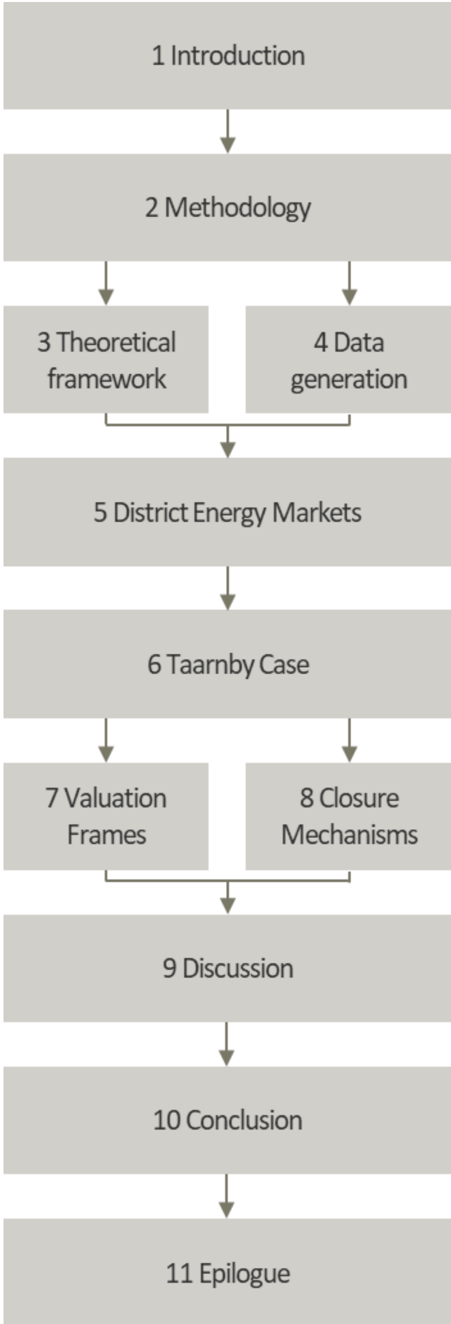

Figure 1 Report structure

Chapter 9 discusses the value of a DHC system compared to a conventional cooling solution and what can be learned from the case study as an energy planner.

Chapter 10 concludes the findings in the previous chapters to answer the research question posed, including the two sub-questions.

Chapter 11 reflects upon the benefits and limitations of the applied research design, theories and methods.

2 Methodology

This Chapter describes the research process and the choice of theories and methods for analysing the subject matter of this thesis.

2.1 Research approach

The research question posed in this thesis entails two dimensions. Firstly, it entails a sociological dimension of how value was created for actors involved in the DHC system. Secondly, it entails a technical dimension of understanding an energy system in order to illustrate the challenges and benefits related to the proposed collective cooling system rather than an individual solution. Combined, the two dimensions form a socio-technical dimension. As identified in the introduction, the combined dimension is often neglected when analysing energy systems, however, being a product of the author's scientific position of interdisciplinary studies of engineering and social sciences, the combined approach is preferred as a valuable knowledge producing approach.

The nature of the research question requires primarily qualitative methods of studying the perceptions and valuations of the DHC system in Taarnby. The choice of interview method will be further illuminated in chapter 4. The field of inquiry is regarded as a case study as it is based on a specific case in Taarnby examining the value creation. Flyvbjerg (2006) argues that case studies can produce reliable knowledge, from an in-depth study and that results can be generalised to a broader understanding of the problem.
The two methods proposed enables the author to create valuable context-dependent knowledge by examining the actors involved in the system to fully understand how a collective system of DHC creates value.

When applying the former introduced approach, a theoretical framework needs to be constructed. Therefore, this thesis draws upon literature within the field of sciences and technology studies (STS) to establish the theoretical framework, which will be elaborated further in chapter 3.

2.2 Theoretical perspective

To construct a theoretical framework, the theoretical perspective acting within needs to be established. When materialising new technologies, such as the DHC into a system, different perspectives can be adopted in order to understand how the innovation came to be a reality. Doganova and Karnøe (2012) outlines two perspectives of this concern being the "*discovery*" perspective and the *"creation"* perspective. The former stating that business opportunities exist already, and simply need to be discovered by experts, the latter stating that the innovator will create the business opportunity by enacting and creating an environment of facts and calculations to form a view of the world. Creating an opportunity implies bringing a reality represented in a business case into a reality in the environment constructed by creating conditions where costumers are willing to engage in the product. (Doganova and Karnøe, 2012)

This thesis adopts the theoretical perspective of creation, thus acknowledges technological innovations as social constructions and outcomes of an organising process. This aligns with Callon (1991) and Pinch and Bijker (1984), suggesting that technology is a product of interaction between diverse actors.

3 Theoretical Framework

This Chapter will elaborate the theoretical framework for analysing the problem identified in the previous chapters. The theoretical framework will firstly introduce how technologies are found as result of a social construction, and secondly establish key concepts relevant to answer the research question.

3.1 Social construction of technology

As presented in the previous chapters, bringing a new technology into reality calls for a social construction of networks, creating an environment where heterogeneous actors can interact. The notion of heterogeneity entails both human and non-human actors in the literature of STS (Callon, 1991; Pinch and Bijker, 1984).

When analysing a materialised network, it is relevant to understand the markets in which it operates. In the case of Taarnby, the DHC system acts within different markets of DH and DC and seek to combine these to form an arena for interaction, thus creating value for the involved actors. The innovation process of a technological artefact can be considered as a multi-directional innovation process rather than a linear process. See Figure 2. (Pinch and Bijker, 1984) A multi-directional model allows to ask why variations of the technological artefact succeed or failed, instead of only examining the successful outcome. In the case of Taarnby it allows us to see the innovation process of the DHC system as a social construction created by the involved actors. Pinch and Bijker uses the notion *interpretative flexibility* to exemplify that technological artefacts can be designed and interpreted in several different ways. This understanding of an artefact

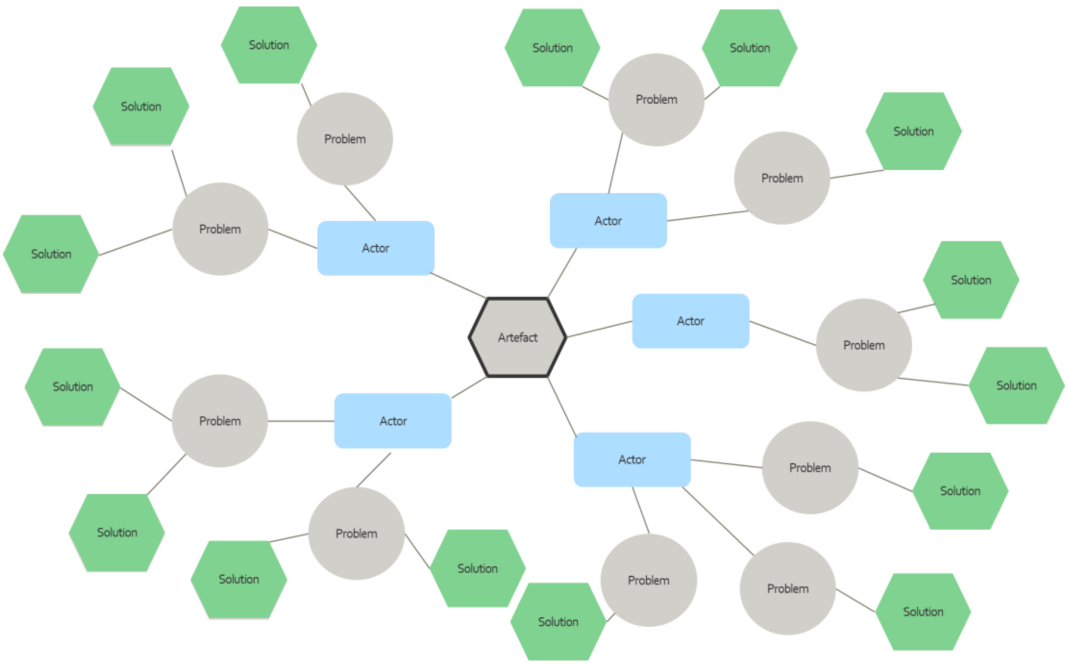

Figure 2 Multi-directional innovation process model. A visualisation of SCOT. (Pinch and Bijker, 1984)

supports the multi-directional model as an unpredictable innovation process, based on more than simple logic.

Figure 2 illustrates the high complexity of a network and visualises relations and conflicts among actors. It exemplifies how several actors can experience the same problem and how a solution to one problem can solve several other problems. The following sections will elaborate the key concepts *valuation frames, economic market paradigms* and *closure mechanisms* applied in the analysis.

3.2 Valuation frames

A socially constructed network consists of heterogenous actors with interpretative flexibility of the technology. To understand how different actors qualify and value the technology, the notion of *valuation frames* is introduced (Doganova and Karnøe, 2012). The notion entails frames or boundaries of a valuation between the qualities found valuable and the those left unconsidered. Valuation frames are rearranged through new business models posing value to qualities not imposed before. Value consists of economic value and social value i.e. environmentally friendly or CO_2 neutral qualities of the technology. The construction of new valuation frames entails recomposing the *valuation networks* i.e. adding or removing actors from the dominant network. When a new valuation frame challenges the dominant frames, controversies are likely to occur, as new qualities are enlightened, demonstrated and valued.

3.3 Economic markets

Various market theories exist but, for the purpose of this theoretical framework, a primary focus has been put on two concepts; a *competitive market* and a *natural monopoly*. These two market understandings are relevant when examining the DHC system in Taarnby, as it operates in both markets.

Competitive market

In market theory, competition mean to achieve an optimal market for the consumer and the supplier. Each actor strives to sell their products of the lowest possible price to attract most costumers. In order to function, certain conditions must be met; several firms with no dominance, free entry and exit, full information and exhibit no externalities. The competitive market is not regulated, as the market itself will create the best optimum for society. (Train, 1991)

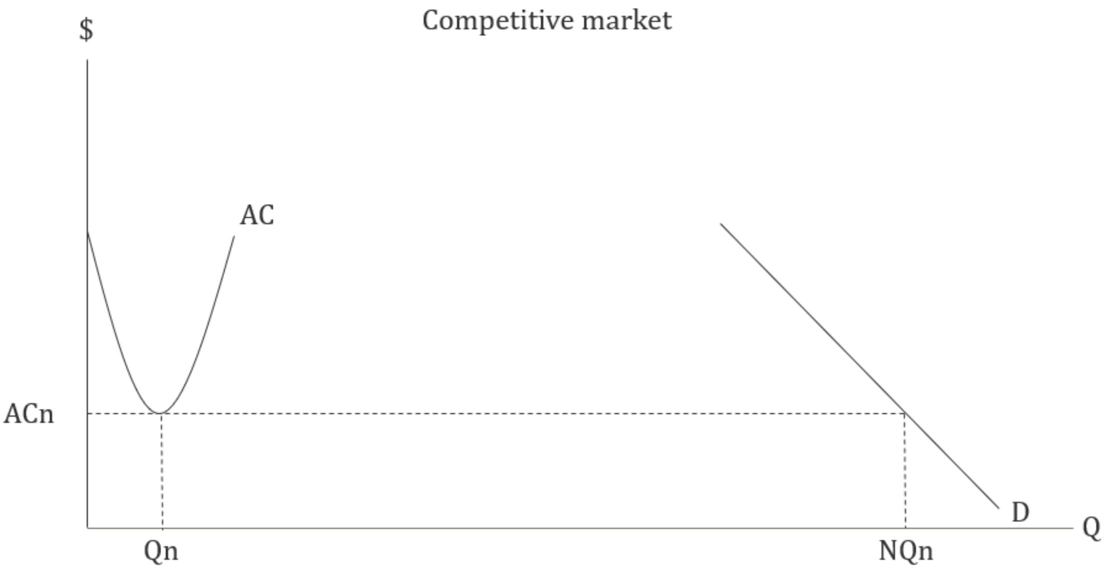

Figure 3 Competitive market, relation of average cost (AC) and demand (D). (Train, 1991)

Figure 3 shows the relation of average cost (AC) and demand (D) in a competitive market. Competition exists when economics of scale (the AC curve) are depleted at a level of output relatively small compared to the demand. This allows for competing companies to enter the market, to offer a similar product at the same average cost or lower. (Train, 1991)

Natural monopoly

In opposition to a competitive market the notion of *natural monopoly* exists. Here an intervention of the market is required to ensure the pursuit of profit does not affect the welfare of society. This represents a situation where it, from a cost perspective, is more profitable to be supplied from a single company. A natural monopoly benefits from *economy of scale* concept. Economy of scale represents the average cost of production decreases when the number of output expands. (Train, 1991)

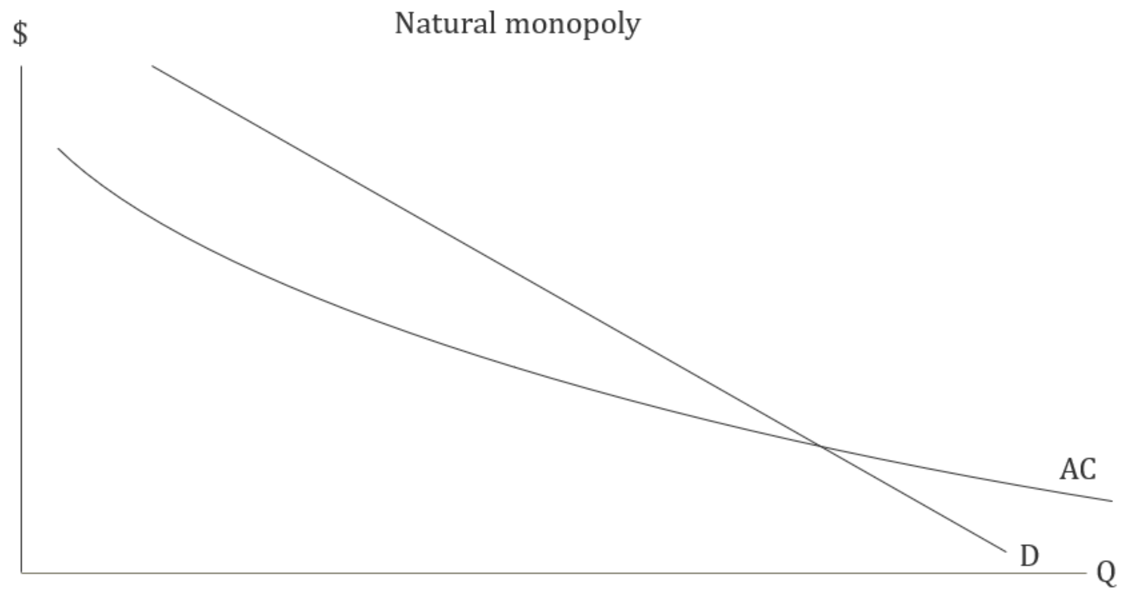

Figure 4 Natural monopoly, relation of average cost (AC) and demand (D). (Train, 1991)

Figure 4 demonstrates how the average cost decreases as the number of output (Q) expands, thus from a cost perspective, representing a societal benefit from having a single supplier of the good. (Trani, 1991)

3.4 Reaching agreement despite different valuation perspectives

Situations of controversy among actors in newly constructed networks are unavoidable (Pinch and Bijker, 1984; Callon, 1991; Doganova and Karnøe, 2012). The controversies are relevant when analysing networks as they exemplify an area of conflict that needs to be resolved, thus leaving room for analysing why this became a conflict in the first place, how it was resolved – or not resolved, and how this impacted the valuation of the technology. Pinch and Bijker (1984) introduces *closure mechanisms* that seek to stabilise the artefact by closing a controversy among actors. Two mechanisms *rhetorical closure* and *redefinition of the problem* will be introduced.

The mechanism of rhetorical closure address whether an actor interpret and understand the controversy as being resolved. The technological artefact is the same, however a rhetorical closure can explain, convince or illustrate how the problem can be solved from the actor's perspective. For instance, finding inspiration from similar technologies to confirm or disconfirm the interpretation of a problem.

The mechanism of redefining the problem seeks to close the controversy by looking at the problem from another perspective. Pinch and Bijker use the example of how air tires for bicycles originally became a solution to another problem than firstly anticipated. The main problem to be solved was to reduce vibrations when riding a bike, but the air tires however proved to solve another concern for cyclists, the ability to ride as fast as possible. By redefining the problem and the use of the air tire from being an antivibration device to be a speed increasing device, the controversy was resolved. (Pinch and Bijker, 1984)

The following chapter will elaborate the methods applied in the perspective of the presented theorical framework.

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4 Methods Generating Empirical Data

This chapter presents the methods applied to compile the empirical data needed to answer the research question. In the following sections, the methods are described individually in regard of purpose and execution. The methods presented is; literature study, interviews and case study.

4.1 Literature study

Literature studies have been used for various parts of this report. Scientific observations can be found and used for further production of scientific statements by building upon established knowledge from endorsed sources. This increases validity and reliability of the statements produced. The two main literature sources are presented in the following, however simultaneously various articles and talks with colleagues and fellow scholars has been an important source of information and inspiration.

The project proposal

As established in the methodology and theoretical perspective, introducing a new technology happens by constructing an environment allowing actors to interact and value the properties of the technology. The project proposal (Ramboll, 2018a; Ramboll, 2018b) serve as the business model constructing the environment. The calculative instruments highlighted in the project proposal, serve as a valuation frame for the entire project. Being able to put numbers to various aspects of the project allow the systems existents, thus representing an important document for the implementation of the project.

Peer-reviewed academic literature

The academic literature has provided insights mainly in two fields in the making of this thesis. Firstly, the theoretically understanding of socio-technical systems, secondly for understanding energy systems dynamics and impacts of implementing a collective system solution over individual cooling solutions. Having the science and technology study literature at hand provides a mean to explaining socio-technical existence of technology in networks and variations in valuation frames. Other theoretical understandings would possibly perceive the problem identified in a different manner, thus perhaps finding different conclusions. Scientific facts and statements should not be understood as a definitive truth, but as situated knowledge creation in a specific area of research.

4.2 Interviews

The subject matter in question entails the dimension of understanding relevant actors' perception and valuation of the DHC system in Taarnby. In order to investigate how the DHC system creates value over a conventional cooling solution eight interviews with different interviewees have been conducted in the research of this master thesis. A conceptual abductive design of research is chosen as it is suitable when examining phenomena that are newly emerged and yet unknown. (Brinkmann, 2013)
Seven of the eight interviews have been conducted as face to face semi-structed interviews, the interview with Skanska was conducted via E-mail, as it was not possible to coordinate a face to face meeting. All face to face interviews has been conducted at the location of the interviewees' workplace. The interviews span in duration from 30 minutes to 2 hours, thus indicating some actors having a more significant part in the constructed network and that some interviewees found it difficult to differ from the interview guide. Brinkmann (2013) defines a semi-structed interview as follows:

> *an interview with the purpose of obtaining descriptions of the life world of the interviewee in order to interpret the meaning of the described phenomena.*

(Brinkmann, 2013 p. 18)

The interview guide addressed several themes related to the DHC system in question. Themes were e.g. participation in the project, historical overview of the decision process and valuation of the system. All interview guides followed a consistent thematical structure, however, due the heterogenous nature of the interviewees, adjustments were made to secure relevance of questions enabling the interviewee to truthfully answer the question.

All interviewees received the interview guide beforehand. This was done in order for the interviewee to be able prepare and have an internal dialog with colleagues before the actual interview. In the nature of a semi-structured interview points and arguments outside the pre-structured questions were embraced and valued. Brinkmann (2013) states *""spill beyond the structure" are often quite important, and are even sometimes the key to understanding the interviewee's answers*" (Brinkmann, 2013 p. 15). A semi-structed interview makes is possible for the interviewer to be visible as a knowledge-producing participant rather than hiding behind a structured interview guide. (Brinkmann, 2013)

Six of the seven semi-structured interviews have been audio recorded in order to fully recover the answers provided during the interview. The interview with Ferring was not recorded, as they did not agree on this. The recorded interviews have not been transcribed word by word, as it was found more productive to transcribe the highlights and most important information provided by the interviewees. Whenever statements are quoted in the thesis it is the transcribed wording.

Afterwards the interviewees have seen, commented and approved the transcriptions of the conversation. The process of sending the transcriptions afterwards was to validate the information obtained through the interviews, as the interviewees had the chance to rephrase or add information in order to make sure the statement is truthful and accurate. The e-mailed answer, the transcriptions and the audio files can be found in the appendix in chapter 13. The interviewees can be seen in Table 1.

Interviewee	Organisation	Interview type
Maria Bauerová	Skanska	Structured / not recorded
Finn Jeppesen	Ferring	Semi-structured / not recorded
Anders Dyrelund	Ramboll	Semi-structured / recorded
Hasmik Margaryan	Taarnby Utility	Semi-structured / recorded
Mads Lehmann & Rune Klitgaard	Taarnby Municipality	Semi-structured / recorded
Troels Brink Jensen	CTR	Semi-structured / recorded
Lars Olsen	The Blue Planet	Semi-structured / recorded
Thomas Bergen, Daniel Kaiser-Almind & Erik Schmidt	Radius	Semi-structured / recorded

Table 1 Interviewees overview

During each interview, the interviewees were asked to identify involved actors in the project. This was done to secure relevant actors were included in the research. An interview with the Danish Energy Agency was desired, however is was not completed within the timeframe of this thesis, due to busyness in the agency. In the absence of interviewing the Energy Agency, a literature study of their granted dispensation letter has been conducted. However, it is the author's understanding that no significant actor has been neglected or overseen, as multiple actors have identified the same actors within the network.

4.3 Analysing the interviews

Having conducted eight interviews examining the valuation of the DHC system a vast amount of data is generated. The approach of *thematic analysis* was applied to identify themes in the interviews. When searching for themes in the material several general themes can be considered e.g. repetitions, similarities and differences or theory related material. Themes were identified following the approach posed by Bryman (2016).

1. Initial coding of the material.
2. Elaborate codes into themes.
3. Examine possible links and connections between concepts and / or how the concepts vary in terms of feature of the case.
4. Justify the themes in relation to the research question.

The following sections describe how each stage were considered for analysing the collected data.

Initial coding

The transcription of the interviews happened shortly after the conducted interview in order to have the collected information fresh in memory and allowing the interviewees to give feedback shortly after the interview. Having the interviews following a semi-structed interview guide served as an initial coding as the interviewees had been asked questions in the same category. The transcriptions were not written word by word, thus leaving the author deciding which of the information provided being relevant for the research question. The relevant information for each transcription were highlighted in the first step of initial coding.

Elaborate into themes

Having initially coded the interviews, the search for themes was initiated looking for repetitions, differences or similarities and statements related to the theoretical understanding. While examining the interviews, quotes supporting a thematical statement was found. Two general themes were identified being *economy* and *technical design*. A further presentation of the themes will be elaborated in chapter 7.2.

Links and connections

The themes identified in the former steps, showed the nature of heterogenous actors, as different valuations of the DHC system were identified. However, it simultaneously visualised groups of actors sharing thematical believes of the DHC system. The connections of perceptions formed groups identified as *suppliers, consumers, authorise* and *competitors*, which will be further described in chapter 6.3.

Relate to research question

The Interviews served two purposes, first to broaden the author's understanding of the decision and design process of the DHC system in order to contextualise the answers provided. Second and most important, to illuminate the actors' valuation of a DHC system over an individual cooling system.

The first purpose is not directly related to the research question and will not be analysed further. However, it has provided valuable insights in the innovation process of a new technology. The second purpose is directly related to the research question. Themes related to the research question will provide data for analysing how the valuation frames was conceived in the case of Taarnby.

4.4 Case study

The conventional interpretation of case studies oversimplifies the case-study research as a preliminary tool to provide hypotheses that can be tested in a larger number of cases. The conventional understanding states that case studies cannot provide reliable knowledge about the general situation. Flyvbjerg disagrees with the conventional understanding of case-study research and argues that case studies can produce reliable knowledge, from an in-depth study and that results can be generalised to a broader understanding of the problem. He furthermore explains that the *""force of example" is underestimated"* (Flyvbjerg, 2006 p. 228) in relation to the misunderstanding of generalisation. The present thesis shares the believes of Flyvbjerg and finds it necessary to investigate a specific case to reach an in-depth understanding of the complex creation of networks and examine how a DHC system can be valued differently.

Flyvbjerg argues that the proximity of a case study gives insights in real-life situations and exposes multiple details of the specific case. For a researcher this is important for two reasons; 1) it develops a nuanced view of reality, including human behaviour, that cannot be fully perceived theoretically. 2) Cases are important for researcher's own learning process in developing good research skills. When studying human behaviour and interaction, context independent general theoretical knowledge cannot stand alone, and context dependent practical knowledge is essential to understand the complexity of the case. (Flyvbjerg, 2006)

Case selection strategy

The intention of this study is to achieve the highest level of information considering the research area is identified as lacking attention in the body of literature. This can be done with a strategic case selection. Flyvbjerg puts up strategies for selection of samples and cases, firstly the researcher needs to determine the purpose of the analysis leading to either a random or information-oriented case selection. This thesis is interested in the information-orientated case selection as the Taarnby case is selected based on an expectation that this case can provide and maximize the insights needed to elaborate the answer to the research question. Flyvbjerg outlines four types of cases; *1) Extreme/deviant case, 2) maximum variation cases, 3) critical cases* and *4) paradigmatic cases*. These cases all serve different purposes and can be selected to obtain insights to the researched problem. The desire is to find a unique case or in Flyvbjerg's terms an *extreme/deviant case* in order to identify information, can be especially good or especially problematic. (Flyvbjerg, 2006) As found in the literature review the case of Taarnby is a deviant case as it represents an implementation of a technology combining heating and cooling in a collective system which has not been done before in a similar way.

When selecting the case to analyse, two main selection criteria were established. The case had to:

- Be implemented or under construction
- Fit the Smart Energy System perspective

The cases reviewed in this research will take a starting point in DC, as this is the least common and developed district energy system, when looking at the thermal sector. If DC is present, in theory DH is also possible, this is not guaranteed reversely. The following cases were examined in order to find the best suited case: HOFOR District Cooling, Frederiksberg District Cooling, Høje Taastrup District Heating and Cooling and Taarnby Utility District Heating and Cooling. They all achieve to meet the first selection criteria, being in operation or under construction. However, the level of achieving the second criteria varies between the different cases. For the HOFOR and Frederiksberg case the focus has solely been on DC with no interest identified in combining heating and cooling. (Ramboll, 2014) In an article (HOFOR, 2015) former director for HOFOR district cooling Henrik Bøgeskov and former chief facility manager for Frederiksberg Utility, Anders Møller-Hansen, praise the separation of DC business units as they argue this provide an economic security for the consumers that unnecessary overinvestments in capacity are avoided. (HOFOR, 2015) Thus, the potential for combining heating and cooling in these cases seems difficult.

Examining the cases of Høje Taastrup and Taarnby Utility the technical systems are similar and achieve the same high level of meeting the Smart Energy Systems perspective. As both cases represent a technology that is uncommonly implemented in the energy sector currently, they both are unique or extreme/deviant cases, which was desirable. (Ramboll, 2015; Ramboll, 2018a)

Brinkmann (2013) argues that the validity of the information collected through interviews is the prime issue, and since the aim of interviews often are interested in retrospective incidents, concerns about human memory and the trustworthiness of the answers must be taken into consideration. Since the valuation of a system is being investigated in this thesis the newest case was chosen, in order to reach the highest possible level of trustworthiness. In the case study Taarnby is selected as it is currently under construction and the actors are having the negotiations, problems and conflicts more present in memory.

5 District Energy Market in Denmark

This chapter describes the market differences between DH and DC, as this complicates the creation of a combined system. Furthermore, the trends within the Danish energy system will be presented to comprehend, why the DHC system in Taarnby is designed the way it is.

5.1 Market differences of DH and DC

From the theoretical framework two market perspectives exist; the competitive market and the natural monopoly. These two perspectives represent the different markets DH and DC operates, however, in theory these markets are described ideally, in reality a mixture of perspectives can be included. The following sections will describe the DH market and the DC market in Denmark.

District heating

DH in Denmark represents a natural monopoly, as extensive networks of pipes have been constructed benefiting from the economy of scale. The market is regulated by the Heat Supply Act (HSA) which purpose is to "*promote the most socioeconomic, including environmental, use of energy for heating buildings and supplying hot water, in order to reduce dependency of fossil fuels.*" (Heat Supply Act, 2019 §1)

One example of regulation that limits the free entry to the market, thus creating a natural monopoly is the possibility for municipalities to offer a loan guarantee for the financing of a heat production unit. However, with the exception of a heat pump co-producing heating and cooling, as the delivery of cooling happens at commercial conditions. (Heat Supply Act, 2019)

Concerns with monopolism are inefficiency and higher average costs. The principal of self-sustaining[1] protects the consumers against unreasonably high heating prices, as the DH companies in Denmark are non-profit companies. Any economic profit returns to the consumers, this is typically done by adjusting the tariffs annually to reach a zero profit. They are either owned by the municipality, as in the case in Taarnby, or by a consumer co-operative.

District cooling

DC companies in Denmark are, as opposed to DH companies, operating at competitive market, which allows them to generate a profit following a business-to-business approach. As the cooling company acts on commercial conditions the DC business unit has to be separated from the DH business unit to avoid cross-subsidisation between DH and DC (District Cooling Act, 2019). While DC is operating at a competitive market, aspects of natural monopoly exist in DC as well. For

[1] In Danish "Hvile-i-sig-selv princippet"

instance, requires DC heavy investment in infrastructure restricting the free entry to markets. As for DH, DC obtain the same benefits of economies of scale due to having a combined system.
Furthermore, the District Cooling Act (DCA) states that municipalities only can engage in DC if they own or partly own the DH company in order to promote energy efficient cooling and utilise the synergies with DH. It is not specified how the synergies can be reached, neither what type of synergies are included. This leaves room for interpretation as synergies can be both organisational or technical. DH companies that are not owned or partly owned by municipalities are excluded from the DCA.
Similarly, DCA states that municipalities are not allowed to provide subsidy or loan guarantee for DC units. (District Cooling Act, 2019) The lack of financial opportunities as present in the DH market leaves it problematic for DC companies to finance the initial investments, even if a project can improve the efficiency of the DH business. The municipal board has to approve cooling projects below 20 MW and can only approve projects that promote energy efficient cooling and utilise synergy effects with the DH. Similar to the former description, the synergy effect is not clarified further.

The HSA include heat pumps that for instance extract excess heat from district or individual cooling units. However, the district cooling part of such a heat pump project is not included in the HSA, as it is covered by the DCA. This complicate the process for municipalities or utilities companies to reach the synergies.

5.2 Trends in the Danish energy market

Electricity

The newly established Danish government has put forward an ambitious goal of reducing 70% of CO_2 in 2030 and 100% in 2050. This calls for rethinking all aspects of the energy system in Denmark. The Climate, Energy and Utility (CEU) Ministry, advocates for a smart energy system, with high levels of flexibility, thus enabling the unitisation of the increasingly fluctuating energy from renewable energy sources such as wind and solar Increasing flexibility includes integration of various energy systems i.e. electricity, thermal and gas, thus creating sector coupling and identifying synergies among multiple supply systems. (CEU Ministry, n/a).

The electricity production in Denmark is being produced increasingly by fluctuating sources such as wind and solar, see Figure 5 and Figure 6. In 2018, 40% of the electricity production came from wind turbines demonstrating the importance of flexibility in the consumption of electricity. The increasing level of renewable electricity in the Danish energy system advocates to integrate in different sectors as much as possible. One of the most straight forward sector couplings is electricity and thermal sector. This will be elaborated in next section.

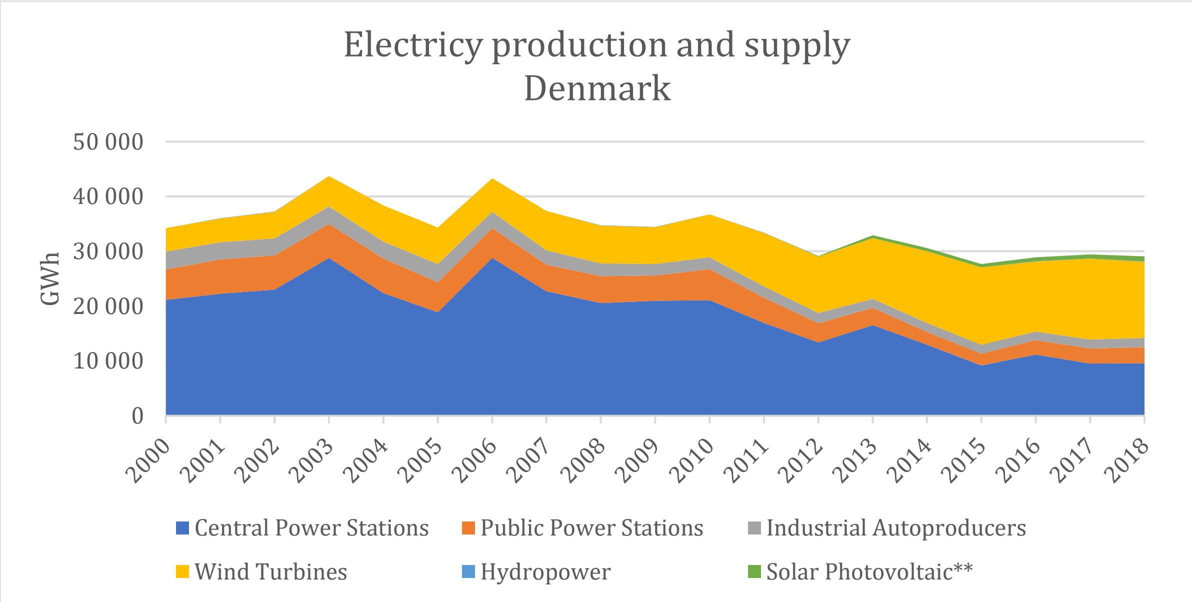

Figure 5 Electricity production and supply in Denmark 2000-2018. (DEA, 2019)

Figure 5 shows the distribution of electricity production from 2000-2018. The yellow area represents the electricity produced by wind turbines and have clearly increased over the last decade. Resulting in a decrease in the electricity production from central power plants, with higher levels of production control. Figure 6 below shows the same numbers as Figure 5, however, divided on share of electricity production instead.

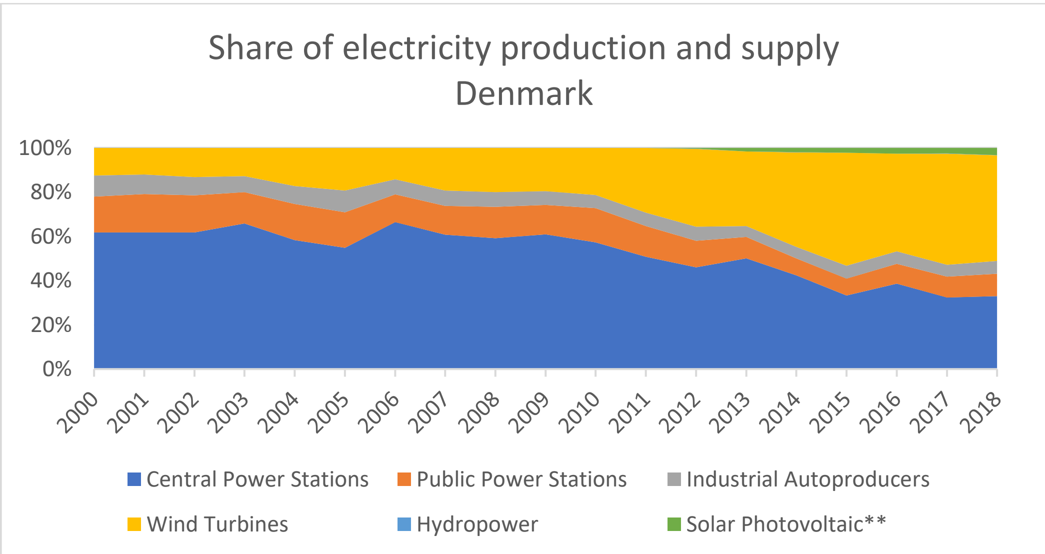

Figure 6 Share of electricity production and supply in Denmark 2000-2018. (DEA, 2019)

*** Solar Photovoltaic in 2012 and 2013 is estimations based on weather data and numbers of plants. From 2014 the estimation is based on actual recordings from around 1.000 plants in Denmark*

Thermal energy

District heating supply 65% of the buildings in Denmark with heat and has been growing steadily ever since it was established, see Figure 7. (DST, 2019) The biggest change has happened in the use of individual heating from oil decreasing from 14% in 2010 to 8% in 2019. Simultaneous individual heat pumps have advanced from 1% in 2010 to 3% in 2019.

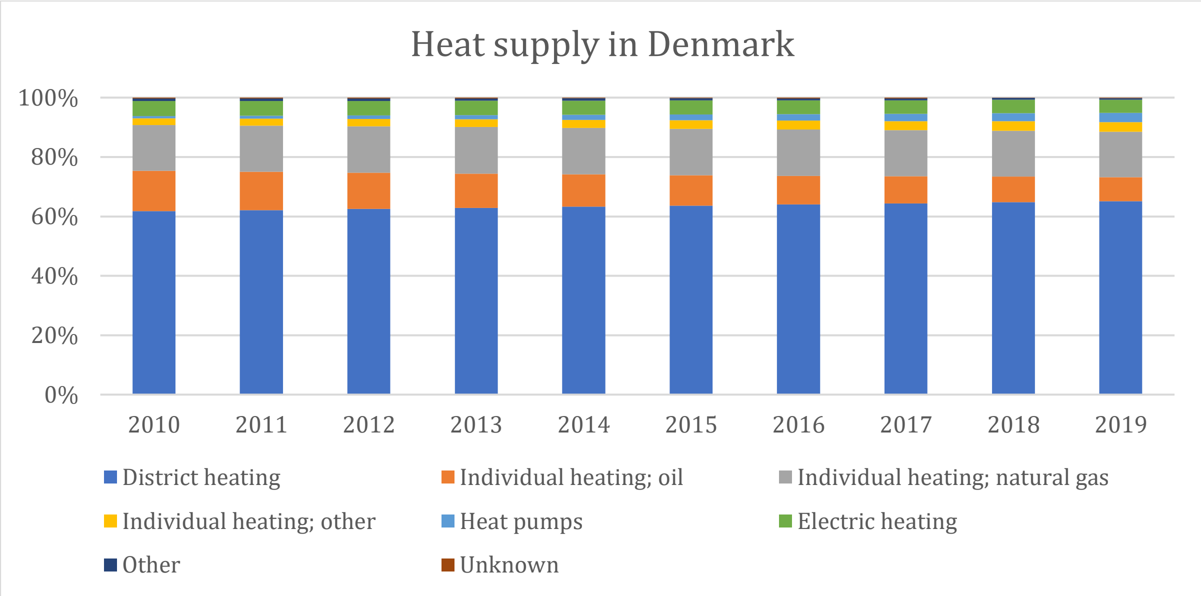

Figure 7 Heat supply in Denmark 2010-2019. Own model based on numbers from Statistic Denmark. (DST, 2019)

Figure 8 demonstrates the trajectory of heat production distributed at energy sources in DH systems in Denmark towards 2035. The left figure illustrates the decentral heat production, with an increasing amount of heat delivered by heat pumps, while the consumption of wood chips decreases. The same situation is predicted for DH systems in larger cities (the right figure), thus replacing coal with heat pumps and wood chips. (Dansk Energi, 2018)

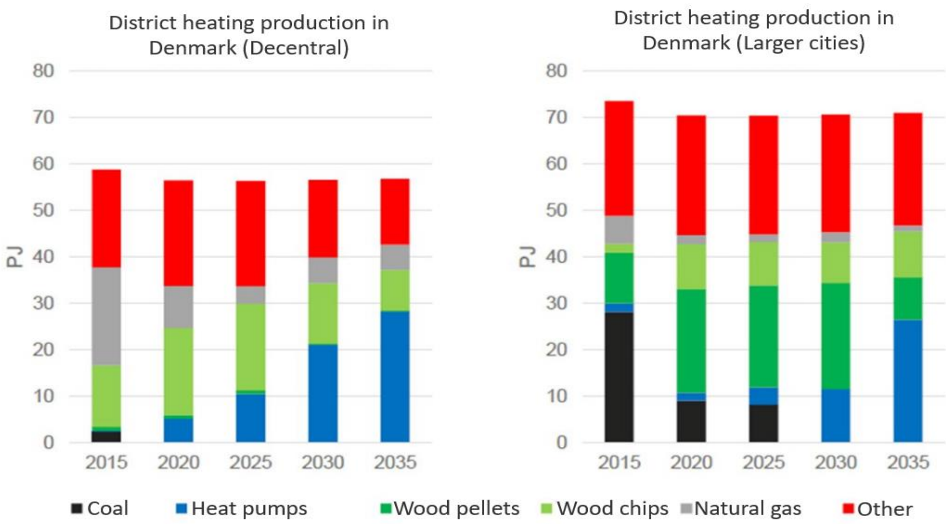

Figure 8 District heating production in Denmark and larger cities in Denmark 2018. (Dansk Energi, 2018)

In Denmark, cooling demands have been dominated by individual cooling. Mostly cooling is produced at electrical chillers where the heat generated, is cooled down in cooling towers. Often this has happened via more or less random expansions of chillers different places in the building as the cooling demand increased. Evidently, this means an ineffective use of the chillers with high levels of electricity consumption. (Ramboll, 2017) Since the DCA was created in 2008 DC companies started to establish in larger cities in Denmark, often completely separated from the production of heating. In 2016 Aalborg University, Ramboll and Danish District Heating[2] made a report concerning the cooling potential in Denmark. The report is to be seen as a natural continuation of the report "*Heat Plan Denmark*", thus the report is called "*Cooling Plan Denmark*". This report demonstrates the transition in the Danish district energy sector, with an increased focus on cooling. The mapped potential for district cooling in Denmark is based on type of industry, square metres with a cooling demand and placement in clusters. The cooling potential was estimated to be 6,700 MW capacity demand equal to 9,500 GWh cooling pr. year. Of the 6,700 MW it is estimated that 2,400 MW could be supplied by district cooling. (Aalborg University, Ramboll & Dansk Fjernvarme, 2016)

[2] In Danish "Dansk Fjernvarme"

6 The DHC System in Taarnby

This chapter presents an overview of the constructed network surrounding the DHC system in Taarnby, including an introduction of relevant actors, infrastructures and market setup for the DHC system. Thus, classifying the system and its actors in order to understand the actors' configurations and various interest in the system.

6.1 Relevant actors

The following sections will present the relevant actors related to 1) district heating 2) district cooling and 3) the energy central.

District heating

Taarnby Utility is part of the DH transmission system in the Greater Copenhagen area consisting of two transmission companies CTR and VEKS and multiple local DH distributers in the municipalities. Figure 9 shows the transmission system and displays that Taarnby Utility lays within the CTR heat supply area (orange area) and at the end of a transmission line.

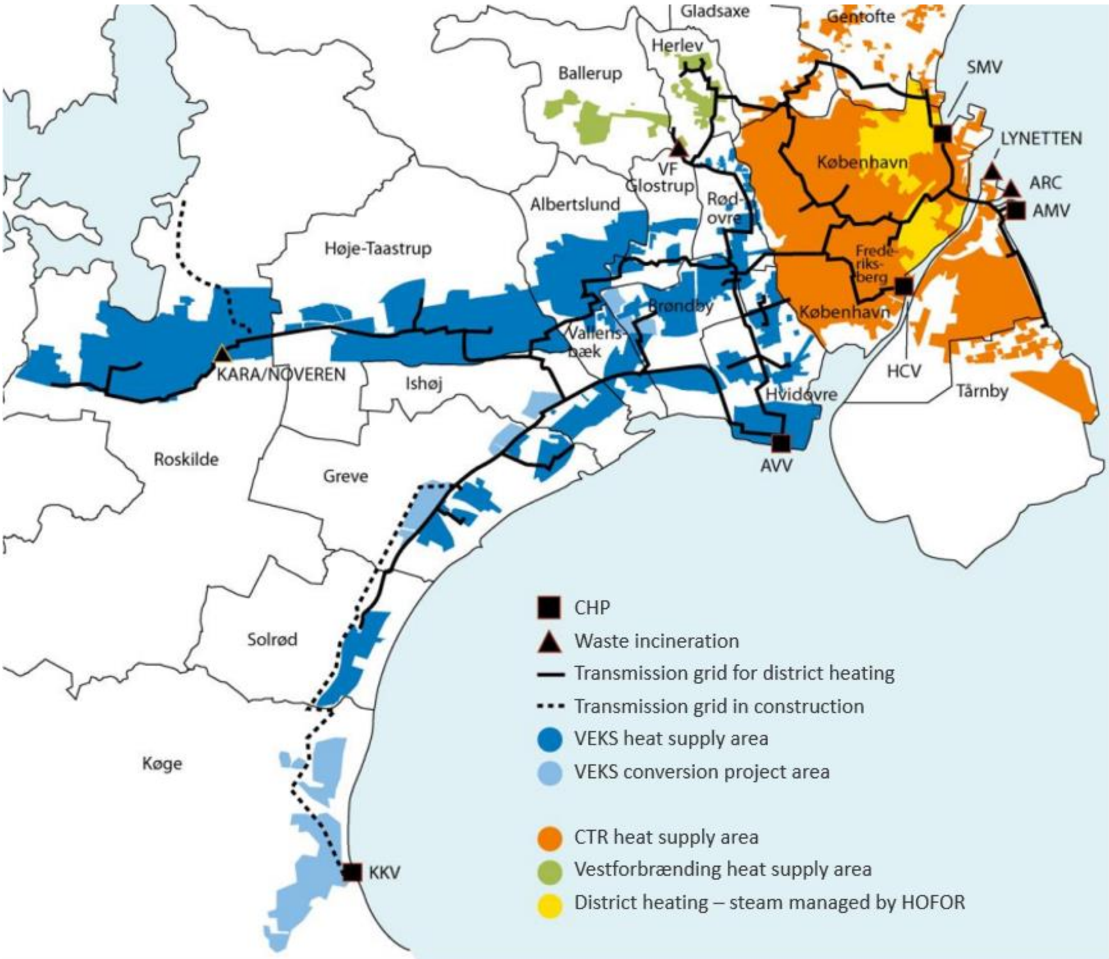

Figure 9 Transmission system of Greater Copenhagen. (CTR, VEKS & HOFOR, 2014)

Taarnby Utility is a heat distribution company, distributing the heat delivered by CTR. The two transmission companies and HOFOR is responsible for the load distribution in the transmission system both at an hourly basis and the long-term basis. Currently, CTR and Taarnby is negotiating how the optimal load distribution from the heat pump can be and what the value of the heat produced should be. CTR use a variable pool price for heat that adjusts to the cost of average marginal cost of production in each month. This, due to the fact that price of heat production varies over the year i.e. it is more expensive to produce heat in the colder months as more expensive peak load units operate e.g. natural gas boilers. The pool price is based on the average marginal cost, thus adding cost of all production units together rather than acknowledge which unit is operating at certain hours. In the project proposal it is argued that the heat from the heat pump often will replace expensive peak load produced heat, thus representing a higher value than the average marginal cost in the pool price. CTR appreciates having the operation of the heat pump in the collective management system of Varmelast, which is a software used to distribute the heat production load in the system. If the marginal cost of producing heat with the heat pump is higher than what CTR can buy heat from elsewhere, the excess heat will be chilled with the wastewater. (Ramboll, 2018a)

The Greater Copenhagen transmission system consists of multiple larger CHP units and waste incinerator units thus forming a central CHP area. Establishing a new heat production unit in this area can only be approved by the municipality, as the local heat plan authority, if the unit is constructed as a CHP unit (Project Declaration, 2018 §14). However, the Danish Energy Agency (DEA) can grant an exemption from this section, if the project is regarded a development- or demonstration project (Project Declaration, 2018 §31).

District cooling

As established in chapter 5, the DH and DC market architecture differ, thus relevant actors related to DC is dominated by the companies being supplied with DC. Figure 10 displays the area supplied with cooling in Taarnby and illustrate the location of the energy central and cooling consumers.

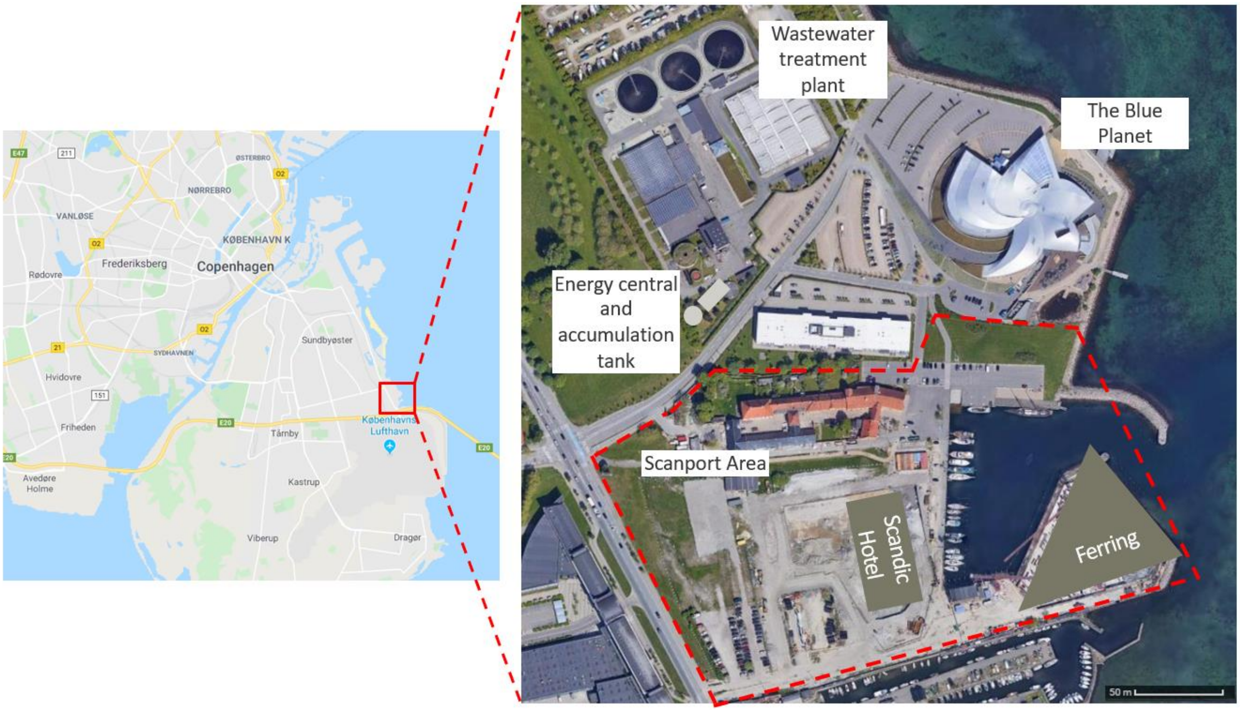

Figure 10 District cooling area, with relevant actors. Own figure.

Skanska's urban development of the Scanport area, including the construction of the domicile of Ferring's headquarters represents the first consumers to join the DC network. The Blue Planet is currently using a conventional individual seawater cooling unit, as the aquarium has been operating for several years before DC was available. However, the Blue Planet experience issues with their cooling unit, thus providing valuable insights in the difference of individual cooling and DC.

The energy central, co-producing heating and cooling is located at the wastewater treatment plant, thus allowing for synergies between wastewater and thermal energy production.

Energy central

As presented in chapter 3, materialising a new technology implies the creation of an environment for actors to interact. Taarnby Utility have investigated the opportunity of supplying cooling throughout the development of the Scanport area. Supported by the consultancy of Ramboll, they collectively created the environment for interaction among heterogenous actors, conceptualised by the business case and project proposal of the DHC system engaging the abovementioned actors in a combined project.

Building an energy central producing thermal energy via heat pumps calls for extensive supply of electricity. Radius is responsible for the electrical transmission in the north-eastern part of Zealand. As the heat pumps are operating at the 10kV transmission network, a local transformer was needed for the energy central to function.

Summary

To recapitulate actors relevant for the DHC system in Taarnby related to DH is; *CTR*, *Taarnby Municipality, DEA* and the legal frameworks of heat planning i.e. the *heat supply act* and the *project declaration*. While, relevant actors related to DC represents; *Skanska*, *Ferring*, *The Blue Planet* and legislation related to DC i.e. the *district cooling act*. Lastly, the DHC system is materialised of the business case proposed by *Taarnby Utility, Ramboll* and *Radius,* representing the last relevant actors in the system.

6.2 Technology uniting actors

Technical system

The conceptual technical system design demonstrates the result of the complex process compiling multiple actors' valuations and perceptions of a technology.

The DHC system consists of four heat pumps that can deliver both heating and cooling using wastewater as energy source. This improves the economy of the heat pump investment as it increases the number of operational hours, thus allowing the heat pumps to accumulative deliver more thermal energy. In the first stage of the project the installed capacity of heat pumps represents 4.3 MW cooling and 6.3 MW heating. In the second stage of the project an aqua thermal energy storage (ATES) have been integrated with additional 2 MW cooling. See

Figure 11 for a simple overview of the DHC system.

To the left in

Figure 11 is the DC side and to the right is the DH side of the heat pump. As the cooling demand primarily is in the summer period, another heat source is needed to produce heating during winter. The nearby wastewater plant was identified as a very profitable heat source for heat production during winter. The wastewater can be used both for production of heating and free cooling. The primary purpose of including the wastewater is to let the heat pump cool down the wastewater in order to produce heat. In other terms, to retract heat from the wastewater. This is useful in periods with high demand for heating and low demand for cooling primarily in winter periods. The secondary purpose is to heat the wastewater in periods with low demand for heating but high demand for cooling primarily in the summer periods. This way the heat pump can produce cooling.

The co-production of heating and cooling in a single heat pump increases efficiency compared to producing it separately, when the demand for heating and cooling is present. At periods with low demand for either heating or cooling it can be favourable to separate the production, the wastewater serves as a medium to adopt the waste energy in case of separate production.

(Ramboll, 2018a) When using wastewater, it entails the need for cleaning the filters, the CIP Rinsing and the Backflush is mechanisms to make sure the filters are clean and operational.
The project is divided in two phases; 1) construction of heat pumps, accumulation tank, DH and DC. 2) ATES is supplementary to the system as a seasonal storage to shift the demand profile of heating and cooling.

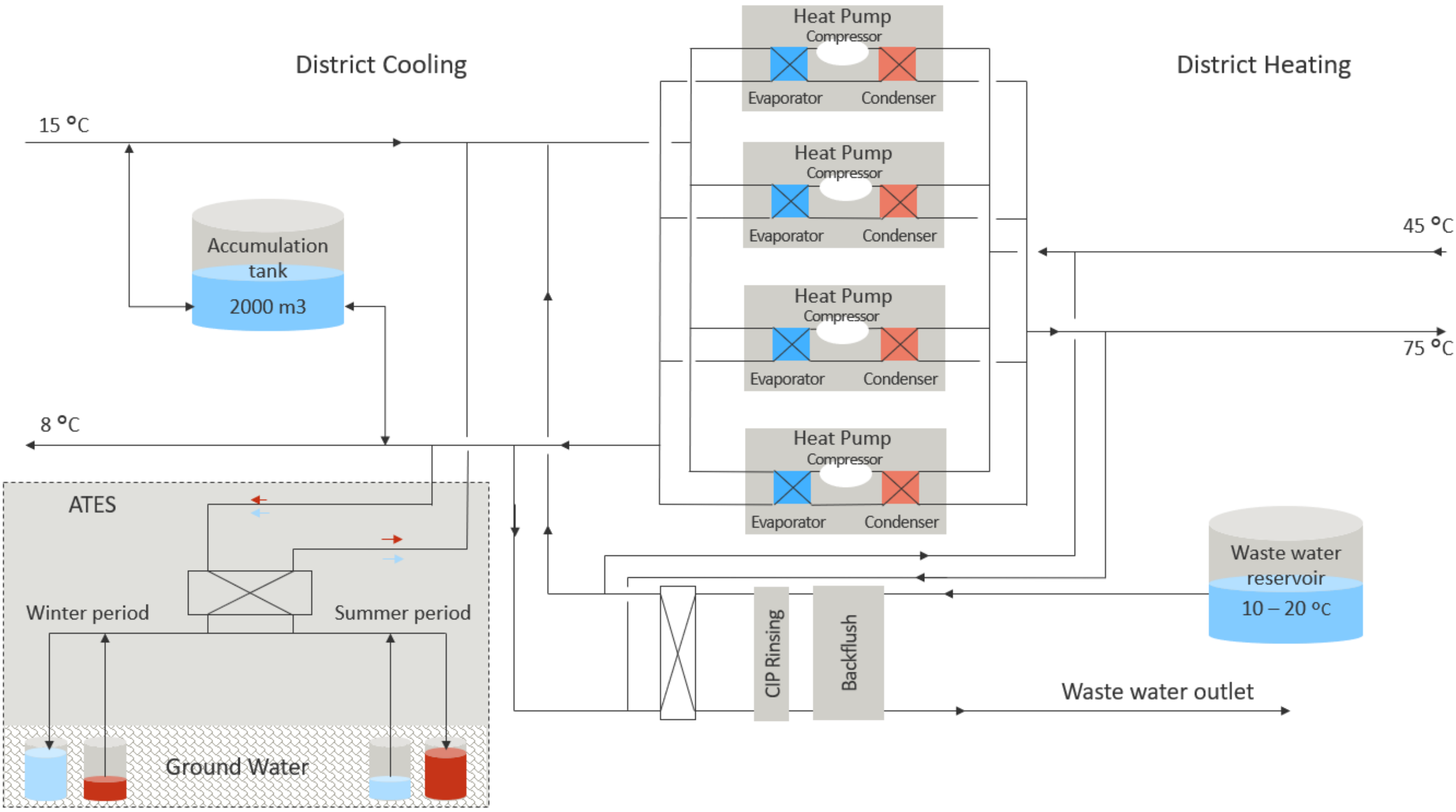

Figure 11 Simple flow diagram of the DHC system. Own drawing.

Economy of the system

Just as the technical system is a result of negotiations, so are the economics of the project. As part of the creation of an environment, the business case presented engaged actors in the system. The following numbers is calculation prices over a 30-year period.

displays the socioeconomic expenses and benefits of district cooling.

Socioeconomics District Cooling Value in 1,000 DKK		Socioeconomic expenses		
		DC	**Individual cooling**	**Benefit DC**
Accumulation Tank Capacity	m³	2,000	0	
Total capacity demand	MW	4.3	4.3	
Total compressor capacity	MW	4.3	4.3	
Calculation price, NPV				
Energy central exclusive scrap value		19,844	0	-19,844
Energy central, scrap value		-1,685	0	1,685
Grid and connection exclusive scrap value		12,873	0	-12,873
Grid and connection, scrap value		-3,208	0	3,208
Consumer investment exclusive scrap value		2,616	39,245	36,629
Consumer investment, scrap value		-562	-1,736	-1,174
Total investment		**29,878**	**37,508**	**7,631**
O&M of plant		10,503	10,798	295
O&M marginal expenses		305	0	-305
Administration		781	0	-781
Flexible O&M of Cooling production		1,486	242	-1,245
Operation of district cooling at the consumer		1,209	0	-1,209
Total O&M		**14,284**	**11,039**	**-3,245**
Electricity for compressors		**2,463**	**6,682**	**4,219**
Levy factor		-514	-609	-94
Calculation price of CO2 emissions		**112**	**133**	**21**
Expenses related to SO2, NOx and PM2.5 etc.		**21**	**25**	**4**
Total with constant electricity prices		**46,244**	**54,780**	**8,535**
Benefit with district cooling		8,535		

Table 2 Socioeconomics of DC. (Ramboll, 2018b)

Comparing the two technologies for cooling supply indicates that total investment cost is higher, when doing individual cooling, while the total operation and maintenance (O&M) of the individual unit is cheaper. The efficiency of having a large-scale heat pump over multiple individual units is represented by the lower cost of electricity for the compressors and by the reduced cost of CO_2 emissions. Based on the proposed numbers in the business case, the DC system alone creates a socioeconomic benefit of 8.5 Mill. DKK over 30 years.

However, for the consumers to engage in the system, the business case needs to prove profitable for both the cooling business unit and the consumers. Table 3 displays the economic assessment of the DC business unit and the cooling consumers.

Business and consumer economic assessment of DC	**Benefit with district cooling**			**Expenses**	
Value in 1,000 DKK	DC Company	Cooling costumers	Local Society	Cooling costumers	
				DC	Individual
Calculations price, NPV					
Energy central exclusive scrap value	-15,067	0	-15,067		0
Energy central, scrap value	1,400	0	1,400		0
Grid and connection exclusive scrap value	-9,763	0	-9,763		0
Grid and connection, scrap value	2,666	0	2,666		0
Consumer investment exclusive scrap value	0	27,882	27,882	-1,993	-29,875
Consumer investment, scrap value	0	-976	-976	467	1,443
Total investment	**-20,763**	**26,906**	**6,143**	**-1,526**	**-28,432**
Connection fee	22,220	-22,220	0	-22,220	
Investment including connection fee	**1,457**	**4,686**	**6,143**	**-23,746**	**-28,432**
O&M of plant	-8,292	8,542	250		-8,542
O&M marginal expenses	-241	0	-241		0
Administration	-613	0	-613		0
Flexible O&M of Cooling production	-193	191	-2		-191
Operation of district cooling at the consumer	0	-956	-956	-956	0
Total O&M	**-9,340**	**7,777**	**-1,563**	**-956**	**-8,733**
Energy expenses for cooling production	-3,939	7,315	3,376		-7,315
Energy expenses for free cooling	0	578	578		-578
Purchase / sale of ordinary cooling	14,887	-14,887	0	-14,887	
Purchase / sale of free cooling	0	0	0	0	
Total Energy	**10,948**	**-6,993**	**3,955**	**-14,887**	**-7,893**
Total benefit with district cooling	**3,065**	**5,470**	**8,535**	**-39,589**	**-45,058**

Table 3 Business and consumer economic assessment of DC. (Ramboll, 2018b)

In Table 3 a negative represents an expense, while a positive represents a benefit. It is estimated that the cooling costumers have gained a benefit of 26.9 Mill. DKK by not having to invest in individual cooling units. This benefit is then reduced due to the connection fee of 22.2 Mill. DKK leaving them with a total investment benefit of 4.6 Mill. DKK.

The DC system benefits the cooling business unit with 3.1 Mill. DKK and the cooling consumers with 5.4 Mill. DKK. The column of local society represents the total benefit of the DC company and the cooling consumers, as they collectively are considered part of the local society, thus generating a benefit of 8.5 Mill. DKK for the local society.

The two tables presented has a sole focus on DC, however the system in Taarnby is co-producing heat as described in the former section. Table 4 displays the economically benefits of co-producing heat and cooling.

Socioeconomic assessment of excess heat from district cooling **Value in 1,000 DKK** Calculations price, NPV	DH company	Cooling costumers	Local Society
Extra investment in heating	-30,154	0	-30,154
Extra investment in heating, scrap value	0	0	0
Sale of capacity / saved alternative capacity	3,333	0	3,333
Total investments and fixed expenses	**-26,820**	**0**	**-26,820**
O&M expenses with excess heat	**-12,258**	**0**	**-12,258**
Energy expenses with excess heat	**-112,428**	**0**	**-112,428**
Sale of heat / saved purchase of heat from CTR	**153,110**	**0**	**153,110**
Extraordinary income	12,846		12,846
Total benefit with excess heat	**14,451**	**0**	**14,451**
Total benefit with district cooling (from Table 3)	**3,065**	**5,470**	**8,535**
Total benefit from co-produced heating and cooling	**17,516**	**5,470**	**22,986**

Table 4 Socioeconomic assessment of excess heat from DC. (Ramboll, 2018b)

The business model shows an extra investment cost of 30 Mill. DKK for the heating components, and an extra O&M expense of 12.2 Mill. DKK. However, the extra investment and variable cost allow Taarnby DH to save 153.1 Mill. DKK of heat purchase from CTR, by producing their own heat. Adding the benefits from DC from Table 3 with the benefits of DH complies the total benefit of co-producing heating and cooling to 17.5 Mill. DKK for Taarnby Utility, 5.4 Mill. DKK for the consumers and 22.9 Mill. DKK for the local society.

6.3 Grouping actors

Throughout the interviews with the relevant actors presented, uniform perceptions of the DHC system appeared in groups of actors. The following section will clarify the groups relevant for analysing the valuation frames in the following chapter. The groups identified is: *suppliers, consumers, competitors* and *authorities.*

Suppliers

The actors creating the business opportunity, thus building an environment for actors to interact, can be grouped as they share the perception of developing a new business opportunity, while the suppliers may have different objectives related to the business created, they can be analysed as a group. The suppliers identified is *Taarnby Utility, Radius, CTR* and *Ramboll* as they supply inputs to the creations of the business opportunity.

Consumers

Clearly, for an emerging technology to exist, consumers are relevant to the system. In the case of Taarnby *Ferring*, *Skanska* and *The Blue Planet* represents the actors directly related to the DC system. As DC is the technology in question, the DH consumers are not included.

Competitors

Creating a new business opportunity implies challenging the existing structures. Actors involved in an existing system being affected by the DHC system, can be categorised as competitors, as their market share is being challenged. The competitors identified are *HOFOR DC or other suppliers of DC* and *Ferring's consultant.* HOFOR DC is the dominant DC supplier in the Copenhagen area thus a direct competitor. The possibility of cooling delivered by HOFOR DC was identified during the interviews, however, other suppliers of DC could have been a competitor as well. Ferring's consultant, designing and constructing the domicile had a biased desire to have an individual cooling unit using seawater, thus representing the competing technology for the DHC system.

Authorities

The last group of actors is the authorities, as they represent the legal body accepting or rejecting the created business opportunity. The authorities identified is *Taarnby Municipality, DEA, the District Cooling Act, the Heat Supply Act* and *the Project Declaration.*

Summary

Table 5 summaries the grouping of actors relevant for examining the valuation of the DHC system in the following chapter.

Groups	Actors
Suppliers	Taarnby Utility
	Ramboll
	Radius
	CTR
Consumers	Ferring
	Skanska
	The Blue Planet
Competitors	HOFOR DC or other suppliers of DC
	Ferring's Consultant
Authorities	Taarnby Municipality
	Danish Energy Agency
	District Cooling Act
	Heat Supply Act
	Project Declaration

Table 5 Summery of actor groups

7 Perceptions and Valuations of the DHC System in Taarnby

Chapter 7 analyses the different perceptions and valuations of the properties of the DHC from the different actors involved in the network based on the groups in 6.3.

7.1 Perceptions of the DHC system

As described in chapter 3 social constructed networks entail interpretative flexibility (Pinch and Bijker, 1984). This notion implies that a novel technology can be perceived differently by various actors involved in the network. The following sections will identify the various perceptions of the DHC system in Taarnby from the perspective of each group of actors.

Suppliers

The general perception of the suppliers includes the creation of a novel business opportunity. Taarnby Utility only had an interest in the project if it allowed them to utilise synergies with their other lines of supplies e.g. wastewater treatment and DH. Taarnby Utility would not engage in the project if it was solely a DC network with no synergies integrated. Furthermore, they are not interested in the commercial part of cooling, as they simply want to increase efficiency by utilising synergies. Thus, perceiving the DHC system as a project increasing synergies across their existing supply services and optimising the use of waste products e.g. excess heat/cooling from wastewater and the heat pump rather than a profit generating activity (Margaryan, 2019).

Ramboll perceived the project as a possibility to demonstrate their mapping of the Danish cooling potential and to implement a technical concept of co-producing heating and cooling. Being able to showcase a materialised concept to other potential customers interested in supplying DC, strengthens Ramboll's market position of planning and constructing DC solutions. (Dyrelund, 2019)

CTR perceive the heat pump as an interesting technology that can provide valuable knowledge, concerning local heat production benefitting the overall transmission network. Furthermore, it can benefit the sustainability of heat production and reduce use of the most expensive peak production. (Jensen, 2019)

Radius are obligated to deliver the necessary electricity, as they are the supplier in that area. However, they perceive the flexibility in the electricity consumption as a benefit for the power grid, thus generating valuable experience with operating a flexible system. (Bergen, Almind-Kaiser & Schmidt, 2019)

Consumers

The consumers perceive the DHC system as an opportunity to buy a service rather than a unit they are responsible for. They see the DHC system as a simpler way of being supplied with cooling, thus allowing them to focus on their primary business rather than being responsible for the operation of a technical unit outside their expertise area.

Ferring and Skanska are constructing new buildings, thus lacking practical experience with individual seawater cooling. Their perception of the DHC system is formed by the experience of the Blue Planet, currently having an individual seawater cooling unit. The Blue Planet have an actual cooling unit to replace, thus perceiving the DHC system as a simpler and cheaper solution (Olsen, 2019).

Competitors

The perception of the DHC system from the competitors are related to the threat it represents to their existing markets share. HOFOR DC was identified throughout the interviews, however they have not provided information regarding their perception of the DHC system in Taarnby. Both Ferring and the Blue Planet mentioned HOFOR's cooling prices as being significant more expensive than an individual solution (Jeppesen, 2019; Olsen, 2019). Several reasons for this can occur, however it is not possible to determine without the consent of HOFOR. One thing is certain, HOFOR was offered an opportunity to supply the Scanport area with DC, however they did not or was not available to engage in this opportunity.

Ferring's consultant perceive the DHC system as a technical alternative to their initial technical design of Ferring's domicile, thus representing a change of their plans and division of labour (Jeppesen, 2019).

Authorities

The general perception of the properties in the DHC system for the group of authorities simply regards concern with approvals and assurance that the system is operating within the present legislation. While the legal perception of a technology is defined in the various acts affected, the DEA perceive the DHC system as a demonstration project, allowing them to grant the needed exception to the heat pump.

7.2 Valuations

Continuing the previous section, the following section will identify the actor's valuation of various properties of the DHC system over an individual cooling unit. As introduced in chapter 4 the interviews have been organised into themes based on repeating arguments and similarities or differences in perceptions of properties in the findings. The following sections illuminate the identified themes of *economy* and *technical design*. The themes consist of various valuations which will be presented in the following.

Economy

Economy of scale

The theme of economy was repeated frequently throughout the interviews, thus being the first theme of investigation. Had the cost of engaging in the DHC system been more expensive than an individual cooling unit, the consumers would not engage in the project. Here the actors in the groups of suppliers and consumers created an environment for negotiation. The consumers proposed the cost of individual cooling units, which was the competing price for the DHC system. The prices put forward by the consumers was according to Anders Dyrelund unrealistically low, thus implying economic pressure on the business case for the DC solution. (Dyrelund, 2019)

> *In the negotiations the cooling customers have put forward unrealistically low prices for an individual solution but due to the good economy of the project, Taarnby [Utility] could give them an offer they could not turn down.*

(Dyrelund, 2019)

The statement from Dyrelund, indicates that the valuation of the reference technology varies among the suppliers and the consumers and that valuations can be used as a tool of negotiation. These prices consist of various externalities that can be included or excluded. The understanding of relevant externalise to include can differ resulting in controversies. In the case of Taarnby the overall economy of the project was solid enough to encounter the opposing valuation. By recomposing the valuation network allowing heat production to be part of the cold production add economical room for negotiating among the suppliers and consumers. From the previously presented economic figures of the project, the benefit from economy of scale is significant when acquiring one larger cooling unit being cheaper than multiple individual units.

Co-producing heating and cooling

The possibility of financing the project proved to be a problem, as the DC business unit cannot be financed with a municipal loan guarantee as the DH business unit can (Heat Supply Act, 2019; District Cooling Act, 2019). The supplier's value the property of co-producing heating and cooling in a collective system, even though this differs from the legal perception of DHC. A. Dyrelund states:

> *In heating projects, it is acceptable to have a negative cashflow the first couple of years, as the investment is seen as a long-term investment. The financing makes it very difficult to get started with district cooling projects and was one of the reasons it failed in the first attempt.*
>
> And
>
> *You can ask yourself, why on earth, when the district heating companies have to make a heat pump to produce heat, and then throw away the cooling, up in the air or into the water. Why are they not allowed to invest in a pipeline so they can supply the neighbour building with cold water and sell that cooling at commercial conditions?*

(Dyrelund, 2019)

Clearly Dyrelund, is frustrated with the legislation concerning the co-producing of heating and cooling, as he thinks it stands in the way of optimising the DH sector and makes it unnecessary difficult to finance the cooling part of the project.

H. Margaryan explain how they got around issue of finance by having the most part of the heat pump financed by the DH business unit, thus considering the cooling as a waste product being sold to the DC business unit (Margaryan, 2019). Thus, the suppliers value the property of co-producing heating and cooling in a larger heat pump, although it is not perceived likewise in the legislation.

Outsourcing O&M

The consumers repeatedly pointed at the O&M of an individual seawater cooling unit to be a concern. This concern was based on the experience from the Blue Planet, as they have practical experience with operating an individual cooling unit. Having the possibility of removing the property of O&M posed a value for the consumers.

It would benefit us economically and make our lives easier [to be part of a district cooling system]. The aquarium is a very complicated building to operate, there is a lot of inconvenient things that needs to be done and the equipment gets worn out quickly, by removing the [individual] cooling plant, more time and manpower will be freed for the rest of the things we need to do.

(Olsen, 2019)

The statement from Olsen indicates that not having the individual cooling unit would make the everyday tasks of operating an aquarium easier. As this is their main profession this represents a value for them. Ferring bases their valuation of having Taarnby Utility facilitating the O&M upon the experience from the Blue Planet. Furthermore, F. Jeppesen identify the valuation of removing the refrigerant ammoniac from the building reducing risk of leaking hazardous substances, thus making the evacuation strategy simpler (Jeppesen, 2019).

Based on experience from other companies with seawater cooling, O&M can be very costly and time consuming. By having district cooling, the operation and maintenance of the cooling system is now facilitated by Taarnby Utility, as opposed to having an individual cooling system.

Another important aspect of choosing district cooling over individual cooling is the use of the refrigerant ammoniac in the individual solutions.

(Jeppesen, 2019)

Figure 12 summaries the valuations identified in the theme of economy.

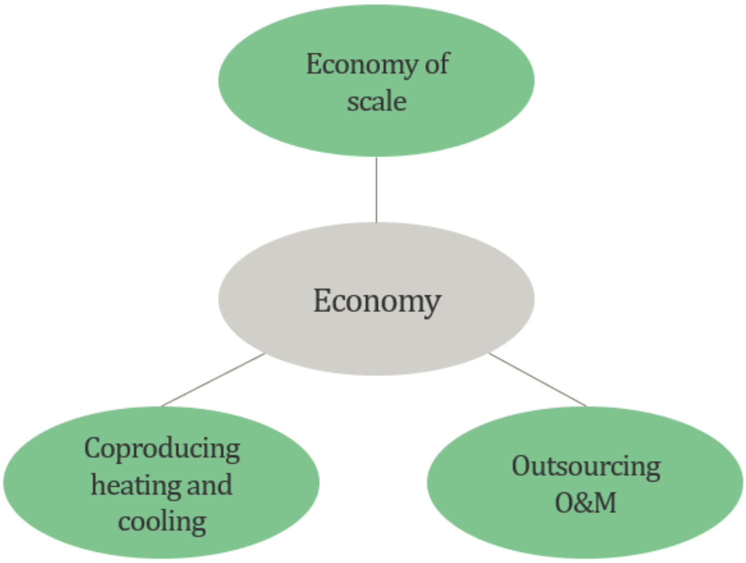

Figure 12 Valuations of the theme economy

Technical design

Flexible production

The technical design of the system unites the actors involved in all groups. A valuation of the DHC system relevant for all groups, is the flexible production of thermal energy. For the group of suppliers, it represents a value in the ability to economically and technically optimise the system in relation to the electricity market, producing thermal energy with low electricity prices and utilising the stored energy in periods with high electricity prices (Margaryan, 2019; Dyrelund, 2019).

For the group of consumers, it represents a value in assessing the precise cooling demand, which proves to be a difficult task (Jeppesen, 2019). By having a flexible system, the concern of having enough cooling capacity is limited as the demand profiles of consumers can vary. To CTR the flexible production of heat, thus having an interaction with the electricity market indicates a value in cheap and clean heat for their consumers (Jensen, 2019).

For CTR the possibility to use the electricity market for more flexible production of heat is interesting. It is considered a green and sustainable energy supply. CTR is concerned with sustainable and cheap heat, and if the heat pump delivers heat to the system, it means that it is the cheapest solution, saving CTR customers money.

(Jensen, 2019)

Jensen's quote on valuation of flexible production, indicates that the heat produced will save CTR's consumers money, rather than seeing the heat produced from the heat pump as a loss of sold heat to Taarnby. This valuation acknowledges the heat pump as a benefit for the entire transmission system, by producing cheaper heat to the consumers in Taarnby.

Supply security

Both the suppliers and the consumers value the high level of supply security related to the DC. H. Margaryan insisted on having more than two heat pumps in the system in order to keep up supply in case of outage in production of one of them. Also, the location enabling wastewater as a steady and secure heat source increases supply security compared to using seawater. (Margaryan, 2019) Installing the accumulation tank and ATES likewise increases the supply security as it gives the system a possibility to use the stored energy in periods with no or limited production. Ferring was given an exclusive right to be supplied, in the case of a black out. (Jeppesen, 2019) This is a way of securing supply via negotiation rather than adjusting the technical solution.

Environmentally friendly

Ferring wanted to have a high sustainability score at the LEED certification scheme of the domicile. Having an individual cooling solution scores lower than being part of a collective grid according to Jeppesen (Jeppesen, 2019). For Skanska the attractiveness of an area, that investors and companies want to be part of, increases with the level of sustainability present in the area (Bauerová, 2019).

H. Margaryan explains how a central production of district cooling can benefit the environment compared to individual cooling thus lowering the CO_2 emissions.

> *Usually when an individual cooling plant is installed it is the cheapest and least advanced technology chosen, there are issues with refrigerants, noise and pollution in the building. When doing a central production unit as the one in Taarnby, you will always use the most environmentally friendly solution.*

(Margaryan, 2019)

M. Bauerová clarifies how having a DC system in a development area increases the attractiveness towards clients with a green profile, as Skanska value the DC as a more environmentally friendly solution than individual cooling.

[…] the district cooling system means [more] space in a building due to no need for [a] cooling central, which would be necessary with the traditional cooling system. It [district cooling] certainly increases the attractiveness for clients and investors with a green profile.

(Bauerová, 2019)

Common for suppliers and consumers is that the DC is perceived and valued as being more environmentally friendly than individual cooling.

Demonstration value

According to the Heat Supply Act (2019) the Danish Energy Agency have to grant a dispensation to install a heat pump larger than 1 MW in a CHP area. This proved to be a decisive problem as it was not clear what the criteria for a dispensation was, and without this dispensation, the project could not be materialised. For the project to be legally accepted, the project proposal was sent to the municipality in accordance with the Project Declaration (2018) as the heat pump delivers DH. The dispensation was only needed in relation to the heat part of the project. M. Lehmann from Taarnby Municipality was the authority processor and explains the process of approving the project proposal.

The final approval of the project proposal from the municipality board was depending on the dispensation from the Energy Agency, which they should provide before there were new conditions of calculation. At that time, it was not possible to approve a project proposal if it was not the newest conditions of calculations used, this is changed, now it is the conditions from the time of application. If the new conditions of calculations were presented before the dispensation from the Energy Agency and the approval from the board, the entire project proposal should have been done all over again. The board administratively approved the project proposal as long as the dispensation were given in time. The dispensation arrived two days before the new conditions of calculation, so everything was OK. But it was close.

(Lehmann & Klitgaard, 2019)

Clearly it was a close call for the dispensation. The dispensation was granted, based on the demonstration value the project represents. The DEA emphasised that the combination of DH and DC in a heat pump with different energy sources such as wastewater and ground water was a new and untested technology that could create valuable experience for future development of energy supply. (DEA, 2018) Thus, the demonstration value of the DHC project secured the legal approvals necessary for the system to materialise and operate.

Furthermore, the materialisation of the conceptual design represents a value for Ramboll, as they can show potential clients an operating system, validating their business case and technical design.

> *Ramboll also wanted to use and show that our mapping of cooling potential in different situations could be a reality. We sometimes see such opportunities passing by, and was thinking are we doing something wrong in our approach?*

(Dyrelund, 2019)

Figure 13 summaries the valuations identified in the theme of technical design.

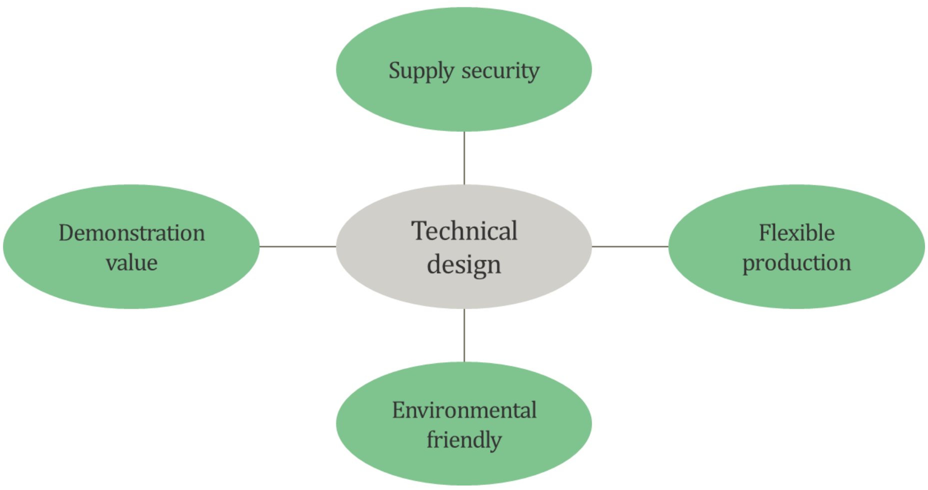

Figure 13 Valuations of the theme technical design

8 Closure Mechanisms

Chapter 8 analyses the controversies among actors occurring due to different perceptions and valuations. Applying the closure mechanisms from chapter 3 allows to identify how these can resolve controversies among actors.

8.1 Rhetorical closure

The Blue Planet have shown interest in joining the DC network, however they are still in the early stage of negotiation. For them the economic valuation for cooling is one of the primary concerns. Seeing other consumers as Skanska and Ferring engaging in the system serve as a validation of the price for the Blue Planet.

> *We have talked with Skanska and Ferring and see them as a good indicator that is it a good idea and business case, if hardcore businesses say OK to having district cooling the economy is probably feasible. Being part of a collective grid and seeing other companies engaging in the systems validates the system and makes it easier for new customers to join the grid.*

(Olsen, 2019)

Being able to present agreements with other consumers becomes a valuable rhetorical closure mechanism, as it illustrates to other potential cooling consumers, doubting the project, that it is feasible and operational. The nature of the companies joining the system, was relevant for the Blue Planet, as they consider Ferring and Skanska as companies with extensive experience within economical feasible decisions.

To Ferring individual cooling using seawater was planned initially in the construction of their new domicile. If the Blue Planet had not shared their experience with seawater cooling and demonstrated the issues with this solution, it might not have been possible to convince Ferring that the individual seawater cooling could represent issues in O&M of the cooling system. F. Jeppesen explains the issues with seawater cooling contributed to a controversy between Ferring and their consultant, as the individual cooling solution was questioned by Ferring. Thus, the practical experience with individual seawater cooling served as a rhetorical closure mechanism as it demonstrated an issue that could be resolved by an alternative solution using wastewater as an energy source instead.

Ferring was in touch with The Blue Planet and HOFOR in regards of experience with seawater cooling and maintenance of an individual compressor. It was found that the individual solution had some issues with mussels and seaweed that needed to be cleaned often.

The cost benefit analysis made by our consultant was the most decisive factor for selecting district cooling. The cost benefit analysis gave us answers to all the questions we had and eliminated some of the doubts.

(Jeppesen, 2019)

The cost benefit analysis F. Jeppesen mentions was initiated based on the experience from the Blue Planet and HOFOR with seawater cooling and the alternative of district cooling. Ferring's consultant would most likely not have done this cost benefit analysis had the rhetorical closure mechanism demonstrating the issues not been available.

8.2 Redefinition of the problem

Anders Dyrelund explains how the consumers demanded the same cooling capacity in the district cooling system, as estimated was needed in their individual solutions during the negotiations.

This way we were forced to overinvest in [cooling] capacity, however this can be used for the expansion of more costumers. By agreeing on more capacity, the customers felt secure, but it also displays that they do not quite understand the concept [of a central production unit]

(Dyrelund, 2019)

This exemplifies how the system has been technically adjusted by Ramboll and Taarnby Utility in order to reach an agreement with the consumers. Even though one of the main advantages in having a collective system is the decreased demand for cooling capacity, the DHC system was designed with an overcapacity simply to persuade the consumers that the system would be able to supply them. The statement from Dyrelund illustrates that the consumers do not quite understand the technical benefits of the concept. However, instead of trying to convince the consumers that a reduced capacity would be sufficient to supply them, Ramboll and Taarnby

Utility used the closure mechanism of redefining the problem. Ramboll and Taarnby Utility expect the DC network to expand in the next phase of the project. At a certain point the capacity would not be sufficient, and they would be forced to invest in more capacity. By agreeing on having overcapacity in the first phase on the DHC project, the future problem of lacking capacity in the next phase with an expansion of more consumers in the system, was already resolved.

Another concern for the consumers was the price of cooling. DC cannot be more expensive than an individual solution to be attractive for the consumers. During the negotiations of the cooling price Ramboll and Taarnby Utility were competing with the reference price of individual cooling put forward by the Ferring's consultants. Anders Dyrelund explains how Ferring was offered cooling during winter almost free of charge, where the cooling demand traditionally is low.

> *They [Ferring] have for instance been offered almost free cooling during winter, the cooling demand during winter is actually an advantage for the project.*

(Dyrelund, 2019)

Having a cooling demand during winter is an advantage for the project, because the heat pump producing heat during winter, generates excess heat usable for producing cooling, which otherwise for the most part would be cooled away in the wastewater. By offering a flexible tariff system with a different valuation of cooling during winter at a lower price, gives an incentive for the consumers to use cooling for processes that they might not have done if the price where higher. Again, Ramboll and Taarnby Utility have used the closure mechanism of redefining the problem, as they have offered an attractive service by having a flexible tariff for cooling, something an individual solution cannot offer, but at the same time created an incentive for a cooling demand during winter benefiting the overall DHC system.

9 Discussion of Value Creation

The aim of this thesis is to understand how a collective DHC system creates value for the involved actors over multiple individual cooling solutions. In the previous chapters a collective system with multiple properties has been evaluated by the actors and compared to individual solutions. This chapter discusses how value was created for the involved actors and how the various valuations contributed to the construction of the novel technology. Secondly, the current legal framework, regulating the sectors of heating and cooling, is being discussed, in the perspective of future development of combined systems.

9.1 Value created for the actors

Economic work of representation

Key numbers of the economic work of representation are presented in section 0, however these numbers are based on multiple assumptions and expectations about the future. Reducing the complex creation of such a system into simple economic figures, displaying a profit or loss, is the foundation of interaction and negotiations among the involved actors. Recomposing the valuation network allowing to combine heating and cooling, similarly allows for including new properties of economy in the project proposal e.g. sale of heat/cooling instead of wasting it. Looking at the key numbers, the socioeconomic benefit increases with 14.5 Mill. DKK when combining heating and cooling, compared to supplying cooling alone. This happens as the heat purchase from CTR can be saved and produced by Taarnby Utility instead. However, it became evident through the interviews, that Taarnby Utility and CTR currently are negotiating how the load distribution share should be, thus also how the heat from the heat pump should be valued (Jensen, 2019). This indicates that the price of heat produced in the heat pump is not definitive, but rather a product of negotiation. In the business plan certain assumptions concerning the price of heat and cooling have shaped the economic work of representation. However, evidently this negotiation is still ongoing, despite the system being under construction. If CTR do not agree with the assumptions made in the business plan, it can impact the entire economy of the project. For instance, if CTR keep the average marginal cost from their pool price, instead of recognising the fact that the heat pump will replace the most expensive peak load unit, the estimated benefit of combining production of heating and cooling is reduced.

Integrating the heat production from the heat pump into the distribution system of Varmelast, should secure the cheapest heat producing unit to operate firstly. However, this can at the same time, result in less heat sold to CTR, if the heat produced by the heat pump cannot compete with the other production units in the transmission system. If this happens the economic benefit of co-producing heating and cooling will likewise be limited.

This aligns with theoretical perspective of *creation* introduced in chapter 2, where a novel business opportunity becomes visible to the consumers through the work of representation i.e. the project proposal to form a certain view of the world. By including sales of heat to CTR, thus generating a positive economy, is part of establishing the "world view" of a system that is attractive for the consumers to engage in. Another aspect is if the socioeconomic dimensions of the project is emphasised, as if it was a traditional heat planning project following the project declaration (2018). Had the focus been solely on cooling the view of the societal benefits and costs could possibly have been of less relevance, as this is not legally required to account for, when simply supplying cooling. Simultaneously, cooling consumers, being mainly companies, is mostly interested in the economic benefit their own business gain rather than how the local society benefit from a novel technology.

By putting the numbers forward in a transparent public document such as the project proposal, displaying estimated prices of production, expected sales of heat and cooling etc. can help build a trust in the business case with the suppliers providing full information regarding the economic work of representation.

The challenge of bringing the constructed reality into reality is related to creating the conditions where consumers are willing to interact and pay for the service put forward. The following section will elaborate how the consumers, given the created conditions, prefer to buy a service of cooling rather than operating their own cooling unit.

Buying a service rather than a product

Based on the valuations of various properties, consumers are more willingly to buy a service than a cooling unit to manage for themselves. Limiting the cost of O&M, having a high level of supply security, reducing the risk of overinvesting in unnecessary cooling capacity and having an environmentally friendly profile are all properties in a DHC system highly valued by the consumers.

One of the benefits of having a collective system is the reduced need for capacity, however in the case of Taarnby, the capacity installed is evidently larger than was estimated technically necessary for the first stage of the project. This raise the question of an "optimal system". What is optimal and to whom? If the suppliers had refused to invest in more cooling capacity, than they found technically necessary in order to construct the technical most optimal system, possibly the consumers would not dare to engage in the system, as they could not see their demand covered. If that was the case the project might not have been materialised at all. However, the suppliers did not strive to create the technically most optimal system, rather they aimed at constructing a system that allowed all actors to engage and interact. A system that could materialise. In the case of Taarnby the current system can be argued the most optimal in the sense that it has successfully connected various actors resulting in a materialised system.

Arguably often technicians desire to construct the technical most optimal system given the existing externalities. This is likewise the procedure in the scientific body of literature, where technical models seek to optimise and develop new technical solutions. However, in reality, the technical most optimal solution is not necessarily equivalent with the solution the involved actors regard. The system successfully gathered diverse groups of actors in a network that is operating at different markets, under various legislations and fulfilling various perceptions of value and property, thus it can be considered optimal in the sense that it exists.

9.2 Future development of DHC

Economy of synergies

The concept of economy of scale proves to be valuable in the case of Taarnby as it is found to be cheaper to acquire one large heat pump, rather than multiple individual chillers. However, it was found that HOFOR DC could not compete with the cost of individual cooling despite having the same advantage of a single cooling unit supplying multiple consumers. From this, the economy of scale itself is perhaps not what creates value to the co-produced system. However, it is difficult to determine as the incentive for HOFOR DC is unknown.

From the abovementioned figures of economy, it is displayed that the DHC system can compete with the cost of individual cooling, even though A. Dyrelund argues that the consumers have put forward unrealistically low prices for individual cooling. This illustrates that establishing a novel business plan based on estimations and assumptions, can be challenged by similar constructed alternative prices for i.e. individual cooling. The constructed calculative device of a price based on certain externalities becomes a tool of negotiation. The consumers putting forward a cost of individual cooling, can e.g. chose to include the absolute minimum technical requirements or chose to value the space occupied by an individual unit different than the supplier of an alternative service. The challenge is to construct a business plan that all involved actors can see themselves in. By constructing a combined system, utilising the synergies between the heating and cooling production, the economic benefits are demonstrated to be significant. Furthermore, the utilisation of synergies and being part of a novel innovative technology serve as a valuable narrative for the involved actors. Arguably, the economy of synergies, can be of greater relevance than the economy of scale, when combing production of heat and cooling.

Even though Dyrelund thinks the prices presented by the consumers are too low, thus implying economic pressure on the project, the prices are accepted to accommodate the consumers and find a common solution. Although the economy is established as one of the most important valuation, each economic argument is associated with uncertainty making other conditions increasingly important in order to convince the consumers to engage in the project.

Demonstration value

Without the value of demonstration, the project could not be materialised, as the DEA thereby could not grant the exemption necessary, however the DHC project in Taarnby was perceived as a novel technology integrating heating and cooling with the electricity market and wastewater treatment. Ironically, having successfully constructed a business plan, creating conditions engaging actors to join a DC network, was endangered by the uncertainty of the granted dispensation from DEA. Thus, the uncertainty of requirements for a grant, and the fact that it has to be a demonstration project, serve a great barrier for future development of combined system, as the one in Taarnby. The opportunity of being allowed to implement demonstration projects is valuable for novel technologies, but at some point, a project cannot be perceived as a novel technology any longer, thus only a limited amount to this type of systems can be created. If the project proves to be successfully after operating for a period of time, will it then open up for further implementation of similar projects in other places? Currently it is not stated anywhere how the DEA values a demonstration project leaving room for interpretation. Neither is it stated anywhere how the newly gained knowledge from an implemented demonstration project should be used for further development.

From the perspective of implementing novel technologies, establishing clear guidelines for which conditions a demonstration project have to fulfil and having a follow-up measurement of success and failures could create valuable knowledge for future projects.

Legal framework – protecting consumers or limiting efficient development?

The financing of cooling projects was identified as one of the biggest challenges. The legal framework in the Heat Supply Act (2019) and District Cooling Act (2019) requires the DH and DC business units to be separated and does not allow for DC activities to be financed on similar conditions as the heating projects i.e. with a municipal loan guarantee. The two utilities are separated due to the nature of the consumers. DH supplies all types of consumers, single family houses, apartments, companies etc. if it is socioeconomic feasible. DC primarily supplies companies and industrial consumers, this supply is only reliant on the agreement between the consumer and supplier with no regard to society as such. The argument is then, that the smaller heat consumers should not take on the risk of investment in cooling projects for the cooling consumers. Therefor the cooling business is legally considered as a commercial business in order to protect the heating consumers.

From the interviews, A. Dyrelund was frustrated with the legislation concerning the co-producing of heating and cooling, as he thinks it stands in the way of increasing efficiency of the DH sector and makes it unnecessarily difficult to finance the cooling part of a heat pump project. There is a paradox in the increased focus on integrating heat pumps in the DH sector as a sustainable way of producing heat and then limiting the opportunity of co-producing heating and cooling in a collective system utilising the synergies available.

The government advocates DH companies to increase efficiency and reduce emissions, however legal frameworks limit the opportunity of increasing efficiency by co-producing heating and cooling. From the case of Taarnby the concept of co-produced heating and cooling increases the efficiency and in fact increases the economy of the entire heat pump project.

DH companies engage in several investments posing an economic risk to the heating consumers e.g. CHP units produce electricity sold at a commercial market and using the waste heat for DH. This example with CHP units is fairly similar to the situation of co-produced heating and cooling, as cooling can be sold at a commercial market producing excess heat for DH. Due to the requirements for a socioeconomic assessment the investment is assured to lower the heat prices or at least not to exceed the existing prices. Therefore, investments in combined heating and cooling can be seen as an efficiency increasing investment rather than financing a service solely benefitting larger cooling consumers.

Based on the case in Taarnby, the legal distinction between DH and DC is not benefitting the promotion of efficient thermal energy production. Having a legal framework that treats the two services equal as a common service, as the case in Taarnby, can evidently benefit a sensible socioeconomic expansion of DC and benefit the electrification of the DH sector increasing efficiency.

9.3 Planning for more DHC

The DH sector in Denmark is increasingly being electrified as a result of converting to more renewable energy production. Heat pumps are identified by several experts to be one of the most significant technologies in this transformation e.g. (CTR, VEKS & HOFOR, 2014; Aalborg University, Ramboll & Dansk Fjernvarme, 2016; Dansk Energi, 2018; Dyrelund et al., 2008; Mathiesen et al., 2015). From the results of this study, combining production of heating and cooling from a heat pump increases the economic benefits of the entire system, thus allowing for more large-scale heat pumps to be implemented in the future. It does not only benefit the DH sector, but also the DC sector. From the case in Taarnby, we know that HOFOR DC was involved in an early stage offering to supply the consumers of Scanport with DC. However, HOFOR's prices were uncompetitive with individual cooling. Whereas HOFOR DC perceive the cooling market as a commercial business opportunity to generate a profit, Taarnby Utility is not interested in the commercial aspect of cooling. Taarnby Utility rather perceives cooling as a mean to lower the heat prices. Furthermore, Taarnby Utility had attempted to create an economically attractive DC network previously, which failed due to poor economy. From these facts it can be argued that a DHC system can promote the expansion of DC network as well as integrating large scale heat pumps in DH networks. Regarding the technical system as a social responsibility, treating it as a DH conversion project within the socioeconomic assessments rules of the project declaration, the synergies can be utilised benefitting the entire system.

However, the current legal framework is not recognising the potential of combining heating and cooling, but rather creates organisational and financial barriers for the creation of a DHC system. In the case of Taarnby, a vast amount of resources was spent at accountants and lawyers in order to make sure the newly established business unit of cooling was legally operational. A. Dyrelund argues that creating a business unit simply to transfer a waste product of heat production to cooling consumers can seem pointless. Retrospective the DH sector was created as a product of utilising excess heat from electricity production at CHP plants. Thus, DH companies already today operates at several commercial markets, such as the electricity market of Nord Pool and the natural gas market.
With this in mind, the commercial market of cooling, could be seen as an addition to the current available market opportunities that DH companies have, to optimise the production of DH. In the future, electricity will be produced increasingly by renewable energy sources such as wind and solar PV, reducing the need for producing electricity at larger CHP plants. This calls for alternative heat sources, and combined heating and cooling produced at large scale heat pumps could be one solution among several others.

Consumers perceiving a collective solution as preferable over individual solutions implies that energy planning authorities, such as the municipality, should actively engage in urban development planning with collective solutions in mind. The benefit of economy of scale in having a collective DHC system increases the ability to compete with novel individual technology with lower efficiency. Municipalities are planning for heating, but in the future cooling arguably could be part of this planning process, recognising the synergies and possibility it brings. Observing an operational system in Taarnby, can possibly promote and demonstrate why planning for a combined system can benefit the local environment in several ways.

10 Conclusion

This thesis has examined how a combined heating and cooling system created value for all actors involved compared to the technical alternative of individual seawater cooling. The results are identified based on a case study of Taarnby Utility currently constructing a DHC system. The case demonstrated the theoretical understanding of actively creating a novel business opportunity, by constructing an environment for interaction and engagement for heterogenous actors, both human and non-human. The following sections will provide answers to the subject matter in question.

10.1 DHC creating value

By materialising the DHC system in Taarnby value was created primarily through the economic work of representation constructed by Ramboll and Taarnby Utility. Being able to formulate and reduce a complex network of actors, technologies and legislations into a business plan relevant for the involved actors created the foundation of interaction and engagement from the consumers.

Through the closure mechanisms and persistency in convincing consumers to engage in a novel technology the suppliers successfully created a common understanding of the benefits related to a DHC system rather than multiple individual cooling solutions. The various perceptions and valuations identified among the heterogenous actors were included in the construction of the business plan and the technical design of the system through several negotiations and compromises.

10.2 Perceptions and valuations

Different groups of actors have been identified from the case being; *suppliers, consumers, competitors* and *authorities.* Each group having a diverse perception of the novel technology proposed. The group of suppliers perceived the system as a mean to optimise efficiency of heat production while simultaneously developing a novel technology concept for further implementation. The group of consumers perceived the system as an environmentally friendly opportunity to have an easier, cheaper and more reliable supply of cooling, than possible perceived with individual cooling. The group of competitors perceived the system as a threat to their existing market position. Lastly the group of authorities perceived the system from a legal perspective rather than a practical. Determining for the system to materialise was the perception of the system as being a demonstration project, which granted the exception of producing heat in an CHP area from a heat pump.

Significant themes of valuations among the actors was identified as *economy* and *technical design* through the thematic analysis of the conducted interviews. Within the theme of economy, the ability of co-producing heating and cooling is the most outstanding valuation among actors. The co-producing of heating and cooling increases the economic benefits for the supplier, consumers and thereby the local society as a whole, by utilising waste products of thermal production i.e. heating or cooling. Evidently, it is cheaper to invest in a collective system rather than several individual units, as it benefits from the economy of scale. In addition, the collective system removes the responsibility of operation and maintenance of the unit, as the utility includes this in the service offered to the consumers.

Within the theme of technical design, the valuation of being environmentally friendly and having a high level of supply security was significant among the group of consumers. Whereas the group of suppliers significantly valued the property of flexible production and demonstration of a novel technology. However, every valued property identified applied to both groups of actors. The flexible production of thermal energy allows the system to economically optimise in regard to the prices of electricity and to utilise the accumulation tank for cold water.

10.3 Closure mechanisms

Controversy is unavoidable in the creation of novel business opportunities recomposing an existing market. The case of Taarnby was not any different. The challenging task for suppliers to convince consumers to engage in a novel technology benefitted from the rhetorical closure mechanism of displaying challenges with individual seawater cooling and by redefining the problem of concern for sufficient cooling capacity. The practical experience using individual seawater cooling from the Blue Planet provided information to Skanska and Ferring concerning the comprehensive operation of such a system. This benefitted the suppliers in the process of convincing and persuading the consumers to engage in a collective system and demonstrated to the consumers that buying a service of cooling rather than an individual chiller could be of value to them.

Controversies of cooling capacity between the suppliers and consumers occurred. One of the benefits from a collective system is the reduced demand for cooling capacity due to the simultaneity factor in a larger system. However, the consumers demanded the equivalent capacity in the DHC system, in order to be convinced that the system could sufficiently supply them with cooling. By redefining the problem of installing more cooling capacity than estimated necessary for the first development stage, the suppliers closed the controversy and simultaneously prepared for future cooling consumers.

10.4 Future of DHC

Combining heat and cold production in a collective heat pump can possibly benefit the electrification of the DH sector and simultaneously benefit the expansion of DC as the investment cost can be split and allows for utilising the synergies.

From the case in Taarnby an extra benefit for the local society was identified due to the synergies of producing heating and cooling. Evidently having a perception of DC as a mean to optimise DH rather than a business opportunity to maximise profit alone, was determining for the materialisation of the DHC system in Taarnby. However, as the incentive of more commercial cooling companies has not been investigated in the present thesis, this statement is not conclusive.

11 Epilogue

This chapter provides reflections on the qualities and limitations of the applied methods and present thoughts and recommendations for further research.

The interdisciplinary approach of this report allows us to understand how a technical system interact with actors. As identified the field of research is heavily focused on technical optimisation of novel energy systems, rather than focusing at implementation of systems in a local context. In the desire to contribute to field identified lacking attention, the technical aspects of the energy system have been undermined due to time constrains. The economic figures and the technical operation of the system has not been tested or questioned, as the primary focus has been on the value creation of a collective system over multiple individual cooling units.
Having developed the technical understanding of the system further could possibly have provided valuable knowledge of the technical benefits of a combined system, and perhaps illustrated issues that have not been identified from the present analysis. Most of the technical information has been gathered from interviews with actors having a positive stance towards the combined solution, thus delimitations of such solutions might have been neglected.

An extensive number of interviews have been conducted in the research of this thesis, and it is the author's understanding that this number is exhaustive giving a trustworthy indication of the relevant actors. The interviews have been conducted individually, however as the relations among actors were of relevance, it could have been rewarding bringing them all together in a group interview or workshop. Doing this could possibly benefit the process of remembering issues or conflicts, but also valuations forgotten. Bringing them together could have provided a ranking of valuations identifying the most significant.

As presented in the conclusion, findings from this thesis indicates having a perception of cooling as a mean to optimise DH rather than a business opportunity to maximise profit arguably can promote the expansion of DC. However, this statement requires further investigation to be conclusive. Thus, to generalise this result an analysis of the incentives from a strictly commercial cooling company could provide valuable information in order to confirm or disconfirm the statement.

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13 Appendix

The appendix with audio files, interview guides and transcriptions can be found online via the following link:

Appendix Master Thesis - Frederik Palshøj Bigum

The link is open from the 10th of January 2020 to the 1st of February 2020 for viewing only. If material is needed outside this period, please contact the author at fbigum14@studnet.aau.dk

The following can be found in the appendix:

- Audio recordings of interview:
    - CTR
    - Radius
    - Ramboll
    - Taarnby Municipality
    - Taarnby Utility
    - The Blue Planet
- Interview guides for all interviewees
- Transcriptions of all the interviews