A Silent Revolution

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Petter Johansson

Doctoral Thesis in Industrial Economics and Management
KTH Royal Institute of Technology
School of Industrial Engineering and Management
Department of Industrial Economics and Management
SE -100 44 Stockholm, Sweden
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petter.johansson@indek.kth.se

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Abstract

Currently, more than half of all Swedish single-family houses have an installed heat pump and more heat is supplied by heat pumps in Sweden than in any other nation. Despite the enormous impact of heat pumps on the Swedish energy system, the transition towards their use has gone relatively unnoticed. Hence the title of this thesis, ‘A silent revolution’.

This thesis provides an in-depth study of the Swedish transition towards heat pumps and how Swedish industries contributed to it. It approaches the topic from the perspective of value networks and ‘coopetition’, combined with the concept of complementarities. This approach has been inspired by the work of Verna Allee (2009) and Erik Dahmén (1991). In this thesis, value networks are networks of actors surrounding a specific business model, coopetition is used to describe the relationships between actors (as both competitive and cooperative), and the concept of complementarities is used to analyze the dynamics between synergistic elements and value networks in Sweden’s heat pump sector and energy system.

Based on this approach, the thesis explains how a durable web of relations and interdependencies between complementarities has developed within the heat pump sector and the energy system in Sweden, and between the two, during the country’s transition to widespread use of heat pumps.

Interest in heat pumps arose in Sweden and other parts of Europe during the 1970s. The Swedish energy system had been caught between international oil crises and national political mobilisation against nuclear power expansion. In this period of negative transformation pressure, the heat pump appeared as a promising alternative that could mitigate the use of oil and electricity for heating. In the 1970s, an early Swedish heat pump industry formed together with a growing heat pump market. A large number of diverse actors became involved in the Swedish heat pump sector, and the intense coopetition dynamics relating to heat pumps following the 1970s oil crisis contributed to durable connections between complementarities during the early stages of the transition.

The 1980s saw a rapid expansion of large heat pumps in Swedish district heating facilities. In the mid-1980s, however, oil prices dropped back to their previous low levels. This change, combined with other factors, such as lifted subsidies and higher interest rates, created a crisis for Swedish heat pump industry. The industry underwent a 10-year period of low sales of small heat pumps and the market for large heat pumps died out and never returned. Nevertheless, several connections between heat pump–related complementarities remained in Sweden after the mid-
1980s. In conjunction with value network reconfigurations, changes in company ownerships and governmental industry support, these complementarities helped the Swedish heat pump sector to maintain both production and service capacity.

Due to developments that took place largely outside the heat pump manufacturing sector, by the mid-1990s it became possible for the struggling Swedish industry to offer more reliable and standardised heat pumps to the Swedish home heating market. During the years after 1995, the Swedish heat pump market grew to become the biggest in Europe. The industry’s early development and growth gave Swedish companies a comparative advantage over its European competitors, with the result that the manufacturing of heat pumps remained concentrated to Swedish-based manufacturing facilities even after the Swedish heat pump industry became internationalised after 2005. As of 2015, Sweden had the greatest amount of heat production from heat pumps per capita of any European nation, and many heat pump markets in other European countries are 10 to 20 years behind the Swedish market in development.

This thesis shows how the Swedish heat pump industry has co-evolved with the market and how developments in the industry contributed towards causing the transition to heat pumps to occur so early in Sweden relative to other European markets. It also shows that coopetition dynamics in a socio-technical transition change with the emergence and characteristics of structural tensions between complementarities, which has implications for the strategic management of external relations and partnerships during socio-technical transitions. It further argues that the combination of the value network, coopetition, and complementarity concepts can be conceptualised for descriptive and exploratory studies on the role of firms and industries in socio-technical transitions, thereby offering a complement to existing dominant frameworks in the area of transition studies.
Sammanfattning

För närvarande har mer än hälften av alla svenska husägare en installerad värmepump. Värmepumpar levererar mer värme per capita i Sverige än i något annat land. Men trots värmepumparnas stora genomslag i det svenska energisystemet har övergången från olja och el till värmepumpar gått relativt obemärkt förbi. Därav titeln på denna avhandling, ”en tyst revolution”.


Denna avhandling beskriver samutvecklingen mellan den svenska värmepumpsektorn och det svenska energisystemet och hur den industriella utvecklingen bidragit till att den svenska övergången till värmepumpar var relativt tidig i jämförelse med andra europeiska marknader. Avhandlingen visar också att aktörsdynamiken i en socio-teknisk övergång förändras med uppkomsten av strukturella spännings mellan komplementariteter, vilket har betydelse för hur externa relationer och partnerskap hanteras av företag och organisationer som genomgår omfattande socio-tekniska övergångar. Vidare argumenteras för att begreppen värdenätverk, coopetition, och komplementariteter kan kombineras i ett konceptuellt ramverk för att beskriva och analysera företags och industriers roller i omfattande socio-tekniska övergångar och därigenom komplettera nuvarande dominerande konceptuella ramverk för studier av omfattande socio-tekniska övergångar.
Preface

My grandparents built a log house with grass roof outside of Skövde in 1972-1973. This type of house was typically found in the Swedish county of Dalarna, not in Västergötland where it was raised. Before it was built, there was a debate in the local municipality on whether it should be allowed to raise this type of house in the heart of Västergötland. More interesting was that no one discussed how the house was going to be heated. In 1972 the municipality of Skövde considered electric heating to be the only viable option, as did much of the rest of Sweden.

When my grandparents raised the log house there was a steady stream of people who went to see the new house, partly because of its odd looks and partly because my grandfather Runo Sundberg was a well-known entertainer at the time, having for the last years been one of the most booked performers at people's parks in Sweden. To reduce the traffic my grandfather put up a "Forbidden Access" sign down the road.

Raising a log house has its benefits: the logs constitute a bearing wall at the same time as they are good for storing heat. A log house typically has more heat inertia than normal houses. However, log houses also tend to "sit down" after a while, meaning that it sinks down a little here and there, leaving cracks between the logs. Cracks let the light in, but they also let the heat out. When I looked up the annual electricity consumption of my grandfather's house I was stunned by how high it was. Even though the house had both a fireplace and an air-air heat pump, the main means of heating was still direct electric heating. In 1972 direct electric heating was a great option from an energy system perspective, because it could substitute oil boilers (Sweden had one of the world's highest dependencies on imported oil at this time) and there was a perceived future abundance of hydro- and nuclear-powered electricity. In Sweden today, direct electric heating is considered to be a very poor option from an energy system perspective while heat pumps are widely considered a good option. There has been a transition not only in the view on the different heating options, but also a substantial technological development and increased competence and better service offerings for heating systems. This transition of the socio-technical heating system in Sweden – from the early 1970s up until today – is at the core of this doctoral thesis. How Sweden could go from a nation with one of the world's highest dependencies on imported oil, to being a nation that was full of direct electric heating, to becoming a nation with an energy system that is literally 'pumped up' with heat pumps. This is a piece of modern history containing many lessons for current energy related challenges.
Today my aunt has taken over my grandfather’s house, she and her husband has fixed the cracks and retrofitted the house with improved insulation, including putting on a new external panel. So now the unconventional log house has disappeared. No one comes along with their car to look at the odd house anymore. And the energy efficiency of the house is much, much better.

I moved from Skövde to Stockholm in 2006 when I started my education to become a Mechanical engineer. When I finished in the summer of 2011 I had the option to either become a consultant at a Swedish consultancy company or start as a research engineer at the newly started division of Business Development and Entrepreneurship at the department of Industrial economics and management at KTH. I chose the latter alternative, which I have never regretted. Soon thereafter I applied for a doctorate position, which I also got. It was in this period, between the summer of 2011 and summer of 2012, that the idea of researching the Swedish heat pump development started to grow on me. I had specialized on the topic of sustainable energy during my engineering education at KTH – which was one of Europe’s top research centres on heat pump and refrigeration technologies – so I was well acquainted with the heat pump technology. But it was not until I began working as a research engineer that I fully understood that Sweden had a unique position concerning heat pumps in Europe. The more I learned about the development of heat pumps in Sweden, the more interested I became. I still consider it a most fascinating story.

When I started to study the Swedish heat pump transition I noticed that there were many articles and reports about heat pumps in Sweden, but none that included an industrial perspective. I thought this a bit peculiar, since there was a relatively strong heat pump industry established in Sweden. That is why I wanted to apply a research approach that included not only policy and market perspectives, but an industry perspective as well.

As I worked back and forth trying to describe the actor dynamics (between policy makers, incumbent industrial actors, new entrants, etc.) I worked my way – with the help from my supervisors – to an approach where I sorted the actors into different value networks depending on the focal business model and business logics of the individual companies and organisations. This approach made it possible for me to sort the complex dynamics and interactions between a large number of actors into manageable and comprehensible entities giving an overview of the development from 1970s until today. I thought of it as a big breakthrough in my studies and it has become a big part of this thesis.
As a PhD student, I have made significant personal advancements in the fields of industrial dynamics, transition studies, and strategic management. But what I am most proud of, from my time as a PhD student, is the work I have done to gather, read, categorize and sort source material relating to the Swedish transition towards heat pumps. I have spent days, weeks and months searching through archives, databases, and libraries for material relating to the Swedish heat pump development. At times, the task to compile all the gathered material into a thesis has felt overwhelming. Luckily, it proved manageable in the end.

I would never have managed to finish this thesis without the invaluable support I have received during my PhD studies, and there are many who I would like to acknowledge as influencers on this thesis.

First, I would like to give my warmest thanks to my three supervisors. It has been a great benefit of having Pär, Martin and Eric as my supervisors. With their different backgrounds, they have complemented each other perfectly as supervisors to me in my PhD studies.

My main supervisor Pär Blomkvist is the sole biggest influence on my theoretical and conceptual work. He has enthusiastically discussed industrial dynamics theories and concepts (preferably concerning large technical infra-systems) with me at any time of day for the last five years. Pär has helped me develop as a researcher as well as a teacher, for which I am more than grateful.

Since I started at KTH my co-supervisor Martin Vendel has freely shared his knowledge and experiences with me and been like a coach in my PhD progress, for which I am highly grateful. I have hopes that Martin’s seemingly inherent curiosity for new knowledge has rubbed off on me.

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The part of studying modern technological history which I have enjoyed the most have been the meetings and conversations with heat pump veterans and experts. My warmest thanks to Svante Färnbo – without Svante’s helpful guidance and opening of doors to Vattenfall archives this thesis would have been something completely different, to Sven-Allan Eklund – who have not only given vivid reproductions of Vattenfall’s actions and views on heat pumps but also given me much valuable feedback, to Lars Kastengren – Lars was literally at the epicentre of the Swedish heat pump ‘revolution’ as an active owner (and for a few years as CEO) of IVT for close to two decades and I am grateful that he shared his story with me, to Eric Granryd and Jan-Erik Nowacki
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Writing a thesis is not just an academic venture. It becomes a life project. I have received nothing but support from my friends and my family during my PhD studies. My thanks and my love to my supporting parents Börje and Ingela – my will to learn comes from you. To my brothers Linus and Daniel – my role-models and best friends. To my grandfather Runo – when I grow up I want to be like you. To my friends, my large family and my parents-in-law Anders and Inger. To Tuco, who was a part of my life as a PhD student since the beginning. But most of all, to my daughter Leah and my wife Annette. There are not words in this world to describe my love for you. Leah, you have always helped me put my work into perspective. There is nothing more important than you. Annette, without your support nothing of this would have been possible. Every day, I want to wake up and go to sleep next to you.

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Petter
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Abbreviations/Acronyms

BFR – Building Research Council (Byggforskningsrådet)
BPA – Bonneville Power Administration
COP – Coefficient of performance
CTC – Celsius, Tellander and Clarin (manufacturer of heat pumps)
CTH – Chalmers University of Technology
DFE – Delegation of energy research (Delegationen för energiforskning)
DSM – Demand-side management
EHPA – European Heat Pump Association
HVAC – Heating, Ventilation, and Air Conditioning
HP – Heat pump
IEA – International Energy Agency
ILC – Industry life cycle
IPCC – Intergovernmental Panel on Climate Change
IRP – Integrated Resource Planning
KF – Kooperativa Förbundet
KFAI – Kooperativa Förbundets Arkitekt- och Ingenjörsbyrå
KTH – KTH Royal Institute of Technology
MLP – Multi-level perspective
NE – The board for energy production research (Nämnden för energiproduktionsforskning)
NUTEK – The agency for industrial development (Verket för näringslivsutveckling)
SCOP – Seasonal Coefficient of Performance
SGU – Swedish Geological Institute (Svenska geologiska institutet)
SIND – The government industrial agency (Statens Industriverk)
SOU – The government’s official investigations (Statens Offentliga Utredningar)
SP – The government testing and research institute SP (Statens Provningsanstalt), now called Research Institutes of Sweden
SSM – Supply-side management
STEV – The government administrative authority for energy policy administration (Statens energiverk)
STU – The government agency for technological development (Styrelsen för teknisk utveckling)
TIS – Technological Innovation System
1. Introduction

The Swedish transition to heat pumps is a large-scale, almost revolutionary technological transition that has gone virtually unnoticed. In spite of the strong growth of wind power in Sweden, heat pumps were in 2015 supplying more renewable energy than wind power plants.\(^1\) Heat pumps offer enormous potential to reduce greenhouse gas emissions. This potential should be highlighted, in many forums and in different ways, to a larger degree than it is today.

Sweden has undergone a comprehensive technological transition towards heat pumps. In the early 1970s, Sweden was heavily oil-dependent and there were almost no heat pumps in Swedish houses. Today, more than half of all Swedish houses contain heat pumps and oil dependence in the building and service sector has greatly diminished.

A heat pump can be described as a refrigerator working in reverse, i.e. a machine that pumps heat from a cold side to a warm one. A modern ground-source heat pump can typically supply, on average, four to five times more heat per kWh of electricity than a direct electric heater.

Professor Harry Frank at the Royal Swedish Academy of Sciences has referred to the heat pump development in Sweden as a ‘silent revolution’ (Bergendorff, 2010). Despite the large impact of heat pumps in Sweden and the large amount of renewable energy that these heat pumps produce, their development has received relatively little public attention.

The Swedish transition towards heat pumps started on a small scale during the 1970s when the country’s energy sector became destabilised, caught between international oil crises and national political mobilisation against nuclear power expansion. In this period, the heat pump appeared as a promising alternative that could reduce dependence on both oil and electricity for heating. A Swedish heat pump industry formed in the 1970s and grew rapidly together in conjunction with the expanding heat pump market. When oil prices dropped and international energy markets stabilised in the mid-1980s, the heat pump industry disappeared in most European countries, but not in Sweden. In the mid-1990s the heat pump market began to grow again, reaching new

\(^{1}\) Comparing electric energy with heat energy is like comparing apples and pears, but this comparison still holds true measured in kWh.
heights in the 2000s before the market started to show signs of saturation.

Today, more than one million heat pumps of different types and sizes have been installed in Sweden, many of which have been developed and produced domestically, and more heat is supplied by heat pumps per capita in Sweden than anywhere else. Markets in other European countries are 10 to 20 years behind the Swedish market in development.

This thesis examines why the transition to heat pumps occurred so early in Sweden (relative to the rest of Europe) and how Swedish industries have contributed to this transition.

Figure 1 presents data on the Swedish heat pump transition in terms of the number of heat pump units sold (not including air-air heat pumps which have typically been manufactured outside of Sweden – see more on different heat pump types in Fact Box 1 and Fact Box 2) together with the development of energy use for the four major means of heating in Sweden's residential and service sector from 1970 to 2015.

Figure 1 shows that the total amount of electricity use for heating has decreased in Sweden despite the increasing number of heat pumps. This is because many of these heat pumps replaced inefficient electric heaters.

This thesis is not the first study of the Swedish heat pump transition, but it is perhaps the most detailed and the first to incorporate an industrial perspective. Both the Swedish energy system and the Swedish heat pump sector – including industrial actors – are included in the analysis. The description of the Swedish heat pump sector is brought down to the level of firm-level 'value networks' (Allee 2009), and the analysis of the co-evolving, interdependent development of actors and elements in the heat pump sector and the energy system applies the concept of 'coooperation' (i.e. apparently simultaneous cooperation and competition; cf. Bengtsson & Kock 2000) and the dynamic analytical concept of 'complementarities' (Dahmén 1989, 1991).

This thesis highlights the importance of taking the industrial context into account in understanding the Swedish heat pump transition. The industrial context has been directly related to organisational factors which have contributed to the early Swedish heat pump transition, e.g. the formation of advocacy coalitions, actor perseverance, and the development of company capabilities.

Along with using this conceptual framework, I also discuss how coooperation dynamics in and between value networks change in relation to emerging potential new alignments of complementarities (i.e. structural tensions) in socio-technical transitions. I show that
coopetition dynamics increase in intensity in conjunction with the emergence of structural tensions, and I argue that this process has managerial implications for companies undergoing large-scale technological transitions.

Figure 1: Total energy use in the Swedish residential and service sector\(^2\) (left axis) and the estimated total number of heat pump units sold, not including air-air heat pumps (right axis) from 1970 to 2015. *Sources: Energimyndigheten 2017; SKVP 2017; Kaijser et al. 1988, p. 79.*

The descriptive depth of the heat pump technology in this thesis is limited due to the scope of the study, but technologically interested readers will appreciate the ‘fact boxes’ that appear periodically. The first of these, on the next page, provides an introduction to heat pump technology. A more thorough explanation of the heat pump principle can be found in Appendix I.

\(^2\) Statistics concerning electricity for heating includes direct electric heating, electric boilers, and electricity used by heat pumps (Göransson, 2006).
Fact Box 1: Introducing heat pump technology

Knowledge of how to ‘pump heat’ is over 150 years old. Just like a refrigerator, the heat pump uses a compressor and a circulating refrigerant to pick up heat from a (relatively) cold location using a heat exchanger and give off that heat in a (relatively) warm location using another heat exchanger. Typically, heat pumps take in ‘free’ heat from the surrounding environment of a building and supply it to the inside of the building. Modern heat pump technology is typically up to five times more efficient than heating with electric boilers.

There are different types of heat pumps (HPs). The most common ones are air-air HP, air-water HP, exhaust air HP and ground source HP. These different HP types all employ the principle described above but use different types of outdoor and indoor units depending on which types of heat sources and heat sinks they are constructed for. (See the illustrations below and those in Fact Boxes 5 and 6.)

*The illustration at the top left shows a typical design of an indoor air-air HP unit. At the bottom left is an outdoor air-source unit that picks up heat from the outside air. These outdoor units look similar for both air-air and air-water HPs. The illustration at right represents a typical indoor unit of a water-based HP connected to a hydronic system.*
Following this introduction, Chapter 2 provides further background on the Swedish heat pump transition; Chapter 3 presents and discusses the research approach used in this thesis; Chapter 4, the first empirically oriented chapter, describes the historical background of the companies that would later form a ‘Swedish heat pump industry’; Chapters 5–9 present the developments and dynamics of the Swedish heat pump transition in five chronological phases; Chapter 10 discusses the outlook as of 2015; Chapter 11 answers the study’s research questions and summarises the dynamics of the Swedish heat pump transition; Chapter 12 discusses implications of the results of this study; and Chapter 13 provides final personal observations.
2. Background of the Swedish heat pump transition

The Swedish heat pump transition intersects many different areas. This chapter presents an overview of the Swedish transition and the different areas it intersects, and it discusses why the development can appropriately be called a ‘revolution’. The overall development of the Swedish heat pump market is described and compared to that in Europe. I also discuss the environmental impact of heat pumps in Sweden and provide an overview of industrial development regarding heat pumps in Europe. Furthermore, this chapter explains economic considerations related to heat pump investments, which have been an important factor in causing so many real-estate owners in Sweden to invest in heat pumps. This chapter ends with a presentation and discussion of current studies on the Swedish heat pump transition and a formulation of the research purpose and research questions for this thesis.

2.1. The Swedish heat pump transition: A revolution

The impact of heat pumps in Sweden is so substantial that it has been compared to a ‘revolution’ or a ‘wonder’ (Bergendorff 2010; Fredrik Lagergren, personal communication, 20 December 2011). The reasons for this view can be divided into three themes: strong heat pump market development (which was relatively early compared to the rest of Europe), strong industrial development, and environmental impact.

2.1.1. An overview of the heat pump market development in Sweden

Sweden tops the statistics on heat pump market penetration in Europe. It has been one of the largest heat pump markets in Europe and the undisputed leader in the ground source heat pump segment (Forsén and Nowak 2010; Nowak 2015; EurObserv’ER 2013).

The total number of sold heat pumps in Sweden, since the market first started to develop during the 1970s, has exceeded 1.5 million units (SVEP 2013), of which two-thirds are still operational (Energimyndigheten 2012b, p.28; 2013). The overview of Swedish heat pump market development shown in Figure 2 indicates that the Swedish market has passed through several different stages of varying market characteristics: an early market expansion in the late 1970s followed by a down period from the mid 1980s, a period of low sales from the mid-1980s until the mid-1990s, a period of 10 to 12 years of strong market...
growth from the mid-1990s onwards, and a relatively stable and slightly declining market from 2005 to 2015. One feature that distinguishes Sweden from many other European nations is the relatively strong growth of ground source heat pumps, seen under the label ‘Closed fluid systems’ in Figure 2; meanwhile, the market segment of exhaust air heat pumps has been relatively stable since the early 1980s. (Note that there has not been a sudden drop in sales of air-air heat pumps in the last few years, as appears in Figure 2; rather, data on these sales were unavailable after 2012.) See Fact Box 2 on page 33 for an explanation of the different heat pump categories in Figure 2.


References in this thesis to the ‘Swedish heat pump market’ include all the categories shown in Figure 2, but do not include the market for large heat pumps (over 1 MW). Whenever I am discussing the market for large heat pumps, I will point this out explicitly.

The statistics for air-air heat pumps in Figure 2 are based on estimates made by the heat pump association SVEP. SVEP stopped making these estimates in 2012 because it lacked sufficient information on these sales, and therefore this category is not included for the last three years.
More than half of all small houses in Sweden, or over one million, have an installed heat pump (SVEP 2013; Energimyndigheten 2015c, p. 13). According to expert Jan-Erik Nowacki (personal communication, 5 February 2013), heat pumps consume roughly 10 TWh of electricity annually, which corresponds to about 30 TWh of total heat supply from heat pumps. In other words, about 20 TWh of ‘free heat’ (or renewable energy, as heat pump proponents call it) is supplied to Swedish buildings by heat pumps.

Current sales of heat pump units are, to a large extent, replacing (or supplementing) existing electric boilers, direct electric heating and oil boilers. But with an expected life span of roughly 20 years, the share of heat pump unit sales replacing older heat pumps is rapidly increasing (Jonasson 2016).

The Swedish well register SGU offers an online tool that shows all registered energy boreholes (for ground source HP) on a map. This tool has been used to show the density of energy boreholes in the Stockholm suburb of Bromma, as seen in Figure 3.

![Figure 3: Map of energy boreholes for Bromma, Stockholm, from Swedish well register SGU (Sveriges Geologiska Undersökning). Source: www.sgu.se, accessed 20 August 2014.](image)

About 35% of small houses in Sweden use biofuels for heating, and about 17% are connected to district heating. Approximately 32,000 houses were still using oil for heating as of 2012, alone or together with electricity (Energimyndigheten 2009b, 2013). In 2013, the Swedish house broker association Mäklarsamfundet conducted a study of its members on to what extent different heating alternatives affected buyers’ interest in bidding on houses. The most popular alternative was vertical ground source HP and the least favoured options were oil-fired heating and direct electric heating (Eiken 2014).
Sweden has the highest level of heat supply from heat pumps per capita in Europe, and Sweden and its neighbouring Nordic countries top the European statistics on the extent of heat pump penetration in building stock (Nowak 2015). But the rest of Europe has started to catch up.

Overall, the European heat pump market grew steadily between the early 2000s and 2008 before stabilising at around 800,000 units sold per year, of which 450,000 were reversible air-air heat pumps (Forsén and Nowak 2010; Nowak 2015). But since 2012, sales have started to increase in Europe again (Nowak 2015) and in 2015 they reached a new peak with sales of 890,302 units (EHPA 2016). The total heat pump stock in Europe is now above 8.4 million units, which means that the market share held by heat pumps in Europe’s building stock is roughly 7% (EHPA 2016).

Sweden had the biggest market for water-based heat pumps until 2006 (not counting reversible air-air heat pump units). But between 2006 and 2008, it lost this top position to France. With decreased governmental support, lower energy prices and an uncertain financial context, the strong growth of the French market halted after 2008 (Forsén and Nowak 2010). When one counts the total number of heat pumps sold, the largest markets in Europe in 2015 were (in order) France, Italy and Sweden. But this comparison is somewhat incomplete unless the shares of each heat pump type are also presented. In Sweden, the more efficient and capital expensive ground source heat pump type constitutes a much larger share than in either the French or Italian market (EurObserv’ER 2013; Nowak 2015). This is the main contributing reason why Sweden remains number one in the total amount of kWh of heat per capita generated by heat pumps in Europe.

2.1.2. The environmental impact of replacing oil boilers and electric heaters with heat pumps in Sweden

The Swedish energy system has undergone a large-scale transition towards increased sustainability by almost completely abolishing oil heating. In the early 1970s, Sweden was largely dependent on oil imports with over 75% of all energy consumption based on oil (Energimyndigheten 2008). The oil crises of 1973 and 1979, which quadrupled the price of crude oil, pushed the Swedish government to reduce oil dependence. The government’s response to rising oil prices entailed large-scale investments in alternative energy sources, preferably renewable and domestic ones (Kaijser et al. 1988).
Fact Box 2: Heat pump categories

A typical Swedish heat pump is based on the electrically driven compression cycle. There are other types of heat pump propellants, but since the electric heat pump is so dominant, the typical heat pump categories are based on size, type of heat source, and type of heat sink.

A sea (literally) of heat sources can be used by heat pumps. For small heat pumps, heat sources are typically the outdoor air, exhaust air (outgoing ventilation air), ground, or water (e.g. lakes or rivers). The heat pump picks up heat from any of these heat sources and gives it off to the heat sink, which is typically air-based space heating, water-based (hydronic) heating, or tap water. Commonly used denotations of heat pumps are air-air, air-water, exhaust air, and ground source. See the illustration of different types of heat sources and heat sinks below.

Heat pump size refers to the maximum heat supply capacity. The dividing line between small, medium, and large heat pumps varies, but Vattenfall (1989) made the following categorisation:

**Small** heat pumps: up to 25 kW_{heat} (typically used for detached houses);
**Medium**-size heat pumps: 25 kW_{heat} - 1 MW_{heat} (typically used for larger buildings); **Large** heat pumps: 1 MW_{heat} and above (typically used for district heating systems).

For further information on the heat pump principle, see Fact Box 4 on page 48.
The housing and service sector in Sweden represented 38% of all energy consumption in Sweden during 2011, a figure that roughly corresponds to the global average (Energimyndigheten 2012a, 2013a). Since 1990, CO₂ emissions from this sector have decreased by two-thirds (Energimyndigheten 2012a). This development can be primarily attributed to the rapid expansion of the Swedish heat pump market, together with reforms at Swedish district heating plants (Energimyndigheten 2015c).

Figure 4 shows the use of fuel oil, also called heating oil, in Sweden for the last 70 years. Fuel oil 1 is the heating oil typically used in detached houses, whereas fuel oils 2-6 are heavier oils used in such places as district heating plants and ships (SPBI 2017). Figure 4 shows that the most rapid decrease of fuel oil use happened during the late 1970s and the 1980s, a period when the use of all types of fuel oils decreased by almost 75%. Heat pumps (both small and large) contributed to this decrease, but most of it came from other measures such as fuel switching and increased expansion of electric heating. However, many of the electric heaters installed to replace oil boilers in the 1970s and 1980s were in turn replaced by heat pumps at a later point. The volume of consumed fuel oil 1 was relatively stable from the late 1980s to the mid-1990s, but decreased substantially from the late 1990s until 2010. During this period heat pumps played a bigger part in the oil reduction than they had done in the late 1970s and early 1980s.

Three aspects to consider when estimating the environmental impact of heat pumps are (1) what alternative heating technology the heat pump replaces, (2) how ‘green’ is the electricity that propels the heat pump (i.e. how much of the heat pump’s electricity comes from renewable energy sources), and (3) the seasonal coefficient of performance (SCOP) and reliability (run time) of the heat pump. Laestadius (2013) described heat pumps as not a ‘green technology’ (i.e. environmentally friendly) per se but a ‘blue technology’, meaning that they can be environmentally friendly depending on the characteristics of the system to which they are connected. For example, if a heat pump is installed to replace a biomass boiler in an electricity system that is highly dependent on fossil fuels, then it does not contribute to decreasing greenhouse gas emissions as much as if an oil boiler is replaced by a heat pump connected to the Swedish electricity grid.

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5 Petroleum-based fuels for transportation are not included in Figure 4.
In Sweden, the average CO₂ emissions from producing electricity were 10 g/kWh in 2005, a very low figure in comparison with the EU average of 415 g/kWh (EME Analys AB and Profu 2006). Since the Swedish electricity system is tightly integrated with those of its Nordic neighbours, it has been decided that the Nordic electricity mix, with roughly 100 g of CO₂ per kWh, should be used to calculate greenhouse gas emissions related to electricity consumption in Sweden (Granström et al. 2011; Forsén 2008a). Based on this assumption, estimated CO₂ emissions reductions from all heat pumps in Sweden total 2–4 Mt annually.⁶

![Figure 4: Use of fuel oil for heating in Sweden, 1946–2017. Source: SPBI 2017.](image)

Although the market for small heat pumps in Sweden is largely saturated, the efficiency of heat pumps continues to increase. Since the

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⁶ This calculation is based on estimates made by Jan-Erik Nowacki, together with the assumption that heat pumps run on the Nordic electricity mix and that all heat pumps in Sweden have replaced either electric boilers, direct electric heating or oil boilers. The European Heat Pump Association has estimated that heat pumps in Sweden saved over 3.3 Mt of CO₂ emissions for the year 2013 (EHPA, 2014).
life expectancy of heat pumps is roughly 20 years, many older pumps will be replaced in the upcoming years (Jonasson 2016). Most of them will be replaced by new units with increased efficiency, decreasing the electricity consumption per kWh of heating and increasing the environmental benefits from the Swedish heat pump stock. See Fact Box 3 on page 38 for more details on how heat pumps’ performance has improved over the last decades.

2.1.3. An overview of industrial development relating to heat pumps in Sweden

In 1979, a special edition of the Swedish HVAC (heating, ventilation and air conditioning) trade magazine wrote:

‘In Sweden, the usage of heat pumps has been very limited. We have no tradition in the area. The number of companies that work with production, service, and maintenance of heat pumps is not large’ (VVS-Tekniska Föreningen 1979, p.3).7

The United States, West Germany and even Denmark were seen as forerunners in the field of heat pumps compared to Sweden in the 1970s (BFR 1975; VVS-Tekniska Föreningen 1979). But many years later, in 2016, the Bosch company called Sweden ‘the motherland for industrial manufacturing of heat pumps’ in Europe (Bosch Thermoteknik AB 2016).

The Swedish heat pump industry formed during the late 1970s and early 1980s, in the same period as the early expansion of the heat pump market. In 2015, it was a medium-sized industry with total revenue of 6 to 7 billion SEK8 and exports of over 1 billion SEK.

The largest heat pump manufacturers in Sweden (and Europe9) in 2015 were IVT/Bosch, Thermia/Danfoss, CTC/Enertech, and Nibe. The

7 The original Swedish stated, “i Sverige har användningen av värmepumpar varit ytterst begränsad. Vi har ingen tradition på området. Antalet företag som arbetar med produktion, drift och underhåll av värmepumpar är inte stort.”
8 The figure of 6 billion SEK is based on estimates made by the EHPA (Nowak 2015) and export statistics from SCB – Statistics Sweden (2017), cross-examined against figures from the consulting firm Gaia Consulting Oy (WWF Finland 2008). SVEP suggests a figure of 9 billion SEK (Wenström 2011), whereas a more recent figure from SKVP, the successor of SVEP, is 6.5 to 7 billion SEK (Jonasson, 2016).
9 There are no exact statistics on the biggest heat pump manufacturers in Europe, but EurObserv’ER (2013) lists Nibe, Danfoss and Bosch together with Daikin, Viessmann, Vaillant and BDR Thermea among the largest corporations manufacturing heat pumps in Europe. With some exceptions, the manufacturing companies within these corporate groups are based in Sweden, Germany, Switzerland, Austria or France. In Germany, some of the most well-known
owners of IVT, Thermia and CTC are located outside Sweden; Nibe is the only industrial heat pump manufacturer with its main office still in Sweden. All these companies are currently internationally oriented.

Over the last two decades, the European markets have been of increasing importance for Swedish heat pump manufacturers. In 2003, Swedish heat pump exports were at 172 million SEK. Five years later, they had risen to 1.2 billion SEK.\(^\text{10}\) Although Swedish manufacturers have been able to get a foothold in other nations, some of the large heat pump manufacturers based in Germany (e.g. Viessmann, Stiebel Eltron and Vaillant) were still facing difficulties in penetrating the Swedish heat pump market as of 2015.

Despite the international orientation of Swedish-based companies, there has been a continued concentration of both development and manufacturing at several locations in Sweden: Markaryd (Nibe), Tranås (IVT), Arvika (Thermia), and Ljungby (CTC). When Bosch acquired IVT in 2005, it relocated all its heat pump production (development, education and manufacturing) to Tranås and Katrineholm in Sweden (Eriksson 2004; Bosch Thermoteknik AB 2014). A few years later, the activity in Katrineholm was moved to Tranås to further concentrate production (Bosch Thermoteknik AB 2009, 2010; IVT 2014).

The Danish company Danfoss acquired Thermia in the same year as Bosch acquired IVT. In 2012 Danfoss declared that they would move all of their manufacturing of heat pumps from five different locations in Europe to the Arvika facility (Thermia 2012). This included shutting down production at a factory in Poland where most of Danfoss’ earlier heat pumps had been made. Of the Nibe group’s 14 production facilities in Europe and North America, the Markaryd facility in Småland, Sweden is one of the three largest and the only one producing heat pumps under the Nibe brand.\(^\text{11}\)

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\(\text{Stat} \)statistic from SCB – Statistics Sweden (2017) using code number KN 84186100 for the period 2006–2014 and code KN 84186190 for the period 1997–2005. According to Statistics Sweden (2017) the code KN 84186100 is defined as ‘Heat pumps, other than air conditioning units as per number 8415 (’Värmepumpar, andra än luftkonditioneringsapparater enligt nr 8415’), which means that reversible air-air heat pumps are not included in these figures.

\(\text{In} \)In Markaryd, Nibe also manufactures tap water heaters and stoves (Nibe, 2016).
Fact Box 3. Heat pump performance improvements

Since the 1970s, the performance of heat pumps has increased steadily. According to heat pump researcher Jan-Erik Nowacki, the efficiency of small heat pumps has improved by an average of 1.5% per year since 1975 (personal communication, 5 February 2013; Granryd 2011). Heat pump veteran Thomas Hallén (personal communication, 10 August 2016) has noticed that since his participation in large-scale tests on ground source heat pumps in the 1970s, in which the pumps’ seasonal coefficient of performance (SCOP) averaged 2.2, the SCOP has roughly doubled to around 4.5 in recent installations.

The universal law for heat pumps is that smaller temperature intervals between the heat source and heat sink gives higher efficiency. Heat pumps designed for a relatively warm heat source (e.g. a borehole of 4-6°C) and an efficient indoor heating system (e.g. well-insulated houses with hydronic heating systems requiring hot water temperatures of only around 25°C) are the most efficient heat pumps, with annual performance coefficients over 5 or even higher. Since it is beneficial to allow heat pumps to work at low temperature intervals, some heat pump types are designed to give off heat at lower temperatures, e.g. 50°C, and then an immersion heater is used to heat the remaining water to above 60°C. Another modern technique uses the hot gases from the heat pump compressor to heat tap water using a hot gas heat exchanger. This requires more compressor power outtake but also allows for lower temperatures in the condenser, which increases overall efficiency (Granryd 2009).

Heat pump researchers at KTH consider the following to be the most important heat pump improvements during recent decades (Björk et al. 2013):

- More compact and efficient heat exchangers with decreased temperature differences
- Increased efficiency of compressors and electric motors
- Ability to control operational speed; the compressors can save energy by adapting the output to the need in different operating modes. Not supplying unnecessary auxiliary heat causes the overall efficiency to increase.
- Smaller temperature differences in heat sources and heat distribution systems (e.g. better uptake of heat in ground collectors)
- More advanced control equipment; e.g. through computerisation the heat pumps are better able to control the system in a more intelligent and energy-saving way
- Decreased energy demand for appliances such as pumps and fans through better system designs

This list shows that increases in heat pump efficiency can result from both improved components and better system applications.
According to Nibe’s CEO, Gert-Eric Lindqvist, it is an advantage to have production and development located close to each other (Weibul 2014) and Nibe has consequently strengthened its production capacity through several production efficiency investments at Markaryd over the last few years (Weibul 2014; Gatu 2015a; Gatu 2015b).

This industrial development in Sweden helps to justify the afore-cited claim that IVT is the motherland for heat pump manufacturing in Europe.

2.2. The economics of heat pumps

A brief summary of the economic aspects of heat pumps will help to clarify the incentives to invest in heat pumps and the economic factors behind the Swedish heat pump transition.

The economic benefits of installing a heat pump depend on several factors, including the investment cost, interest rates, heating demand, electricity prices and alternative costs. Figure 5 illustrates how the economic benefits of heat pump investments, relative to the alternatives, depends on the electricity–oil price ratio.

Oil price [SEK/m²]

![Figure 5: Illustration of the influence of the oil–electricity price ratio on the economics of heat pumps, adapted from Vattenfall (1989b); Granryd (2011); Björk et al. (2013).]
This figure in Figure 5 has appeared in several reports on heat pumps in Sweden (e.g. Vattenfall 1989b; Granryd 2011; Björk et al. 2013). It illustrates that heat pumps benefit when both the prices of electricity and oil are relatively high, although electricity can’t be too high compared to prices for alternative fuels. A more modern example would replace the y-axis in Figure 5 with biofuels instead of oil, but the logic would be the same.

A factor not included in Figure 5 is the cost of loans. Since heat pumps are more capital-heavy investments than e.g. oil burners, the economic benefits of installing heat pumps are affected by the interest rate. High interest rates are beneficial for heating alternatives with low fixed cost and high variable cost.

Figure 6 shows the normalised price developments for electricity and fuel oil for heating in Sweden. These developments can be compared with the investment logic presented in Figure 5 to show that over time, electricity and oil price increases have encouraged investment in heat pumps. Note the price increases corresponding to the international oil crises in 1973 and 1979.

Figure 6: Final prices of electricity, heating oil and district heating for end consumers (including grid fees and taxes) in Sweden, 1970–2015, normalised against 2016 monetary values. Source: Energimyndigheten 2017b.
Users’ heating demand is another factor to consider when calculating the economic payback offered by heat pumps (HPs). It is difficult to justify costly investments in a ground source HP, even though it might be the most efficient alternative, if the heating demand is too low. For well-insulated houses – so-called ‘low energy houses’ or ‘passive houses’ – it can be more economically sound to invest in other heating alternatives with smaller initial investment costs than ground source heat pumps (Ruud 2010). In cases of low energy demand, an air-air HP might be sufficient for space heating. But for larger houses with large heating demand, investing in a ground source HP is more likely to be a sound economic choice, and for mid-range homes with hydronic systems an air-water HP might be the soundest economic investment. These decisions, of course, to a large degree depend on the initial investment costs of each option.

Another issue when calculating heat pump investments is how much of the total heating demand over the whole year the heat pump should cover. A heating demand curve for a standard house is illustrated in Figure 7. This figure shows that if a heat pump is large enough to cover all the heating requirements for the whole year, it will run at maximum capacity for only a few hours even in winter (the x-axis represents how many hours per year that require a certain amount of heating in kW). For most of the year, it will run below maximum capacity.

![Figure 7: Annual heating demand for a standard Swedish house](image)

If the heat pump instead is designed to cover 80% to 90% of heating needs instead of 100% – as illustrated in Figure 8 – this allows for a much smaller and less expensive heat pump, and therefore a smaller up-front capital expenditure. However, this also requires a second heating alternative to cover the peak load. If this alternative is an immersion heater, then high electricity costs will result during the cold months of the year. From a cost perspective, it is typically preferable to use biofuels...
or other alternatives to supply this extra heating, but that also requires a more expensive initial investment.

Figure 8: Annual heating demand for a small house with a 3kW heat pump

These discussions show why system considerations should be taken into account when installing a heat pump, not only for technological performance but also to maximise economic and environmental performance and benefits. It also shows that to be a sound investment, heat pumps are (or at least they were, in earlier phases of their development), dependent on complementary technologies.

Positive economic benefits and reasonable return on investment are foundational requirements for creating a strong base of heat pump customers. But these are not on their own sufficient factors to explain the Swedish heat pump transition. It has also depended on the availability of reliable and efficient products, environmental benefits, awareness and a sense of trust among potential customers concerning the technology, and other factors. Looking at previous studies of the Swedish heat pump transition offers additional insights into these factors.

2.3. Previous studies of the Swedish heat pump transition

Several previous studies that have described and/or analysed the whole or parts of the Swedish heat pump transition (e.g. Kaijser et al. 1988; Nilsson et al. 2005; Neij et al. 2008; IEA 2010; Lind 2011; Kiss et al. 2012; Dzebo & Nykvist 2015, 2017; Laue 2002; Russell et al. 2009; Björk et al. 2013; Karlsson et al. 2013).

The more technologically oriented descriptions of Swedish heat pump development, e.g. Björk et al. (2013), point to the importance of
beneficial climatological and geological conditions in Sweden and commented that heat pumps fit well into the country’s relatively clean electricity system.

An early study on the Swedish heat pump transition was conducted by Kaijser et al. (1988). This early work gives an insightful contemporary description of the socio-technical development of heat pumps in Sweden, based on first-hand sources. Kaijser et al. (1988) emphasise that heat pumps were not seen as a system-disturbing technology and that there were few conflicts over the technology as it quickly expanded in the market. The authors speculate that the electricity power industry saw heat pumps as a technology that could strengthen the position of electricity in the long term. The development of heat pumps also contributed to strengthening the position of district heating in the Swedish energy system. Heat pumps have not required the build-up of a new infrastructure of 'sociotechnical systems', but could enter as a component in the existing systems.

Kaijser et al. (1988) observe that energy suppliers, equipment manufacturers and energy users are the foremost stakeholders in the heat pump transition. Kaijser et al. (1988, p. 86) state that "where heat pumps have been successful there have been coinciding interests [among the main stakeholders] that could be realized through the technology".

Another interesting piece came from professor emeritus Eric Granryd (2011), who provides interesting insights from his own experience of Swedish heat pump development since the 1970s. Granryd states that heat pump development can be characterised as 'an evolution in many steps, one that in total results in radically different designs compared to what was built a few decades ago. This applies not least to refrigerants. It has been an all-encompassing change' (Granryd 2011, p. 20). Granryd points to the developments in the individual components of the heat pump (development of compact and efficient heat exchangers and the increase in compressor efficiency from 50% to 70% since the 1970s) and the functioning of the heat pump as a system. The efficiency of heat pumps has on average improved by 1.5% per year since the 1970s (from a SCOP of around 2.5 to 4). Granryd (2011) also points out heat pumps’ reliance on beneficial electricity–oil price rations due to the high initial capital cost of heat pumps, the increasing efficiency and performance of borehole drilling and the synergies of heat pumps and district heating. Regarding that last point, Granryd emphasises that the conflict between heat pumps and district heating is often exaggerated, and that there are synergies from a system perspective as the electricity from district heating power plants, produced when they supply heat to their district
heating grid in times of cold weather, can also run heat pumps in houses outside dense urban areas.

Nilsson et al. (2005) provided one of the most thorough contemporary studies of Swedish heat pump development. Their specific purpose was to contribute towards an understanding of government’s role in relation to technological and societal transitions. The authors conclude that the market success of heat pumps can be explained in terms of beneficial electricity–fuel price ratios (together with the widespread use of electric heating), the perseverance of key actors, the successful formation of a heat pump advocacy coalition (which to a large extent lacked opposition), and the learning that has taken place in the policy arena.

The work of Nilsson et al. (2005) was continued in two articles by Lena Neij, Bernadett Kiss and Martin Jakob (Neij, Kiss and Jakob 2008; Kiss, Neij and Jakob 2012), who compared heat pump development in Sweden and Switzerland. In these articles, the authors illustrate the role of ‘policy influence and effectiveness’ in the development and introduction of heat pumps. They highlight the changes in attitude towards heat pump technology among all types of actors involved in the transition (e.g. homeowners, architects, installers, utilities) as an important factor in these countries’ success (Neij et al. 2008). They also argue for the importance of long-term government support and efforts towards quality assurance, stating that support efforts should be aimed not only at R&D but also towards learning processes for the use of heat pumps.

Lind (2011) aimed to draw on lessons from Swedish heat pump development and apply them to the New Zealand context. Lind summarises the success factors for heat pumps in Sweden as encompassing ‘government support, research and development of heat pump systems, an independent heat pump association, certified installers, quality standards, environmental benefits, and a high level of awareness among the general public and decision makers in government municipalities’ (Lind 2011, p. 18).

In a report entitled ‘Regime analysis of the Swedish heating system’ Dzebo and Nykvist (2015) take a more industry-inclusive approach, studying lock-ins and path dependencies of the ‘socio-technical regimes in the Swedish heat domain’. The authors identify the following factors as contributing to the success of heat pumps in Sweden: the Swedish low-carbon policy and the carbon tax introduced in 1990, the relatively low electricity cost, the fact that Swedes don’t tend to move frequently (encouraging long-term investments of high capital cost), and the extensive research on and testing of heat pumps in Sweden. Furthermore, they highlight lobbying by advocacy groups in the early
1990s and a ‘well-coordinated market transformation and technology procurement programme’ combined with ‘test and certification programmes, policy incentives, subsidies and massive information-sharing activities’ (Dzebo and Nykvist 2017, p. 118). They suggest that focus on knowledge development, quality control, credibility and legitimacy resulted in the development of higher-quality heat pumps, which boosted heat pump demand in the mid-1990s. The authors also highlight the complementarity between heat pumps and district heating, which strengthened the position of both energy solutions during the 1980s, though in recent years the tensions between the two have increased. However, although the authors discussed the role of industry, they did not study the microfoundations behind the factors listed or go into detail on how the heat pump industry contributed to knowledge development, quality control, credibility and legitimacy of the heat pump technology. Dzebo and Nykvist (2015, p. 10) also state that ‘it is difficult to explain this high uptake [of heat pumps] in Sweden since for example Finland, with similar culture, climate, geology, and infrastructure has only a relatively small number of HPs’.

To conclude, although the Swedish heat pump transition has been described and analysed in several previous studies, a more comprehensive and probing study is still needed. The previous studies have covered the policy and governing perspective – looking to policy makers’ measurements and how these have influenced the transition – of the Swedish heat pump transition very well. But a policy perspective alone is not enough to explain the high uptake of heat pumps in Sweden. European nations that have had an early market development of heat pumps other than air-air heat pumps (such as Sweden and Switzerland) have had a domestic heat pump manufacturing industry supplying many of these pumps. The possible effects of the presence of national industries on domestic heat pump market developments have not been covered in previous studies.

Therefore, the present thesis will complement existing studies by delivering both a higher level of detail and greater incorporation of an industry-actor perspective. Such a study could add to prior research and offer new insights regarding the Swedish heat pump transition.

2.4. International studies and reports of heat pump transitions

Although this thesis is delimited to Sweden, a brief look at developments in other nations can help to put the Swedish heat pump transition in context.
The European countries with the earliest and strongest heat pump markets (in alphabetical order) were Austria, Finland, France, Germany, Italy, Norway, Sweden and Switzerland (Forsén and Nowak 2010). If reversible air-air heat pumps – which are typically supplied by producers from Asia such as Daikin, Fujitsu General, LG, Mitsubishi Electric, Panasonic and Sanyo (Zimny et al. 2015) – are removed, Italy falls out of this list, as does Norway (though Norway also has some ground-source heat pump installations supplied mainly by producers in Sweden and Germany). The Finnish market is also dominated by reversible air-air heat pumps, but has a larger share of ground-source heat pumps than Norway. The Finnish market has also depended largely on solutions from Sweden (Hirvonen 2014).

The remaining countries on the list – Austria, France, Germany, Sweden, and Switzerland – are also the countries where the largest European heat pump manufacturers are based (EurObserv’ER 2013; EREC 2004). This fact indicates a close connection between the development of heat pump industries and markets in nations that have been forerunners in heat pump transitions.

A report called ‘Campaign for take off for renewable heat pumps in Ireland’ (Arsenal Research 2004) compared heat pump market developments in Austria, Germany, Sweden and Switzerland. Based on its study of these four nations, the report lists a set of general requirements for success in heat pump market development: (1) availability of heat pump techniques, which refers to the presence of domestic or foreign heat pump manufacturers and the structure and organisation of educated retailers; (2) economic incentives that make it economically profitable to install heat pumps rather than other heating alternatives; (3) political decisions, i.e. legislative initiatives, standards or regulations that benefit heat pumps over other heating systems; (4) training and education of installers (e.g. plumbers, electricians and drillers), retailers, after-sales personnel and service technicians; (5) awareness amongst end users; and (6) attaining a general acceptance of heat pumps by assuring heat pump reliability and quality (Arsenal Research 2004).

Several articles and reports have described and analysed either successful heat pump markets in Europe (e.g. Zimny et al. 2015; Zogg 2008; IEA 2010) or developing markets such as Denmark (Nyborg and Røpke 2015), Poland (Zimny, Michalak and Szczotka 2015), the UK (Bergman 2013; Hannon 2015), and Holland (Raven & Verbong 2004). A comprehensive, in-depth and up-to-date study of the Swedish heat pump transition can potentially be useful for comparative studies.
between Sweden and other nations, just as Nyborg and Røpke (2015) expressed hope that their study of Denmark could be used for comparative purposes and as Hannon (2015) applied lessons from heat pump development in Finland to the UK context.

2.5. Research purpose and research questions

The purpose of this thesis is to explore the heat pump transition in Sweden and how Swedish industry contributed to making this country an early adopter of heat pumps. Two specific research questions are posed: (1) How has the industrial context of the Swedish heat pump sector contributed to the early Swedish heat pump transition? (2) How did the Swedish heat pump sector survive the ‘reverse oil crisis’?

Pursuant to the research purpose and research questions, I have attempted to construct an empirically rich description of the Swedish heat pump transition and to approach its analysis with a conceptual framework that builds on the concepts of value networks, coopetition, and complementarities (Allee 2009; Bengtsson and Kock 2000; Dahmén 1991). This research approach is discussed more fully in the following chapter.
Fact Box 4: The heat pump principle

The heat pump is, in its simplest version, a construction with relatively few main components: a motor-driven compressor, heat exchangers (a condenser and an evaporator), an expansion valve, and refrigerant (see figure below). Other parts include pumps and/or fans and control equipment. These components combine to form a cycle in which heat is transported from a cold heat source to an even warmer heat sink.

The figure displays the processes in the heat pump principle. The compression loop is divided into a hot, high-pressure side and a cold, low-pressure side. The ‘trick’ that the heat pump utilises is the different boiling points that a refrigerant can have. When a refrigerant goes from a gas to a liquid state, it gives off heat; when it goes from liquid to gas, the opposite relations apply. The above figure shows that the compressor increases the pressure and thus also the temperature at which the refrigerant condenses (illustrated by the red colour), allowing the refrigerant to give off heat at a higher temperature than at normal atmospheric pressure. When the refrigerant has completely condensed into a liquid state, it passes the expansion (pressure) valve to the low-pressure side. At the lower pressure, it can now pick up heat from the environment in the evaporator heat exchanger. When the refrigerant has completely evaporated into a gas state, it passes through the compressor again, and so the cycle continues (see Björk et al. 2013, p. 19 for more details on the heat pump principle).
3. The research approach to the Swedish heat pump transition

The research approach to the Swedish heat pump transition in this thesis builds on the concepts of value networks (Allee 2009), ‘coopetition’ (Bengtsson and Kock 2000) and complementarities (Dahmén 1991).

The value network perspective is used to explore and describe how industry actors have contributed to the Swedish heat pump transition and how firm-level industrial dynamics have changed during the transition. The concept of coopetition describes the changing interrelations within and between heat pump value networks during the transition. Finally, the concept of complementarities is used to explore and analyse how interdependencies, value networks and coopetition dynamics have developed and changed during the transition.

This chapter starts by presenting the conceptual framework of the thesis and its theoretical background in greater detail. The following part discusses the theoretical positioning of this thesis in the fields of industrial dynamics and transition studies and goes deeper into the background of the conceptual framework. The final part of this chapter presents and discusses the research structure and methods applied in the thesis.

3.1. Conceptual framework

The conceptual framework used here began as an extension of work by Blomkvist and Larsson (2013) and Blomkvist and Johansson (2014) and has been further developed by Blomkvist and Johansson (2016) and in this thesis, and in parallel with Blomkvist and Nilsson (2017).

The idea of value networks aggregates actors into groups based on their business logics and their active participation in business models. The coopetition concept describes how different value networks and complementarities can be in both competitive and collaborative (synergistic) relations at the same time. The concept of complementarities encompasses the organisational, technological, institutional and infrastructural features that describe interdependencies and synergistic relations between elements or system components (thereby generating positive externalities) in socio-technical systems. The misalignment of complementarities may cause structural tensions to appear, which in turn invites entrepreneurial activity (Dahmén 1989, 1991).

A more detailed description of each of the foundations of this conceptual framework appears in the following sub-sections.
3.1.1. Value networks

The value networks concept has its background in management research (Håkansson and Snehota 1995; Allee 2000; Moore 2006). A value network can be viewed as ‘any purposeful group of people or organisations creating social and economic good through complex dynamic exchanges of tangible and intangible value’ (Allee 2009, p. 429). A value network includes both social and technological components, but does not include the current institutions, i.e. the ‘rules of the game’.

According to Verna Allee, all organisations – companies as well as governmental agencies and non-profits – can be described and understood as value networks (Allee 2000). The value network concept, in Allee’s wide definition, can thus be applied to units within an organisation as well as to relations between organisations. In this thesis, industrial value networks will mostly be discussed on a firm level, i.e. what Allee describes as ‘external-facing value networks’. An external-facing value network includes networks between ‘the organisation and its suppliers, its investors (including venture capitalists), its strategic business partners (e.g. a business with a complementary product), and its customers’ (Allee 2009). This definition is also in line with Clayton Christensen’s (1997, p. 296) definition of a value network as a ‘collection of upstream suppliers, downstream channels to market, and ancillary providers that support a common business model within an industry’.

There exist well-developed tools for describing a firm’s business model (e.g. Osterwalder et al. 2005) and established frameworks for delimiting value networks (Peppard and Rylander 2006). In this paper, the boundaries of the studied value networks are set by mapping actors directly to focal business models related to heat pumps.

Figure 9 shows a hypothetical example of two suppliers with two different value network types that involve slightly different business logics. The main suppliers (e.g. heat pump manufacturers and importers) appear in the middle in blue, with upstream suppliers and downstream channels in light blue. The cross-network actors – or actors directly involved in more than one value network, such as technical universities, energy companies and industry associations – appear at the top in yellow and the customers are in green at the bottom of Figure 9.

The mapping of value networks in this thesis is delimited to the network of actors that have direct influence on the core common business model in the value networks under examination. For example, if a supplier’s supplier has little direct influence on the common business model, then it is not included in the value network mapping.
Figure 9: Illustration of a simple value network including two supplier types with different business logics

In academic research, the value network concept is closely related to and interlinked with the concepts of business networks (Håkansson and Snehota 1995) and business ecosystems (Moore 2006). Both business networks and business ecosystems can be viewed as types of applied value networks. The literature around these different concepts highlights the collaborative or coopetitive nature of value networks and the co-evolutionary aspects of industrial and economic development.

Note that a distinction is made between individual value networks (e.g. the value network surrounding a certain heat pump manufacturer, such as Thermia or IVT) and value network types (e.g. the value networks of Thermia and IVT are of the same type, since they have similar industrial background and the same core business logic).

As discussed by Herbert Simon (1955), analyses of decision making by economic actors should not treat them as rational actors with access to perfect market knowledge. It can be more fitting to describe them as ‘boundedly rational’, looking for satisfactory solutions rather than optimal ones. The value network perspective does not give complete insight to the rationales of the actors coupled to a value network, but it
does illustrate the logic of the value network, which can be assumed to constitute a part of the rationale of value network actors.

3.1.2. Coopetition

The concept of coopetition is used to describe the simultaneous and paradoxical existence of both complementary and competitive relations between actors. Bengtsson and Kock (2000) explain:

‘Actors involved in coopetition are involved in a relationship that on the one hand consists of hostility due to conflicting interests and on the other hand consists of friendliness due to common interests. These two logics of interaction are in conflict with each other and must be separated in a proper way to make a coopetitive relationship possible’.

The coopetition concept describes how actors interrelate and co-evolve in socio-technical transitions from these two conflicting logics of interactions. It permits one to gain a more nuanced perspective on actor interactions during a socio-technical transition and on how external relations of firm-level actors change during that transition. For example, an incumbent actor may both compete and cooperate with a new entrant who is offering a sustainable and potentially disruptive technology to the market. In such a case, the incumbent is not trying solely to either support or hinder this potential transition process.

Current dominant approaches to transition studies have been critiqued as too structuralistic and functionalistic in their approaches towards actors, i.e. not taking the complexity of actor roles, rationales and influences in socio-technical transitions into sufficient account (cf. Foxon 2011; Farla et al. 2012; Markard et al. 2012; Fuenfschilling and Truffer 2016). Approaches that divide actors into binary types, e.g. as either regime-level or niche-level actors (Geels and Schot 2007) or as enactors and selectors (Suurs and Hekkert 2012), provide limited room for analysing the complex actions of actors and changes in their roles and interrelations during the time period of a transition.

Sjoerd Bakker (2014) shows that there are many reasons for incumbents to partake in transition activities, both short- and long-term, even though the transitions are not always aligned with their own interests. Admittedly, the value network perspective does not give insight into the rationale of actors, but it tells something about what the bounded rationality of the studied actors might be and it avoids the pitfall of sorting actors into those who fully support or fully oppose a transition. More background on socio-technical transition studies will be given later in this chapter.
This thesis seeks to highlight significant changes in value network and coopetition dynamics during the Swedish heat pump transition. There exist few studies on how coopetition dynamics change during a socio-technical transition, but there are many adjacent research fields from which relevant knowledge can be drawn, such as industrial dynamics and strategic management, as will be further discussed later in this chapter.

The approach used in this chapter to analyse the changes in value network and coopetition dynamics incorporates the dynamic analytical concepts of complementarities, structural tensions, and development blocks.

### 3.1.3. Complementarities

The Swedish heat pump transition has been characterised by multidirectional causalities between and across system elements. In co-evolutionary studies situated in complex settings, such as the Swedish heat pump transition, it becomes less meaningful to discern dependent and independent variables and more meaningful to focus on dynamic relationships between elements in the studied system (Lewin and Volberda 1999). For such types of studies, the dynamic analytical concept of complementarities can be useful.

The complementarity concept is a systems-related concept. Markard and Hoffmann (2016) state, ‘Complementarities arise if the value of a combination of specific elements or assets is greater than the sum of the value of each individual element.’ This definition lies close to the classic definition of a system as a whole that is greater than the sum of its parts (cf. Bertalanffy 1950).

In this thesis, the concept of complementarities is used to explore and analyse how relational interdependencies and coopetition dynamics have changed during the transition towards heat pumps in Sweden. This application of the concept is inspired by the work of Swedish economist Erik Dahmén (1989, 1991), who originally introduced the concept in his licentiate and doctoral theses (Eklund 2005; Dahmén 1950). Dahmén explained that development happens in ‘blocks’ of complementary investments and that an investment in a new venture can create pressure (or tensions) for complementary investments to be realised: ‘Economic success at certain stages in a development process might require the realization of one or more specific complementary stages’ (Dahmén 1989, p. 138). Without these complementary stages or investments, the potential of the original venture may never be fulfilled. Development blocks that lack complementarities risk collapsing under negative ‘transformation pressure’.
Dahmén (1991) defined a development block as ‘a sequence of complementarities that by way of a series of structural tensions, i.e. disequilibria, may end up in a balanced situation’. Dahmén stressed that for a development block to be complete – for it to reach its developmental potential – there must be a good fit between organisational, technological and institutional complementarities. A development block that cannot realise the next developmental stage is still incomplete, but may become complete at a later point.

Dahmén himself said that this analytical approach belonged to what he called ‘Schumpeterian dynamics’ (Dahmén 1989, p. 137), by which he meant the transformation of industries and economies in change processes as described by economist Joseph Schumpeter. Dahmén’s approach followed Schumpeter’s focus, which was not on economic equilibria and optimal allocation of resources (as was the dominant approach in established literature at Dahmén’s time) but on the disequilibria of economic development and industrial transformations. Dahmén introduced the concept of structural tensions to conceptualise economic disequilibria as tensions between complementary parts in different development stages (Dahmén 1991).

The concept of structural tensions can be compared to the concepts of ‘salients’ and ‘reverse salients’ developed by Thomas Hughes (1983), which have a close family resemblance to that of Dahmén (Novotny and Laestadius 2014). Hughes borrowed the term ‘reverse salient’ from military history. It denotes a passage that cannot be passed through, creating a backwards bulge for the advancing front. A famous historical example is the battle for Verdun, where the German front was halted by the reverse salient of Verdun, held by the French. In the same way, Hughes describes reverse salients appearing in tightly connected large technical systems, where they lag behind and hinder the development of the whole system. A structural tension, like a reverse salient, creates an impulse for innovation, but only if it is recognised as such by entrepreneurs, innovators or system builders (Blomkvist and Johansson 2016).

Dahmén’s concepts are not used here as part of a full ‘Dahménian approach to economic development’ (cf. Enflo, Kander and Schön, 2008; Schön, 2012), but more in line with how the concept of complementarities has been used in recent transition studies, as a stand-alone concept to describe interdependencies and synergistic relations between elements or system components that generate positive externalities in socio-technical transitions (cf. Geels 2004; Coenen, Benneworth and Truffer 2012; Markard, Raven and Truffer 2012; Markard and Hoffmann 2016).
3.2. Theoretical positioning

The theoretical positioning of this thesis is in close relation to the research fields of industrial dynamics, socio-technical transition studies and strategic management, and knowledge is drawn from all three of these research fields.

3.2.1. Industrial dynamics

The Swedish heat pump transition is closely linked to the heat pump–related industrial transformation in Sweden. Much knowledge can be drawn from studies and theories in the field of industrial transformation and dynamics to shed light on how industrial developments have contributed to the Swedish heat pump transition, and on the changing interdependence between the Swedish heat pump sector and energy system during this transition.

Industrial dynamics research is a relatively new field with its theoretical roots in micro-economics, innovation theory and evolutionary economics (Blomkvist et al. 2016; Carlsson 2016). But its roots date back much further, to the work of Joseph Schumpeter (1911, 1942) and other important influences such as Erik Dahmén (1950, 1991), Herbert Simon (1955), Nelson and Winter (1982) and Giovanni Dosi (1982), among others.

Industrial dynamics research teaches that economic growth can be described but never explained at a macro level (Carlsson 2016), and that a combined micro and macro perspective (or a ‘meso’ perspective) is useful to understand economic growth.

One of the main themes of industrial dynamics is the study of the boundaries of the firm and the degree of interdependence among firms, and how these factors change over time (Carlsson 2016) – e.g. the study of industry life cycles (ILCs). An ILC represents the pattern of business and innovation evolution of a given industry. Research on ILCs shows how an industry passes through different dynamic phases in relation to innovation, market structures, growth, and mergers and acquisitions during its life cycle (Utterback and Abernathy 1975; Abernathy and Utterback 1978; Utterback and Suaréz 1993; Utterback 1994; Klepper 1997; Klepper and Simons 2005; Malerba 2006).

A new ILC is typically initiated by a process of ’creative destruction’, in which radical technical innovations transform existing industries and create new values by destroying previous economic structures and values (Schumpeter 1942). Creative destruction thus gives birth to new industries that grow, mature and eventually, again through the process of creative destruction, die.
A new industry typically undergoes several stages of innovation focus. According to William Abernathy and James Utterback, the focus in the early (fluid) stage is typically on product innovation. As the industry evolves, the focus on product innovation decreases while that on process innovation increases. As the industry becomes increasingly stable, investments in both product and process innovation decrease (Utterback and Abernathy 1975; Abernathy and Utterback 1978). The shift from product to process development is typically marked by the appearance of a dominant design, which Utterback and Suaréz (1993, p. 1) describe as following:

‘A dominant design usually takes the form of a new product (or set of features) synthesized from individual technological innovations introduced independently in prior product variants. A dominant design has the effect of enforcing or encouraging standardization so that production or other complementary economies can be sought’.

The entry of a dominant design is also related to changes in actor dynamics in an evolving industry. According to Klepper (1997), the first phase of an ILC is characterised by small markets, large uncertainties, and low entry levels, with many actors joining the industry. After this initial phase, the competition increases, primarily through product innovation. After the appearance of a dominant design, the number of actors exiting the industry increases, and eventually the market is dominated by only a few actors (Klepper 1997, pp. 148-49). Utterback and Suaréz (1993, p. 1) sums up the changes in actor dynamics in an ILC in this way:

‘Prior to the appearance of a dominant design, we expect to see a wave of entering firms with many varied, experimental versions of the product. Following the dominant design, we expect to see a wave of exits and consolidation of the industry.’

The research on ILCs show how tightly coupled the patterns of actor dynamics are with patterns of innovation and technological development, and the ILC concept can be a useful tool helping the transition analyst to understand changes in actors’ behaviour during socio-technical transitions.

Recent advancements have also included a co-evolutionary, or coopetitive, perspective on ILC studies. For example, Hynes and Wilson (2012) propose that early and late stages of an ILC are characterised by co-evolutionary dynamics, whereas the middle stage (the period of growth after a dominant design has been established) is characterised by survival of the fittest.
Although the ILC concept has a great range of applicability, life cycle literature (including product, technology and industry life cycles) has been criticised as inconsistent (Routley et al. 2013) and even as confused and incomplete (Taylor & Taylor 2012). It has been shown that ILC dynamics vary across industries and that the applicability of ILC theory depends on the industrial context (Klepper 1996, 1997; Routley et al. 2013).

When industry evolution is studied at a finer level, the application of life cycle theories becomes even more difficult. Vermeulen (2012) conducted an in-depth exploration of the interrelations and interdependencies between firms, value networks and industry development. Vermeulen found that value networks did not pass through uniform life cycle phases, as compared to the generic life cycle stages of industry life cycles (Utterback and Suaréz 1993; Klepper 1997). Some reasons why value networks don’t have uniform life cycles are that the past form of a value network affects its future form (i.e. it is dependent on industrial history) and that firms have different needs and ways of focusing on increased efficiency (‘synergistic attuning’) versus combinatorial flexibility in different regimes (Vermeulen 2012). In other words, value networks are too context-dependent to permit generalisations concerning their patterns of evolution.

3.2.2. Transition studies

Industrial dynamics and transition studies are two closely connected and partially overlapping research fields. For example, innovation systems research (common in transition studies) is largely rooted in industrial transformation and dynamics research (Coenen, Benneworth and Truffer 2012). Conversely, innovation systems research can be seen as a sub-area of industrial dynamics research (Carlsson 2016).

Transition studies is a cross-disciplinary research area focusing on transitions of socio-technical regimes, or fundamental change in a set of processes that fulfils societal functions (Markard et al. 2012; Geels 2002, 2004). The Swedish heat pump transition can be understood as a transition of socio-technical regimes, away from oil boilers and electric heaters and towards heat pumps.

The conceptual framework of this thesis is generally consistent with the most common used frameworks used in transition studies (e.g. the multi-level perspective). Fridlund (1999) has argued that the concepts of a socio-technical system and a development block can be used interchangeably. Knowledge about the characteristics of socio-technical systems derived from transition studies, e.g. why a socio-technical system becomes destabilised and open to change, can thus also be useful
in understanding characteristics of development blocks, such as why they may develop more quickly in some periods than in others.

A transition study typically focuses on several units of analysis, but the core unit of analysis is usually the socio-technical regime that undergoes the transition (Bolton and Hannon 2016). The elements of a socio-technical regime fall into three main categories: actors (e.g. individuals, firms, government organisations), rules and institutions (norms, standards, regulations, user practices, etc.), and technologies and resources (e.g. knowledge, human capital, financial capital, natural resources) (Geels 2002, 2004; Verbong and Geels 2007). Geels (2014) stated that a socio-technical regime represents ‘the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems’. As an example, the Swedish energy system can be viewed as a socio-technical regime so as to characterise the dynamic stability of its existing political, economic, cultural, social, institutional and technological structures. The stability of regimes described by Geels is closely related to the stability and resistance to change that come from joint complementarities that are in balance, as described by Schön (2012, pp. 25–26).

The concept of socio-technical regime draws on knowledge from evolutionary economics and on the concepts of technological regime and technological paradigm (Dosi 1982; Nelson and Winter 1982; Dosi and Nelson 1994). The technological regime concept initially represented a set of shared beliefs among engineers and described trajectories of innovative processes in industrial sectors. The term ‘technological regime’ evolved into ‘socio-technical regime’ after discussions by sociologists (e.g. Bijker 1995) on the importance of including social actors such as researchers, policy makers, users and associations in the regime concept (Geels and Schot 2007).

Studies on the history and sociology of technology have also influenced the development of socio-technical transition studies (Hughes, 1983, 1987, 1992; Bijker, Hughes and Pinch, 1987). In fact, historians have long studied societal, industrial and technological transitions, but without explicitly defining them as transition studies (cf. Kaijser, Mogren and Steen 1988; Kaijser 1994; Blomkvist and Kaijser 1998; Högselius and Kaijser 2007). Studies entailing an explicit focus on socio-technical transitions towards increased sustainability are a more recent phenomenon.

A system perspective is useful to understand the tightly coupled interrelations and interdependencies among actors, institutions and technologies in a socio-technical transitions. A socio-technical system
can be considered as a whole that is more than the sum of its parts and as a system that is open to its environment; like all open systems, it is characterised by emergence, hierarchy, and equifinality (Von Bertalanffy 1950, 1968). A socio-technical system can also be viewed as a seamless web of social, political, economic, cultural, technological and institutional components (Hughes, 1983; Blomkvist and Johansson, 2016). This system perspective is just as foundational for the concept of a socio-technical system as for the concept of a development block.

The expressed need for increased environmental and societal sustainability has been a significant reason for the increased focus on socio-technical transitions in recent decades (van den Bergh, Truffer and Kallis 2011). According to Geels, the stated ambition of transition researchers is to provide insights to political and social actors to ‘help them manage and navigate the future transformation of society in sustainable directions’ (Geels 2011a, p. 194).

In transition studies, the term socio-technical transition is often used synonymously with sustainability transitions. The difference between the two is that a sustainability transition explicitly focuses on socio-technical transitions towards increased sustainability – addressing grand challenges such as climate change (Weber and Rohracher 2012) or limits to growth (Meadows et al. 1972) – and therefore is typically focused on guidance and governance perspectives (Markard, Raven and Truffer 2012).

Van den Bergh et al. (2011) divides current approaches to sustainability transitions into four categories: innovation systems, multi-level perspectives, transition management based on complex systems analysis, and evolutionary systems and multi-agent modelling. The distinctions between these four approaches are not very sharp, however. The two approaches that have perhaps gained the greatest traction with the transition research community are the Technological Innovation System (TIS) approach and the Multi-Level Perspective (MLP) approach.12

The MLP approach to transitions was developed by Rip and Kemp (1998) and Geels (2002). The analytical levels in the MLP encompass three dimensions: a landscape level (which constitutes the contextual

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12 In my own experiences – from attending the International Sustainability Transitions 2016 conference and being a member of the Sustainability Transitions Research Network (transitionsnetwork.org) – most transition scholars tend to prefer these two approaches to transition studies.
environment), a socio-technical regime level (e.g. the energy system with its technological, institutional and organisational set-up), and a socio-technical niche level (where innovations can be formed and developed without being exposed to market mechanisms). Geels (2014, p.3) summarises the MLP framework as follows:

‘In a nutshell, the core logic is that niche-innovations build up internal momentum (through learning processes, price/performance improvements, and support from powerful groups); changes at the landscape level create pressures on the regime; and destabilisation of the regime creates windows of opportunity for the diffusion of niche-innovations. The alignment of these processes enables the breakthrough of “green” innovations in mainstream markets where they struggle with the existing regime on multiple dimensions (economic, technical, political, cultural, infrastructural).’

The value network perspective is not well aligned with the division of actors into niche or regime-level actors. The Swedish heat pump transition is an example of a transition when technologies and innovations developed within the existing socio-technical regime, rather than in a niche where it would be protected from market mechanisms. Instead of being developed by niche actors outside the dominant regime, heat pump technology was picked up and supported by incumbents at a very early stage, long before it had been proven as a reliable technology. Therefore, the division of actors into niche-level and regime-level actors provides little explanatory power in this instance.

The other dominant transition studies approach in transition studies is the technological innovation systems (TIS) approach, which focuses on dynamic knowledge and competence networks – or flows of knowledge and competencies – in a system, often relating to synergistic clusters of technologies within an industry or a group of industries. TISs can be seen as a set of structures (i.e. actors and institutions) and functions (what ‘happens’ in the system). The TIS framework, which stems from innovation system studies, was not originally designed for studies of socio-technical transitions but has developed over time into a key framework for this purpose (Markard, Hekkert and Jacobsson 2015). TIS-oriented studies have shown that formal networks play a crucial role in the formation and build-up of such systems (Musiolik et al. 2012), and this finding has helped to encourage study of value network dynamics in socio-technical transitions.

Both MLP and TIS are under continuous development (Geels 2011b; Markard, Hekkert and Jacobsson 2015) and are also becoming
increasingly integrated (Markard and Truffer 2008). One of the main differences between these two frameworks is that MLP has been more focused on the stability (and destabilisation process) of existing socio-technical regimes while TIS has been more geared towards innovative performance of a system. Both approaches have also been criticised for inadequate focus on actor agency, conflicting interests among actors, and ‘politics in transition’ (Farla et al. 2012; Markard, Hekkert and Jacobsson 2015). Critics have called for a more explicit conceptualisation of actor strategies and resource mobilisation in transitions (Farla et al. 2012).

This expressed need for a conceptualisation of actor strategies and conflicting interests among actors in socio-technical transition studies have acted as a motivation for the development of the conceptual framework of this thesis.

3.2.3. Strategic management

Transition studies focusing on the role of firms and firm strategies in transitions has increased over the last decade (Smith et al. 2005; Genus and Coles 2008; Markard and Truffer 2008; Farla et al. 2012; Markard et al. 2012; Berggren et al. 2014; Fuenfschilling and Truffer 2016; Bolton and Hannon 2016). Firms are at the core of sustainability issues in transition studies as upholders of unsustainable business practices as well as sources of innovation and solutions to sustainability problems. Incumbent firms may attempt to either hinder (e.g. Jacobsson and Johnson 2000; Jacobsson and Bergek 2004) or support transitions (e.g. Dzebo and Nykvist 2017). But often, an industry actor’s relation to transitions is more complex than either of these options (cf. Bakker 2014).

Transition studies focusing on the role of firms and firm strategies can draw on knowledge from the literature of strategic management.

Strategic management is a wide area which spans many fields and approaches to strategy and management. The typical questions for a strategist concern ‘the purposes, direction, choices, changes, governance,

13 As is typically the case with new research strands, several new concepts have been developed in parallel, each based on different motivations for analysing the role of firm strategies in sustainability transitions; these include co-evolutionary frameworks (Foxon 2011), agent-based modelling approaches (Holz et al. 2015) and theoretical concepts of institutional work (Fuenfschilling and Truffer 2016). Yet another is the business model–oriented approach to transition studies (Boons and Lüdeke-freund 2013; Wells 2013; Tongur and Engwall 2014; Bolton and Hannon 2016; Schaltegger et al. 2016; Wainstein and Bumpus 2016).
organization and performance of organizations in their industry, market and social, economic and political context’ (Pettigrew, Thomas and Whittington 2002, p. 3). This thesis foremost draws on knowledge from the field of strategic management relating to the concepts of business models, value networks, coopetition and dynamic capabilities.

Business model research has gained much attention within strategic management research during the last decade largely due to the work by Osterwalder et al. (2005). Osterwalder’s concept of the business model canvas has quickly become an established tool in both industry and academia for evaluating business models, i.e. how firms can create, deliver and capture value. Recently, however, others have criticised this concept as representing too static a perspective on the use of business models (Gabriel and Kirkwood 2016; Cosenz and Noto 2017) and have emphasised the need for a more dynamic perspective (Cosenz and Noto 2017).

The value network and coopetition concept are consistent with the business model concept but with increased relational focus. Combined with the dynamic analytical concept of complementarities it provides a dynamic approach to the development and changes in external relations of an organisation and its core business model.

The conceptual approach in this thesis can also be compared to the ‘dynamic capabilities’ approach on how organisations can develop strategic agility and manage technological transitions (Teece, Pisano and Shuen 1997; Teece 2007).

Teece et al. (1997) defines dynamic capabilities as:

‘the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions’.

The process of allocating and mobilising external resources and competencies, as described by Teece, Pisano and Shuen (1997) and Teece (2007), is consistent with and comparable to the process by which companies manage external coopetitive relations in their value networks in order to manage, develop and align complementarities during a socio-technical transition.

The conceptual framework introduced in this thesis can potentially contribute to the expressed need for a dynamic perspective on business models and offer an analytical tool for organisations to develop and manage external relations and partnerships in order to improve their
organisational flexibility and capability to manage comprehensive socio-
technical transitions.

3.3. **Research structure and methods**

This thesis relies on extensive data related to technological, institutional and organisational developments in heat pumps. Data collection began in 2012. The compilation and presentation of data follow the logic of the conceptual framework presented previously. The delimitation of the data presented in this thesis is based on the areas of the Swedish heat pump industry, the Swedish heat pump sector and the Swedish energy system.

3.3.1. **Structure of the empirical data presentation**

The empirical description on the Swedish heat pump transition covers the next seven chapters of this thesis. Chapter 4 presents the industrial background to the developments that would eventually grow into the Swedish heat pump industry. Chapters 5–9 present five different phases of the Swedish heat pump transition. The division of the transition into these five phases is primarily based on changes in value network dynamics within the Swedish heat pump sector.\(^{14}\) The content of these five chapters is guided by but not limited to the time frame of each phase.\(^{15}\)

The five time frames are as follows:

- Chapter 5: a formative period, about 1970–1979
- Chapter 6: a period of early heat pump market expansion, about 1979–1985
- Chapter 7: a period of negative transformation pressure, about 1985–1995
- Chapter 8: a period of strong market expansion in Sweden, about 1995–2005
- Chapter 9: a period of internationalisation and expansion into new markets, about 2005–2015

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\(^{14}\) The periodisation of the Swedish heat pump transition into these five phases was determined through an iterative process in which several different periodisations were tested, the first based on the division of periods proposed by Nilsson et al. (2005).

\(^{15}\) For example, it may be necessary to explain the background of a development in one phase by describing developments in a previous phase. Also, developments that start in one phase may stretch into the following phase, but it would be confusing to divide the description of such a development across two separate chapters, so such stories are told in their entirety in one chapter.
Each of these chapters is structured so that the societal context, policy and energy system developments related to heat pumps are presented first. After that, the developments in the heat pump sector is described, down to the value network level. The value network and coopetition dynamics related to the development of complementarities are summarised at the end of each chapter.

The final empirical chapter, Chapter 10, covers the status of heat pumps around 2015 and discusses the outlook for heat pumps in Sweden and Europe.

### 3.3.2. Definitions and delimitations

Co-evolutionary studies have multiple units of analysis (Lewin and Volberda 1999), and so does this thesis. The units analysed include value networks and complementarities in the Swedish energy system and the Swedish heat pump sector. The complementarities in the Swedish energy system and the Swedish heat pump sector (i.e. the complementarities of the heat pump development block) change in different periods – in other words, what is a complementarity in one period may not be so in another period. Therefore, the empirical description will not be based on a description of a single ‘Swedish heat pump development block’ but will instead focus on two main entities: the Swedish energy system and the Swedish heat pump sector.

The heat pump sector is here used as a wider entity than the Swedish heat pump industry. Following Merriam-Webster (2017), an industry described in this thesis is defined as a ‘distinct group of productive or profit-making enterprises’, i.e. heat pump manufacturers and profit-making enterprises related to them (e.g. suppliers, installers, retailers). The Swedish heat pump sector, on the other hand, also includes non-profit organisations and cross-network actors.

A cross-network actor is directly involved in more than one value network in the heat pump sector. Examples of cross-network actors are technical universities, energy companies and industry associations. A

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16 Dahmén (1991, p. 13) stresses that industrial transformation cannot be separated from ‘historical circumstances’ and that studies of economic phenomena should be put in a broader context of ‘social, political, institutional, psychological, ideological, and other dimensions in which they occur’. Similarly, Lewin and Volberda (1999) note the importance of including historical circumstances and ‘economic, social, and political macrovariables’ in organisational co-evolutionary studies. That is also why the ‘macrovariables’ related to the transition towards heat pumps in the Swedish energy system are included and described in the beginning of Chapters 5–9.
cross-network actor is not limited to supporting activities as described by Porter (1985, 1991). Cross-network actors are autonomous and have their own agendas. They can contribute to creating an innovative environment for industry and can shape the environment of heat pump technology.\footnote{Cross-network actors can sometimes be considered as intermediaries between (not within) value networks. In innovation systems literature, intermediaries are seen as ‘an intermediate organisation that functions in the midst of the users and producers of knowledge’ (Smedlund 2006, p. 210). An intermediary organisation has a ‘network brokerage function’ to overcome market and system failures by helping to close the information gaps between actors in the system (Klerkx and Leeuwis 2008). In socio-technical transition studies, intermediary organisations are also seen as important actors in the process of reconstructing the institutional frameworks surrounding a technology or innovation (Bush et al. 2017). Two examples of prominent intermediary cross-network actors in the Swedish heat pump transition are the technical university KTH and the energy company Vattenfall.}

The ‘energy system’ is defined in this thesis as a large socio-technical system focused on the supply of energy. The energy system can be divided into two interrelated and overlapping sub-systems: the heat energy system and the electricity energy system. Each system consists of actors, rules, institutions, technologies and resources that contribute to the societal function of supplying heat or electricity, respectively. Since heat pump technology runs on electricity and supplies heat, it is connected to both the heat energy and electricity energy systems. Hence the discussion of energy system developments in this thesis is not limited to either sub-system. Moreover, it includes large-scale developments (e.g. expansion of nuclear power) and other occurrences that directly influenced heat pump sector developments. Describing complementarities in the heat pump development block means that the technological delimitation is wider than simply covering Swedish heat pump technology itself, because this technology develops in interaction with many other parts of the energy system, including developments of oil usage, district heating, electric heating, and electricity production developments.

The spatial delimitation of the description of the Swedish energy system and heat pump sector goes beyond the geographical boundaries of Sweden. Both the Swedish energy system and the Swedish heat pump sector are and have been tightly associated with developments outside Sweden. Heat pump knowledge and artefacts have been imported from other countries, and the Swedish-based heat pump industry has expanded across Scandinavia and Europe, even reaching North America. The delimitation of developments outside Sweden has focused on those
events that can be directly connected to Swedish industry and energy system developments relating to heat pumps.

The time-related delimitation of this thesis has followed the recommendation by Lewin and Volberda (1999, pp. 527–528) that organisational co-evolutionary studies should cover a long period of time and should take the historical context of the studied actors and their environments into consideration. In general, the thesis covers the years 1970 to 2015, but events prior to 1970 are included if they are significant in shaping the later historical context.

### 3.3.3. Sources and source criticism

The empirical data gathering in this thesis has been based mainly on printed source materials, interviews with informants who were active in the Swedish heat pump sector between 1970 and 2015, and literature. I have sought to use a wide variety of sources to strengthen the validity of the thesis by triangulating findings through independent sources and by using materials based on contemporary and primary data (cf. Ågren 2005). To further strengthen the validity of my work, earlier drafts have been continuously evaluated by senior researchers and supervisors involved with this research project, and key informants have also been given the opportunity to read drafts and offer feedback (cf. Yin 2013, 2014).

The gathering of empirical data in this thesis can be divided into two parts: a pre-study from early 2012 to early 2013, and a main study from 2013 to 2017. In the pre-study, the collection of empirical data followed an exploratory, flexible and opportunistic data gathering process (Eisenhardt 1989, p. 533). For example, an interview with one informant might lead to establishing new contacts with potential new informants, or reading one report could direct me to other useful reports.

In this pre-study, I carried out an initial mapping of the heat pump sector and transition in Sweden, identifying early research questions that would later guide the searches and delimitations of the main study. The interviewed informants in the pre-study\(^\text{18}\) were affiliated with either KTH\(^\text{19}\) or the heat pump interest organisation SVEP (or both) in some

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\(^{18}\) The interviewed informants in the pre-study included Dr. Fredrik Lagergren, Jan-Erik Nowacki (two interviews), Prof. Emeritus Eric Granryd (three interviews), Dr. Martin Forsén (two interviews), Anne-Lee Bertenstam, and Prof. Björn Palm.

\(^{19}\) KTH has been active in heat pump–related research for many decades and KTH-affiliated researchers have been part of the Swedish heat pump transition since the 1970s. During the pre-study, several informants from KTH encouraged my continued investigation of the
way. The interviews were in-depth and flexible. The informants were told that the research concerned an effort to map the Swedish transition towards heat pumps. They were not given any information concerning any hypotheses of the interviewer. The questions were open-ended and I sought to avoid any value-laden formulations that might influence the informants’ answers.

After the pre-study, two preliminary research questions were formed: why was the transition towards heat pumps so early in Sweden (compared to other similar countries), and how had Swedish industry influenced this transition? These two questions guided the initial search during the following part of the study.

The main study was less opportunistic and more focused on uncovering unknown information relating to the heat pump transition. More focus was also devoted to triangulating data so as to determine if multiple, independent data sources confirmed the findings.

The interviews in the main study were still flexible but more structured than those in the pre-study. A wide range of informants with varying academic, governmental and industrial backgrounds were included. Some informants were asked to participate in a second or even a third interview, including informants from the pre-study, if questions remained unresolved or if potential new findings required confirmation by other sources to be considered sufficiently reliable. The interviews in the main study were also open-ended and avoided value-laden formulations, but they were more closely guided by a questionnaire designed prior to the interviews. The questionnaire was slightly modified for each interview depending on the background of the informant and the current status of the data collection process, e.g. what issues still needed to be covered or what findings awaited triangulation with an independent source. Questions falling into these categories were not always open-ended but always placed near the end of the interview, to avoid steering the key informant into discussing what he or she perceived as the topics of greatest concern to the interviewer and the

Swedish heat pump transition. In the main study, informants from other organisations than KTH were targeted to complement the findings from the KTH informants.  

20 The interviewed informants in the main study included Lars Segerstolpe, Svante Färnbo, Dr. Anders Johansson (two interviews), Sven-Allan Eklund (three interviews), Lennart Spante (two interviews), Hans Lindström, Bengt Sandström, Lars Kastengren, Leif Olsson (two interviews), Thomas Nowak, Prof. Emeritus Enno Abel, and Tomas Hallén.
The interviews ranged in length from about 30 minutes to more than three hours, with an average of slightly over 90 minutes. For an example of an interview form, see Appendix II.

The printed source material used in both the pre- and main study included governmental reports, research articles, magazines, newspapers, documented presentations, etc. One source worthy of special mention, which makes the present thesis unique in comparison to previous studies, is Vattenfall’s company archives. Physical access to these extensive archives (in the catacombs of Vattenfall’s main office in Solna) was granted in early 2014 through the assistance of Vattenfall Culture Heritage Committee member and Vattenfall employee Svante Färnbo. This opened up a vast source of contemporary material from primary sources on the development of the Swedish energy system and Vattenfall's involvement in the development of the Swedish heat pump sector. Unfortunately, my access to these archives ended when Svante Färnbo retired from Vattenfall at the end of 2015. This data source also created a risk that data selection could become skewed towards Vattenfall’s sources. This in turn intensified the need for considerations of source criticism; e.g. any potential bias tendency of Vattenfall’s material needed to be considered (was it in Vattenfall’s interest to convey any specific angle on what was being told, was the material produced for marketing purposes or for internal use, etc.) and whether other independent sources confirmed the information obtained from Vattenfall. (These measures were taken with data from all sources, of course, but the great amount of data derived from Vattenfall called for special attention to avoiding bias.)

Other sources of material used in this thesis included the heat pump interest organisation SVEP (subsequently SKVP), the European Heat Pump Association, the Heat Pump Centre in Borås, journal articles, the Thomson Innovation patent database, the International Energy Agency and Swedish Energy Agency, Folksam’s insurance reports on failed heat pumps, research reports from Swedish technical universities, annual

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21 Informants were never directly asked to verify a finding from another source. Instead, much care was taken so that questions would guide the informant to the specific topic where complementary or confirmatory information was sought, but without revealing what finding in this area needed to be complemented. 

22 For example, journal articles on heat pumps from Svenska Dagbladet and Dagens Industri were located through the search engines of the National Library of Sweden and the Royal Institute’s Library in Stockholm.
reports from heat pump manufacturers, Elforsk, the Swedish Rikstad and additional governmental sources.

Published literature have been used to describe contextual developments that have influenced the Swedish heat pump transition, and sometimes as primary source material. For example, the book *Att ändra riktning* (In English: ‘To change direction’) by Kaijser et al. (1988) was treated as a primary source because of the writers’ proximity to Swedish heat pump sector developments in the 1980s and the reliability of the sources used.

In interpreting all the data collected, I carefully took into account the possibility that descriptions of certain events or developments may have been affected by bias, uncertain recollections, hearsay or other sources of inaccuracy. These issues were managed by taking the background of the informant or author into account and by using independent sources to triangulate the findings.

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23 The National Library of Sweden was an important source in helping me to find any available annual reports from heat pump manufacturers from the 1970s onwards.
4. The background of the Swedish heat pump industry

The heat pump technology was invented and had its first commercial application in the 1850s. But the Swedish heat pump industry did not start to take shape until the 1970s. When it did, there were three primary points of emergence: the international air conditioning industry, the Swedish refrigeration industry, and the Swedish heating (or HVAC) industry.

This chapter briefly describes the historical background of what would eventually become the Swedish heat pump industry. Understanding the background and context of the industry provides a basis for grasping the value network dynamics of the heat pump sector in later years.

4.1. A 19th-century invention

The first large-scale commercial applications of both small and large heat pumps took place in the USA and in European nations such as Great Britain and Switzerland during the 1930s (Egli 1940; Laue 2002). But by then, the heat pump was an old technology, invented over 70 years earlier.

William Thomson (1852), better known as Lord Kelvin, made the first known description of the heat pump principle in 1852 (Laue 2002). Thomson's advancements were preceded by both the invention of the first known patented refrigerator (by Jacob Perkins in 1834) and the introduction of the thermodynamic principles formulated by French physicist and military engineer Nicolas Léonard Sadi Carnot. Carnot had published an article in 1824, at age 28, on what is now known as ‘Carnot's cycle’, which is the basis for the second law of thermodynamics (Laue 2002). In that article, Carnot described how thermal heat can be converted to work and also how the opposite process could occur – important insights for developing heat pumps.

The first actual heat pump, following Thomson’s description, is believed to have been constructed in Austria in the mid-1850s by the inventor and industrialist Peter von Rittinger (Halozan 2005). It supposedly functioned at 14kW and was made to improve the economy of drying salt in Austrian salt marshes. Although the pump apparently functioned, the pilot was not successful and von Rittinger ended his heat pump projects after only a few years (Zogg 2008; Granryd 2011). For the next 70 years, heat pump projects were virtually non-existent, whereas the closely related field of refrigeration achieved substantial development of
technologies, turbines and compressors in the second half of the 19th century.

The world’s oldest heat pump still in operation is a 175 kW pump installed in the city hall of Zürich (Laue 2002). Before 1955, around 60 medium-sized heat pumps had been installed in Switzerland, using ground, lake and waste heat as heat sources (Zogg 2008). Switzerland’s strong turbine and compressor industry (e.g. Sulzer, Escher Wyss, and Brown Boveri) helped to make Switzerland a pioneering heat pump nation. The Swiss heat pump expansion died out with falling oil prices in the 1950s and 1960s, however, and did not make a comeback until the 1970s oil crises.

4.2. Heat pumps in the refrigeration industry

At the very heart of a heat pump is its compressor. And Swedish industry has had, like Switzerland, a rich industrial tradition and history of international successes in compressor and turbine manufacturing (Almqvist et al. 1992). The Swedish refrigeration industry followed its Swiss colleagues and delivered its first commercial heat pump appliances during the 1950s.

As a heat pump has the exact same main components as a refrigeration unit – a refrigerant, a compressor, heat exchangers, an expansion valve and steering equipment (as described in Fact Box 4 on page 48) – refrigeration companies had the competence and resources to supply heat pump products if there was demand for them.

The companies that delivered the first heat pumps produced turnkey, site-built products tailored to match specific customers’ needs. The refrigeration companies had existing supplier networks of all the main components to construct heat pump units – as stated above, they were the same as those for cooling units – and also gave their customers a guarantee concerning the quality and performance of a delivered heat pump unit. This meant that the heat pump suppliers in this network took responsibility for the contractors and their sub-contractors who installed the heat pumps. All in all, it was a tightly integrated value network.

One of the earliest and best-known successes in the Swedish refrigeration industry was the development of the safe and silent refrigerator by KTH students Baltzar von Platen and Carl Munters. During the 1910s, the inventor and professor Edvard Hubendick (inventor of, among other things, the famous Penta-engine manufactured at Skövde Mekaniska Verkstad, which later switched its name to Penta-verken and subsequently Volvo Penta) started teaching courses in refrigeration technology after a donation of equipment from...
an industrial partner of KTH. Munters and von Platen had Hubendick as their supervisor when they constructed their revolutionary refrigerator, which was acquired first by AB Arctic in 1923 and then by Electrolux in 1925. Electrolux achieved international success with the silent and safe refrigerator (Almqvist et al. 1992). Ever since Hubendick’s time, KTH has been a research centre on refrigeration and applied thermodynamics, and this research would play an important role much later in the heat pump transition.

Electrolux was one of several established and mature refrigeration companies, together with STAL Refrigeration, AGA and Frigoscandia, in the 1970s. The Swedish refrigeration industry developed in synergy with the Swedish turbine and compressor industry, led by Svenska Rotormaskiner AB (SRM) and STAL-Laval (currently Siemens) in Finspång (Almqvist et al. 1992).

The Ljungström compressor – a double rotational radial steam turbine – provided the basis for the formation of the two companies Ljungströms Ångturbin (which later became SRM) and Svenska Turbinfabriks AB Ljungström (STAL) in 1908 and 1913, respectively. The inventor Alf Lysholm worked for SRM in the 1930s, before he became a professor of steam technology, and in 1934 he developed the so-called Lysholm compressor, a screw compressor that had a major impact on the refrigeration industry in the 1960s. Until the 1990s, practically all global manufacturing of screw compressors for refrigeration appliances took place through licenses from SRM (STU 1988, s.13-15; Almqvist et al. 1992, p. 80–82). Lysholm’s screw compressor was in the range between 30 to 40 kW and therefore suitable for mid-sized heat pumps.

Another branch of the refrigeration industry was the heat exchanger industry, which included companies such as ALFA Laval, SWEP and the current heat pump manufacturer CTC. Swedish plate heat exchanger manufacturing has also been internationally successful, capturing about 30% of the global market for plate heat exchangers (Lagergren in Braunerhjelm et al. 2009, p. 116).

### 4.3. Heat pumps in the air conditioning industry

Reversible air-air heat pumps are the most common heat pump internationally as well as in Europe (Laue 2002). Although an air-air heat pump can both chill and heat the inside air, it is typically optimised for either cooling or heating. Internationally, it is more common to find air-air heat pumps optimised for cooling, or reversible air conditioning units. In fact, it is just recently that the globally dominant air conditioning manufacturers of international brands have started to
manufacture and supply the Swedish market with air-air HPs optimised for supplying heat and adapted to the cold Nordic climate.

The heat pumps that the Swedish refrigeration industry offered from the 1950s to the 1970s were always site-built heat pumps tailored for the customer’s need, which meant that they did not benefit from economy of scale and were relatively expensive products. As a result, individual homeowners’ potential interest in possessing a relatively small-sized heat pump was not met by the refrigeration industry. Instead, these homeowners had to look to the international air-air heat pump market to find a product suitable for their need.

The air-conditioning industry has its roots in the US, where the first air conditioning units that could run in reverse, i.e. air-air heat pumps, appeared in the 1930s (Zogg 2008).

The American market for air conditioning units and air-air heat pumps blossomed in the 1950s (Laue 2002; Granryd 2011). Inventor Willis Carrier laid the foundation for this market at age 25, when he created an air conditioning machine for the printing company that employed him. Further developments and applications resulted in the creation of Carrier Engineering Corporation, specialising in air conditioning appliances. The air-air HP development came from advances in air conditioning units that could run in reverse to supply heat during winter. The market for these air-air HP units expanded in the late 1950s, and in 1963 there were more than 300,000 air-air HP units in the US. But due to dependability problems, the market suffered a set-back and it took some time for public trust in the technology to be re-established (Granryd 2011; BFR 1975).

In the 1950s, the Japanese corporations Mitsubishi and Daikin began producing air conditioning units. Later South Korean companies, and more recently Chinese companies, have entered the competition with American brands for international markets. It is, by all measurements, a quite mature and international industry.

4.4. **Heat pumps in the Swedish heating industry**

The Swedish heating, or HVAC, industry has played a central role in the commercialisation of heat pumps amongst homeowners and the large-scale transition away from oil and towards heat pumps in the Swedish energy system.
Fact Box 5: Air-source heat pumps

<table>
<thead>
<tr>
<th>Diagram</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Air-air heat pump" /></td>
<td>The air is a good source of heat, considering its accessibility and the ease of installing outdoor units. The disadvantage is that air has its lowest temperature in winter when the heating demand is at its peak. The typical design of an air-air heat pump is relatively simple, with one outdoor unit taking up heat from the outside air and supplying it to the indoor unit, which gives off the heat indoors. This process can also be run in most modern air-air heat pumps. An air-water heat pump uses heat from the outside air to heat tap water or for space heating. Though the air-water heat pump typically has a larger-size outdoor unit so that it can function under the heavier loads that preparation of hot water requires. It has historically been challenging to control the operation of air-water HPs due to the varying temperature of the heat source. There was a boom of air-water heat pump sales in Sweden during the 1980s, but due to regulatory issues they almost disappeared from the market before computerisation facilitated the operation of these pumps (cf. Granryd 2010). The exhaust air heat pump uses air as a heat source, just like the two abovementioned heat pump types, but is different in that it is primarily a heat recovery technology. The exhaust air heat pump uses exhaust air in a house as a heat source to heat tap water and for space heating. Cold incoming air enters the house through supply air vents. The cold air is in turn heated by the space heating. The heated indoor air passes through the exhaust air heat pump as it is ventilated. The heat pump takes up the heat in the outgoing air for heating tap water and space heating.</td>
</tr>
<tr>
<td><img src="image2" alt="Air-water heat pump" /></td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Exhaust air heat pump" /></td>
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</tbody>
</table>
Unlike the previously mentioned industries, the heating industry had little to no experience or knowledge of refrigeration or heat pumping cycles before its first encounters with heat pumps in the 1970s and 1980s. The first mechanical workshops and manufacturing factories in the heating industry that started to assemble components into heat pumps had much learning ahead of them.

The typical business logic of heat pump manufacturers in the heating industry was different from that of the previously mentioned heat pump suppliers. When they started manufacturing heat pumps, they did not import ready-to-use heat pumps units as suppliers of air-air heat pumps did, nor did they deliver custom-made, site-built heat pump units as suppliers from the refrigeration industry did. Instead, they assembled their own heat pumps, typically adapted for hydronic heating systems and the cold Nordic climate, from components that they either made themselves or bought from a Swedish or international supplier.

Heat pump types for hydronic heating systems include air-water heat pumps, ground- or water-source heat pumps, and exhaust air heat pumps. Although several manufacturers in Sweden offer all these types, it was initially more common for a manufacturer to start by offering only one type.

The heat pump suppliers in the Swedish HVAC industry can be divided into two groups: ventilation entrepreneurs and pipe-laying entrepreneurs. The large Swedish company AB Svenska Fläktfabriken – generally referred to as Fläkt – is an example of a ventilation company that for a time manufactured heat pumps for its HVAC systems (Energiforskningsnämnden 1985). But primarily, the pipe-laying side of the HVAC industry has been responsible for heat pump technology.

Four of the most prominent HVAC companies (in terms of total sales) within the Swedish heat pump industry have been Thermia in Arvika, IVT in Tranås, Nibe in Markaryd, and CTC in Ljungby. IVT was not initially a player in the HVAC industry but entered it later, whereas Thermia, CTC and Nibe all had a background as heating product manufacturers. Thermia, CTC and Nibe have supplied over the years what the heating market has demanded, including electric and oil boilers. Heat pumps are a relatively new part of these established heating companies’ product offerings.

Thermia was founded in 1923 by the local industrial strongman Per Andersson as a manufacturer of cooking stoves. Its scope later widened to include water heaters, radiators, wood-fired and oil-fired boilers, and other heating products, and Thermia became a well-established supplier
to the Swedish HVAC industry (Sundelin and Lomander 1995; Thermia 2012).

CTC was, like Thermia, a heating product manufacturer initially founded in 1923. CTC took its name from the initials of the founders (Celsius, Tellander and Clarin) in Göteborg. In 1931, CTC started producing boilers for heating in Ljungby, where the company remains to this day. In the 1970s, CTC had a similar range of products to Thermia but was stronger in some product areas, such as heat exchangers (Leif Olsson, personal communication, 30 March 2016).

Nils Bernerup started Nibe in 1952 through the acquisition of a stove manufacturing company. In 1955, Nibe also began producing water heaters. Nibe was a typical heating company and domestic product supplier to the Swedish HVAC industry when it entered the heat pump area in the early 1980s, with around 300 employees at its production site in Markaryd (Nibe, 1983).
Fact Box 6: Ground-source heat pumps

There is large variation amongst ground-source heat pumps (GSHPs). The most common types are the vertical ‘borehole’ GSHP and the horizontal ‘earth’ GSHP. Another similar type is the water source ‘lake’ heat pump.

The vertical GSHP positions the collector in a borehole. Typically, the collector in the vertical GSHP is closed-loop, but there are also open-loop GSHPs that pump up the underground water instead of using a ‘brine’ to transport the heat as the closed-loop collector does. The borehole installation is the most common GSHP, mainly because it does not require occupying land area next to the house as the earth GSHP does (Björk et al. 2013, p. 23). The earth GSHP uses a horizontally positioned collector that is typically buried at a depth of about 0.7 to 1 meter. Both GSHP types have a fairly stable heat source during the year's seasons.

Water-source heat pumps (WSHPs) are less common than the GSHPs just described, but they were more prevalent during the earlier exploratory days of heat pumps, i.e. during the 1980s. A WSHP can use either an open or a closed loop. In the case of an open loop, the water is taken from a lake, sea or groundwater and passes through the evaporator, where the heat is extracted. The water is cooled down and then returned to the water source, preferably as far away from the extraction point as possible (Poppius 1984, p. 36). A closed-loop WSHP – as illustrated at left – instead uses a collector that takes up the heat from the water and has similar collector types to those in the vertical GSHP, but with the collectors immersed in a lake bottom or seabed instead. A challenge for these collectors is to fix the collectors to the bottom of the water basin. There have been several examples where the collectors of closed-loop WSHPs have floated up to the surface (Lennart Spante and Hans Lindström, personal communication, 17 February 2014).
5. The first phase: Pressure on the energy system and the formation of heat pump value networks in the 1970s

This chapter covers the time period during which the first value networks in the Swedish heat pump sector formed, primarily the 1970s. Value networks relating to heat pumps had first formed in the 1950s, when refrigeration companies began selling heat pumps as an add-on feature to place-built cooling or air conditioning units. But most of the formative activity of heat pump value networks took place in the 1970s, following intense developments in the Swedish energy system. During the 1970s, two international oil crises occurred, nuclear power expanded in the Swedish electricity grid, and energy supply became a central issue in Swedish politics.

The heat pump was an untested technology in Sweden in the 1970s, and a variety of different technological solutions were offered by the first heat pump suppliers. The value network structure around the first heat pump offerings was directly related to the industrial background of the central actors in the value networks. Most heat pump suppliers in the housing market had issues with either poor reliability, poor efficiency of performance, or both. To support the development of higher-quality offerings, both energy companies and technical universities started to engage in heat pump technology during the 1970s.

5.1. The societal and international context of heat pumps

The 1970s was an eventful period in the energy area at an international level and most certainly also for Sweden.

On October 6, 1973, Egyptian and Syrian forces launched a surprise attack on Israel during Yom Kippur, the most holy day in Judaism. Egyptian forces crossed the Suez Canal in the south at the same time as Syrian forces advanced into the Golan Heights, areas occupied by Israel since the Six-Day War in 1967. The attackers were initially successful but were eventually driven back by Israeli forces.

The US began to supply Israel with arms shortly after the start of the war. This caused the Organization of Arab Petroleum Exporting Countries (OAPEC) to declare an oil embargo against the US and its allies, including Canada, Japan, Netherlands and the United Kingdom. Within a year, the international price on crude oil had increased by 350%
(BP, 2012). Even though Sweden was not included in the boycott, the higher price of oil hit the Swedish economy hard. Before the oil crisis, about 75% of all Swedish energy supply was based on oil (Energimyndigheten 2008). Few other nations had such a high level of oil dependency (Vattenfall, 1981c), which meant that the oil crisis put significant transformation pressure on the Swedish energy system. There were considerable disagreements in the Swedish parliament on what efforts Sweden should take to reduce its oil dependency. The road ahead was anything but mapped out.

The oil crisis in 1973 ruffled the Swedish energy system, but was at the time not expected to lead to any long-term difficulties for Swedish growth. Large-scale investments in Swedish industry continued after 1973, and in 1975 the Swedish economy was at a relative economic peak compared to other western nations (Schön 2012). But after 1975, Sweden also landed in a deep economic recession.

The 1973 oil crisis did contribute to the start of several governmental projects and efforts aimed at reducing Sweden’s dependence on oil, which had a direct effect on the formation of a Swedish heat pump sector.

5.2. Energy system and energy policy developments

In response to the situation, the development of the Swedish energy system took a new track, with increased politicisation.

5.2.1. Energy system developments before the first oil crisis

Up until the 1973 oil crisis, the Swedish energy system had been characterised by a stable supply of energy at relatively low prices. Exploitation of the rivers in northern Sweden gave a stable supply of domestically produced electricity, but the primary source of energy supply (71% as of 1973) was oil, followed by water (13%), biomass (9%) and coal (4%) (Energimyndigheten 2015c).

The corporate agency Vattenfall, an electric utility, played a central role in the build-up of the Swedish energy system. Up to 1992, Vattenfall acted as both a power generation company and transmission system operator (TSO) and was responsible for expanding its generation capacity to match long-term demand as well as regulating the stability of the grid on a short-time basis.

Since 1909, Vattenfall (first named Kungliga Vattenfallstyrelsen, then Statens Vattenfallsverk, then simply Vattenfall) had been a driving actor in expanding hydropower generation in Sweden, supplying both cities
and industries with electric power. The first electricity systems in Sweden were decentralised local ones, established in the 1880s. These systems were initiated and maintained by local actors, e.g. municipalities supplying lighting to buildings or factory owners that wanted electricity for their manufacturing. These local grids grew and became interconnected into regional grids as high-voltage lines connected the industries and cities with alternating current and local power companies were formed with municipalities and companies as shareholders. In the 1930s, it was decided to connect all regional grids into a national grid, although the actual development of this process did not start until after World War II (Kaijser 2008). Vattenfall was responsible for this national interconnection, which was completed by 1952, at which time most households already had access to electricity (Kaijser 2008).

In the 1950s and 1960s, the demand for electricity increased substantially. The state and Vattenfall met this demand by exploiting Swedish rivers, mainly in northern Sweden. Vattenfall had collaborated closely with a company called ASEA to build efficient high-voltage transmission lines to supply southern Sweden, where most households were located, with power from the north (Fridlund 1999).

The expansion of hydropower developed together with strong economic growth. Between 1950 and 1970, the Swedish GNP doubled, industrial production tripled and Sweden soared to become one of the world’s richest countries.

The strong economic growth benefited the Swedish population and workers. The average industrial worker quadrupled his salary between 1955 and 1965 while the price index barely doubled. The same worker also benefitted from social reforms, such as the reduction from a 48- to a 40-hour work week and two to four weeks of vacation annually. Or he could move with his family in to one of the million apartments built in the so called ‘million programme’ (miljonprogrammet) run by the Swedish government to reduce the housing shortage (Giertz 2008, pp. 122, 217).

The large-scale construction of multi-family buildings in the million programme also made it possible for district heating to expand rapidly between 1965 and 1974 (Kaijser et al. 1988). District heating has since been the dominant heating alternative for multi-family buildings in Sweden and a substantial part of the Swedish energy system. As of 2005, more than 75% of all multi-family buildings were connected to district heating, whereas only 6% had heat pumps installed (Formas 2005, p. 121).
The first district heating grid in Sweden was established in the city of Karlstad in 1948 (Formas 2005, p. 140). During the 1950s, district heating grids were established in nine other municipalities. The rationale for installing the first district heating grids was to improve the local environment by reducing the smoke from small chimneys and relocating all the pollution to one big chimney just outside the city. As of 1970, 98% of district heating was supplied by oil (Energimyndigheten 2015c), and thus the oil crises exerted strong pressure to convert existing district heating facilities to other fuels. With the expansion of nuclear power in the 1970s, many district heating facilities installed electric boilers. The reduced demand for electricity also meant that some district heating facilities converted from combined heat and power plants to just heat power plants.

5.2.2. Energy system developments after the first oil crisis

Energy supply planning had not been seen as a political issue before the oil crisis, but rather as a task for Swedish government officials (Kaijser et al. 1988). But after 1973, energy supply became a priority issue on the parties’ political agenda. Efforts to reduce Sweden’s oil dependency had already begun in the 1950s and 1960s through substantial hydropower expansion and investments in ‘peaceful usage of nuclear energy’ (Palme and Johansson 1975, p. 7). The 1973 oil crisis intensified the focus on alternative energy technologies that could replace oil, such as solar and wind energy, and partly even heat pumps.

Sweden’s first energy plan (Prop. 1975:30) was put forward by a Social Democrat-led government in 1975, proposing ‘significantly increased governmental efforts in the energy area within the framework of a three-year programme’ (Ahlmark and Johansson 1978, p. 2). The energy plan covered both supply and demand (Energiforskningsnämnden 1985) and included an allocation to energy-related research of 360 MSEK (corresponding to about 2.3 BSEK24 in today’s monetary value). The proposal also included further expansion of nuclear power (in 1975 it had already been decided to build 11 reactors, and the proposal suggested two more), allocating recourses to the mining company LKAB to carry out uranium extraction in Ranstad, and expanding the Swedish oil reserves. Heat pumps were briefly mentioned in the proposal as a possible long-term energy-saving measure. The Industry ministry was also giving grants for construction of a few experimental heat pump rigs.

24 Calculated using the consumer price index from SCB – Statistics Sweden (2017).
In 1973, the expansion of hydropower was at a definite standstill. Three years earlier, the Social Democrat government had decided not to exploit the river Vindelälven, even though this was originally a part of the plan for Swedish hydropower expansion guided by Vattenfall. Protests against the exploitation had been ongoing since 1962, even though most local residents supported the planned hydropower plants. But the anticipated expansion of nuclear power caused politicians to consider further hydropower expansion less necessary. The ‘battle for Vindelälven’ marked the end of the exploitation of the large Swedish rivers in the north, and any further hydropower expansion was limited to already exploited rivers (Jewert 2014).

The Swedish expansion of nuclear power had begun long before the oil crises, with the first test facility placed in operation in 1954 and the first large-scale commercial reactor going on line in Oskarshamn in 1972. When hydropower expansion was halted, nuclear power provided the most concrete measure to reduce oil dependency. The idea of nuclear power making Sweden energy-independent and self-sufficient had been formed in the 1940s and 1950s through the development of ‘the Swedish line’ (Den svenska linjen), which envisioned establishing a complete nuclear cycle – from extraction of uranium to storage of atomic waste – in Sweden (SKI 2005). One aspect of this integrated nuclear power plan (which was never fulfilled) involved building culverts from nuclear power plants to nearby cities to use the plants’ waste heat for district heating (Palme and Johansson 1975).

The 1975 energy plan widened the scope of energy policy beyond hydro and nuclear power, envisioning investments in both solar and wind power. The government agency for technological development STU (in Swedish, Styrelsen för teknisk utveckling) had already started a small-scale wind energy programme a few years earlier, and the first Swedish wind power plants were built in 1975. These were initially small plants with capacity of 100 kW. STU’s main objective was technology development, not reducing oil dependence. In 1975, STU’s wind energy programme was taken over by the energy-oriented governmental organisation Nämnden för energiproduktionsforskning (NE) (Ahlmark and Johansson 1978).

In 1976, a right-wing coalition won the election and the Social Democrats lost their previously dominant position in Swedish politics. The Centerpartiet party, which had campaigned against the expansion of nuclear power, made significant gains in the 1976 election. In 1978, the right-wing government extended the energy research plan from 1975 for three more years (Prop. 1977/78:110). The plan renewal increased the emphasis on demonstration projects and experimental facilities. There
was also a notable increase in the amount of attention given to heat pumps, perhaps due to the market expansion of heat pumps that had taken place in the intervening years.

Much of the content in the 1978 energy research proposal was been prepared by the government commission for energy research DFE (In Swedish: Delegationen för energiforskning). DFE had been formed in 1975 in conjunction with the first energy research plan. Together with the building research council BFR, DFE had substantial influence on policy initiatives concerning energy developments in the built environment.

Suggested research areas related to heat pumps in the 1978 energy proposal were alternative (non-electric) driving energy (e.g. diesel) and heat sources other than air (such as ground, lake and waste heat). DFE suggested that the focus should be on large, central heat pump facilities and multi-family buildings (thus omitting small heat pumps for single-family houses). DFE considered heat pumps ‘relatively close to commercial application’ (Ahlmark and Johansson 1978, p. 33) and suggested an allocation of 27 MSEK of governmental grants to heat pumps, with 12 MSEK for research and development and 15 MSEK for experimental and demonstration facilities. In comparison, solar heating research was to be granted 60 MSEK (Ahlmark and Johansson 1978, pp. 30, 33).

On an international level, the 1973 oil crisis induced large-scale governmental investments in energy technologies such as light-water nuclear reactors, fusion and offshore oil drilling. The largest investments in renewable technologies were aimed at solar power, with considerable efforts in both the US and Germany. These two nations also invested in the development of heat pumps for multi-family and office buildings. Furthermore, a gas-driven heat pump was developed in Germany (Ahlmark and Johansson 1978, pp. 90–92).

International collaboration on developing renewable energy technologies took place through the International Energy Agency (IEA). Sweden joined four of the six collaborative agreements formed by the IEA, one of which concerned the use of heat pumps (Ahlmark and Johansson 1978, p. 92).

Though heat pumps were already included in the energy plan put forward in 1975, investments in heat pump research were relatively modest during the 1970s. But the pressure on the Swedish energy system to reduce oil dependence, combined with the hope for a future characterised by abundant nuclear-powered electricity, opened up
opportunities for several previously untested technologies, heat pumps being one of them.

5.3. Heat pump sector developments

Heat pump technology had not been an area of special interest to either academic or governmental organisations and authorities prior to the oil crises of the 1970s. The first cross-network actors – i.e. actors that influenced and played active parts in the formation of heat pump value networks – were primarily technological universities, some governmental organisations and energy companies. In this period, these cross-network actors led the effort to compile international knowledge concerning heat pumps, as seen for example in the 1974 Heat Pump Symposium held by the Swedish building research council (BFR) and state-owned energy corporation Vattenfall (BFR, 1975).

5.3.1. Illustrating the heat pump sector in the late 1970s

The formation of heat pump value networks in the 1970s was, together with the engagement of governmental actors, academics and energy companies, a first step towards an emerging heat pump sector in Sweden. It laid the foundation for the developments that occurred in the following period of the transition. Using Dahmén’s terminology, the heat pump sector at this time can be described as an incomplete development block. Dahmén (1991) explains how an incomplete development block can be formed by a group of entrepreneurs in coordination or by different entrepreneurs who are unaware of each other. In this period, we see primarily examples of the latter, though there were some coordination efforts amongst government actors and energy companies, as illustrated in Figure 10.

The value networks in the Swedish heat pump sector generally formed independently of and parallel to each other. The emerging heat pump sector seen in Figure 10 was made up of loosely connected activities and value networks spread out across different Swedish sectors and industries, with little interrelational communication between the value networks.

There had been some testing of heat pumps in Sweden prior to the 1973 oil crisis, but this activity increased significantly after the crisis. Sweden’s high oil dependence – with 71% of all energy supply coming from oil – meant that the increased oil prices struck hard at the Swedish energy system, with grave consequences for Swedish industry and society. This resulted in an increased political and governmental focus on supporting the development and implementation of alternatives to oil. BFR and STU, along with the temporary commission DFE were the governmental
actors that engaged in supporting heat pump development in the 1970s. These governmental actors appear in yellow in Figure 10 together with the other two main cross-network actors in this period, the energy companies Vattenfall and Sydkraft. Vattenfall and Sydkraft directly influenced the heat pump market by their procurement of heat pump test facilities, often in conjunction with STU.

Figure 10: Illustration of the emergence of a heat pump sector with different types of business models and value networks in the mid-1970s

[Diagram showing various actors and their interactions in the heat pump sector]

Cross-network actors are illustrated in yellow, suppliers in blue, upstream suppliers and partners in light blue, and customers in green.
The 1973 oil crisis also contributed to the beginning of market formations for air-air, air-water, and ground-source heat pumps in Sweden. Figure 10 illustrates the differences and similarities between value networks for small heat pumps in the 1970s. The main difference in value network characteristics was that air-air heat pumps were imported, air-water heat pumps were imported and then modified, and ground-source heat pumps were locally assembled. The big similarity was that they were all distributed in the typical way in which heating products were distributed in Sweden in the 1970s, i.e. through wholesalers. This also marks a big difference between the refrigeration industry–based heat pump value network, shown at the left in Figure 10, and the HVAC value networks (e.g. small heat pumps for detached houses) shown at right.

The refrigeration industry–based heat pump value network (to the left in Figure 10) was based on an existing value network. It did not have a wholesaler step as the HVAC value networks (to the right in Figure 10) did. Because of the refrigeration industry’s business model, with custom-tailored products and turn-key solutions, this value network was designed for direct relations with the end customer, typically one with special needs (and willingness and ability to pay for custom solutions).

In the HVAC value networks, the wholesaler is in an intermediate position. The manufacturers in the heating industry were accustomed to working with wholesalers and not having direct relations with their end customers. This structure worked well for manufacturing and selling water heaters and heating boilers, but (as we will see) it was not optimal for supplying heat pumps to the housing market.

### 5.3.2. Early tests and research on heat pumps in Sweden

In 1940, professor Matts Bäckström wrote an article titled ‘Wood firing, electric boiler or heat pump?’ (Vedeldning, elpanna eller eldriven värmepump?) in which he weighed the pros and cons of the different heating options against each other (Granryd 2011). A few years later, the first known installation of heat pumps in Sweden occurred in the southern village of Ugerup (Blomqvist, 1948). The appliance was called a ‘cow heat pump’ (Jan-Erik Nowacki and Eric Granryd, personal communication, 5 February 2013) and its aim was to supply the residential house on a farm with heat from the animals in the barn. The installation was in response to the energy crisis that had struck Sweden and Europe as a consequence of World War II.

A 1958 article by Tore Brandin at STAL in Finspång described the ‘to be or not to be’ of heat pumps as directly dependent on the availability of fossil fuels. Brandin argued that a future shortage of fossil fuels would
have positive consequences for the heat pump technology and stated his conviction that ‘time works [in favour] of the heat pump’ (Almqvist et al. 1992). Brandin was right in the sense that, just as with the oil shortage of World War II, there would be positive consequences for the heat pump technology arising from the 1970s oil crises.

Heat pumps were not a research subject in their own right at technological universities in Sweden during the 1970s. Some research competence was present, such as in the institution for mechanical heating theory and refrigeration technology at KTH, but the topic was only briefly covered in the lectures and literature given to students (Jan-Erik Nowacki, personal communication, 5 February 2013).

When BFR and Vattenfall arranged a symposium on heat pumps in 1974, KTH researcher Eric Granryd opened it with a general overview of the technology and its theoretical underpinnings (BFR, 1975). But otherwise, the competence concerning heat pumps was spread across different companies and research institutions.

When interest for heat pumps increased, the question of what institution was best suited for research on heat pumps became more pressing. At Chalmers, a cross-disciplinary research called Jordvärmegruppen (‘Earth Heat Pump Group’) formed, composed of researchers from the geology, heating technology and mechanical engineering, and architecture departments (Jacobson 1979). The interdisciplinary group published a series of reports from its formation in 1978 to 1987, covering both technological and techno-economic aspects of heat pump development (cf. Jacobson 1979; Berntsson and Ågren 1982; Jacobson 1982; Rhen 1982; Wilén 1985). By the end of the 1980s, during the period of the ‘reverse oil crisis’, the research group was dissolved (Englund 1992).

5.3.3. Government organisations acting as cross-network actors

The government organisations that were most active in the formative stage of the heat pump transition were the government agencies for technological development (STU) and the Swedish building research council (BFR), together with the temporary commission for energy research (DFE). STU focused on technological development in general, BFR held responsibility for energy use in the built environment, and DFE was appointed to prepare the 1978 energy research programme extension by compiling and evaluating the efforts within the first energy research programme. Other organisations with influence on the policy decisions concerning heat pumps (but without being active cross-network actors in the heat pump value networks) were Svenska elverksföreningen (the Swedish Electricity Association) and the

STU and BFR together controlled the state funds given to energy usage projects in the built environment, including heat pumps (Ullsten and Tham 1979, p. 268), while BFR and DFE had the biggest influence on policy initiatives concerning energy developments in the built environment. BFR was also active in compiling and communicating knowledge concerning heat pumps together with other actors, such as Vattenfall.

5.3.4. Vattenfall's role in heat pump value network formation in the 1970s

The state-run corporate agency Vattenfall has had large responsibilities for the development of the Swedish energy system, and it was the main responsible actor in both hydropower and nuclear power expansion in Sweden.

Vattenfall’s involvement in heat pumps dates back to before the oil crisis induced by the ‘October War’ in late 1973. Vattenfall had conducted some small-scale tests, which were described by its planning director responsible for innovation, Bengt Nordström, in the company magazine as early as February 1973 (Vattenfall 1973).

Nordström would lead Vattenfall’s investments in heat pumps for a long time to come, but this 1973 article is among the first records of him discussing heat pumps in Vattenfall’s historical archives. Nordström was on Vattenfall’s executive board and in close contact with the company’s Director General, Jonas Norrby. Norrby would later sit alongside Nordström on Vattenfall’s heat pump research council, formed in 1979 (Vattenfall, 1980).

In 1973, Vattenfall formed a testing and measurement programme together with Sydsvenska Kraftaktiebolaget (called Sydkraft from 1977 on). Sydkraft was owned by a group of municipalities in southern Sweden and was the country’s second-largest energy company. Other members of the test programme were home builders and heat pump suppliers (Vattenfall 1973; Ahlmark and Johansson 1978). The aim of the test project was to gain experience on how to increase the efficiency of energy usage. The results of the tests were presented in joint publications.

The test programme included installing measurement equipment in already existing heat pump facilities as well as installing new heat pump appliances. The tests focused first on air-air heat pumps; later they expanded to include air-water heat pumps and eventually ground-source
heat pumps and larger-size heat pumps as well. The air-air pumps were typically imported from the US and the air-water pumps were typically made by Swedish manufacturers, but in some cases even home-made heat pumps were included in the tests (Vattenfall 1978).

The actors and their relationships in the test programme are depicted in Figure 11, which shows how the energy companies Vattenfall and Sydkraft prepared demonstration and testing sites and ordered the installation of heat pumps by heat pump suppliers. The suppliers typically used contracted installers, who in turn used their own subcontractors, making coordination difficult for the main contractor (Vattenfall 1978b).

Vattenfall’s first initiative was to install a heat pump and measuring equipment in a test house outside Skara, together with installing measurement equipment in properties that already had heat pumps installed, including a few houses on the west coast and a retirement home in Vingåker that already had nine heat pumps (see the examples of ‘Demonstration projects’ in Figure 11). At the time, according to Bengt Nordström at Vattenfall, the biggest brands in the small Swedish market were Lennox and Westinghouse along with the Swedish brand Kryotherm26 (Vattenfall, 1974). As already noted, the tests initially concerned air-air heat pumps, which were the only fully commercialised small heat pumps on the market. Although air-air HPs were a mature product, early tests showed that air-air heat pumps often malfunctioned due to the cold Swedish climate. If the temperature went below negative 10°C, the pumps typically had to be turned off (Vattenfall 1973).

Sydkraft’s first tests also targeted an air-air heat pump, but after some time the measuring method was considered too poor and needed changing, and shortly thereafter the entire heat pump was considered too poor as well. So in autumn 1974 Sydkraft did a restart of its heat pump tests (Vattenfall, 1978b). Sydkraft, like Vattenfall, used both existing facilities and new installations of heat pumps for its measurement tests and was initially focused solely on air-air HPs.

After two years of testing, Vattenfall expanded its programme with another 1.5 MSEK of investment to extend the number of testing facilities (Vattenfall 1975). The tests also began to include air-water HPs (Vattenfall 1978a, 1978b). The air-water HPs included in the tests were often based on imported and modified air-air models.

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26 Kryotherm was a refrigeration and ventilation company started in 1967 (VVS Forum 2011).
The air-water HP tests were also plagued by problems. One heat pump tested, of the brand Metro-Modul, actually attained a COP below 1 in the tests (which means that it was less efficient than an electric heater). Vattenfall noted in its report that the odd result was not due to measurement errors (Vattenfall 1978a). Another problem concerned the manufacturer Kryotherm, which delayed the delivery of its heat pump to such an extent that Vattenfall eventually chose to terminate the order.

Other brands included in the tests were Projectus, Tour Agentur, Autoterm, Westinghouse and Carrier. The best results were attributed to the Örebro company Autoterm, which achieved a COP of 2.2 to 2.6, though only during the warmer parts of the year. But even so, the
Autoterm heat pump supplied only 40% of the house's total annual heating demand (Vattenfall 1978a).

The heat pump problems in the tests often related to stresses on the compressors, 27 failing components, refrigerant leakage or frosted outdoor units. Many of the failing components concerned the steering components, e.g. wrong dimensions on the expansion valves, malfunctioning circuit boards for steering the modes of operation in conjunction with ancillary units (e.g. oil boilers), valves that clogged with dirt, malfunctioning defrost sensors, and pressure switches that failed due to too large (or too small) pressure differences in the heat pump. There were also other issues that Vattenfall and Sydkraft staff couldn't even figure out the root of (Vattenfall 1978a).

The tests did help to resolve some of the problems – for example, defrosting of the outdoor unit for air-water and air-air pumps and problems with stops due to expansion valves that triggered pressure switches. The latter issue was resolved when the Danish company Danfoss developed a new, improved expansion valve for this purpose (Vattenfall 1978a, p. 11).

In the mid-1970s, the average efficiency of compressors was about 50% (Björk et al. 2013, p. 21). The piston compressors used for small heat pumps were designed for refrigeration applications and not for the operation modes of heat pumps (Poppius 1984, p. 20). An article from 1973 describes the problems with compressors and the cold climate, noting how the long run times in cold temperatures stressed the equipment and caused various disturbances (Vattenfall, 1974). The imported heat pumps from the US were designed to be silent, and therefore their piston compressors were fitted with a bigger ‘dead space’ than normal, which made them quieter but also increased the stress on the compressors (Thomas Hallén, personal communication, 10 August 2016).

Another highlighted problem during this period was failed adjustments to the existing heating systems of the houses where the heat pumps were installed. This was partly blamed on the long chain of contractors and subcontractors involved in the installations (Vattenfall 1978a).

Altogether, the results from Vattenfall and Sydkraft’s tests were mixed and did not live up to initial expectations (Vattenfall 1978c). For air-air

27 In an interview on 17 February 2014, Hans Lindström of Vattenfall recalled that when he evaluated the so-called Surte project in the 1970s, a large portion of the malfunctions noted were due to compressor failure.
heat pumps, the dependability was fairly good but the energy savings did not exceed 15–20%. The tests with air-water heat pumps had yielded increased energy savings, but with dependability problems and unplanned stops. Quite often the air-water heat pumps did not work at all and only in exceptional cases did they deliver a COP above 2 (Vattenfall 1978b). Trivial errors were responsible for many of the operational interruptions, with long periods of downtime as the time spent waiting for spare parts and service had been exceptionally long (Vattenfall 1978a). The service network was severely underdeveloped at this time.

The conclusion drawn from the test programme was that much development work was still needed before an adequate heat pump could be available on the private customer market (Vattenfall 1978a). The required development involved not only technological but also organisational issues.

5.4. **Formation of the first heat pump value networks**

The Swedish heat pump value networks were formed in various time periods. The refrigeration-based value network first formed in the 1950s, whereas the exhaust air and direct expansion heat pump networks were not formed until the early and late 1980s, respectively.

The first Swedish value networks formed around existing companies and industries that had competence in heat pump technology and/or were established in the existing heating market. As described in the previous chapter, the Swedish value networks had three main points of origin: the refrigeration industry, the international air conditioning industry and the heating (or, more broadly, the HVAC) industry. The Swedish refrigeration industry possessed greater competence concerning the heat pump cycle, whereas the HVAC industry had an established nationwide network of service companies and installers well positioned to serve the Swedish housing market. These were two different points of departure for entrepreneurial heat pump activities in the 1970s.

The heat pump aimed at the housing market was an assembled product, manufactured by assembling sub-components into a functioning system and packaging it as a complete product. Different requirements were placed on different actors who added value to the network: quality components from the suppliers, capabilities to manufacture cost-efficient quality products from the manufacturers, and competence to install heat pumps amongst downstream retailers and installers. A sufficient level of awareness concerning heat pump technology among
potential customers can be considered another requirement for the formation of the early heat pump value networks.

5.4.1. Formation of the refrigeration-based heat pump value networks

Most of the formation activity of heat pump value networks occurred after the 1970s oil crises, but the first commercial applications of heat pumps in Sweden (not for research purposes) had already happened in the 1950s (BFR 1975, pp. 288–293). They were delivered by STAL Refrigeration, making this company a pioneer in the history of Swedish heat pumps.

STAL Refrigeration's main competitor during the 1960s and 1970s was the Danish refrigeration company Sabroe, with an affiliate situated in Göteborg (BFR 1975). Figure 12 illustrates a simplified value network of the turn-key heat pump installations made around the 1960s in Sweden, with STAL Refrigeration and Sabroe as main suppliers.

Figure 12: Illustration of the value network of early site-built, medium-size reversible heat pumps
The first commercial heat pump installations took place at a time when oil was both relatively cheap and in secure supply. These heat pumps were site-built installations for customers with specific cooling and heating needs, e.g. hospitals (with high comfort needs) or ice arenas (where it was essential to quickly melt and freeze the ice on the rink). As shown in Figure 12, early customers of heat pumps include Göteborgs Idrottsnämnd (in 1958), Östra Sjukhuset in Göteborg and industrial facilities such as Saab Flygmotor and Bofors. A typical heat pump installation delivered by STAL Refrigeration at this time was a reversible cooling unit ranging from 100 to 500 kW of cooling power and delivered as a turn-key service (BFR 1975, p. 291).

Because the early heat pump appliances were specially designed turn-key solutions for customers with specific needs, a close supplier-customer collaboration was typically built into the central business model.

In the 1960s and 1970s, both STAL Refrigeration and Sabroe had a collaboration with the cooperative company Kooperativa Förbundet (KF). These collaborations were organised by KF’s architecture office, KFAI, which designed KF’s large, modern, central department stores in Sweden.

KF’s interest in heat pumps was partly based on the competition KF faced from Åhléns City. In 1964, Åhléns’ new mall in central Stockholm was inaugurated with the slogan ‘Spring all year round’, thanks to the mall’s modern, air-conditioned ventilation (Collin 2014). KF wanted to outdo its competitor not only in air conditioning but also in providing heat during winter. Moreover, it wanted to become less dependent on the district heating monopolists (Sven-Allan Eklund, personal communication, 20 August 2014). The new technology was developed by KFAI in collaboration with STAL Refrigeration and Sabroe. From 1967 onwards, KF installed 17 heat pumps in its Domus department stores, 12 delivered by STAL and five (around the Göteborg-area) delivered by Sabroe (BFR 1975, p. 288).

The experience gained from these collaboration projects showed that having a reliable and well-performing heat pump unit required not only careful design and construction of the system, but also correct installation by competent installers. For example, the installers of KF’s first heat pump delivered by STAL Refrigeration did not properly follow the installation instructions from KFAI. Instead, they did as usual when installing air conditioning unit batteries and tilted the condenser so that the condensed refrigerant could run only one way. This resulted in malfunctions when the unit was run in reverse to supply heat (Sven-Allan Eklund, personal communication, 17 December 2013).
5.4.2. Formation of the air-air heat pump value network

The housing heat pump market in the first half of the 1970s was dominated by imported air-air heat pumps. When interest in air-air heat pumps first arose in Sweden, American brands, such as Carrier and Lennox, were the main ones imported, sold and tested. These reversible air-conditioning units were typically not well adapted to the cold Swedish winters, but their arrival contributed to the formation of a Swedish heat pump market for houses during the 1970s. As of January 1975, there were about 1,000 heat pumps in Sweden; by the end of 1977, this number had quadrupled. About 85% of these 4,000 heat pumps were the air-air type, often with relatively low heating effect. More than half of them could not deliver more than 5kW of heating effect (Glas 1978, p. 132).

![Diagram of the newly formed air-air heat pump value network](image)

**Figure 13: Illustration of the newly formed air-air heat pump value network**

Figure 13 illustrates how the air-air heat pump value network first formed as existing HVAC companies, which had an established value
network around heating and ventilation products, started to supply air-air heat pumps to private customers. These HVAC companies either directly imported reversible air-conditioning units as general agents for internationally established brands (e.g. Carrier, Lennox or Mitsubishi) or ordered them through external heat pump wholesalers (Eklund 1980). If the HVAC companies didn’t have installers (i.e. craftsmen and electricians) established locally, they could use sub-contractors for the installations and services, as shown in Figure 13.

The formation of the air-air heat pump value network did not disturb any existing value network structures but was – as with the refrigeration companies that supplied heat pumps – simply an add-on to the existing offerings of existing value networks.

5.4.3. Formation of the air-water heat pump value network

Air-air heat pumps dominated the heat pump market for private customers throughout most of the 1970s, but in the mid- and late 1970s an air-water heat pump value network formed (Glas 1978, p. 132). From the late 1970s through 1981, the accumulated sales of air-water heat pumps in Sweden represented about 6,700 units, even more than the accumulated sales of air-air heat pumps in the same time period (SVEP 2013).

In the 1970s, the imported American air-air heat pumps achieved low SCOP (i.e. low annual performance) because they were poorly adapted to the cold Swedish conditions. The first Swedish manufacturers of air-water heat pumps attempted to resolve this issue. The first air-water heat pump value network, illustrated in Figure 14, developed as manufacturers and entrepreneurs imported air-air heat pumps and tried to modify them to make them more suitable for Swedish conditions. For example, a report from Vattenfall (1978, p. 8) describes how the Swedish company Parca-Norrahhammar imported Lennox air-air heat pumps and exchanged the indoor heat exchanger for a condenser manufactured internally so that the heat pump could be connected to a water heater. This meant a slight difference in value network structure compared to air-air heat pumps and a demand on mechanical manufacturing capabilities for the supply of air-water heat pumps. The initial customers for air-water heat pumps were similar to those for the air-air type, except that they were limited to those homeowners who had hydronic systems.

The formation of the air-water heat pump value network meant that knowledge of the heat pump principle and understanding of the practical challenges of manufacturing heat pumps was starting to increase, on a small scale, among Swedish companies and workshops.
5.4.4. Formation of the ground-source heat pump value network

In the mid-1970s the first ground-source heat pump value networks started to gain traction in the market along with the air-water heat pump value network (Glas 1978, p. 132). In 1977, a total of 4,000 heat pumps were sold in Sweden, of which 500 were either air-water or ground-source types (Glas 1978). But in the following years, and especially after the second oil crisis, the demand for ground-source heat pumps rose. The accumulated sales of ground-source heat pumps in Sweden through 1981 was about 13,500 units, or more than twice the number of air-water pumps (SVEP, 2013).
Because the development of ground-source heat pump value networks has been largely unique to Sweden, a more thorough discussion of its formation will be provided.

The world's first ground-source heat pumps were commercialised in the 1940s and early 1950s (Zogg 2008), but they did not have the same type of market impact as air-conditioning units had, partly because of the drop in oil prices during the 1950s and 1960s.

Denmark, not Sweden, was the pioneering nation in this technology in Scandinavia. Research projects on horizontal ground-source pumps began in Denmark during the 1960s (Vattenfall, 1973), and in fact the first series production of ground-source heat pumps in Sweden was based on a Danish model.

The early Danish tests were disheartening (Vattenfall, 1973), primarily due to the high cost of installing piping in the ground. Placing collectors installed in the ground was considered risky because of frost heaves and permafrost, and leaks were costly to locate and repair (BFR 1975, p. 20). In the Danish tests, a piping system had been used instead of tubes for horizontal collectors. At a heat pump symposium in Stockholm in 1975, the problems of ground-source heat pumps were exemplified by a case from Denmark, in which the excavator that had just been used to install the pipes for the ground collector crossed the field where the pipes lay. All the pipes where the machine crossed were promptly broken (BFR 1975, pp. 66–73).

The first complete value network for ground-source heat pumps in Sweden was formed by Thermia in Arvika. Around 1972, a company called Geoterm contacted Thermia concerning contract-based manufacturing of a new type of ground-source heat pump. At this time, Thermia was an established mid-sized player in the heating industry with 420 employees, an annual production of about 40,000 stainless steel water heaters (ranging from 15 to 110 litres) and about 20,000 copper plated heaters (Leif Olsson, personal communication, 30 March 2016). Thermia was then part of the so-called Corona Group, in which the CTC company was also included.

Geoterm consisted of five consultants and was a Swedish affiliate of a company in Denmark. Geoterm contacted Thermia because its principals had gotten hold of a Danish heat pump concept and had an idea for making a complete heating package by connecting the ground-source heat pump to a Thermia water heater. A group of people at Thermia sat down to discuss the possibility, and soon two questions emerged: how big should the water heater be so that the heat pump could deliver temperatures of 55°C (the answer being around 300 l), and how big a
A water heater was needed to fit a heat exchanger coil in the heater (the answer being around 320 l). Other uncertainties regarding this new type of heat pump remained, such as how much heat could be taken from the ground without hurting the soil and how deep the ground collector should be. Some participants suggested a depth of 1.5 to 2 meters, but Thermia thought that a depth of no more than 90 to 100 cm should be used for the heat pump to use heat from the sun.

Thermia soon began small-scale production, through orders from Geoterm, on this heat pump package with an extraordinarily large water heater. Thermia manufactured the stainless-steel heater, but the mounting of the heat pump’s electronic circuits was initially performed by another company in Karlstad that had refrigeration expertise. The first heat pump of this type, later named the JBC-400 and shown in Figure 15, was first tested in fall 1972.

Figure 15: Illustration of Thermia's JBC-400, a large and heavy geothermal heat pump, in a modern (at the time) orange colour

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28 In the 1970s and 1980s, it was common to market heat pumps as a solar technology. Chapter 6 discusses this dynamic further.
The JBC-400’s internal unit was extremely big due to the large water heater, and during 1973 only a few units were sold. But when the price of oil started to become a serious concern during the first oil crisis, sales started to increase. Eventually they grew to a point at which Geoterm, the small company that was formally manufacturing these heat pumps and managing the customer relations, had difficulty keeping up with the increased demand. Geoterm proposed that Thermia should take over the whole supply chain for this heat pump, which it did (Leif Olsson, personal communication, 30 March 2016).

A visual depiction of the first value network to form around ground-source heat pumps – when Thermia was still a subcontractor to Geoterm, before Thermia took over and internalised the heat pump product business model – appears in Figure 16.

![Figure 16: Illustration of the first ground source heat pump value network](image)

Among the early customers for ground-source heat pumps – illustrated in green in Figure 16 – were people who had the money, technological interest and time to maintain a heat pump, such as retired engineers (Martin Forsén and Anne-Lee Bertenstam, personal communication, 27
November 2012). Other groups of early customers for vertical ground-source heat pumps included farmers, who had both the equipment and the land area to install the needed heat collector tubes (Leif Olsson, personal communication, 30 March 2016) and environmentally aware customers who wanted to reduce their dependence on both oil and energy companies (Thermia 2010).

There were few ground-source heat pump manufacturers in Sweden during the 1970s other than Thermia. The second-largest at the time was the Tranås-based company IVT (Leif Olsson, personal communication, 30 March 2016). IVT was a small, entrepreneurial company founded in 1968 by three brothers, Harald, Elis and Billy Peterson. Initially, IVT manufactured drying equipment for the graphics industry, but it was quick to join Thermia in manufacturing ground-source heat pump units including water heaters. According to long-time Thermia employee Leif Olsson (personal communication, 30 March 2016), the first IVT heat pump model was very similar to Thermia’s model, and after Thermia released an updated model, IVT shortly thereafter released a similar update of its own model.

5.5. **Summing up the dynamics in the first phase of the heat pump transition**

In the mid 1970s, the oil-dependent Swedish energy system faced negative transformation pressure, forcing structural changes to replace its high oil dependence with greater use of other, preferably domestic energy sources. The negative pressure on the energy system caused previous connections between complementarities to be destabilized and the system to be more open to new connections between developing and established complementarities.

During the 1970s, the heat pump became increasingly highlighted and positioned as a heating alternative that could contribute to structural changes in the Swedish energy system, but there was an overall need for knowledge development and dissemination concerning how to adapt them for Nordic conditions. Heat pump technology was largely untested on hydronic heating systems in the cold Nordic climate, and competence concerning how to manufacture cost-efficient heat pumps for such systems was relatively spread out amongst different companies and industries.

There was also a lack of knowledge and awareness concerning heat pumps amongst Swedish policy makers. The Swedish policy proposals presented in the mid-1970s (e.g. Prop. 1975:30) barely considered heat pump technology as an alternative to oil. The lack of inclusion of heat
pumps in policy making was also manifested by the fact that the building and planning boards did not award loans for heating systems to cover costs higher than the expense of installing an oil burner, which meant that the financial support was much less than that needed for the initial costs of a heat pump (Vattenfall 1975). This misalignment between emerging heat pump value networks and government support helped to keep the market formation level relatively low in the 1970s.

An increased knowledge exchange from the company level to the government level was required to increase government resource allocation and policy support for heat pumps. In the 1970s, the existing competence concerning heat pumps was spread out across different organisations and research institutions. There were no research units at any technical universities that focused on heat pumps, limiting the ability of universities to act as knowledge-developing and knowledge-diffusing complementarities to the heat pump value networks.

The coordinating efforts needed to complement the heat pump value networks in their early stages were partly taken on by energy companies, in the form of the Vattenfall and Sydkraft’s joint activities from 1973 to 1978 (Vattenfall 1978b). These joint efforts also provided a learning period that could be utilised in future heat pump projects.

5.5.1. Complementarities and coopepetition dynamics

The low level of public awareness held sales down in the 1970s, but the disequilibria between identified potential – through the initial steps of aligning new heat pump–related complementarities – and actual sales of heat pumps also stimulated continued entrepreneurial activity.

When the demand for small heat pumps increased in the 1970s, the strongest knowledge of heat pumps in Sweden was located in the refrigeration and heating industries. But whereas the refrigeration industry had the best knowledge about the heat pump cycle and its theoretical principles, the Swedish heating industry had stronger knowledge concerning customers, how hydronic heating systems worked, contacts with retailers and installers, etc. In other words, the two industries were complementary to each other as one industry contained the competence to develop the product but another contained the capability to manufacture it and sell it to homeowners. Increased cooperation was required to develop well-performing, new value networks related to small heat pumps. The coopepetition activities of Vattenfall and Sydkraft on heat pumps, together with increased academic engagement in heat pump technology, helped to increase knowledge flow in the early stages of the Swedish heat pump sector.
When the Swedish heating industry started manufacturing heat pumps, it needed to acquire knowledge concerning heat pumps from outside its companies. This was also the case when Thermia launched the first Swedish-made ground-source heat pump, the JBC-400, in the 1970s. At this time, Thermia lacked the necessary competence concerning both heat pumping cycles and steering equipment for heat pumps, but it had a high level of knowledge related to customer demands and needs. When the Danish consulting company Geoterm approached Thermia, it sought not only a contract to manufacture heat pumps but also Thermia’s help in developing the product to suit customers. This collaboration resulted in the first ground-source heat pump on the Swedish market with all indoor components situated in one unit.

At the time, this was a ground-breaking project, even though the unit was very large and weighed several hundred kilograms. Although Geoterm supplied knowledge concerning heat pump principles, Thermia still had to ship the heat pumps to Karlstad to have another company install their steering equipment. Internalising this knowledge allowed for cost reduction and decreased manufacturing flow times. Thermia also used consulting firms that knew refrigeration to create their own test rig, so that each heat pump that left the Thermia factory had been properly tested before shipping. Moreover, to further improve the product, Thermia sought assistance from researcher (and future professor) Eric Granryd, who helped the company to develop new, much lighter heat exchangers for its next heat pump. Thermia was thus the main actor behind the formation of the first ground-source heat pump value network in Sweden, but cooperation with other actors who had different competences was necessary to form and develop a value network based on a reliable heat pump product.

The energy companies Vattenfall and Sydkraft identified many technological challenges for heat pumps, which often varied depending on the type of pump, in their test programmes during the 1970s. For example, imported air-air heat pumps suffered from poor fitness to Swedish conditions with resulting component malfunctions, sub-par energy savings, and poor operational reliability. Similar problems were found for air-water heat pumps. However, the ground-source heat pumps pioneered by Thermia and Geoterm received positive judgements for their reliable performance (Vattenfall 1978a). The growing structural tension for Thermia and ground-source heat pump manufacturers was instead largely of an organisational character: they suffered from an absent or underdeveloped network of supply, service and installation that could cause a trivial malfunction to take several weeks or months to
Another weakness was the limited knowledge and competence among the installers.

As the market started to grow in the late 1970s, competition amongst the increasing number of heat pump manufacturers increased, while at the same time – to overcome many of the identified challenges related to heat pump technology in the housing market – there was a continued need for both increased cooperation between companies and increased knowledge flow within the forming heat pump sector.

**5.5.2. The setting before the next phase**

As of the 1970s, the Swedish heat pump sector had just started to take shape. Both fundamental knowledge development and knowledge diffusion were needed for the Swedish heat pump sector to be able to address the technological and organisational tensions related to small heat pumps in the housing market. Cooperation between actors had started to take place, and the level of knowledge among policy actors, energy companies, manufacturers and their networks of retailers and installers had begun to increase. Even though the development was largely uncoordinated, dispersed learning and knowledge accumulation processes were taking place at multiple companies and organisations in this period. Progress included adaptations of heat pump technology to Swedish climate conditions and to hydronic heating systems, but the technology was still far from a mature state. By the late 1970s, the Swedish heat pump development block remained largely incomplete.

After the 1979 oil crisis, interest in the heat pump sector drastically increased and the emerging coopetition dynamics increased in intensity, with more cooperation and stiffer competition at the same time. This rush towards heat pumps after 1979 would likely not have happened without the small first steps taken in the Swedish heat pump sector during the preceding years.

In 1979 there was a wide variety of technological variations of heat pump technology. Diesel- and gas-driven heat pumps were seen as alternatives to electric heat pumps, absorption heat pumps were compared to gas-compression heat pumps, and so on (VVS-Tekniska Föreningen 1979). Apart from the air-air heat pump product segment, heat pump technology was in a fluid state without the appearance of a dominant design in sight.

The 1979 oil crisis set off a big interest in heat pumps from a large number of actors. Policy makers, energy companies, large Swedish corporations, small manufacturers and new company start-ups were among the actors investing in heat pump projects of various kinds. Opportunistic actors who lacked either the competence or capacity to supply reliable heat pumps also joined the sector. The previous phase of the Swedish heat pump transition had been characterised by few active heat pump companies and low levels of both cooperation and competition. After 1979, the intensity of coopetition increased along with the greater transformation pressure on the Swedish energy system. The actors in the heat pump sector competed for increased shares of the growing market while also searching for new opportunities, new partnerships and organisational and technological cross-synergies.

The boom in heat pump sector development incentivised government actors, energy companies and established heat pump suppliers to try to control and coordinate the growth, and to define the role and responsibility of involved actors while still supporting the technological development of expanding marketability of heat pumps.

Between 1979 and 1986, Vattenfall ran a comprehensive R&D programme on heat pumps, which involved collaborations with a large number of heat pump producers as well as educational efforts aimed at heat pump suppliers and installers.

The Swedish heat pump market for houses grew to over 25,000 units sold in 1984, which was remarkably rapid growth considering that sales had been fewer than 1,000 units ten years earlier. However, the biggest
heat pump impact in the 1980s was not in the housing sector but in the
district heating sector. From 1982 onwards, there was a rapid growth of
large heat pumps in Swedish district heating systems. This expansion
halted in the late 1980s, but by then some of the world’s largest heat
pump systems had been installed in Swedish district heating grids. This
expansion, together with changes in related policies, contributed to the
formation of new alignments of complementarities, which in turn aided
the survival of the heat pump sector during later stages of the Swedish
heat pump transition.

6.1. The societal and international context of heat
pumps
In the late 1970s, Sweden underwent a deep recession and a structural
crisis spread across Swedish industrial sectors (Schön 2012), powerfully
impacting industries that had formed the backbone of the Swedish
economy, such as shipbuilding (Giertz 2008). During the 20 years after
1975, the economy’s growth rate was much slower than it had been
during the previous 20 years (Schön 2012).

In the midst of the industrial and economic crisis, the 1979 oil price
increase created increased challenges for the Swedish economy. These
factors together with the heated debate on nuclear power in Sweden
helped to make energy supply one of the most important political issues
of the time.

A structural crisis can have positive effects on certain technological
areas. This was the case for heat pump technology during the period
when the Swedish energy system faced negative transformation
pressure. Sweden’s heavy oil dependence was identified as one of the key
contributors to the economic crises in the 1970s, and the heat pump
offered a rational solution to mitigate that problem. Investing in heat
pumps was thus rational from an energy-system perspective.

The second international oil crisis followed a series of events around the
years 1978 to 1980. Massive protests among workers in Iran’s oil fields
had caused a shortage of oil supply from Iran in 1978. When Ayatollah
Khomeini took power during the Iranian revolution in early 1979, the
Iranian output once again decreased and became increasingly
unpredictable. In 1980, the tensions between Iran and Iraq erupted into
an eight-year war, diminishing Iran's oil exports further and cutting off

29 In this thesis, references to the ‘heat pump market’, unless stated otherwise, mean small heat
pumps aimed at the housing market in Sweden.
Iraq’s oil exports completely. Though the global oil output was reduced by only 4%, the market panicked. Between 1978 and 1979, the global crude oil price doubled, as seen in Figure 17.

The peak oil price in 1979–1980 provided an aftershock to Western energy systems, contributing to expanding oil production in the North Sea and Alaska, increased gas extraction, and investments in alternative energy technologies (Difiglio, 2014). Meanwhile, Sweden’s heavy oil dependency became an even bigger issue for policy makers, industry, and any energy customer that used an oil boiler. At the same time, there were widespread political disagreements concerning nuclear power in Sweden, resulting in large uncertainties regarding the country’s future energy supply.

Figure 17: The crude price of oil, 1970–2015, normalised against 2016 monetary values. Source: BP 2017.

6.2. Energy system and energy policy developments

The Swedish energy sector became highly politicised during the 1970s. The expansion of hydropower had come to an end and the expansion of nuclear power was highly controversial amongst the public and political decision makers. The second international oil crisis was met with oil reduction efforts aimed at the built environment sector in Sweden, which at the time required 40% of Sweden’s total energy supply and was 90% dependent on oil (Vattenfall 1979; Energimyndigheten 2009).
6.2.1. The expansion of nuclear power

After the expansion of hydropower ended, Vattenfall continued its power generation expansion through nuclear power. Between 1972 and 1985, 12 nuclear power plants began operation in Sweden, with Vattenfall as major shareholder in seven of these plants.

The first nuclear power plant reactor (R1) in Sweden was a test facility built deep under the university KTH in central Stockholm in 1954. The second reactor (R2) was built in Studsvik in 1960 and the third (R3) in Farsta in 1963.

The fourth reactor (R4), in Marviken, was principally finished in 1970 but never began operation, as Sweden abandoned its heavy-water reactor line (Marviken was a heavy-water reactor) in favour of American light-water reactor technology. The first large-scale light-water reactor went on line in Oskarshamn in 1972, followed by five more in the 1970s and another six during the 1980s (Högselius and Kaijser 2007).

Because of this extensive nuclear power expansion – within a decade, almost half of all Swedish electricity was supplied by nuclear facilities – the price of electricity was kept low. The large energy-intensive industries in Sweden, e.g. paper mills and the steel industry, could thereby keep their costs down. Another effect was that heating based on electricity instead of oil became increasingly rational – a development that had a positive effect on the expansion of heat pumps as well.

The original plan was to build 20 nuclear reactors, but only 12 were completed. The book Silent Spring by Rachel Carson (1962) had had a big impact on environmental discourse in Sweden (Medina 2013) and contributed to the formation of a Swedish environmental movement, which opposed nuclear power. The protests increased further after the Three Mile Island (US) nuclear accident in 1979. The increasing political disagreements led to a 1980 referendum on the expansion of nuclear power in Sweden. There were three ways to vote: in favour of nuclear power, against it, or an option in between that proposed to phase out nuclear power but with ‘common sense’. The common-sense alternative narrowly won the vote, and the expansion of nuclear power halted.

The plan to dismantle nuclear power caused uncertainties in future electricity prices and security of supply (in spite of the promise to dismantle the system with common sense). The government’s focus during the years following the 1980 referendum was thus not only to reduce dependency on oil, but also to prepare for a future shortage of electricity supply as well.
6.2.2. Energy policy developments after the second oil crisis

Energy policy had been a hot topic in Sweden ever since the first oil crisis and the elections of 1976, in which nuclear issues played a major role.

In 1976, a right-wing coalition had formed with the Centerpartiet (which was anti-nuclear) as the biggest party and together with Folkpartiet and Moderaterna (both pro-nuclear). The internal strife within the government, especially on the nuclear power issue, was a leading reason why Prime Minister Fälldin filed for the dismissal of his own government in 1978. A new minority government consisting only of ministers from the liberal party Folkpartiet was formed until new elections in 1979.

When the new minority government took office in 1978, its main task would be to deal with the political controversies surrounding energy issues. On his first day, the new Prime Minister, Ola Ullsten, declared that amongst the government’s main tasks would be to generate proposals for ensuring a secure energy supply that could find wide parliamentary support (Ullsten 1978). The energy policies put forward by the minority government were also made in widespread agreement with those of the parliament (Vattenfall 1981, p. 6).

In the midst of the second oil crisis in 1979, the temporary government put forward a new energy proposal (Prop. 1978/1979:115). The proposition focused on security of supply, limiting environmental impact due to energy system transition (partly by substituting coal for oil) and reducing uncertainty in a number of areas (Energiforskningsnämnden 1985, p. 9).

The proposal began by stating that the 1980s would mark a transition towards sustainable, preferably renewable and domestic, energy sources with the least possible environmental impact (Ullsten and Tham 1979). Not all suggestions contained within the proposal met these criteria, however. The proposal called for replacing oil dependence with coal power plants and using heat from nuclear power plants to substitute for oil in district heating plants (Vattenfall 1979a). It was estimated that 10% of Sweden’s total oil usage could be replaced by waste heat from nuclear power plants (Ullsten and Tham 1979, p. 193).

6.2.3. Increased policy focus on heat pump and solar technologies

Heat pumps had been only briefly mentioned in the 1975 energy proposal, but received considerably greater attention from 1979 on. Although political awareness of the potential value of heat pump technology had increased during the second half of the 1970s, heat pumps were still often considered and discussed as an auxiliary or extra
item to provide increased economy of solar heating systems (Vattenfall 1979a). In the 1979 energy proposal, Energy minister Carl Tham stated that ‘heat pumps are another issue that is of great interest both in the general energy context and by heat pumps being part of low temperature systems, e.g. solar systems’ (Ullsten and Tham 1979, p. 44). But according to Vattenfall’s own calculations, the most economic choice for a heating system involving solar panels, energy storage and a heat pump, was typically to skip the other two alternatives completely and just install the heat pump (Lennart Spante and Hans Lindström, personal communication, 17 February 2014).

Heat pumps were quite often marketed as a solar technology. For instance, Vattenfall’s ‘Solar Project’ spent 80% of its budget on heat pumps and only 20% on solar heating technologies. The usual answer to what heat pumps had to do with solar heating was that the air or ground (except for vertical ground-source pumps) was heated by the sun and that this stored solar power was then used for heating (Eric Granryd, personal communication, 7 September 2012).

The situation was similar in the energy proposal. Heat pumps were included in the discussions, but largely in the shadow of solar power technology. Solar power, in theory, met all the energy plan’s requirements: it was sustainable, renewable and a domestic energy resource. Therefore, the 1979 energy proposal included directives on a new ‘targeted solar heating programme’ called ‘Sol 85’, which consisted of research and development, installations of test projects and dissemination of knowledge (Ullsten and Tham 1979).

Government funding of the solar and heat pump areas expanded substantially due to Sol 85 (Energiforskningsnämnden 1985, p. 9; Vattenfall 1979, p. 9). BFR and STU, which shared the responsibility to ‘promote research and rationalisation within the built environment’ (Energiforskningsnämnden 1985, p. 33), were given the task of distributing grant funds within the Sol 85 programme. Together, BFR and STU awarded loans of 175 MSEK and BFR gave grants of 96 MSEK to different research, development and demonstration projects concerning heat pumps up until 1984 (Energiforskningsnämnden 1985, p. 40).

6.2.4. Financial support for heat pumps

The years 1978 to 1984 witnessed a succession of government funding initiatives in which heat pumps were eligible for support. The support instruments were formed to affect prices and thereby temporarily increase heat pump demand. These support instruments took the form of subsidised loans or direct subsidies. However, the financial aid was
relatively small, covering no more than 10–15% of the total investment cost (Engebeck and Zingmark 1987). About 28,800 owners of small houses were granted subsidies between 1981 and 1985, together with 7,600 medium-size and larger heat pump installations (Engebeck and Zingmark 1987). In 1984 and the first half of 1985, financial support of 250 MSEK was granted, which corresponds to about half a billion SEK in 2015 monetary value.

Beginning in 1981, support was given to larger heat pump installations as well as the already subsidised smaller heat pumps. Support for multi-family buildings was initially comparable to that offered to individual homeowners (covering 10–15% of the investment cost), but changes in 1982 increased the value of the aid so that up to 50% of the total investment cost could be covered (Engebeck and Zingmark 1987, p. 21).

After 1984, heat pump subsidies for owners of small homes were no longer available, whereas larger heat pumps could receive support through other energy programmes for another year. The advance announcement of the end of subsidies likely increased the orders of heat pumps in 1984 so that users could apply for subsidies (Engebeck and Zingmark 1987, p. 4); in doing so, it may have delayed the structural transformation of the heat pump industry, considering the large number of small heating companies that were manufacturing heat pumps. After 1985, the subsidies ended completely.

Manufacturers believed that the government support had substantial effects on the commercial development of heat pumps in Sweden (Energiforskningsnämnden 1985, p. 95). The signals sent to the market that heat pumps were an appropriate installation contributed to the quickly increasing demand for them. The government therefore played a central role in the market formation that took place in this period.

6.2.5. Expansion of electric heating and new building regulations

The volume of fuel oil consumed in the Swedish heating sector fell during the 1980s, primarily due to expansion of electric heating, heat pumps and biofuels.

The incumbents in the fuel oil sector mounted little opposition against heat pumps. Heat pump technology was not pushed by new entrants but, rather, was being implemented and adopted by incumbents within the energy system and heating sector, such as Vattenfall and district heating companies. Moreover, to a large extent, manufacturers of oil boilers also started to manufacture heat pumps. Thus, the potential opponents of
this market shift were all positioning themselves to become beneficiaries of heat pumps as well.

Heat pumps faced greater technological competition from electric heaters and boilers than from oil boilers. The electric boiler was cheaper, simpler and more robust than the heat pump, and electric boilers of all sizes have competed for investment with heat pumps ever since the heat pump was first commercialised in Sweden. For larger appliances, heat pumps have also faced competition from solid-fuel boilers (Engebeck and Zingmark 1987, p. 22).

For a long time, electric boilers were also the most economic option for homeowners because of the low price of electricity. The planned expansion of nuclear power made electric heating a popular choice for both tap water and space heating in newly built houses during the 1970s. From 1970 to 1985, electricity use for heating increased fivefold, from 5 to 25 TWh (Nilsson et al. 2005, p. 8). That electric heating was seen as the biggest competition for heat pumps is revealed in a survey of representatives of the heat pump industry in 1984 (Energiforskningsnämnden 1985). The main concern expressed by survey respondents was that the low price of electricity could possibly prevent future development of heat pumps (Energiforskningsnämnden 1985, p. 110). Heat pump stakeholders were more concerned about competition from electric heating than from oil boilers or other alternatives.

In Sweden, about 75% of all single-family houses built in the late 1970s were equipped with electric heating as their primary heating system (Ullsten and Tham 1979, p. 196). With increased conflicts concerning the expansion of nuclear power, the government was endeavouring to reduce the use of electric boilers in Sweden (Ullsten and Tham 1979, p. 3).

Despite its very low capital cost and technological simplicity relative to a heat pump, electric heating was not without its own issues. With increased electric heating during the 1960s and 1970s, the lack of ventilation became a common problem. Until the 1960s, most Swedish houses had been built with a chimney. These traditional houses with a chimney were typically not very energy-efficient, but the natural ventilation from the chimney helped to protect the houses from the threats of moisture and mould.

When the chimneys disappeared, replaced with electric heating, the natural draft also disappeared. The change led to increased energy-efficiency but also to moisture-related problems. As a result, mechanical ventilation became a common practice from the 1970s onwards. In 1980, a new building regulation on heating and ventilation of houses, SBN
1980, came into force (Statens planverk 1980). This regulation mandated that new houses be built with some sort of ventilation that not only exchanged the air in the house every two hours but also recovered at least half of the heat being ventilated away. In practice, this meant that home builders had to install either an efficient FTX heat exchanger (which required a forced ventilation system to be built as well) or an exhaust air heat pump. The new building regulations became a considerable factor in the exhaust air heat pump market’s growth during the early 1980s.

### 6.3. Heat pump sector developments

After 1979, government policies were introduced to support heat pump installations, the number of academic research projects on heat pumps at various Swedish technical universities quickly increased, and Swedish state-owned energy corporate agency Vattenfall launched a major development programme primarily involving heat pumps. The heat pump sector attracted a wide number of companies with different backgrounds, and in a few years the number of heat pump brands in Sweden had risen to over 100. The Swedish heat pump sector could be described as in an overheated state, but the intense levels of competition and cooperation also resulted in a rapid sector development.

#### 6.3.1. Sales of small heat pumps until 1985

The increase in heat pump sales between 1977 and 1980 was interrupted in 1981 (Kaijser et al. 1988, p. 79) but growth resumed from 1982 to 1984. There are no exact figures for 1979–1981, which is why Figure 18 contains data only for the years 1982–1985.

Of all heat pumps installed through 1985 (around 110,000), about 70% had been manufactured in Sweden and only 30% were imported (Engebeck and Zingmark 1987, p. 57). The reasons for the strong growth during 1982–1983, according to the manufacturers themselves, were high oil prices, low electricity prices and energy policies in the form of loans and subsidies (Energiforskningsnämnden 1985, p. 95).

Imported air-air heat pumps represented only a small fraction of the growing market. Instead, both air-water and ground-source heat pumps expanded rapidly. This was the first period during which air-water heat pumps became increasingly popular. Due to difficulties regulating the operational control of heat pumps in winter, the popularity of air-water heat pumps decreased after this period and did not make a large-scale comeback until the 2000s, when the operational control problems finally improved (see Figure 31 on page 187).
6.3.2. An illustration of the heat pump sector in the early 1980s

After 1979, the Swedish heat pump sector grew rapidly as more and more companies entered. By 1983–1984, there were over a hundred different heat pump brands on the market. Many of these heat pumps had been made in Sweden and ranged from small-scale, handcrafted pumps to large ones manufactured by large incumbent industrial actors.

The business logic underlying many of these companies’ investments in heat pump manufacturing was based on the consensus among policy makers concerning the need to reduce the nation’s oil dependence, along with their own ability to assemble heat pump components and put them in a sheet metal casing. As CTH researcher Per Fahlén (in Axell et al. 2008, p. 31) stated, ‘The late 1970s and the early 1980s was a gold-rush period when most people with a rudimentary knowledge of refrigeration, and a lot of people with no knowledge, felt a calling to assist in the national programme of making Sweden independent of heating oil.’

The complexity and increased level of collaboration between the large number of actors who joined the heat pump sector are illustrated in Figure 19. The suppliers of heat pumps are divided into four categories in this overall illustration of the sector: air-air heat pump importers, assemblers of small heat pumps for the housing market, producers of medium-size heat pumps for larger buildings, and large heat pump manufacturers. This division is based on the differences in core business logics and targeted customer groups amongst these four supplier types.
Cross-network actors are illustrated in yellow, suppliers in blue, upstream suppliers and partners and downstream channels and partners in light-blue, and customers in green.
Vattenfall is given a central role in Figure 19, largely due to the ‘Solar Project’ that was in full swing in 1983 and in which Vattenfall collaborated with companies supplying small to large heat pumps of various types.

Several government actors engaged in attempts to bring stability to the increasingly complex and growing heat pump value network (e.g. the consumer agency Konsumentverket and SP) in this period, while other government actors (e.g. STU and BFR) took measures that spurred heat pump market demand. Vattenfall’s actions, on the other hand, were aimed at both controlling and supporting the growing heat pump market and the Swedish heat pump sector. Vattenfall was also engaged in increasing knowledge development and knowledge flow within the heat pump sector, sharing this task with technical universities such as CTH and its ‘Earth Heat Pump Group’ in Göteborg.

During this period, the HVAC industry dominated the market for small heat pumps and also expanded into the medium-size heat pump segment (multi-family houses and industrial buildings), which had previously been dominated by refrigeration companies. At the same time, refrigeration and turbine companies expanded into a virgin market as they started to install large heat pumps (over 1 MW) at Swedish industries and district heating companies. A value network for large heat pumps had formed by 1981, as shown to the right in Figure 19, but was discontinued after less than a decade.

The illustration in Figure 19 is just an overall depiction; the dynamics of the heat pump sector during this ‘gold-rush period’ are described in greater detail below.

6.3.3. The heat pump suppliers with the largest market shares during the rush into the heat pump sector

The industrial manufacturing of heat pumps in the late 1970s and early 1980s was characterised by the quickly increasing number of companies, including many small companies together with a few larger ones (attracted by the state subsidies of the heat pump market), that joined the industry.31

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31 This period represents the typical pattern of an early industry life cycle (Utterback and Suárez 1993; Utterback 1994). From an industry life cycle perspective, this period can be characterised as a fluid phase, with growth in the number of actors, a wide and diverse line of product offerings and competition focus on functional product performance (Abernathy and Utterback 1978; Utterback 1994).
The smaller companies could be innovative manufacturers or even entrepreneurial individuals who ordered components and assembled them into heat pump units in their garages (Axell et al. 2008).

Among the larger companies that had joined or were joining the industry were the previously mentioned STAL-Laval and STAL Refrigeration together with AGA, Asea, Saab and Fläkt. Whereas AGA, Asea and Saab joined the heat pump business mainly through acquisitions, the ventilation company Fläkt developed its own heat pump product, called Amplitherm.

In 1979, there were approximately 30 heat pump manufacturers and importers in Sweden. In about four years, that figure grew to more than 80 (Eklund 1980; Eriksson 1984; SVEP 1984; Malmqvist 1986; BFR 1989). According to interviews, the actual number was even higher than what the records show, with somewhere over 100 heat pump manufacturers and suppliers participating (Hans Lindström, personal communication, 17 February 2014). Not all the companies that joined the industry were serious; the rush also attracted opportunistic actors who lacked sufficient competence to deliver functioning heat pumps.32

Few heat pump manufacturers were dedicated only to manufacturing this product; most had other products in their portfolio as well. Amongst refrigeration-oriented manufacturers, the other products were typically related to ventilation and refrigeration installations. For a heating-oriented manufacturer, the other products were typically boilers, stoves, water heaters, etc.

The heating companies viewed both the conversion market and the home construction market as focal market segments. Between 1975 and 1986, the number of newly built houses decreased in Sweden, causing the conversion market to increase in importance. Heat pump sales increased during this period despite an overall decrease in demand for heating products (Nibe, 1984).

The energy politics and varying government support for heat pump installations contributed to changes in the market during the early 1980s, forcing the companies adjust to ‘continuous developments’, according to Nibe’s CEO at the time, Rune Dahlberg (Nibe 1984).

32 One company in the heat pump sector offered a ‘closet heat pump’. This heat pump was to be installed in the closet without being connected to a heat source outside the house, thus giving no extra net heat to the house at all.
In a research report, Engebeck and Zingmark (1987, p. 67) listed some of the top grossing heat pump firms in Sweden during the years 1982–1984, seen in Table 1. Thermia was one of the largest manufacturers of small heat pumps in 1984 and also the one most dependent on heat pump sales. IVT was also gaining most of its revenue from small heat pumps, but lagged behind Thermia in market share during the 1970s and early 1980s. The largest heat pump supplier in absolute figures was the manufacturer of large heat pumps Asea Stal.

Table 1: Revenue and turnover for some of the largest companies in the heat pump business, 1982–1984

<table>
<thead>
<tr>
<th>Company (Owners)</th>
<th>Profit [MSEK]</th>
<th>Total turnover</th>
<th>Portion of revenue from heat pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1982</td>
<td>1983</td>
<td>1984</td>
</tr>
<tr>
<td>CTC Ljungby AB (Saab)</td>
<td>7</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Elektro Standard AB (Hasselfors)</td>
<td>17</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>IVT AB (Frico)</td>
<td>N/A</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Kryotherm AB (Prordia AB)</td>
<td>12</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>Asea Stal (Asea)</td>
<td>N/A</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Stal Refrigeration (Asea)</td>
<td>N/A</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Thermia AB (Asea)</td>
<td>neg.</td>
<td>neg.</td>
<td>7</td>
</tr>
</tbody>
</table>

Thermia and CTC were briefly part of the same company when they were in the Corona Group. After AGA acquired the Corona Group together

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33 In 1985 IVT managed to get a prestigious order for a heat pump at the residence of the royal family Drottningholms Slott - a 300 kW unit that would save 200 m³ of oil annually, and a feather in the cap for IVT (IVT 2015a).
with AB Bahco to form the new conglomerate AGA Heating (AGA 2014) it changed the name of the merged companies CTC and Thermia to AGA CTC Thermia. But after a short period of time, AGA decided to split the two companies again by transferring Thermia to a part of the AGA-owned conglomerate Pharos. The idea was to split up the production offers between the two companies. Thermia was supposed to focus on products for renewable energy sources while CTC concentrated on oil-, electric-, and wood-fired boilers, water heaters and heat exchangers.

During the 1970s, CTC had major success in selling oil boilers on the Scandinavian as well as the German market. When oil prices rose in the late 1970s, CTC was forced to change its production range to adapt to the new conditions. In 1982, CTC made a big investment in developing an exhaust air heat pump called CTC Master. It became a big success for CTC with over 10,000 units sold. In 1983, CTC was sold by AGA – which was divesting its company holdings to streamline its assets – to Saab-Scania and was incorporated into the newly formed Saab-Scania Enertech, including the companies Bentone and Parca Norrahammar. In 1985, CTC launched an air-water heat pump called CTC Rebel, but its timing was poor – the reverse oil crisis had just struck the market – and after a few years of low sales, production was stopped (CTC 2015).

In 1984, Thermia and its affiliate TETAB were sold by Pharos to Asea (Engebeck and Zingmark 1987, p. 66). Asea also owned Fläkt during a short period, as well as the manufacturers of large heat pumps Asea Stal and STAL Refrigeration.

Saab-Scania had through CTC, Bentone and Parca Norrahammar a more concentrated focus on small detached houses and, to some extent, multi-family buildings (Kaijser et al. 1988, p. 85). Both Saab-Scania and Asea were owned by the famous Swedish Wallenberg-sphere, which thus dominated the heat pump sector during this period.

Manufacturers of heat pumps often used Swedish-made heat exchangers and steering equipment for their heat pumps, whereas the compressors were typically imported.

A 1984 survey showed that Swedish heat pump manufacturers viewed the country’s level of competence in the field as good, even world-leading. But the lack of Swedish manufacturers of compressors was a problem, because there was a need for small compressors adapted to the heat pump compression cycle. Without a better source of compressors, manufacturers had to use the ‘least inappropriate’ compressors available (Energiforskningsnämnden 1985).
Another finding from the 1984 survey was that education of retailers and competence of installers was a main issue (Energiforskningsnämnden 1985).

6.3.4. Cross-network actors seeking to control development

The quickly growing number of companies in the heat pump market made it difficult for customers to navigate the wide range of available products. And many products were of subpar quality, some not even functioning at all. The foremost problems concerned poor performance and malfunctioning heat pumps, but there were other issues too, such as the heat pump being too noisy or too unaesthetic (Löfving and Lilie, 1986).34

The considerable problems with heat pump product quality caused several agencies to call for action. The building and planning agency Planverket (today called Boverket), the consumer agency Konsumentverket and the Swedish testing institution SP all demanded that an industry association be formed, so as to assemble a representative part of the industry for discussions with the agencies (Lindholm 2011; Englund 1992, p. 105).

In 1981, the industry association SVEP was formed, which included many of the established heat pump manufacturers and suppliers. SVEP’s initial purpose was originally to develop rules for product warranties that would apply to all members, encourage educational activities, act as a consultative body and develop a database that would eventually encompass over 30,000 heat pump installations (Lindholm 2011).

The frequent problem of poor installation and application of heat pumps was mainly caused by poor competence amongst heat pump installers. A wide variety of actors (both private and public) contributed efforts to counteract this problem, which was increasing with the growing market demand. The actors involved in the process of educating heating product installers included manufacturers, government agencies, industry associations and electric utilities. A 1986 trade magazine article stated that ‘the industrial actors did cope to respond on a sufficiently broad front to the accelerating interest in heat pumps’ (Elmenius 1986, quoted in Kaijser et al. 1988, p. 88).

34 There were also reports of problems with homeowners who couldn’t bake without the house turning ice-cold after installing a heat pump, and another customer whose hair turned green in the shower after installing a heat pump (Löfving and Lilie, 1986).
Vattenfall was another governmental organisation that sought to increase the quality of heat pumps. Its educational efforts took place largely through Vattenfall’s ‘Solar Project’. In the 1979 state energy plan, Vattenfall had received clear directives to engage in the development of solar and heat pump technologies:

‘Vattenfall should play a role not only as state electricity producer and distributor on a commercial basis, but also as an important state resource, directly in the energy system, to develop and introduce the technology required for the energy policy intentions to be fulfilled’ (Ullsten and Tham 1979, p. 44).

The ‘technology required’ referred to both solar and heat pump technology. Following the energy proposal Vattenfall launched its ‘Solar Project’ (Solprojektet) – described in detail later in this chapter – in 1979. The Solar Project started with a budget of a few million SEK but grew tenfold in size within a few years, situating Vattenfall as a central node in the increasingly complex heat pump value network.

### 6.3.5. The role of technical universities and personal mobility between academia and industry

The two most prominent technical universities active in the heat pump area during this period were CTH in Göteborg and KTH in Stockholm (Jan-Erik Nowacki, personal communication, 5 February 2013). At CTH, the previously described Earth Heat Pump Group accounted for most of the research activities; at KTH, it was the department of mechanical heating theory and refrigeration technology.

Although heat pump manufacturers viewed the support received from research efforts as having had marginal effects on the commercial success of their products (Energiforskningsnämnden 1985, p. 95), there was considerable personal mobility between academia and industry.

For example, a group of researchers from the Earth Heat Pump Group started a company in the 1980s. The participants included Enno Abel, professor of installation technology, and Thore Berntson, professor of heating technology and machine learning (Thomas Hallén, personal communication, 10 August 2016). Abel and Thomas Hallén were also active in both Vattenfall’s heat pump investments and sat on the BFR board (Hallén, personal communication, 10 August 2016). The Earth Heat Pump Group also hosted the Nordic Symposium on ground-source heat pumps at Chalmers in 1979, which brought representatives from Swedish government agencies together with international researchers and company representatives (Earth Heat Pump Group CTH 1979).
Another example of the positive effects of personal mobility between academia and industry is KTH researcher Eric Granryd’s excursion to industry between 1978 and 1984. During the 1970s, Granryd was a researcher with a licentiate degree at KTH under professor Bo Pierre (Englund 1992). In January 1978, Granryd started working for AGA Heating but remained at KTH part-time as an R&D project leader (Eric Granryd, personal communication, 5 February 2013 and 11 September 2014).

Granryd, during his time at AGA Heating, addressed one of the most pressing technological limitations facing heat pumps at the time: the size of heat exchangers, which were often big and bulky coaxial items in copper. Other contemporary heat exchange types were finned tube batteries, tube boiler evaporators and tube boiler condensers (Poppius 1984, p. 21). A bulky condenser meant that the indoor unit took up considerable space and typically needed to be located into a special boiler room or the basement instead of the laundry room or under the staircase, which would have simplified the installation and attracted more customers.

In the late 1970s, the needed theoretical knowledge on how heat exchangers should be designed for efficient heat transfer was in place already, but the knowledge on how to practically build such heat exchangers were lacking. Existing plate heat exchangers could have met the requirements, but they couldn’t cope with the high pressures that a heat pump accomplished without being ‘blown up to large balloons’ (Granryd, personal communication, 5 February 2013).

AGA Heating was the parent company of Thermia, so Granryd started to work with Thermia to develop a smaller and more efficient heat exchanger. The result was a heat exchanger with extruded mini-channels spaced about 0.7 mm apart (Granryd, personal communication, 11 September 2014). Compared to the coaxial heat exchangers with tubes 20 mm in diameter, this was a huge improvement. The new heat exchanger had higher heat transfer efficiency and could withstand high pressure loads without deforming, which made it possible for Thermia to considerably downsize its heat pumps to a size no larger than a refrigerator’s outer dimensions.

Thermia patented the technology, and a process was developed so that the company could conduct the difficult soldering (Eric Granryd, personal communication, 16 April 2012) of the small channels and manufacture the small and effective heat exchangers at a high rate. Thermia made the strategic choice not to license the patented manufacturing process to other companies or start its own retailing of
heat exchangers; rather, the company manufactured them only for its own use (Jan-Erik Nowacki & Eric Granryd, personal communication, 16 April 2012).

Thermia had played an active role in opening up a new market for ground-source heat pumps through its large and robust JBC-400 series. With Granryd's new heat exchangers, Thermia launched a new model called DUO8 and exhibited it at the annual HVAC/plumbing fair in 1981. After considerable testing by Thermia's staff during 1980 – confirming that everything Granryd had calculated was indeed correct – the first DUO8 was released. Retailers and installers happily welcomed the new, lighter model (Leif Olsson, personal communication, 30 March 2016).

Another example of personal mobility between academia and industry was the founder of the heat pump producing company IVT. As previously mentioned, three brothers (Elis, Harald and Billy Peterson) founded IVT in 1968, but they relied primarily on the knowledge that Elis had acquired while studying at KTH during the 1960s. IVT originally produced drying equipment for the graphics industry before starting to manufacture its own heat pumps (IVT 2015a), which became a successful undertaking, enabling the company to grow significantly during the late 1970s and early 1980s.

6.4. **Vattenfall's 'Solar Project'**

Vattenfall's ‘Solar Project’ played such a big role in the Swedish heat pump transition that it deserves extensive coverage in this chapter. The project ran from 1979 to 1987 and provided interesting insights into Vattenfall’s cross-network function during this period. The company spent hundreds of millions of SEK on heat pump development during this project. The recipients of the support included a wide variety of actors – from small entrepreneurial firms to large incumbents – and a wide variety of heat pump technologies and innovations.

The Solar Project also provides insights into the ‘coopetitive’ relations between heat pump actors in this phase, as heat pump firms competed with each other at one level while teaming up at another level, and how the heat pump was dependent on complementarities on the technology level (e.g. district heating and solar).

6.4.1. **How the Solar Project started**

In 1979, Vattenfall launched the Solar Project as an RD&D (research, development and demonstration) programme. It had a relatively small budget during its early years but quickly grew in size and became one of Vattenfall's largest development programmes before it ended in 1987. In
spite of its name, the Solar Project focused primarily on heat pumps, on which it spent over 80% of its total budget, evaluating and testing all types of pumps.

The Solar Project was, according to Vattenfall, a direct response to the government directive to ‘introduce into practice technology and products required to make solar energy commercially available for heating purposes’ (Vattenfall 1981, p. 16). Vattenfall was guided by its own interpretation of this directive in investing most of the project’s resources into heat pumps. Vattenfall early on noted that solar heating demanded much development before it could be commercially competitive, whereas heat pump technology already was a real alternative for heating buildings (Vattenfall 1981b).

From a business logic standpoint, it was rational for Vattenfall to attempt to replace oil boilers with electric heat pumps. However, this move was not equally rational from a short-term profitability perspective as it means selling less electricity while not improving the problems of peak load on the grid. Therefore, the Solar Project had some internal sceptics (Lennart Spante and Hands Lindström, personal communication, 17 February 2014).

Replacing direct electric heaters was instead motivated by the above-mentioned directives and, according to Sven-Allan Eklund (personal communication, 17 December 2013), by a desire to ‘do good for the nation’. In the Solar Project, Vattenfall took on a government agency’s role in relation to homeowners, manufacturers, importers and installers.

6.4.2. Anchored at the top

Vattenfall board member, Head of Staff and Planning Director Bengt Nordström was appointed head of the Solar Project by the company’s Director General, Jonas Norrby. Nordström remained on Vattenfall’s executive board but took leave of absence as Head of Staff as of 1 July 1979 (Vattenfall 1979b). He continued as head of the Solar Project until 1985, after which he remained in the heat pump sector by operating his own company and in the IEA Heat Pump Centre (IEA Heat Pump Centre 1987).

Before Nordström became head of the Solar Project, he had been engaged in heat pump technology for some time. Nordström promoted this technology in Vattenfall’s internal magazine, Vi i Vattenfall, even before the first oil crisis (Vattenfall 1973). By 1979 he was well acquainted with heat pump technology and believed in its potential. Nordström held a presentation of heat pumps at Vattenfall’s 1980
Customer Day, where he expressed his belief that a big breakthrough for heat pumps was imminent (Nordström 1980).

The Solar Project’s anchoring at Vattenfall’s top management level became apparent during the course of the project. Norrby, who was also a member of the Solar Project’s research council, indicated on the television news programme *Aktuellt* in 1985 (a film clip supplied by Svante Färnbo at Vattenfall, personal communication, 10 October 2014) that heat pumps were the next big thing, and that the heat pump sector had already started to ‘develop in a very good way’.35

### 6.4.3. The project set-up

Since the Solar Project was an RD&D project, it focused more on demonstration projects and field tests than typical R&D projects did. It gave most of its support to mature projects close to being commercialised, in contrast to the strategy followed by BFR and STU in the ‘Sol 85’ programme (Efn 1985, p. 45).

Vattenfall did not initially engage in any product development itself, but instead took on the role of pushing technological development forward amongst manufacturers and universities and ensuring that the products on the market were of sufficient quality.

In its first year, the Solar Project expended 4.2 MSEK, of which most (2.2 MSEK) went to solar heating projects and the rest (2 MSEK) to heat pump development projects. The original plan was to increase the project budget to 12 MSEK for the year 1981–1982 and then to 15 MSEK by 1984–1985 (Nordström 1980). The actual figure in 1984–1985 however, turned out to be more than 40 MSEK (Vattenfall 1985).

The Solar Project was divided into two main units: a project administration unit in Stockholm and an R&D unit at Vattenfall’s research facilities in Älvkarleby, roughly 150 km north of Stockholm. The R&D unit had room for 5 to 10 technicians who worked on tests of solar energy and heat pumps (Vattenfall 1981, p. 50).

The main activities at the R&D unit involved testing how well heat pumps worked in different conditions (logging the inputs and outputs). Not until the end of the project did the activities include more product development focus as the R&D unit started working with direct

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35 This is my translation from the Swedish; the original comment was ‘Värmeupumparna är ju det stora slagnumret, och det har ju redan kommit, det här, att utvecklas på ett mycket bra sätt.’
expansion heat pumps. In this instance, Vattenfall engaged in actual technological development and evaluated the role of the direct expansion heat pump’s components with regard to overall performance (Lennart Spante and Hans Lindström, personal communication, 17 February 2014).

The direct expansion heat pump is very different from the types described in Fact Box 5 and 6 (pages 75 and 78). Instead of using secondary collector loops connected to the heat pump through heat exchangers, it uses collectors as evaporators, meaning that there is no need for a ‘brine’ and one fewer main component in the heat pump unit than in typical ground-source heat pumps. The challenge for direct expansion pumps, however, is to control the evaporation process in the collectors and the whole compression cycle.

6.4.4. Partners in the Solar Project

The CEO of industry association SVEP has claimed that for heat pump technology to make a breakthrough in a given country requires support from the large energy companies in that country (Forsén 2008). And indeed, collaborations and joint projects were a central part of the Solar Project. Vattenfall collaborated with energy and heating utilities, energy-intensive industry companies (i.e. large energy consumers), manufacturers of heat pumps, government agencies, academic research units, individual scientists, self-employed entrepreneurs and heat pump customers – such as the Vattenfall employees who used their homes as test rigs.

Over time, the collaborations in the Solar Project both increased in number and deepened in nature. The partners who participated in the project are illustrated in Figure 20.

Vattenfall’s collaborations with Sydkraft and the German energy company RWE continued into the Solar Project (Vattenfall 1981b). The company also developed a collaboration with French EdF. But whereas these collaborations consisted of exchanges in knowledge only, Vattenfall has made several joint investments with municipal energy companies in Sweden (Vattenfall, 1981c).

Government partners, such as the BFR and STU, also contributed to the project. These partnerships were mostly of a financial nature. Vattenfall did not just use funds from its own budget to finance heat pump development projects. In fact, it also applied for grants from the BFR and from the board for energy production research, NE, for some projects (Vattenfall 1981c).
Other agency partners included the telecommunication agency Televerket – acting as both partner and customer – and the testing agency SP. SP and Vattenfall conducted joint heat pump tests, created heat pump standards and educated heat pump installers.

Figure 20: Illustration of Vattenfall's Solar Project

6.4.5. Heat pump suppliers and manufacturers

The typical investment in heat pumps from Vattenfall occurred through procuring newly developed prototypes from Swedish manufacturers and testing and monitoring them in close relation with the manufacturers (Vattenfall 1981a).

As of 1983, more than a hundred different projects had been launched within the Solar Project. Vattenfall had divided its heat pump efforts into three sizes: small, medium-size and large heat pumps. With the exception of some large absorption heat pumps, typically all pumps tested were electricity-driven, compression-cycle heat pumps.
Vattenfall expressed different ambitions for its development projects depending on the size of the heat pump. For smaller pumps, the company focused on collaboration with manufacturers and entrepreneurs in system development, gathering experience, and testing, measuring and monitoring these small pumps over a longer period of time. The desire was to monitor the installed heat pumps over a five-year period (Vattenfall 1983). For larger heat pumps, the aim was to develop and test different concepts together with the manufacturers, with the overall goal of increasing technology development and expanding the market (Vattenfall 1983).

At the beginning of the Solar Project, Arvika-based AGA-Thermia was the best-known and most established heat pump manufacturer in Sweden, and Vattenfall's tests of small heat pumps initially used AGA-Thermia products (Nordström 1980). Eventually more manufacturers, such as IVT, Nibe and Elektro Standard, also became partners with Vattenfall and received support through procurements and testing of newly developed prototypes (Vattenfall 1989c).

6.4.6. The Solar Project's research council

Collaboration with technical universities and academic researchers was another part of the Solar Project. Both heat pump researchers Eric Granryd (at KTH) and Enno Abel (professor at Chalmers) acted as academic consultants to Vattenfall (Granryd, personal communication, 16 April 2012).

Figure 21 shows members of the Solar Project’s research council and comes from an article in Vattenfall’s company magazine. Here some of the most prominent heat pump personas are gathered in one picture: Bengt Nordström, head of the project and member of Vattenfall’s executive board; Enno Abel, professor of installation technology at Chalmers; Eric Granryd, licentiate (later professor) at KTH and researcher at AGA; and Jonas Norrby, Director General of Vattenfall. The picture also includes Albert Danielsson, professor of industrial economics and management at KTH.

The photo reinforces the fact that the Solar Project was a prestigious programme, with a research council that involved professors from different faculties and the Director General, the highest-ranking position at Vattenfall, personally involved. From this picture, it seems that the atmosphere in the group was good as well.

6.4.7. The Solar Project and small heat pumps

At the beginning of the Solar Project, Vattenfall considered horizontal ground-source heat pumps and air-air heat pumps to be already
established in the market and therefore decided that these types did not require any extensive testing (Vattenfall 1981, p. 51). The initial testing of small heat pumps instead focused on other types.

Figure 21: Members of the Solar Project’s research council. From left: Albert Danielsson, Bengt Nordström, Enno Abel, Eric Granryd, and Jonas Norrby. Source: Vattenfall 1980.

Vattenfall viewed air-water heat pumps as having especially great potential to replace oil burners in existing houses. Therefore, it made substantial investments in this heat pump type and tested over 120 installations of the following brands: Thermia, Parca Matic, Tour & Andersson, Happel, Essef-Service and Kryotherm (Vattenfall 1989b). The largest problem in general for air-water pumps was defrosting failures, which caused the evaporator to freeze, leading to subsequent downtime and decreased COP. Other issues concerned continuously running auxiliaries, such as circulation pumps, which also affected the heat pump’s COP negatively (Vattenfall 1989b).

Furthermore, Vattenfall tested 30 vertical-borehole ground-source pump installations of the following brands: DEBE GM 40, Thermia DUO12 and Modul 12, VENT Tekn VTVP, Ahlsell Combi Nather and Eufor Myggan.
Both Ahlsell Combi and DEBE GM 40 were also used for tests of 17 groundwater heat pump systems.

Of the vertical-borehole ground-source heat pumps tested, 14 were equipped with recharging systems using either solar panels or outside air heat exchangers. These proved to be completely uneconomical as the ground ‘recharges itself’ and the added heat from the recharging system was only marginal. Drilling deeper boreholes instead was found to improve the economic performance of ground-source heat pumps (Vattenfall 1989b).

Vattenfall’s tests of exhaust air heat pumps were performed on Elektro Standard’s Aquaes 260, CTC Master 102 and Nibe Fighter.

By the end of the project Vattenfall had also, despite its initial stated intention, performed some tests on horizontal ground-source pumps, including Thermia JBC 400 M, Thermia Modul 8, Ahlsell Combi LJ Nather and Terra Term (Vattenfall 1989b).

A review of Vattenfall’s tests shows that the ground-source heat pump pioneer Thermia participated in all tests except those of exhaust air pumps. The three exhaust air heat pump suppliers were the three established heating product firms Nibe, CTC and Elektro Standard.

Developing the technique for drilling boreholes for vertical ground-source pumps was also included in the Solar Project. According to Zogg (2008) and Granryd (2010), the depth of boreholes was limited to around 50 meters in 1980, in 1985 the limit was 100 meters, and in 1990 the borehole technique had been made so efficient that it was possible to drill up to 200 meters in just one day.

**6.4.8. The Solar Project and medium-size heat pumps**

The physical conditions for medium-size heat pumps (ranging from about 25 to 1000 kW) were not very different from those for small heat pumps, except that the systems were larger and had more powerful compressors (typically a screw compressor).

A large portion of Vattenfall’s investments in medium-size heat pumps was spent on improving the heat uptake from lake and ground collector systems. These efforts, according to Vattenfall, resulted in improved system operation between the facilities heating system, the heat pump system and the heat source (Vattenfall 1989a).

The tests of medium-size heat pumps showed that the cause of many heat pump failures could be traced back to faulty application of the heat pump to the heating system. Compared to smaller heat pumps, Vattenfall noted fewer failures of components.
One of the first tests conducted at the Älvkarleby R&D facility during the Solar Project occurred in spring 1980 and involved a so-called ‘icing heat pump’. The idea behind this 150 kW heat pump was to use the latent heat in the water from the river Dalälven by making an ice slurry of the river water and pumping the slurry back to the river (Lennart Spante and Hans Lindström, personal communication, 17 February 2014; see also Vattenfall 1981). The initial plan was to test a smaller unit at R&D before building a much larger icing heat pump at ‘MW-size’ (Vattenfall 1981a). But no MW-size icing heat pump was built. The problems with the prototype were too many and too substantial: it froze, the defrosting didn’t work and it was very noisy. At Älvkarleby, the icing heat pump had been installed close to office spaces and the noise was so loud that it caused ‘workplace environment problems for everybody who sat on that shelf’ next to the pump (Lennart Spante and Hans Lindström, personal communication, 17 February 2014).

6.4.9. The Solar Project and large-size heat pumps

Tests on large heat pumps did not begin until a few years into the Solar Project. However, in spite of this late start (and initial technical problems) the collaboration between Vattenfall, municipal district heating companies and Swedish compressor and turbine suppliers in the Solar Project became the starting point for a rapid expansion of large heat pumps, making a big impact on operations at Swedish district heating plants during the 1980s.

In 1980, oil represented the largest part of Swedish district heating plants’ energy mix (Energimyndigheten 2008, p. 28), but in the following decade, other fuels were substituted for oil and, thanks to this shift and other measures, the total amount of emissions from the plants started to decrease (Fröling et al. 2007, p. 28). Biofuels, peat and household waste have been the primary substitutes for oil, but large heat pumps also made a strong contribution to the decreased emissions during the 1980s.

Since 1991, there have been no new installations of large heat pumps and yet, to this day, some of the largest heat pump facilities are found in Swedish district heating plants.36 In the early 1990s, heat pumps supplied roughly 5 TWh of heat to Swedish district heating grids annually. Although this number has slowly dwindled over the years, heat

36 The heat pump facility in Ropsten, Stockholm has a total effect of 256 MW of heat; it is probably the world’s largest heat pump (Fortum 2011).
pumps still constitute a fairly large part of these plants’ heating capacity. In 2014, large heat pumps produced 10% of all heat in Swedish district heating grids (Bergman 2014, pp. 97–98). I will return to issues of large heat pump development in the next section of this chapter.

### 6.4.10. After the Solar Project

Eric Granryd (personal communication, 16 April 2012) recalls how Bengt Nordström came by car to KTH, accompanied by a pile of books from the Solar Project stacked half a metre high. According to Granryd and Jan-Erik Nowacki (personal communication, 16 April 2012), the project had a large and lasting impact on the Swedish heat pump industry.

In the end a total of 380 MSEK were spent on the Solar Project, of which 80% went into heat pump development projects (Vattenfall 1989b). In current (2017) monetary value, that figure corresponds to about 600 MSEK invested just in heat pumps. And this figure does not include the grants that Vattenfall received from BPR and the board for energy production research, NE.

Nordström resigned as head of the Solar Project in 1985, and his replacement had considerable work on her hands to finish and summarise all the different projects still ongoing. Some critique was also aimed towards the management of the Solar Project for not having spent the budget responsibly, e.g. making unnecessary expenditures on projects that were doomed to fail from the start and on items that had nothing to do with the projects, like expensive taxi rides (Lennart Spante and Hands Lindström, personal communication, 17 February 2014; Sven-Allan Eklund, personal communication, 17 December 2013; Lars Jacobsson, personal communication, 17 May 2013).

According to Lindström (personal communication, 17 February 2014), the growth of the Solar Project was largely attributable to Bengt Nordström himself, despite the subsequent criticisms of how he spent money. In the project that followed the Solar Project (called Uppdrag 2000), the directive from Vattenfall was to ‘hold the damn money tight!’

When Vattenfall financed the investments of large heat pumps in municipal district heating plants the initial idea was to split the profits between Vattenfall and the municipal energy company in a so-called

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37 This is my own translation from ‘håll nu för fan i pengarna’ (Lars Jacobsson, personal communication, 17 May 2013).
contracting model. But determining the amount of profit proved
difficult, and differences occurred between Vattenfall and the municipal
energy companies. The end result, according to Lars Segerstolpe
(personal communication, 17 May 2013, Solna) was that Vattenfall
simply ceded the heat pumps to the municipal energy companies for free.

In Vattenfall’s next large-scale R&D project, Uppdrag 2000, heat pump
development projects continued but on a much smaller scale.

As for the largely forgotten solar part of the Solar Project, the Swedish
Energy Commission stated in 1995 that the industrial production of solar
panels in Sweden was on ‘hand craft level’ (SOU 1995, p. 216) and that
sales remained low. In 2007, there were still no more than
approximately 20,000 houses with installed solar panels in Sweden
(Energimyndigheten 2009a).

### 6.5. Development of large heat pumps

The development of large heat pumps in Sweden played out in a
relatively short time-frame (roughly between 1982 and 1990) and is
relatively easy to delimit. Part of this development was also described in
sub-section 6.4.9.

In the 1980s, the number of large heat pumps increased drastically,
making a substantial impact on several of the Swedish district heating
energy systems and the national energy system. Seen from another
perspective, district heating power plants and grids became
 technological and infrastructure complementarities to heat pump
technology during this period. The effects were positive for heat pumps
at the technology level, meaning that this activity contributed indirectly
but positively to smaller-size heat pumps as well.

There were a number of reasons for this cooperative development of
district heating and heat pumps at the technology level in the 1980s. One
was that STAL-Laval had existing relations with a network of the
country’s district heating companies (from previously delivering and
installing turbines for the district heating companies’ combined heat and
power plants). Another was the support from Vattenfall, building on the
previous Solar Project.

### 6.5.1. Sales of medium- and large-size heat pumps

The first heat pumps commercialised in Sweden were of medium size
(25–1,000 kW). Not until about 1980 did small heat pumps (<25 kW)
become the largest market category. The numbers for the different heat
pump categories are shown in Table 2.
Before the 1980s, medium-size heat pumps had primarily been installed for customers with high comfort demands or special heating and cooling needs, e.g. hospitals, department stores and ice halls, as described in the previous chapter. The market category of medium-size heat pumps expanded together with the small heat pump market in the late 1970s as new markets such as multi-family properties opened up.

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38 Engebeck and Zingmark (1987, p. 56) identify as their sources Statens Provningsanstalt (SP) for the period until 1982 and the industry association SVEP for the period 1983–1985, together with the organisation ‘Kraftverksföreningens utvecklingsstiftelse och leverantörerna’. 
Even though the market for small heat pumps dropped after 1984, the heating effect from all installed heat pumps in Sweden was significantly larger in 1986 (635 MW) than in 1984 (558 MW) because the annual installation of large heat pumps continued to increase. In the six-year period from 1981 and 1986, heat pumps totalling over 2.5 GW of heating effect were installed, out of which more than half of the heating effect could be attributed to large heat pumps (Vattenfall 1989b). The expansion of large heat pumps decreased in 1987 (from about 500 MW of installed effect in 1986 to only around 100 MW in 1987) and new installations of large heat pumps did not continue into the 1990s (Kaijser et al. 1988, p. 77; Vattenfall 1989b; Energimyndigheten 2015c). In 1991, heat pumps supplied 7.4 TWh of heat, compared to the 3.2 TWh they had supplied in 1985 (after having supplied nothing in 1981). Despite the halt in the large heat pump market after 1990, most large heat pumps are still in use today, though their use have declined over the last few years (Energimyndigheten 2015c).

### 6.5.2. Large-size heat pump actors and the rapid heat pump expansion in district heating grids

Relatively few actors were involved in the installation of large-size heat pumps. All large heat pumps were delivered as turn-key units with one supplier as main contractor, unlike the installation of small heat pumps which (at the time) were delivered through a chain of contractors and subcontractors.

Vattenfall’s partners for large heat pumps were initially STAL Refrigeration and STAL-Laval in Finspång, later joined by Thermia’s affiliate TETAB.

The first large heat pump (over 1 MW) installed in Sweden was ordered by Vattenfall in Sala-Heby and used waste heat from the municipality’s sewage water (Vattenfall 1981a). The installation was made by STAL Refrigeration as main contractor, and the facility was to deliver an effect of 3.0–3.6 MW with a 1 MW compressor (rated power of 1,400 kW and 6.6kV) (Vattenfall 1982). The compressor was regulated using a slider valve control, which caused vibrations when run on partial load. This resulted in noise and broken or loose pipelines and valves. After a long period of trouble with the partial-load operation, the problem was remedied by a suction throttling valve and bypass of the condenser. But with the suction throttle, the power output was regulated using lighter gas instead of changed volume, which impaired performance during partial load considerably (Lennart Spante and Hans Lindström, personal communication, 17 February 2014; Vattenfall 1989b). In spite of the substantial technical problems, Vattenfall procured an identical model
for a heat pump installation at the Vattenfall-owned municipal company GEAB in Visby (Spante and Lindström, personal communication, 17 February 2014; Vattenfall 1989c).

Another challenge was the difficult techno-economic situation of running a system of heating technologies in the district heating plants with an energy mix that would be as efficient and profitable as possible. In Sala-Heby, the energy mix in the district heating system was constituted of coal, oil, electric boilers and heat pumps. To optimise the run-time of a heat pump in such a system is no straight-forward operation (Hans Lindström, personal communication, 17 February 2014).

The Sala-Heby heat pump, the first large-size heat pump in Sweden, was fitted with a screw compressor manufactured in Sweden.

In the 1980s, STAL Refrigeration manufactured both piston and screw compressors. But the piston compressors used in the assembly of small heat pumps in Sweden were principally all based on imported piston compressors. STAL Refrigeration was the only manufacturer of piston compressors left in Sweden, and it ceased production in the late 1980s, moving to screw compressors instead (Almqvist et al. 1992, pp. 78–79). The screw compressors were suited for larger heat pump applications in the range of 500 kW to 5 MW (Almqvist et al. 1992; Bäckström 1983).

Another type of compressor suitable for even bigger output ranges was the turbo-compressor. In 1981 and 1982, a few engineers at the turbine manufacturer STAL-Laval in Finspång got the idea of delivering large heat pump applications to municipal district heating plants using turbo-compressors. STAL-Laval had supplied turbines to municipal heat and power plants and had an established network of contacts with Swedish municipal energy companies, which became potential customers (Almqvist et al. 1992).

STAL-Laval imported large turbo-compressors from the Swiss manufacturer Sulzer Brothers Ltd. and offered a turn-key solution, as STAL Refrigeration did. The first turbo-compressor heat pump order was a 11 MW heat pump for ASEA in Ludvika, and the first one placed in operation was at Tekniska Verken in Västerås in June 1982 (Almqvist et al. 1992, p. 106).

The payback time for large heat pumps were surprisingly short; most were paid off in only a few years. However, there were several technical challenges with the large heat pumps. In addition to the aforementioned problems with capacity regulation, other difficulties included leakage of oil and refrigerants, as well as corrosion and dirt coating at the evaporator. The leakages in the first heat pump installations were substantial. Around 0.5–1 dl of lubricating oil could leak out in one day
during normal operation, and this was seen as acceptable. During
downtime, several tons of refrigerant CFC12 could leak out from just one
heat pump unit (Vattenfall 1989b).

From 1982 on, the market for large heat pumps expanded quickly
(Almqvist et al. 1992). Up through 1986, there had been installations of
heat pumps with a total heating capacity of 2,533 MW, of which the great
majority came from large heat pumps. In 1986, large heat pumps were
installed with an effect of about 530 MW of heat, compared to 1984 and
1985 when a total of 300 MW of heat had been installed (Vattenfall
1989b).

In 1983, a group of four engineers from STAL-Laval formed Elajo
Värmevärmepumpar AB, financed by the Elajo company in Oskarshamn, and
managed to get exclusive rights to sell some Sulzer Brothers Ltd. turbo-
compressor models. In 1988, Elajo Värmevärmepumpar was liquidated and
ASEA STAL took over the maintenance of the 11 heat pump facilities on
216 MW that Elajo had installed (Almqvist et al. 1992, p. 107). Thermina
launched its own company delivering medium- and large-size heat
pumps as well, called Thermina Energiteknik AB (TETAB). According to
Leif Olsson (personal communication, 30 March 2016), TETAB was a
temporary organization that was started when Thermina noticed the
increasing demand for large heat pumps.

Up to 1989, installations of heat pumps in Swedish district heating
plants had a total effect of 2.5 GW (Vattenfall 1989b). Heat pump sales
constituted about 15–17% of the total turnover for ASEA STAL and STAL
Refrigeration in 1984 (Engebeck and Zingmark, 1987). But then the
development stopped as quickly as it had begun, and in 1991 ASEA STAL
delivered its 50th and last heat pump unit. By then, over 100 large heat
pumps had been installed in Sweden.

Different market mechanisms applied to large heat pumps from those for
smaller heat pumps, which did not suffer as much from the reverse oil
crisis, as seen in Figure 22. Not until 1987 that the installations of large
heat pumps start to decrease, but then the drop was just as dramatic as it
had been for small heat pumps a couple of years earlier, with only 100
MW of installed capacity in 1987 (Kaijser et al. 1988, p. 77).
Figure 22: Total heat pump effect taken into operation in Sweden through 1986. Source: Vattenfall 1989a.

6.6. Value network formation and forward integration

Between 1979 and 1984, two new heat pump value networks were formed: the previously described large heat pump value network and the exhaust air heat pump value network. But there was also a reconfiguration of existing value networks, both to overcome and manage existing technological and organisational challenges and to form new partnerships and alliances to counter the increasing competition from new entrants.

6.6.1. Formation of the exhaust air heat pump value network

Chronologically, air-air heat pumps were the first commercialised small-size heat pumps, followed by air-water and ground-source heat pumps. But shortly thereafter, exhaust air heat pumps became commercially
available to Swedish customers. The accumulated sales of exhaust air heat pumps in Sweden through 1981 were about 4,500 units, roughly the same amount as for the sales of air-air heat pumps in the same time period (SVEP 2013). The sudden increase in sales of exhaust air heat pumps was directly related to the new building regulations.

An illustration of the early exhaust air heat pump value network can be seen in Figure 23. The value network was, like many previous networks, set up within an existing network. The new regulations mandated heat recovery for all newly built houses, and the home builders, who paid close attention to the changes in building regulations, saw heat pumps as an economic alternative to FTX heat exchangers for heat recovery. So this value network formed to a large extent around the home builders rather than the exhaust air heat pump manufacturers.

Figure 23: Illustration of the early exhaust air heat pump value network

The commercial development of exhaust air heat pumps in the 1980s was led by CTC in Ljungby, Nibe in Markaryd and Electro Standard in Katrineholm (Vattenfall 1989b). Elektro Standard was the first mover in this market segment, soon followed by Nibe and the year after by CTC. Nibe was a manufacturer of both water heaters and wood stoves, among other heating products, and in 1981 it commenced production of exhaust air heat pumps. These pumps were delivered in a package together with a ventilation system and a water heater using an immersion heater aimed at the construction market (Nibe 2015). In 1982, Nibe was
followed by CTC, which during the 1960s had been one of the flagship companies within the Corona group (of which Thermia was also a part during a period in the 1970s). CTC focused mainly on oil-fired boilers but also made other products such as laundry machines.

The Corona group enjoyed strong growth in the 1960s with as many as 3,000 employees, most of them located in Ljungby. CTC even owned a company airplane with a full-time hired pilot. But overly optimistic investments and declining markets put the Corona group in an acute crisis in the early 1970s. After many turns and an investment battle between Wallenberg’s Incentive AB and the AGA group, the Corona group was eventually sold to AGA. CTC's oil boilers sold relatively well, especially in the German market, during the 1970s, but these sales plunged amidst the high oil prices of the early 1980s. Therefore, CTC made large investments in developing and initiating the manufacturing of exhaust air heat pumps in 1982 (CTC 2015).

6.6.2. Producers integrating vertically downstream

Poor installations had been identified early on as a critical customer satisfaction problem and as a common weakness in execution due to lack of knowledge among the installers. The problems were related to the fact that pipe-laying installers from the HVAC industry, accustomed to installing boilers, were doing the installations. The existing HVAC industry had nationwide coverage, which was required to get the heat pumps out on the market on a large-scale basis. The problem was that the market grew so fast that it gave installers inadequate time to educate themselves concerning the new heating technology.

An example of how lack of knowledge among installers could cause problems was the failure to understand that heat pumps always benefitted from giving off heat at as low temperatures as possible. Within the HVAC industry, it was normal to regulate the indoor temperature by blending the return in the radiator systems with hot water from a boiler (e.g. an oil boiler) through a shunt valve. Some installers connected the heat pump in the same manner, so the heat pump always shunted in hot water at unnecessarily high temperatures, instead of heating the return water to the desirable level directly (not by blending cold and hot water). Having the heat pump set to deliver only hot water drastically decreased its efficiency. Professor Eric Granryd (e-mail, 11 September 2014) wrote the following about this problem:

Getting the industry to realise that this should not be done took me years and made me desperate at times. It is (was!!) a delusion that the heat pump (and for that matter refrigeration units in general) does not work well by working with variable condensation
temperatures – in reality it is the opposite way. Heat pumps should be driven by the lowest possible condensation temperature.\textsuperscript{39}

Organisations such as Vattenfall, BFR and SVEP made efforts to educate heat pump installers and elevate their competence.

The refrigeration industry never had the same type of issues with installations, at least not to the same extent. The typical model in the refrigeration industry was that the supplier would take complete responsibility from retail to final installation. The HVAC industry was historically much more divided and separated into the traditional industry chain of manufacturers, wholesalers, installers and consultants (Kaijser et al. 1988).

The division into these value chain steps did not assign unambiguous responsibility for installed heat pumps, which was often needed. There were conflicts of interest over heat pump technology between the differences in knowledge and routines in the refrigeration and HVAC industries. Much communication was needed to create understanding between the industries, along with much closer collaboration between all stakeholders than most were used to (Englund 1992, p. 107). From this, it emerged that the most appropriate approach to heat pump sales was turn-key installations with responsibility for both warranties and performance functions (Englund 1992, p. 107; Kaijser et al. 1988, p. 88).

Some heat pump manufacturers adopted this model by semi-integrating forward and taking responsibility for the installations made by ‘their’ installers (Englund 1992, p. 107). For example, Thermia had already started to build its own network of installers and also launched an education programme for its dedicated retailers and installers called the ‘Thermia-school’ (Leif Olsson, personal communication, 30 March 2016).

According to Olsson, the incumbent refrigeration industry started grumbling over the newly formed heat pump industry when discussions about policy support to the heat pump market began. Lobbyists representing the refrigeration companies demanded that heat pumps be seen as a refrigeration technology, therefore requiring certified

\textsuperscript{39} The original Swedish was as follows: ‘Att få branschen att inse att man inte skulle göra så tog många år, och gjorde mig emellanåt helt förtvivlad. Det är (var!!) en vanföreställning att värmepumpen (och för den delen kylanläggningar i allmänhet) inte må be bra av att arbeta med variabel kondenseringsstemperatur – i själva verket är det ju tvärtom. Värmepumpen ska köras med lägsta möjlig kondenseringsstemperatur.”
refrigeration installers to do the installations. Policy makers agreed to this demand, categorising the heat pump as a refrigeration technology and thus introducing refrigeration-based requirements for heat pump installations. The response by Thermia was to create and develop its own education and certification programme for Thermia-affiliated installers, which government officials later approved as sufficient (Olsson, personal communication, 30 March 2016).

The reason why Thermia had its own network of installers dated back to a series of events in 1976 and 1977. During these years, the quickly increasing demand created a delivery problem for Thermia. Thermia’s production capacity was at the maximum possible, and heat pump deliveries had to be postponed. Soon wholesalers started cancelling delayed orders and chose other heat pump suppliers. In response, Thermia reconsidered the role of the wholesalers. In 1977, Thermia collected a group of pipe-laying HVAC contractors and asked them if they wanted to be a part of Thermia’s own chain of retailers. With 14 positive responses, Thermia launched its own retailing. The network of retailers soon expanded, reaching about 100 dedicated retailers around 1978–1979.

But this caused a conflict with the wholesalers, who felt bypassed. In response, they threatened not to sell any Thermia products unless Thermia dismantled its own network of retailers (Leif Olsson, personal communication, 30 March 2016). Thermia chose to continue with its own network for distribution, retailing, installation and service, which meant that the company could more easily ensure high-quality installations of its products (which only its own installers were allowed to do) by personnel educated and certified through the Thermia-school. IVT would later go through the same steps and processes, as would CTC. Nibe was the only large heat pump producer that chose to keep the wholesaler as a step in its value chain.

Thermia’s actions to integrate forward not only protected its quality of installation, but also heightened its competition against the refrigeration industry.

6.7. Summing up the dynamics in the second phase of the heat pump transition

The ‘coopetition’ dynamics of heat pump technology and heat pump value networks in the 1980s were both complex and intense. There were cross-technology coopetition activities at a technology level, for example with solar technologies and district heating, and coopetition activities at a value network level, e.g. joint efforts among heat pump suppliers to
increase the competence of installers and ban opportunistic companies from the heat pump sector.

At the same time, as new cooperations formed, the competition in the heat pump sector also increased. There was competition between similar value networks (e.g. Thermia vs. IVT), between different value network types (e.g. heating-based and refrigeration-based) and between different technological heating alternatives.

The increased coopeetition intensity in this phase had its background in the 1970s energy system developments. The international oil crisis and the Swedish economic recession had put increased negative transformation pressure on the Swedish energy system. Apart from the efforts to reduce oil dependence, the move towards dismantling nuclear power in Sweden threatened to increase electricity prices and there was genuine concern about future electricity rationing. This negative transformation pressure on the energy system required the development of new complementarity assets that could contribute to reducing the total demand on oil and electricity, which in turn put a positive transformation pressure on the heat pump sector.

6.7.1. Technology-level complementarities and coopetition

During the period from 1979 to 1985, there was an intense search for new solutions and alignment of new complementarities in the energy system and related industries. As a result, heat pump technology became increasingly aligned with other complementary technologies, including other heating technologies such as district heating and solar technology, which would otherwise be competing technologies with heat pumps. But from an oil dependence mitigation perspective these technologies were complementary to each other.

The issue of the relatively high investment costs of heat pumps serves as an example of this pattern. The capital intensity of heat pumps was an economic issue that could hinder investment. One way to reduce the investment cost was to reduce the size of the heat pump. A heat pump designed to cover the entire heating demand was much more expensive than one with less capacity but that could still cover 85% of the year’s heating needs. Thus, to make an investment in a heat pump economical, it was beneficial to have another heating technology installed at the same time, one that could help during the year’s peak load (in the cold winter months). Therefore, heat pumps, especially heat recovery pumps (i.e. exhaust air heat pumps), benefitted from having a second heat source installed, e.g. a wood-fired stove or a pellet boiler. The most common companion energy source, however, was electric heating. Without access to a backup system, the heat pump quickly would have become an
increasingly uneconomical option compared to many of the heating alternatives available at the time. The heat pump was, in other words, largely dependent on complementary heating alternatives in the early stages of the Swedish heat pump transition.

This example was on a home heating system level, but heat pump technology was also in different ways dependent on other heating technologies at an energy system level.

**Solar**

In the 1970s, solar technologies were more popular than heat pump technology. There were common misconceptions concerning heat pumps, such as that the air or ground did not contain enough heat to use for heating, or that the ground would quickly freeze and result in permafrost if a ground-source heat pump was installed. These misconceptions not only worried potential customers but were spread amongst government agencies, lending institutions and industry associations as well (Mogensen 1979). Having the positive attention of policy makers was important for both market formation and to influence the institutional settings to favour heat pumps.

In this context, one ironic reason why Swedish policy makers paid increasing attention to heat pump technology was that its proponents marketed it as a solar technology (because it extracted heat from the air and the ground that the sun had heated). In this way, they utilised the favourable public view of solar power to give heat pump technology forward momentum while overcoming the widespread lack of knowledge concerning heat pumps (cf. Vattenfall 1979, p. 9).

As one example, when Vattenfall was given the directive to make solar energy technologies commercially available for heating purposes, the Vattenfall staff in the Solar Project made their own interpretation of the directive and redirected 80% of its support to heat pumps. The steering of resources towards heat pumps and away from solar technology was also possibly a strategic choice by Vattenfall. Supporting heat pumps would mean that customers would still be dependent on electricity for heating (though less so than if they had direct electric heating).

**District heating and large heat pumps**

District heating technology competed with heat pumps in the single-family home heating market, but in the 1980s the competition from heat pumps in this market was still relatively limited. The idea that heat pump technology was perhaps better in larger models, ranging over 1 MW in district heating grids, started to gain traction among district heating companies after 1981. The economic motivation to invest in
large-size heat pumps was based on the high fuel prices and affordable (but not too low; see Figure 5 on p. 39) electricity prices. The payback time for a district heating company's investment in a large heat pump dropped as low as two to three years in the 1980s.

The rapid expansion of large heat pumps was made possible by a set of incumbent actors that reconfigured their existing value networks in order to form a new type of heat pump value network focused around very large, site-built pumps. The set of key actors was relatively small: suppliers of large heat pumps (i.e. STAL Laval, STAL Refrigeration, Elajo, etc.), Vattenfall, and district heating companies (or industrial companies with large heating needs).

The first installations were of quite poor quality, but since Vattenfall was part supplier and part customer, it formed a bridge between the suppliers (STAL Refrigeration and STAL Laval) and the district heating companies that would use the large heat pumps. This gave the suppliers time to fix their early technological difficulties, improving performance for future applications.

The rapid expansion of heat pumps in district heating systems strengthened the position of both district heating technology and heat pump technology in the energy system. It meant that the district heating power plants could quickly reduce a large portion of their oil dependence and/or their use of electric boilers. In the long term, however, it became increasingly difficult for district heating lobbyist to argue against the use of small heat pumps when the district heating companies themselves were using heat pumps. The broader use of large heat pumps unintentionally strengthened the perception of heat pumps generally as a functioning, reliable and cost-efficient heating alternative. The logic was that if heat pumps were good enough to use in district heating plants, then they were good enough to install directly at the house (and avoid the heat losses in the district heating distribution grid).

6.7.2. Value network-level complementarities and coopetition

The relatively quick development of the heat pump market after 1979 created organisational tensions at a value network level. Improving heat pump functioning, reliability and performance depended not only on the heat pump manufacturers’ competencies and capabilities, but also on those of the component suppliers, business partners and the installers. Cross-network actors, such as energy companies and technical universities, contributed to increasing the knowledge level within the whole heat pump sector, and to finding cross-network complementarities. And the direct coopetition between value networks
helped to strengthen the position of both the heat pump sector and heat pump technology in the heating market.

**Suppliers & business partner**

In the early 1980s, many technological issues still plagued heat pumps: malfunctioning compressors or other components, poor system reliability, too big, too noisy, leakages, defrosting failures in the outdoor unit, etc. Many of these issues were located in the domains of component suppliers and business partners and were thus partly outside the heat pump manufacturers' control.

One such technological challenge concerned boreholes. Vattenfall had tested recharging single boreholes, but realised that it was much more economical to drill longer boreholes. The companies that drilled boreholes in 1979–1985 had existing equipment for this task, i.e. water well drilling companies. With their complementary resources and capabilities, these companies became important partners to heat pump companies and installers. Significant advancements in borehole drilling were made during the 1980s, with a doubling of the borehole drilling capacity from 1980 to 1985 (Zogg 2008) and another doubling between 1985 and 1990 (Granryd 2010). By 1990, the borehole technique had become so efficient that it was possible to drill up to 200 meters in just one day. This development was an important technological complementarity to ground-source heat pumps and was fundamental for the future development of this type of pump in Sweden. Other examples of technological developments that took place outside of the heat pump sector includes improved heat exchangers and compressors.

When academic researcher Eric Granryd helped Thermia to develop new lightweight heat exchangers, he made it possible for Thermia to produce much smaller and lighter indoor heat pump units, further improving the company’s competitive advantage. Fairly soon, Thermia’s competitors were able to order plate heat exchangers with about the same properties as Granryd’s heat exchanger, enabling them to catch up with Thermia. These plate heat exchangers were also made in Sweden. The opportunity for the heat pump manufacturers to have close collaborations with nearby industry areas was an advantage at the technology level for the entire heat pump industry.

This new configuration of interconnected actors (partner companies, component suppliers, manufacturers, consultants, experts from academia) was a key to making possible quick product development in the 1980s and a big reason why 70% of all installed heat pumps in this period were manufactured in Sweden.
Installers

One of the main challenges at the heat pump value network level was the division of responsibilities between suppliers, manufacturers, retailers and installers. The previous division of responsibility that had worked well within the HVAC industry, by which the manufacturers took responsibility for the technological performance of their products but not for how the product was installed, now became a pressing issue.

When manufacturers of oil boilers, electric water heaters, wood stoves, etc. started to manufacture heat pumps, they did so in their existing business context. They manufactured some parts themselves (primarily doing plate and steel work) and bought other parts from their component suppliers. They then sold their finished products to wholesalers, who sold to HVAC retailers, who in turn sold the product to and installed it for the end user. This value chain had been highly functional for decades and there was no need to change a winning concept – until they started to manufacture heat pumps.

Heat pump technology proved to have quite different properties from other home heating products in the 1970s and 1980s. The efficiency of an installed heat pump depends heavily on how well adapted it is to the properties of the heating system to which it is connected and the properties of the heat source that it utilises (e.g. the outside air or a horizontal or borehole collector). One can compare the situation to that of an oil boiler, which fires up, get hot, and heats the water to intended degree using a shunt coupling (mixing hot water with cold water). The heat from the oil boiler that is not used to heat the water typically becomes waste heat. The waste heat also heats the house (primarily the basement, where it is typically installed) and fulfils other functions (for example, keeping mould at bay). Exchanging the oil boiler with a heat pump was not as straightforward as many heating companies seemed to have thought at first. Numerous problems arose, as previously described in this chapter.

Considering that the heat pump technology was a refrigeration cycle run in reverse, it was perhaps no surprise that the heat pump assemblers (e.g. Thermia) turned to the refrigeration industry to see what those companies did when they installed their (typically much larger) heat pumps.

The heat pump assemblers were influenced by the turn-key business model logic of the refrigeration industry. Heat pump manufacturers, with Thermia in the lead, started to reconfigure their existing value networks by (at first only partly) skipping the wholesaler step and integrating vertically downstream to take increased control over the
retailing and installation step in the value chain. This change came at the cost of losing good relations with the industry’s wholesalers. But having a closer relationship with one’s own network of installers (which the wholesalers, by their nature, hindered) meant being able to guarantee not only the quality of the heat pump unit but also the quality of its installation. This was exactly what the companies needed in order to supply end users with heat pump products that lived up to their technological potential at the time.

**Cross-network actors**

Government organisations that acted to increase competence in the heat pump sector during the late 1970s and early 1980s included BFR, STU, NE, Televerket, SP, Vattenfall and others. These organisations contributed by supporting heat pump development and conducting tests to try out new concepts and increase the lower bound of heat pump performance.

Increasing the level of competence in the industry also required increased cross-actor and cross-network interrelations. For example, partnerships and collaborations with other companies, universities and consultants helped companies to improve their capabilities to produce, develop and test new heat pump units.

Vattenfall took on the role of a central cross-network actor that acted as intermediary between the different value networks in the heat pump industry, increasing the knowledge flow and also working – together with companies and other government organisations – to increase the level of competence among installers.

**Manufacturer coopetition**

The companies that started their learning curve in the 1970s – such as Thermia – had an advantage in making quality products over their competitors. But at the same time, Thermia was weighed down by the poor reputation that heat pump technology would suffer from the sub-quality heat pump products available on the market. Increased quality over the entire industry would have therefore benefitted Thermia in one sense, though it would have also decreased the company’s competitive advantage.

The relationship between Thermia and IVT exemplifies a sound coopetition relationship. IVT was one of the earliest and most successful heat pump manufacturing firms, founded by the three Peterson brothers in Tranås. According to Thermia employees, IVT followed Thermia’s developments very closely in the 1970s and early 1980s. But Thermia was also spurred on by IVT; together, the two firms developed a sound
competitive development. Together they could also more strongly counteract lobbying activity from the refrigeration industry concerning heat pumps, and they both built up their own network of installers and took larger responsibility for the applications of their products. There was also some exchange in staff between the companies.

6.7.3. The situation before the next phase

In the heat pump sector, the five-year period ending in 1984 was marked by organisational learning processes relating to technology and a rapid market expansion. The heat pump sector became populated by new entrants, some of them large and established, others being small handcraft ‘basement production’ firms.

In the period from 1979 to 1985, the different heat pump value networks increasingly acted in complementary fashion relative to each other, in mutually beneficial coopetitive relationships. Strong connections between complementarities were established that would not easily break, and the efforts to improve technology competence in the industry and develop and diffuse heat pump knowledge contributed towards building up a ‘path dependence’ around the technology in the heat pump sector.

During these years, large incumbent Swedish corporations had entered the heat pump sector, in what can almost be described as a mutual consensus with the Swedish government, which had started to subsidise private investments in heat pumps in 1979. But in the years following 1985, the large corporations would exit the Swedish heat pump sector as fast as they had entered it.

The negative transformation pressure on the Swedish energy system had placed a positive transformation pressure on the Swedish heating sector. But the sector did not constitute a complete development block. In 1985, some technological and organisational complementarities were still missing before the heat pump development block could be called complete. After this phase, we will see less complex heat pump value network interactions at a cross-network/technology level.

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40 The coopetition dynamics between value networks in the heat pump sector contributed to the formation of what can be called a Swedish heat pump ‘industrial cluster’ (Porter 1991; Nuur 2005).

The period from 1985 to 1995 starts with the so-called ‘reverse oil crisis’, which resulted from the drop in international oil prices in the mid-1980s together with the removal of heat pump subsidies and other macro-variables that had a negative effect on the heat pump sector.

After 1985, the dynamics in the heat pump sector changed. Only the exhaust air heat pump market segment remained somewhat untouched by the reverse oil crisis, and several heat pump value networks were either discontinued or reconfigured in the following years. Vattenfall, which had played an important role in previous developments, took on a new role in the heat pump sector after 1985 as it shifted its organisational form to become a state-owned company with a focus on international expansion.

In spite of the reverse oil crisis, technological development did not stop during this phase. As heat pump manufacturers struggled to survive, technology development centred on other actors in the sector. Many of the connections between complementarities that had been formed prior to 1985 continued through this period, and as the reconfigurations and changed ownerships among heat pump manufacturers contributed to the eventual development of a more mature sector, an increasingly complete Swedish ‘heat pump development block’ started to emerge in the mid-1990s.

7.1. The societal and international context of heat pumps

The heat pump’s inverse relation to Swedish economic development continued through the second half of the 1980s. When the Swedish economy had overcome the recession and international oil prices decreased, investments in structural changes to decrease Sweden’s oil dependence also decreased, with a direct negative effect on investment in heat pumps. In other words, when the negative transformation pressure on the Swedish energy system was lifted, the positive transformation pressure on the Swedish heat pump sector also disappeared.

7.1.1. The reverse oil crisis

The reverse oil crisis consisted of the combination of effects from lowered oil prices (cf. BP 2017), removed heat pump subsidies (Nilsson
et al. 2005; Russell et al. 2009) and increased interest rates (cf. Waldenström 2007).

The period up to 1985 had been marked by uncertainties in future electricity prices, as discussed previously. When oil prices suddenly dropped, uncertainty regarding what heating alternative to invest in increased among potential customers. Prior to the reverse oil crisis, the main concern among heat pump actors had been that electricity prices might fall too low due to the anticipated abundance of electricity from the new nuclear reactors. But since the 1980 nuclear referendum, the government was preparing for a future increase in electricity prices as a consequence of shutting down the reactors (Energiforskningsnämnden 1985, p. 110; Nibe 1987).

The drop in oil prices and uncertainty regarding future electricity prices coincided with higher interest rates for bank loans (Waldenström 2007), which made capital-intensive heat pump investments less beneficial than other options with lower fixed costs and higher variable costs. The end of heat pump subsidies also made this option less economical than other heating alternatives after 1985.

All these factors – lower oil prices, uncertain future electricity prices, increased interest rates and phased-out heat pump subsidies – resulted in a period of low demand for all types of heating products. As Thomas Hallén explained (personal communication, 10 August 2016), everybody just stood still and waited to see what would happen. The heating market was largely dependent on government energy policy – as perceived by the customers – and development of energy prices. In general, customers with old heating systems decided to keep their systems for a little while longer (Nibe 1987).

7.1.2. A deregulation and privatisation trend in Sweden

Vattenfall's role in the heat pump sector changed during the years 1985–1995. This shift should be placed in the larger context of deregulation and privatisation trends in Europe and Sweden.

The late 1980s were characterised by an increased level of global trade. The internationalisation of Swedish companies was especially strong, as many large Swedish companies focused on activities that were less nationally based and more transnational in nature and thus focused on international competition rather than domestic markets. This is shown by the many mergers of Swedish companies that took place in the 1980s and 1990s, e.g. the merger of ASEA and Brown Boweri into the international corporation ABB (Schön 2012).
To help the Swedish economy to adapt to the internationalisation of the economy, the Swedish government carried out a series of reforms from the mid-1980s to mid-1990s, such as deregulation of credit markets and the electricity market (Giertz 2016). Sweden’s entry into the European Union in 1995 marked another important step towards internationalisation. Joining the EU brought the European markets closer to Sweden, but it also meant that Swedish agencies faced new limitations in terms of how they could support Swedish industry.

The Swedish electric utility Vattenfall was one of a number of Swedish firms that shifted focus from domestic to international markets in this period. Under the lead of Director General Carl-Erik Nyquist, Vattenfall worked towards internationalisation and ‘corporatisation’. According to Nyquist, Vattenfall needed to be ‘corporatised’ to have the same ability as other large electricity companies to compete in the internationalised and liberalised European markets (Högselius 2009). As an agency, Vattenfall faced juridical difficulties when competing with other companies in international markets, but when it became a state-owned company, these hindrances were eliminated (Nilsson et al. 2009).

In 1991–1992, Vattenfall shifted its organisational form from a corporate agency to a state-owned company (Högselius & Kaijser 2007). The main purpose of the corporatisation, pushed by Vattenfall itself and most certainly by Nyquist, was to enable expansion beyond Sweden’s borders. In the corporatisation process, Vattenfall lost some of its agency functions to other agencies, and it also lost both opportunities and incentives to work on demand-side management issues. As discussed by Högselius & Kaijser (2007), the interest and directives from the owners shifted as Vattenfall restructured from a corporate agency into a company. Instead of directives to supply affordable electricity so as to maximise development possibilities among people and companies, now the main directive was to maximise profits.

The change in the liberalisation of markets and Vattenfall’s changed organisational form led to a major change in the company’s role in the heat pump sector during this period. Between 1985 and 1995, Vattenfall changed both its perspective on and its support for heat pump technology.

### 7.1.3. A ban on freon (chlorofluorocarbon) refrigerants that affected the Swedish heat pump industry

The global agreement to ban chlorofluorocarbons hazardous to the ozone layer, more commonly called by the product name of freon, had a significant impact on heat pump developments and related academic research from the late 1980s onwards.
Refrigerant leakages were a common phenomenon for decades, but because the environmental implications of these leakages were unknown, they were treated primarily as an economic problem and not an environmental one. The first discovery of the degrading and hazardous effect of chlorofluorocarbon (CFC and HCFC) refrigerants on the ozone layer occurred during the 1970s (Björk et al. 2013, p. 17).

The first international attempt to limit the potential hazard of CFC and HCFC refrigerants was made at the 1985 Vienna convention (Björk et al. 2013, p. 17; Naturvårdsverket 2003), which focused on limiting the damage on the ozone layer and promoting international research on the matter. Shortly thereafter, in the same year, the large ozone hole over the Southern Hemisphere was discovered, and the importance of reducing the leakage of CFC and HCFC refrigerants became even greater. Two years later, a new meeting was set up in Montreal. The discovery of the ozone hole contributed to the agreement by a large number of countries, through the 1987 Montreal Protocol, to halving use of the most hazardous CFC refrigerants as well as tightening their regulations on how these refrigerants should be treated (Naturvårdsverket 2003, p. 26). The Montreal Protocol took effect on 1 January 1989 and was subsequently revised seven times to increase its restrictions and also to limit the use of HCFC refrigerants (IEA 2010).

The Swedish environmental protection agency Naturvårdsverket prepared a new regulation standard for refrigerants (SFS 1988, p. 716) based on the Montreal Protocol but with even stricter regulations than what the agreement mandated (Lindholm 2011). For example, ‘to show that it was technically and politically possible’, the Swedish government decided to abolish CFC refrigerants earlier than was mandated in the Montreal agreement (Naturvårdsverket 2003, p. 26). The first step in the phase-out of CFC refrigerants was a ban on installations using these refrigerants in 1995. Three years later, it was forbidden to refill existing units with CFC refrigerants, and in 2000 it became illegal to use CFC refrigerants in any way, with the exception of special stationary units where less than 900 g of refrigerant was used. These were allowed until 2005 (Naturvårdsverket 2003).

The heat pump is a tightly coupled system of components, which means that it can be heavily affected by only slight changes in its environment or in individual components. When the ozone-hazardous CFC refrigerants (such as the popular refrigerant dichlorodifluoromethane R-12) were banned, this affected the whole heat pump system. To replace R-12 and other CFCs or freons, different refrigerant blends were used. These blends often had a temperature glide during the phase change transition from gas to liquid and liquid to gas, which R-12 did not have.
The temperature glide required different operational modes in the heat pumps, in turn imposing changed requirements on the other components in the heat pump system as well. Fredrik Lagergren (personal communication, 20 December 2011) compares the refrigerant of a heat pump to a cogwheel in a mechanical machine. It is not possible to replace a cogwheel in a mechanical machine with a new cogwheel of different size and a different number of cogs; if you change the cogwheel, you have to adapt the whole machine.

7.2. Energy system and energy policy developments

There were few drastic changes in the Swedish energy system after 1985. The oil dependence reduction process slowed down. While oil prices dropped considerably between 1984 and 1986 (see BP 2017), the price of heating oil for Swedish customers remained quite stable (compare Figure 6 with Figure 17) due to increased taxation. Nuclear expansion stopped but no dismantling of reactors occurred until 1999 and 2005, when the two Barsebäck reactors were shut down. District heating grids continued to expand in Swedish cities, but not as quickly as before. Natural gas made a modest entry in the Swedish energy system in the mid-1980s but never grew to any significant proportion, and the use of biofuels continued to increase steadily but slowly. Overall, the development and transition process of the Swedish energy system slowed down significantly after 1985.

The subsidy scheme for heat pumps, which had taken on different forms but had been ongoing since 1979, was halted in 1985 (Nilsson et al. 2005; Russell et al. 2009). Nilsson et al. (2005) points out that the Social Democratic party, which won the election in 1982, switched the government’s energy policy focus from homeowners to residents of multi-family buildings.

The political position of nuclear power proponents was greatly weakened by the Chernobyl accident – the biggest nuclear power disaster of modern times – in 1986. Before any news of the accident came from the Soviet Union, the increased level of radiation had been picked up outside the Swedish nuclear reactor Forsmark, leading to rumours of leakage from Swedish nuclear reactors. There were many reports of radioactive fall-out in different parts of Sweden during the following days and weeks, contributing to increased fear over the negative effects of nuclear power (SR 2011).

The plans to shut down nuclear power put pressure on the government to take new actions in the energy area. One such action was to increase
the ‘rational use’ of electricity, which resulted in recommendations not to use only electricity for heating houses (Nibe, 1986).

### 7.3. Heat pump sector developments

The reverse oil crisis had profound effects on the Swedish heat pump market and industry. The results of falling oil prices and the removal of government support for heat pumps was a quick change in transformation pressure on the sector, from positive to negative. For heat pump suppliers, the situation was made worse as homeowners, in the face of these uncertainties, postponed their planned conversion away from oil or electric boilers.

Manufacturers that produced exhaust air heat pumps were left relatively untouched by the reverse oil crisis, as the building regulation demanding heat recovery for new built buildings remained. Many other heat pump manufacturers were forced to exit the industry. A few heat pump manufacturers were able to survive the period of low sales that followed the reverse oil crisis, but they also had to go through frequent changes in ownership and company restructures. These companies eventually ended up in more stable situations, as the new owners had the ability to build new external relationships and reconfigure the existing value networks.

In the second half of the 1980s, Vattenfall launched a new large-scale programme called Uppdrag 2000, which was much more market-oriented than the previous Solar Project. Uppdrag 2000 had a more heavily commercial intent, in place of the ‘for the good of the nation’ intent that had characterised the Solar Project. Vattenfall discontinued its role as a cross-network actor for the entire heat pump sector and instead deepened its collaboration with a few heat pump producers, one being a small company named Eufor that manufactured direct expansion heat pumps.

The role of academia also changed, as funds for heat pump research became increasingly difficult to secure.

#### 7.3.1. A period of low volume in heat pump sales

The reverse oil crisis, loss of subsidies and increased interest rate had a significant effect on the heat pump market in Sweden (SVEP 2013). Sweden was not unique in this regard; similar patterns of heat pump market collapses could be seen in other European countries at this time as well (Raven and Verbong 2004).

Just as air-water heat pumps had expanded more rapidly than ground-source heat pumps they also disappeared faster from the market after 1985, as shown in Figure 24. The market segment that felt the least
effects of the dropping oil prices was the exhaust air heat pump market. Reasons for this result will be discussed later in this chapter.

![Figure 24: Heat pump sales in Sweden, 1986–1990. Source: SVEP 2013.](image)

The air-air segment had an upswing around 1990, but dropped in sales again during the rest of the 1990s. The exhaust air heat pump segment also decreased in the first half of the 1990s with the decreasing number of newly built houses (SCB 2012, p. 51). The ground-source heat pump segment had its low points in 1988 and 1989, but then slowly increased in sales again, with the exception of a drop in sales in 1992 (see Figure 24 and 25).

![Figure 25: Heat pump sales in Sweden, 1991–1994. Source: SVEP 2013.](image)
7.3.2. Illustrating the heat pump sector in the late 1980s and early 1990s

The number of collaborations between different actor types decreased after the reverse oil crisis as companies became more focused on their key partners and on cutting costs. The complexity of interactions in the heat pump sector also decreased in this period, compared to the heat pump boom of the early 1980s (compare Figure 26 with Figure 19 on p. 117).

Figure 26: Heat pump value networks in Sweden in the late 1980s

41 Cross-network actors are illustrated in yellow, suppliers in blue, upstream suppliers and partners and downstream channels and partners in light blue, and customers in green.
Several actors that played key roles in the earlier stage of sector development changed their roles after 1985. Many government actors withdrew their engagement in the heat pump sector, and as they did, the heat pump industry association SVEP acquired an increasingly central role in the sector. One task for which SVEP took responsibility was to keep opportunistic actors out of the sector. Another difference in this period compared to the previous one is that the government organisations aimed their support at manufacturers in this period rather than at customers and at increasing market demand, as they had done in the previous period.

Perhaps the most notable role change after 1985 was that of Vattenfall, which, as already discussed, no longer functioned as an intermediary cross-network actor linked to all heat pump value network types. Instead, Vattenfall had chosen to focus on one technology, the direct expansion heat pump, and on a strategic partnership with Eufor, an entrepreneurial and inventive heat pump firm that had started out as an installer of heat pumps during the early 1980s. Eufor had actively developed heat pump technology during the 1980s and had several collaborations in the heat pump sector, including contracts with the two relatively large manufacturers Thermia and IVT (Bengt Sandström, personal communication, 21 March 2014). Following the partnership with Eufor, Vattenfall invested in Eufor to develop direct expansion heat pumps and started selling Eufor’s heat pumps in its own networks – e.g. through its affiliated municipal energy companies and other affiliates – as illustrated in Figure 26.

7.3.3. Exits from the heat pump sector

While the installation of large heat pumps grew between 1984 and 1986, sales of small heat pumps dwindled due to the effects of the reverse oil crisis. In 1986, the market demand for electric boilers dropped by half and the demand for heat pumps dropped even more. This caused a general over-capacity among heating product manufacturers (Nibe 1987), which resulted in more than half of all suppliers of heat pumps exiting the industry and caused the large business conglomerates to divest their heat pump assets.

With some exceptions, heat pump sales remained low for almost a decade, wreaking ‘chaos and bankruptcies’ in the heat pump industry, according to Thomas Hallén (personal communication, 10 August 2016).

Yet another challenge hit the heat pump industry in the form of the discovery of the harmful effect of CFCs on the ozone layer was discovered in 1987–1988.
Fact Box 7. Heat pump patent development in Sweden and globally

The effects of the reverse oil crisis are visible in the number of registered patents related to heat pumps after 1985. A drop occurred both in Sweden and on the international scene.

Registered patents found for country code ‘SE’ (Sweden) by the search phrase ‘heat pump*’ in Thomson Innovation’s international patent database

Registered patents found for all country codes using the search phrase ‘heat pump*’ in Thomson Innovation’s international patent database

An interesting difference between the pattern of applied patents in Sweden and the international pattern is that the drop in applications begins somewhat later in Sweden, whereas the drop in international registrations exactly follows the drop in international oil prices. Perhaps the delayed interest in Sweden can be connected to the many R&D projects from both academia and government agencies.

The increased number of international patents from 1994 onwards came mostly from Japan and Korea, later surpassed by China.
The growth and drop in the number of heat pump suppliers in Sweden is shown in Figure 27, which counts both active domestic manufacturers and importers noted in various sources.

The most solidly established companies remained in the industry, as shown in Table 1 on page 120, except for the large heat pump suppliers ASEA STAL and STAL Refrigeration. Although the suppliers of exhaust air heat pumps continued to do well, things were much harder for the companies manufacturing ground-source and air-water pumps. Companies like Nibe and Elektro Standard faced minor challenges, whereas companies like IVT and Thermia faced much larger challenges and were eventually even forced out of business and into reconstructions.

The drop in industrial and research activity in the area of heat pumps, both in Sweden and internationally, are reflected in the patent registration patterns shown in Fact Box 7 on page 162. The drop in registered patents illustrates the entire sector's shift from a production focus to a survival focus.

7.3.4. Changed roles of cross-network actors in the heat pump sector and academic focus on refrigerants

The work of the heat pump industry association SVEP became increasingly important to the sector from the mid-1980s onwards. SVEP
collaborated with several government agencies, including Vattenfall, the government testing and research institute SP, the building research council BFR and the government administrative authority for energy policy administration STEV.

In the late 1980s, SVEP worked to prevent opportunists in the heat pump industry from selling sub-standard heat pump products and spreading misleading information to customers. The problems mainly concerned importers and suppliers of air-air heat pumps, but the negative rumours spawned by these actors’ behaviours affected the whole industry (Lindholm 2011). In 1989, SVEP even banned a company from the association for not exhibiting good conduct and for spreading misleading information.

The academic research concerning heat pumps was scaled down after 1985, as research funds for heat pump projects became harder to get. The cross-disciplinary Earth Heat Pump Group at CTH was dissolved at the end of the 1980s. But whereas that group had been divided among different institutions, at KTH the heat pump research was largely localised in a single department, where it had become almost institutionalised. Eric Granryd had taken over the professorship after Bo Pierre at KTH and continued the research activity on heat pumps (Englund 1992).

Under Granryd’s leadership, there was considerable focus on brines, a mix of water and salts that could be used as secondary refrigerants. Researcher Åke Melinder conducted extensive tests of brines with different salt levels to map out their different behaviours. For a while, these tests were the only available tests on brines and they became of increasing value when the later need arose to abolish CFC refrigerants in both refrigeration and heat pump units around the world (Björn Palm, personal communication, 25 January 2013; Fredrik Lagergren, personal communication, 20 December 2011). After the Montreal Protocol was signed in 1987, considerable research focus moved to finding alternative refrigerants for refrigeration units as well as for heat pumps.

The research at KTH gave some continuity to the heat pump sector, as one stable research institution remained focused on heat pump technology. The research conducted at KTH during the 1980s also laid a foundation for the urgent efforts to abolish use of the so-called ‘freon-refrigerants’ in the 1990s.
7.3.5. Vattenfall’s changed role in the heat pump sector, Uppdrag 2000 and direct expansion heat pumps

Vattenfall downsized its engagements in heat pump technology after the reverse oil crisis. Bengt Nordström had left Vattenfall and the Solar Project was being wrapped up. The focus had already switched from reducing oil dependence to the big new challenge in the Swedish energy system: how to manage the dismantling of all nuclear power reactors.

Vattenfall had been given new directives to focus more on the rational use of electricity than on decreasing oil dependency (though this was also a part of the directives). At the same time, Vattenfall began its journey towards corporatisation. This was all manifested in the new programme called ‘Uppdrag 2000 – Vattenfall’s projekt för rationell el-effektvisering’ (Mission 2000 – Vattenfall’s project for rational electricity efficiency), which ran from 1986 until 1991 (Widegren-Dafgård 1991; Sven-Allan Eklund, personal communication, 17 December 2013).

Uppdrag 2000 was much more market-oriented than the Solar Project had been, driven by the purpose of exploring different ways to increase the rational use of electricity (Widegren-Dafgård 1991). When Uppdrag 2000 was at its peak in 1989, it consumed a third of Vattenfall’s total R&D budget, or 115 MSEK (Vattenfall 1989a). One motivating idea behind Uppdrag 2000 was that future expansion of electricity production could be avoided by offering energy services that would result in more rational and consistent electricity consumption (Widegren-Dafgård 1991).

The project’s design was extensively influenced by a visit that Vattenfall’s executive board made to the Bonneville Power Administration (BPA), a US energy agency, in 1984. At BPA, a system called Integrated Resource Planning (IRP) was being applied to reduce the differences between supply and demand; it encompassed both supply-side management (SSM) and demand-side management (DSM). IRP, SSM and DSM were focused on managing all parts of the electricity system, e.g. to avoid spikes in the grid. This background undergirded the initiation of Uppdrag 2000.

Some of the research on heat pumps conducted by the Solar Project was transferred to Uppdrag 2000, but now with a much more market-oriented approach. During the Solar Project Vattenfall had begun collaborating with Eufor, and by the end of the project it had increased its focus on the direct expansion technology that Eufor used in its heat pump solutions. In the Solar Project, Vattenfall had spread out its support amongst many different companies and technologies, thereby aiding the entire heat pump sector. But now Vattenfall turned to a ‘pick
the winner’ approach and focused exclusively on direct expansion solutions.

The direct expansion heat pump was an attempt to construct a heat pump with fewer and simpler components, in order to push down both the cost of installation and the unit cost. The operation of direct expansion heat pumps is, however, typically more difficult to control than that of heat pumps that uses a secondary refrigerant for heat extraction (direct expansion uses the same refrigerant for all processes). Swedish direct expansion heat pump development was therefore dependent on further R&D, which Vattenfall financed to a large extent.

Direct expansion heat pumps had both benefits and drawbacks. The major benefits were the simple set-up of components and the simple installations, which reduced costs substantially. The technology could work with either horizontal or vertical ground-source collectors and required relatively short collectors (typically around 60 metres). Air-air heat pumps were a somewhat cheaper alternative, but whereas air-air heat pumps couldn’t deliver heat if outside temperatures dropped below -10°C, direct expansion heat pumps did not have any such limits. Among the drawbacks was the high amount of refrigerant needed, since the ground collector was used as a direct evaporator; also, the evaporation process that occurred in the ground was difficult to steer (Lennart Spante, personal communication, 14 January 2014).

Direct expansion pumps have been more popular in central Europe, especially Austria, than in the Nordic countries. But between 2006 and 2009, the direct expansion heat pump market in Europe decreased steadily (IEA-ETSAP & IRENA 2013). The Austrian manufacturers of direct expansion heat pumps are described as small companies with ‘employees highly skilled in both refrigeration systems and heating systems’ (IEA 2010), which is a basic requirement for supplying correctly designed and installed direct expansion pumps.

By the end of the 1980s, Vattenfall started to market itself as an energy service company (instead of an electric utility or energy producer), and in the early 1990s it began to sell Eufor heat pumps through its distribution channels, which were local municipal affiliates and service offices such as Huddinge el, Smedjebackens el, etc. (Bengt Sandström, personal communication, 21 March 2014). This business model and value network set-up for the direct expansion are shown in Figure 28.
The direct expansion heat pump offers a completely different business logic from most other heat pump types, with low-cost pumps but with higher efficiency than the alternative air-air heat pump, because of the use of the ground as a heat source. The direct expansion option was often aimed at the handy homeowners who could install the heat pump themselves, which meant that the direct expansion heat pump did not need as large a supplier network and could skip both the wholesaler and installation contractor steps in its value chain.

Vattenfall and Eufor’s partnership resulted in a temporary increase in direct expansion heat pumps in Sweden. Eufor had a unique position among Swedish manufacturers as Vattenfall's supplier, which caused some discontent among other manufacturers and their retailers (Bengt Sandström, personal communication, 21 March 2014). Some people at Vattenfall even referred to Eufor’s heat pumps as ‘their’ heat pumps, since they had contributed so much to the development of the units.

But Vattenfall was not used to selling physical products. According to Sven-Allan Eklund (personal communication, 17 December 2013), the company did not have the organisation for it. Some local offices sold a lot of heat pumps while others sold none. Overall, Vattenfall did not have a large enough service organisation to cover the large geographical area where heat pumps were installed (Lars Segerstolpe, personal
communication, 17 May 2013, Solna). And considering the initially low sales volumes, creating such an organisation would have been very costly. According to Sven-Allan Eklund (personal communication, 17 December 2013), another reason why the heat pump sales (as well as the whole ‘energy service’ approach) did not work was the focus by top management on turning Vattenfall into a state-owned company instead of a corporate agency, and on geographical expansion rather than developing the domestic market.

When Vattenfall shifted its organisational form in 1992, there were some confusion internally on which markets to expand into: the internal ‘service markets’ (which Vattenfall had focused on since 1986 through Uppdrag 2000) or elsewhere in Europe (Högselius 2009). In the end, management favoured international expansion and Vattenfall stopped marketing itself as an ‘energy service’ company.

7.4. Value network reconfigurations

After the reverse oil crisis, sales of ground-source heat pumps dropped to just 10% of those during the record-setting year of 1984. The air-air heat pump segment also dropped significantly, whereas the air-water heat pump market segment almost disappeared completely for a few years, besieged by technological problems.

By the end of the 1980s, installations of large heat pumps had virtually disappeared as well; they were completely discontinued in the early 1990s.

The diminishing heat pump market segment forced many suppliers to exit the industry, and several existing value networks reconfigured to adapt to the changed business environment. However, the exhaust air heat pump market segment remained relatively untouched.

7.4.1. Exhaust air heat pumps continue to do well

At a time when most of the Swedish heat pump manufacturers were in a state of crisis, the exhaust air heat pump value networks were largely unaffected by the reverse oil crisis. The exhaust air pump manufacturer Nibe reported a drop in sales for the period 1985–1986, but then the demand increased again in 1987 (Nibe 1987).

Nibe had been able to join the heat pump sector quickly through its existing value network, as it held a well-established position among Swedish home builders – a relatively small and manageable customer group – and sold through wholesalers.

Due to the nature of the exhaust air heat pump value chain, the demand for exhaust air pumps had a lot to do with the number of new houses
being built, as well as with the changes that had occurred in formal regulations. Since 1980, Swedish building regulations had mandated installation of some sort of heat recovery system in newly built houses (SBN 1980). In reality, this requirement left home builders to choose between the effective FTX heat exchangers or exhaust air heat pumps. In the long run, the latter has become the more popular choice with over 80% of market share (Forsén, 2008b). The 1980 building regulation thus became an important factor in the success of exhaust air heat pumps in Sweden (Fahlén in Axell et al. 2008, p. 81).

With over 80% of the market share for new home construction, sales of exhaust air heat pump sales closely mirrored trends in construction. As the number of detached small houses increased in the late 1980s (see Figure 29), orders of exhaust air pumps also increased. The same relationship was true for district heating and the larger multi-family buildings, which also increased in number by the late 1980s.

![Figure 29: Number of completed residences by house type in Sweden, 1960–2010. Source: SCB 2012, p. 51.](image)

Also important to note, from a heat pump perspective, in Figure 29 is the large number of houses built during the 1960s and 1970s in Sweden. These houses were in need of heating system refurbishment and reinvestment 20 to 30 years after they had been built. The spike in houses built during the 1970s (often with oil burners or direct electric heating as a heating system) was a contributing factor in explaining the strong conversion market in the 1990s and 2000s, as seen in Figure 30 and 32.
A closer look at Nibe in Markaryd

Nibe in Markaryd is currently the largest Swedish-owned heat pump producer. Nibe likes to promote itself as an orderly company with a high work ethic and deep roots in the Swedish county of Småland, as shown by its annual reports.

Nibe was able to deliver good profit margins to its owners during the whole decade of the 1980s except for 1986 and 1987. This was far from the case for many of the other companies in the heat pump sector, but Nibe was also tilted towards exhaust air heat pumps.

Nibe had relatively strong finances and was in no need of new capital or new ownership. But in 1989, its owners, the Bernerup family, wanted to sell the company, which had been in the family since its founding by Nils Bernerup in 1952. The whole Nibe group (including Nibe-Verken and Backer Elektro-Värme) was sold in a management buy-out to a consortium constituting of 17 members of the management staff (who acquired 50% of company shares) and external investors in Merchant Venture Investments, who bought the other half (Nibe 1989; Veckans Affärer 2007). Following the reconstruction, Gerteric Lindquist became the CEO of Nibe, a position he still holds today, almost 30 years later.

For a long time, Nibe made the strategic decision to focus only on exhaust air heat pumps, a move that limited the negative effects of the reverse oil crisis. Nibe also chose not to adopt the step that Thermia and IVT had taken in bypassing the wholesalers (cf. Russell et al. 2009, p. 9).

A benefit of exhaust air heat pumps was the forced but energy-efficient ventilation. At the end of the Solar Project, Vattenfall was working on the problems of lacking ventilation (and resulting mould) when oil boilers were replaced with heat pumps and removed the house’s natural ventilation. To try to overcome this issue, Vattenfall tested small exhaust air pumps.

In 1989, Nibe CEO Gerteric Lindquist said that there were two dominant schools of thought at the time: one promoting the use of outside air for heat pumps and one promoting the use of exhaust air. Nibe chose, according to Lindqvist, the latter (connected to a water-based heating system) because it provided better internal climate and comfort (Nibe 1989).

Nibe was also oriented towards other products in the HVAC industry, e.g. Contura wood stove manufacturing, which lessened the impact when the demand for exhaust air heat pumps fell in 1992 and afterwards. Also, as explained previously, a Contura wood stove can very easily complement a Nibe exhaust air heat pump in a house’s heating system.
7.4.2. Changed ownerships and reconfigured value networks of ground-source heat pump manufacturers

The two companies that had the largest share of the ground-source heat pump market prior to the reverse oil crisis were Thermia and IVT. Under this sub-heading, the development of these two companies from 1985 to 1995 is presented in detail.

As the heat pump market failed in the mid 1980s, heat pump companies started to exit the industry while the remaining companies struggled for survival. Company owners started to divest their heat pump assets, and between 1985 and 1995 all the major heat pump firms experienced changes in ownership. With new owners came new leadership, company reorientations and, eventually, a reconfiguration of the existing value networks. The fact that both Thermia and IVT ended up under relatively stable ownerships, with owners who were closer to the production side than their predecessors, contributed to the development of the Swedish heat pump sector during these years and laid the foundation for further development after 1995.

**Thermia**

Thermia had ground-source heat pumps as its core business and therefore suffered heavily from the reverse oil crisis. After Hans Lindström (personal communication, 17 February 2014) was recruited from Vattenfall to become head of Thermia’s R&D unit in February 1986 he was forced to fire more than half of his team before the end of summer.

Between 1984 and 1995, Thermia changed owners frequently. It was sold by AGA to ASEA-Selfa in 1984, and two years later, ASEA-Selfa sold Thermia to Sörmlands Invest (later renamed Energiinvest). In 1992, the Arvika-based businessman Bengt Gustafsson acquired Thermia through his family company Örbege Invest AB.

Thermia passed through a period of insufficient leadership after AGA sold it in 1984, according to Leif Olsson (personal communication, 30 March 2016). ASEA didn’t value Thermia strongly and more or less gave the company away in 1986. The new owners started by selling all the company facilities and then hired two consultants to implement just-in-time at Thermia – something that was popular at the time, according to Olsson. These consultants found new solutions to improve production, and so the company owners invited them to take over the leadership of Thermia. These two new owners, one based in Münich and the other in London, also employed a new CEO. But because of internal strife
between the two owners and distrust among Thermia’s retailers, results remained poor for Thermia.

In 1992, when Thermia entered bankruptcy, the new CEO tried to sell the company to government-owned Samhall (a company that employs persons with disabilities to give them meaningful work), but the plans were stopped by Thermia’s employees and Bengt Gustafsson was instead able to take over as the new owner and head of the company (Leif Olsson, personal communication, 30 March 2016).

When Gustafsson took over, the leadership was once again moved close to the production. Gustafsson was both a company leader and a real-estate owner in Arvika when he took over Thermia. He had expressed a desire to acquire Thermia back in 1986 but had not been considered at that time.

When Gustafsson officially became Thermia’s owner on 1 November 1992, the company had 45 employees, or less than one-tenth of its workforce before the crisis. Gustafsson considered the frequency of sick leave too high and the employees’ competence too narrow, so he invested in employee training and education programmes and job rotation; these measures had positive impact on both sick leave and productivity (Sundelin and Lomander 1995).

In 1992, Thermia was focused on water heaters, boilers and climate roofs, and it also had some subcontracting production (Sundelin and Lomander 1995). Thermia continued its focus on these segments, including heat pumps, but also widened its product offering range to connect with new customers whom Gustafsson, through his network, could reach (VVS Forum 1992).

Thermia’s R&D unit had been shut down during the second half of the 1980s, and now that the company wanted to renew its offerings it had to reassemble the competencies that were spread out across different work stations at Thermia.

In 1993, Thermia launched a new heat pump that had all the main components in one module and was the size of a standard home appliance, i.e. 60 x 60 cm. This new product was achieved by coordinating different employees to develop a new and more efficient heat pump, and then by using the test rig to connect all the needed components and test their function. After that, the technicians at Thermia had the task of making all the components fit into a case of 60 x 60 cm, which they also managed to do. Today, having all heat pump components gathered within these total dimensions is part of the dominant design.
Thermia also managed to develop a new heat pump for the NUTEK heat pump procurement competition that started in 1993. It was not one of the winners, but according to Leif Olsson (personal communication, 30 March 2016), that was because Thermia chose not to downsize its heat pumps and downgrade the performance as the other competitors did. Accordingly, Thermia felt that it walked away from the competition with its ‘honour kept’.

IVT

IVT had expanded quickly under the management of the three Peterson brothers. In 1985, IVT grossed 100 MSEK annually. But from 1985 to 1989, IVT changed ownership six times. The Peterson brothers sold their company at its peak to a manufacturer of air curtains in Göteborg called Frico. But as the conditions for the heat pump market changed, Frico wanted to divest and exit the heat pump industry, and the following year it sold the company back to the Peterson brothers. In 1987, the brothers sold their company a second time and IVT was merged with a company in Jönköping called Triator, taking the new name of IVT-Triator. Triator was in turn owned by a company called Convexa, which was owned by Stikkan Andersson, manager of the ABBA music group. Convexa was Andersson’s investment company, which he used to invest in Swedish industry. But Andersson had little direct involvement in the acquisition of IVT, according to Lars Kastengren (personal communication, 5 February 2015). Convexa had an affiliate named Movexa to which IVT-Triator was transferred. The role of Movexa was to control the industrial part of Convexa’s holdings. An IPO was planned for Movexa, but the launch was fraught with problems and instead IVT-Triator was bought in 1989 by Gillesvik Holding, a family company run by Kastengren, a real-estate owner. Kastengren remained the major shareholder of IVT until German company Bosch acquired the company in 2005.

Kastengren was, like Bengt Gustafsson who took over Thermia, a real-estate owner. Through that business, he had been a customer of IVT for many years. He described himself as an ‘energy technology enthusiast’ with a background within the Philips Group. When Kastengren left the Philips Group, he wanted to develop the family’s property holdings by focusing on two costs: interest rates and energy. He became involved in sophisticated efforts to find technological solutions to problems related to losses from the hot chimney smoke. These solutions involved using heat pumps, and as a result Kastengren became a customer of IVT in the early 1980s (Kastengren, personal communication, 5 February 2015).

At this time IVT used seminars to market their heat pumps, and Kastengren participated in these seminars and posed many questions.
Kastengren had problems with poor applications of IVT's heat pumps, and according to Kastengren himself (personal communication, 5 February 2015) he was so demanding as a customer that the IVT representatives at these seminars told him, 'If you think we're so bad at this you can buy this damn company and try to do it better yourself.' Kastengren's response was 'Okay, let's do it.'

In the fiscal year of 1988 IVT grossed about 80 MSEK, had 60 employees and barely broke even (From a Movexa press-release in 1989, provided by Kastengren, personal communication, 5 February 2015). Since Movexa and its mother company Convexa were planning an IPO, the group wanted to divest its holdings in the problem-filled IVT-Triator. Kastengren and the Movexa representatives spent some time discussing the terms of Gillesvik's take-over. According to Dagens Industri (1989), the official sum was 15 MSEK, but Kastengren says that the actual amount was much lower. Kastengren's initial motivation to acquire IVT was to cut costs at Gillesvik's own properties, to have 'functioning heat pumps for our properties'. But there was also an interest in 'marketing the idea [of heat pumps] as far as possible, and getting a development worth the name' (Kastengren, personal communication, 5 February 2015). Kastengren saw the acquisition as getting an industrial business connected to the property sector, giving him the possibility of integrating Gillesvik backwards in the value chain.

The acquisition of IVT by Gillesvik became formal on 1 March 1989 and was welcomed by the employees at IVT-Triator (Tranås-Posten 1989). Kastengren spent time in the production facilities and created personal relationships with his employees to explore what could be improved and done even better. Kastengren said that he identified some 'brilliant brains' at IVT and judged that there was greater potential in the company than was actually realised (personal communication, 5 February 2015).

Under Kastengren's leadership, IVT focused more on selling imported air-air heat pumps during this period. These sales constituted a big part of the whole turnover of the company, but these heat pumps were also creating increased after-market issues as they were (still) relatively poorly adapted to the Nordic climate. The heat pumps could freeze to the extent that the service personnel had to 'ice-skate to get to the outside unit' (Kastengren, personal communication, 5 February 2015).

Kastengren described the development of heat pump technology as a central issue for IVT. The technological development was, according to Kastengren, primarily attributable to a few key persons, one of whom was Håkan Persson. Persson had, according to Kastengren (personal
communication, 5 February 2015), ‘a fingertip sensitivity and feeling concerning technology that was beyond any possible education that a man could get’. Persson’s ability to discuss technology was also a contributing factor in IVT’s success in building a strong relationship with the Japanese compressor and air-air heat pump supplier Sharp. IVT even managed to become the general agent for Sharp in Sweden in 1990.

Under Kastengren’s management, IVT worked hard to develop the supply chain so as to improve its heat pumps and gain strategic advantages. For example, IVT’s development of water heaters did not take place at its production facilities in Tranås but was accomplished by putting new, high demands on its water heater suppliers. Previously, IVT had ordered water heaters from Nibe, but it didn’t want to keep filling up the ‘enemy’s treasury’, so instead it collected offers from different manufacturers and established high performance demands (Kastengren, personal communication, 5 February 2015).

During the years after Gillesvik took over, IVT was very exciting to Kastengren personally but there was little company development. The market demand for and interest in heat pumps was still relatively low. In 1992 IVT Industrier was divided into two affiliates, IVT Energy and IVT Atema. In June 1992, IVT Atema filed for bankruptcy after acute liquidity problems. After a reconstruction, IVT Energy and Atema merged back into one company (IVT Industrier) and Kastengren rehired all the employees in Tranås who had been affected by the bankruptcy and made new deals to protect his good relationship with all affected suppliers. Kastengren also ousted CEO Anders Björklund and took over as CEO himself for the next following three years. In 1995, Kastengren recruited internally and appointed engineer Johnny Wärnelöv as CEO for IVT.

During this period, IVT worked to increase its demands on both retailers and installers and sought to gain greater control over what was being communicated to customers. It also started the ‘IVT University’, just as Thermia had started its ‘Thermia School’ about 15 years earlier. IVT’s retailers and installers came to Tranås from all over Sweden to get the latest education. IVT also created support units so that it would have the capability to quickly give support to any installer or retailer who experienced a problem. ‘If anyone had a problem, he would get a reply

42 When Gillesvik took over IVT, the current CEO, who had been appointed by Movexa, stayed as CEO of IVT for some time before being replaced by Anders Björklund, the former CEO of Thermia.
instantly’, Kastengren claimed (personal communication, 5 February 2015).

According to Kastengren, the work by IVT paid off in increased market shares, but from 1992 to 1995 all heat pump markets were shrinking – even the air-air heat pump segment. This made financing of IVT a crucial problem. In 1992, the OK bank, which had provided financing for IVT, decided that it did not want IVT as a customer anymore. Kastengren had some contacts with Östgöta Enskilda Bank, which agreed to give IVT a loan if it could contribute other capital. At this point, Kastengren opened up the financing of IVT to let some ‘good friends’ invest in the company, as well as offering the employees the chance to buy so called convertibles43 (Kastengren, 2015, personal communication, Stockholm, February 5). Kastengren also used his real estate as a security and used resources from his property holdings to keep IVT alive (personal communication, 5 February 2015). Furthermore, a deal was reached between IVT and the municipality of Tranås, which bought IVT’s properties in return for the promise that IVT would buy them back once the company was in better shape, which IVT also did a few years later.

7.5. **Summing up the dynamics in the third phase of the heat pump transition**

When the Swedish energy system was under strong negative pressure, up until the mid-1980s, the heat pump sector was the beneficiary of similarly strong but positive pressure. During this phase, it developed quickly but unevenly, with some immature parts in relation to other complementarities as of the mid-1980s. Market development was still in an early and formative stage, and heat pump technology was in a phase of product development rather than process development, not yet mature enough for a dominant design to appear.

Many heat pump manufacturers had been caught off guard by the lowered price of oil. They had, like many other actors, been concentrating on changes in electricity prices until 1985 (Energiforskningsnämnden 1985). With the removal of subsidies and uncertain future energy prices, many potential customers chose to delay their planned investments in new heating systems, and this market

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43 Convertibles were shares of the company which could later be converted. Some employees later regretted that they had invested in the convertibles, and Kastengren (personal communication, 5 February 2015) said that he bought them back from these employees. Those employees who kept their convertibles for a longer period of time achieved strong earnings on their investment, however.
change disrupted value networks that were either discontinued or reconfigured.

The disequilibria between different heat pump market segments increased during this phase. The two market segments that made Sweden partly unique amidst the otherwise collective collapse of heat pumps in Europe were large heat pumps and exhaust air heat pumps. For various reasons, these two market segments did not suffer from the drop in oil prices in the same way as other segments did. As a result, these two segments became important complementarities to the other value networks in the heat pump sector.

7.5.1. Complementarities and coopetition dynamics

While most heat pump manufacturers downsized and focused on survival, other actors in or connected to the sector continued to develop heat pump technology.

The drop in sales of ground-source and air-water heat pumps was counter-balanced by the continuity of the exhaust air and large heat pump markets. The exhaust air heat pump market and the expansion of large heat pumps during the late 1980s distinguished Sweden from the prevailing trend in other European countries, e.g. Germany or Switzerland. The large-scale adoption of heat pump technology amongst district heating companies contributed to its institutionalisation within the Swedish energy system. For example, through the expansion of large heat pumps, the total electricity consumption and heating supply of heat pumps started to become a part of the annually collected Swedish energy statistics (whereas small heat pumps have never been included). The exhaust air heat pump segment also kept heat pump technology alive within part of the Swedish home heating market and contributed to its retention in the overall Swedish energy system.

The survival of manufacturers of ground-source and air-water heat pumps was essential for the sector’s development during the 1990s. For these companies to survive, they had to develop new capabilities and form new partnerships, which were possible due to both changes in ownership and reconfigurations of existing value networks.

On top of the reverse oil crisis, there were still many technological challenges for the heat pump industry to resolve. For example, the steering problems with air-source heat pumps had proven much more difficult to overcome than was first expected. Varying outdoor temperatures required sophisticated steering that air-source heat pumps did not have at this time. Customers might tolerate poor performance by cheap air-air heat pumps, but not by the more expensive air-water
pumps. Consequently, the air-water heat pump segment suffered heavily after the reverse oil crisis.

The work of cross-network actors increased in importance in this phase. The Swedish heat pump association SVEP contributed as a lobbyist for the heat pump sector which lobbied against government actors to support heat pumps, e.g. through procurement competitions.

Researchers at technical universities, at least at KTH, continued to focus on heat pumps even while the market was struggling. Research on refrigerants at KTH contributed to the heat pump sector’s ability to replace ozone-hazardous CFCs during the 1990s.

**Exhaust air heat pump complementarities**

The 1980 building regulation mentioned heat pumps, but its focus was on ventilation and heat recovery. Still, the 1980 building regulation had a long-lasting positive impact on the exhaust air heat pump technology.

When the oil boiler of a house was replaced by electric (or heat pump) heating, the natural draft disappeared. To avoid mould, the house often needed to be retrofitted with forced ventilation, and for newly built houses, sufficient ventilation had to be secured from the start. But then building regulations also required some sort of energy recovery, and the cheapest option in such a case was to install an exhaust air heat pump. This meant that the value of the exhaust air heat pump was twofold, allowing for forced ventilation while at the same time recovering the heat in the outgoing air. When the home construction market expanded in the late 1980s, the exhaust air heat pump market also increased – in opposition to the other small heat pump market segments.

Because the exhaust air heat pump segment was not dependent on either oil prices or governmental subsidies but on other institutional complementarities, it was largely untouched by the effects of the reverse oil crisis. This also meant that the manufacturers in this segment could bring some stability to the otherwise beleaguered industry.

**Value network reconfigurations and capability acquisitions**

The air-water heat pump market segment disappeared by 1987, and by 1988 the ground-source heat pump market segment seemed to be going the same way. The ground-source market survived only because it managed to reconfigure enough to secure other revenue streams and acquired new capabilities to adapt production to the current business conditions. Without the perseverance of ground-source heat pump manufacturers and their value networks, there would not have been an industry left to support by the 1990s, and thus their persistence is an
important part of the overall story of the Swedish heat pump transition. These companies retained knowledge, competence and networks concerning ground-source heat pumps that were useful during the procurement competition and increased market demand that ensued in the second half of the 1990s.

After the reverse oil crisis, the Swedish heat pump industry had to cope with a rapidly declining heat pump market. Many of the companies that had entered the industry a few years earlier now made quick exits. The large Swedish corporations that had joined the industry followed the government out of it, divesting their heat pump assets. These divestments were followed by a period of frequent owner changes and instability for manufacturers such as Thermia, IVT and CTC. CTC left the industry while IVT and Thermia eventually ended up in more stable situations, with owners who had the capability to reconfigure the companies’ internal as well as external networks to adapt to the current situation.

After a rocky period after 1985, Thermia ended up in a more stable position under local strongman Bengt Gustafsson’s ownership in 1992. During the preceding years, Thermia had weakened and decreased significantly in size. Gustafsson optimised Thermia’s resources and competencies (e.g. production facility and staff) to widen Thermia’s product and service offerings. Gustafsson’s leadership role was closer to the production than that of previous owners, enabling him to be more responsive to production needs and possibilities. Under Gustafsson’s leadership, Thermia widened its production offers while also scraping together the remaining heat pump competence in the company and using the new compressors and heat exchanger components now available in the market to design a heat pump that fit into a 60 by 60 cm sheet metal casing, laying the foundation for increasing future heat pump sales.

IVT also underwent changes in ownership and leadership during this period. In 1988 the new owner was Gillesvik, which was led by the head of the family business, Lars Kastengren. Kastengren also became connected to production and thus responsive to the company’s opportunities and needs. He widened IVT’s product offerings, for example through becoming a general agent for Asian air-air heat pump manufacturer Sharp in 1990. In the late 1980s, the ground-source heat pump segment was doing poorly but the air-air heat pump market was much stronger.

Kastengren also brought a large established network of contacts to IVT, along with flexibility and capability to network. These flexibilities and
capabilities were manifested in how IVT managed to get new financing through investors and loans, selling real estate to Tranås municipality, selling convertibles to employees, etc. Under Kastengren’s leadership, IVT also put increased pressure on its network of suppliers to deliver products that were adapted to IVT’s need, tightened its relations with retailers and installers, started educating its installers (as Thermia had done) through IVT University, and supplied them with improved support. All these value network reconfigurations contributed to IVT’s survival and its ability to retain its in-house heat pump competence, which was part in why IVT managed to be one of the winners in NUTEK’s heat pump procurement competition in 1995.

7.5.2. The situation before the next phase

The value network development that took place in this phase, as exhaust air heat pumps became a stable part of the institutional setting for heating newly built houses while other heat pump value networks were disrupted and either discontinued or reconfigured, formed the basis for the next phase, during which the demand for heat pumps revived.

We have already seen how government actors change their stance relatively often with regard to long-term plans. In this phase, the trend on how to support industry among government organisations was to have procurement competitions. Within a few years, three procurement competitions were held for heat pumps, the final one – the NUTEK competition – often being referred to as the turning point for the heat pump market and industry (though there was much more behind this turnaround than the NUTEK competition).

In this phase, the competition between heat pump manufacturers and between their networks of suppliers and installers increased. The number of acquisitions and product developments also increased as entities moved to integrate horizontally.

The 1990s were also a time period when the development involving Eufor and Vattenfall, which largely took place within Vattenfall’s Uppdrag 2000 research programme, could have become a big market success. Why it didn’t will be discussed in the following chapter.
8. The fourth phase: Growth and competition, 1995–2005

This chapter covers a period in the Swedish heat pump transition when heat pump complementarities formed a complete development block, without structural tensions. This phase was characterised by increased value network structure stability, growth in value network supply capacity, and increased competition between value networks, involving both horizontal integration and company mergers and consolidations.

From the mid-1990s on, the markets for small heat pumps grew steadily. The value networks were dynamically stable, meaning that the actor types and value network structures had relatively stable roles even though the quantity of actors in the value networks increased.

Improved computerisation helped air-source heat pumps to become increasingly popular in this period and the air-water heat pump made a comeback. One can also observe the emergence of a dominant design for heat pumps connected to hydronic heating systems, i.e. air-water and ground-source heat pumps, which may have contributed to these segments’ recovery.

This phase begins with the procurement competitions held by Swedish governmental organisations BFR, STEV and NUTEK. Around this time, ground-source heat pump manufacturers needed financing and increased cash flow, first to invest in new product development and then, when market demand increased, to invest in increased production capacity.

After a few years of positive cash flow, manufacturers started to integrate horizontally to increase their market shares. The competition between heat pump value networks also increased in this period, compared to the more collaborative time of the 1980s. The increased competitive climate was manifested in the expulsion of IVT from the Swedish heat pump interest organisation SVEP.

8.1. The societal and international context of heat pumps

As the threat of climate change began to be taken seriously at an international level during the 1990s, the environmental aspects of heat pumps also received increasing attention.

International awareness of the threat of climate change was manifested in the 1992 Rio convention and the 1997 Kyoto Protocol. These were the
first large-scale international attempts to do something about global warming. However, both Rio and Kyoto were failures in the sense that several industrialised nations, such as the US and Russia, did not sign the protocol and because they did not include developing nations. Consequently, the direct effects of these agreements on global greenhouse gas emissions were limited, but they became important milestones in the setting of environmental agendas at both national and international levels for the years to come.

The Swedish heat pump industry grew strongly after 1995. The Swedish economy also expanded, following a previous period of internationalisation processes and economic reforms. However, in the late 1990s a widespread belief in a ‘new economy’ contributed to overinvestment in IT companies in Sweden, creating an economic ‘IT-bubble’ that burst in 2000 (Schön 2012). Vattenfall was one of the Swedish companies that overinvested in IT projects between 1995 and 2000 (Svante Färnbo personal communication, 10 October 2014).

In the years following 1995, the market demand for small heat pumps increased. This caused a need to invest in increased production facilities, which in turn required added external capital amongst heat pump manufacturers. Both IVT and Thermia received added capital through state-owned venture capitalist companies. In 1995 Atle-owned Företagskapital AB invested in IVT, and in 1998 Industrifonden-owned Bergslags Invest AB invested in Thermia.

To provide further background on these investments, let us consider the changes that had occurred in Swedish industry policies. Företagskapital AB had been founded in 1973 by the Swedish government as the nation’s first venture capitalist company (NE Nationalencyklopedin, 2017); as of 1995, it was 75% owned by state holding company Atle AB. State-owned trust Industrifonden AB had been founded by the Swedish government in 1979, at a time when state industry policy aimed to retain the profitability of Swedish industry and to steer capital towards investments that were beneficial for the Swedish economy and society (Riksrevisionen, 2014).

Following the internationalisation and outsourcing of production among large Swedish companies in the 1980s and early 1990s, Swedish industrial policy by the mid-1990s was characterised by heightened concern as to whether incumbent companies could guarantee high employment levels in Sweden (Giertz, 2016). Industrial policy increased its focus on new and small to mid-size ventures to secure future economic growth, and the Swedish state made targeted efforts to
improve small and medium-size Swedish companies’ access to venture capital (Persson and Åsbrink 1996).

In 1992, the Swedish government transferred means from the ‘wage-earned funds’\(^44\) to the venture capital market through the state-owned holding companies Atle AB and Investment AB Bure. After these two holding companies were introduced and listed on the stock market, the remaining part of the state’s share in Atle and Bure was transferred as a capital injection to Industrifonden (Riksrevisionen 2014). The investments in IVT and Thermia by state-owned investors can thus be seen against this background, with the resources coming from wage-earner funds and directives being given to state-owned venture capital investors to provide small- and middle-size companies with capital.

8.2. Energy system and energy policy developments

The governmental interest in heat pumps became renewed in the 1990s, though it was highly uncoordinated. It consisted first of small series of unrelated procurement competitions aimed for heat pumps, later followed by a series of on-and-off subsidy schemes.

After the deregulation of the Swedish electricity market in 1996, competition increased with a series of new electricity suppliers entering the market. The costs of transmission and electricity supply were also clearly separated on the electricity bills from 1996 on, with transmission operators working under a highly regulated natural monopoly and electricity suppliers working on an open and competitive market (Högselius and Kaijser 2007; Giertz 2016). In spite of these measures, prices for households increased significantly between 1995 and 2005.

In 1991, the government agency STEV (Statens Energiverk) together with SIND (Statens Industriverk) and STU, formed the new organisation NUTEK (Verket för näringslivsutveckling). Between 1991 and 1998, NUTEK provided support to the Swedish heat pump sector, most notably through the 1993–1995 NUTEK heat pump competition (Lögdberg 1995; NUTEK 1995).

In 1998, the Swedish Energy Agency (Energimyndigheten) was formed when this function was separated from NUTEK. This rearrangement

\(^{44}\) The wage-earner funds came from taxation of companies’ profits to buy equity shares for their employees; they were introduced by the Social Democrats in 1983 and cancelled by a right-wing coalition in 1991. See Giertz (2016) for more details.
followed parliamentary decisions in 1997 that resulted in a new energy policy programme. The newly formed agency was assigned to execute most of the energy policy programme, which focused on securing supply of energy and electricity from renewable energy sources and included the closing of the first Barsebäck reactor in 1998 (Energimyndigheten 1998). Since taking over NUTEK’s prior involvement in the energy sector, the Swedish Energy Agency has been a financier of academic research on heat pumps (Granryd and Björk 2010), commissioned heat pump tests (Nordsyn 2015), and compiled reports on heat pump support efforts and other developments in Sweden (e.g. Energimyndigheten 2004, 2009c, 2015b), among other functions.

8.2.1. Energy prices in the 1990s-2000s

Statistics on the price of electricity for heating, oil prices and district heating are available from 1986 onwards (Energimyndigheten, 2016b). The price relationships are shown in Figure 6 on page 40, which shows the final cost for end customers, after taxes and other fees. In spite of the sometimes high-pitched debate in the first half of the 1980s on future oil and electricity prices, Figure 6 shows that the energy prices and ratios were quite stable for the following ten years. Not until the mid-1990s did the price of fuel oil start to increase. In the 2000s, prices on electricity took off as well. The cost increase for customers resulted to a large extent from increased energy taxes (Energimyndigheten 2012a; Russell et al. 2009). From 1995 to 2009, the tax on electricity increased from 0.09 SEK/kWh to 0.282 SEK/kWh, and between 2000 and 2008 the tax on oil increased from 1,801 SEK/m³ to 3,804 SEK/m³ (Russell et al. 2009). The actual international price on crude oil started to increase again after 1998 (BP 2017).

The economic benefits of heat pumps improved somewhat after 1996 and substantially after 2001. This also coincided with the pattern of increased heat pump sales, which exploded after the year 2000.

8.2.2. Reintroduced government financial support for heat pumps

Between 1985 and 1998, there were no subsidies for heat pumps. The first reintroduced heat pump subsidy scheme ran between 1998 and 1999 (Regulation 1997:635) and aimed to support conversions away from direct electric heating. The entities eligible for support were those who partly or completely wanted to convert away from direct electric heating to other alternatives such as heat pumps or bio-fuelled boilers. The subsidies were ended in 2000 and then reintroduced between 2001 and 2003 (Russell et al. 2009).
Other measurements were also taken, apart from direct subsidies. In 2002, the Swedish Energy Agency (the successor of NUTEK) launched a campaign called ‘Heat in the Villa’ (Värme i Villan), with a budget of one million SEK. The aim was to inform Swedish homeowners concerning the different technological alternatives for heating houses (Russell et al. 2009).

8.3. Heat pump sector developments

In the 1990s, the role of several cross-network actors in the heat pump sector changed. The importance of academia grew stronger once more and the testing institute SP took on increasing responsibility, whereas Vattenfall decided to leave the heat pump area completely.

The early 1990s saw several procurement competitions aimed at heat pumps. Thomas Hallén (personal communication, 10 August 2016) noted that policy support can vary between multiple trends, and in the early 1990s the trend was to give government support through procurement competitions.

At this time, the heat pump industry was viewed as ‘weak, almost of the character of small-scale craftsmanship’ (Energimyndigheten 2004). The low interest in heat pumps was also made visible in other ways. In May 1994, the building research council BFR was to have a one-day seminar on heat pumps in Stockholm. The first presentation was titled ‘Have we forgotten about heat pumps in the energy debate?’ But the seminar had to be cancelled because no one signed up to attend (Plomgren 1994).

8.3.1. Increasing heat pump sales

In the first half of the 1990s, the Swedish heat pump industry was in a weak state. Internationally, the air-air heat pumps dominated. Of the approximately 90 million heat pumps installed globally in 1997, only 5% were located in Europe; of these 4.5 million, 70% were air-air heat pumps located mainly in southern Europe where the main need was for cooling (Laue 2002). Heat pumps optimised for heating were still, on the international scene, very much a marginal phenomenon.

By the mid-1990s the conditions had changed in favour of heat pumps once more. The uncertainties in future energy prices had decreased; nuclear power was no longer under direct threat of dismantling and oil was increasingly perceived as an uneconomic and unsustainable means of heating. Most of the customers who had previously put off the refurbishment of their home heating systems now returned to the market.
Many houses built during the 1960s and 1970s needed upgrading of their heating systems during the 1990s and 2000s (Anders Johansson, personal communication, 11 June 2013). In 1995, around half a million houses were using oil boilers and 800,000 houses were using electricity for heating in Sweden (NUTEK, 1995). Most of these customers wanted to convert to some other option, especially if their current systems were approaching the end of their life cycles. However, choosing a heat pump was not an obvious choice. The technology was still marked by rumours of unreliability, at the same time as district heating and bio-fuelled boilers were making advancements among homeowners (Energimyndigheten 2016b).

But as prices on heating oil and electricity rose, the will to invest in more energy-efficient solutions, such as heat pumps, increased among customers (Öfverholm 1997). The segment least willing to convert to heat pumps was the district heating segment, but out of Sweden’s roughly 1.8 million small houses, less than 10% were connected to district heating grids (Fröling et al. 2007).

By the mid-1990s the external economic factors for the heat pump were starting to become aligned with the heat pump properties. But there remained the challenge of gaining the customers’ trust in the technology – which was part of the reason behind the NUTEK competition.

After this competition’s launch, the sales of ground-source heat pumps started to go up and close to quadrupled within a couple years (see Figure 30).

![Figure 30: Heat pump sales in Sweden, 1995–2000. Source: SVEP 2013.](image-url)
The exhaust air heat pump segment also increased, which meant that the total number of heat pumps continued to increase each year despite the ground-source HP segment declining slightly in 1999. The air-air heat pumps continued to perform relatively poorly and air-water heat pumps were continuously almost a non-market.

Energy prices, including both electricity and oil, increased during the 1990s. Many of the performance problems associated with heat pumps related to imported air-air pumps that still hadn’t been sufficiently adapted to the Swedish climate (Energimyndigheten 2006b). In Sweden, either the ground or waste heat (in exhaust air) was a preferred heating source over the often cold outside air. But in 2000, air-air heat pumps once again started to gain market share (see Figure 31).


As air-air heat pumps recovered in the market, from 2002 onwards the same trend could be seen for the air-water heat pump segment. One reason for this increase was the improved regulation present in both types of heat pumps, leading to better SCOP and reliability.
The ground-source heat pump market segment enjoyed record years in 2004 and 2006. But after hitting a peak in 2006, the conversion market – i.e. the customer segment with existing heating systems based on oil or electric heating – showed signs of saturation (Forsén 2008). Since ground-source heat pumps primarily targeted these customers, the market ceiling for that segment in Sweden had been reached.

8.3.2. Increased competition between heat pumps and alternatives

The competition faced by heat pumps between 1995 and 2005 consisted primarily, as in previous decades, of electric heating, oil boilers and biofuel boilers.

After the reverse oil crisis, the price of fuel oil was relatively stable until the mid-1990s. In the five-year period after 1996, the fuel oil price increased by over 80%, levelled out somewhat between 2001 and 2003, and then continued to increase in price for another five years. The steep price increase had substantial negative effects on the heating oil market in Sweden (Österlund 2004; Pettersson 2005). Some of Sweden’s suppliers of fuel oil had widened their portfolio with biofuels to mitigate the risk of losing their existing oil customers. Quite possibly, the fuel oil suppliers thought that their existing customers would choose the simple and environmentally friendly option of converting their oil boilers to pellet boilers. In such a case, the suppliers could keep their customer stock and the same business model. But from the mid-1990s onwards an increasingly large portion of the fuel oil suppliers’ customers replaced their oil boilers and oil tanks with heat pumps instead of a pellet boiler. The company known as Statoil, at the time a stakeholder in both fuel oil and pellets, argued that replacing an oil boiler with a heat pump had a negative effect on the climate and that the best option would be to install a pellet boiler instead (Säll 2006; Säll and Fornstedt, 2006). The argument was based on the assumption that all heat pumps ran on margin electricity being imported from coal plants in Poland. The calculations were based on data supplied by the government organisation SP (Sweden Technical Research Institute). In response to this claim, SP published a response indicating that the picture was more nuanced and that if instead the calculations had been based on the Swedish electricity mix, the heat pump CO₂ emissions would have been equivalent to the CO₂ emissions of pellet boilers (Axell 2006).

The argument that heat pump CO₂ emissions should be calculated on the electricity margin (i.e. that coming from Polish coal-powered plants) has been going on for a long time (Wirtén 2015). Opponents of heat pumps, e.g. fuel oil and district heating lobbyists, have argued for calculating
emissions based on marginal electricity while proponents of heat pumps, e.g. the heat pump industry association (SVEP, now SKVP), have argued against this reasoning.

The manufacturers of heating equipment have stayed relatively neutral in this process, partly because manufacturers such as Nibe and CTC have produced both oil boilers and heat pumps at the same time (Sandström 2004; CTC 2015). When one market segment decreased for these manufacturers, they gained shares in another market segment.

8.3.3. Illustrating the heat pump sector in the late 1990s

The extensive exit of actors during the reverse oil crisis had increased the structural stability of the remaining networks in the heat pump sector. Fewer types of actors were involved, and as heat pump demand increased from the mid-1990s on, the number of actors increased while the number of actor types remained the same. See Figure 33 for an illustration of the value networks in the heat pump sector in the late 1990s.

The ground-source and air-water heat pump manufacturers continued to develop their installer network by making sure that newly joining installers got an education in heat pump installations (e.g. through the Thermia school or IVT University). These manufacturers also integrated horizontally into the exhaust air heat pump market, either through acquisitions (IVT) or organically (Thermia). IVT’s horizontal integration was more successful than Thermia’s, perhaps as a result of the stability of the network structures within the sector at this time, which made it difficult for Thermia to reprocess and engage new entrants into the home construction market. In contrast, IVT could utilise the existing network that it had obtained by acquiring the exhaust air heat pump manufacturer Elektro Standard.

Two heat pump types with different business models had shared the winning prize in the NUTEK competition, one of them (IVT) based on ground-source heat pump technology and the other (Eufor) on direct expansion technology. These two technologies had different value network structures, but to a large extent they were aimed at the same market segments, while direct expansion technology was partly aimed directly at homeowners, as seen in Figure 32. The direct expansion alternative had for a long time received support from Vattenfall, but when this ended in 1995 – due to state directives that Vattenfall could not sell or promote products containing fluorinated refrigerants – the value network of direct expansion technology was heavily weakened and, within a few years, outdistanced by the increasingly dominant ground-source heat pump value network.
8.3.4. The procurement competitions

Between 1989 and 1995, there were three procurement competitions aimed towards heat pumps. The first one resulted from the Swedish parliament’s decision in 1988 to initiate a programme for increased efficiency of electricity usage and replacement of electricity. The budget was 150 MSEK and the responsibility to divide the money was given to

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45 Cross-network actors are illustrated in yellow, suppliers in blue, upstream suppliers and partners and downstream channels and partners in light blue, and customers in green.
the government administrative authority for energy policy administration STEV.

In 1989, BFR and STEV – encouraged by the industry association SVEP – initiated an idea competition for heat pumps. The winning contribution would get a prize of 250,000 SEK plus guaranteed sales of 100 units (Lindholm 2011). In 1991, STEV launched another competition in which four prizes of 100,000 SEK each were given to reconstruction projects shifting houses with direct electric heating to heat pump heating systems instead. Neither of these two competitions had any direct measurable effect on the heat pump market, however.

In 1991, the Swedish government decided on a five-year programme to increase energy efficiency. Most of the programme was orchestrated by the NUTEK (the successor of STEV). It had a 750 MSEK budget for technology procurements plus a pot of 150 MSEK (from the ‘energy technology fund’) for larger demonstration projects (SOU 1995, pp. 139 and 207-208). From 1993 to 1995, NUTEK orchestrated a third procurement competition, much larger in scale than the previous two competitions held by STEV.

The NUTEK competition started in 1993, during a period when all heat pump market segments were in a declining state. Both the heat pump industry and the market needed an injection (Lars Kastengren, personal communication, 5 February 2015).

The goal of with NUTEK’s heat pump procurement competition was to reduce the use of direct electricity and oil for heating. The terms for the competition were that the competitors had to develop a 30% cheaper and 30% more effective heat pump than what the market currently offered (Energimyndigheten 2004). Of the 23 submitted applications, 10 were selected for the second round, in which they received 50,000 SEK each to continue developing a prototype.

Thorough testing of the prototypes was made at Vattenfall’s laboratory in Älvkarleby as well as at SP in Borås. The two winners of the competition (IVT’s IVT-Puls Greenline and Eufor’s Markus 2500 Kombi) each received a prize of 300,000 SEK. Both heat pumps would cost around 36,000 SEK to buy and install, and the first 100 buyers of each model would get 3,000 SEK in support from NUTEK (NUTEK 1995).

Along with the competition, NUTEK also undertook a large information campaign with brochures, articles and participation at energy and home shows to both promote and disseminate knowledge about heat pumps (Energimyndigheten 2004). Two people were employed full-time to travel around the country and provide information about the winners and on heat pumps in general (Stigh, 2007).
According to Lars Kastengren (personal communication, 5 February 2015), the impetus for the NUTEK competition came partly from the heat pump industry and IVT. IVT had contact with ‘heat pump veteran’ Arne Lögdberg who worked at NUTEK, and Kastengren and IVT pressed Lögdberg, saying that the market needed an injection. In response, Lögdberg orchestrated the whole procurement competition and was able to get all the remaining incumbent heat pump manufacturers to contribute to it (Lögdberg, 1995).

Eufor’s winner, the Markus 2500 Kombi developed in close collaboration with Vattenfall, was a ‘very simple and elegant heat pump’ using direct expansion (Eric Granryd, e-mail correspondence, 11 September 2014; see Figure 33), for which Eufor was given a design award.

Figure 33: Schematic illustration of the Markus 2500 Kombi heat pump. Source: Rogstam 1997.

The Markus 2500 Kombi was designed to heat the room where the indoor unit was placed by using a radiator. The model had low power output and therefore the cheapest possible components were used to keep the price down. It was marketed by Eufor as a ‘people’s heat pump’ (folkvärmepump) (Westmar 1995). By using the collector as an evaporator, as shown in Figure 33, Eufor was able to eliminate several expensive components, such as a long secondary collector and an evaporating heat exchanger (Rogstam 1997). This heat pump type had the advantage, despite its low cost, of giving a good COP even during winter (unlike the low-cost alternative of air-air heat pumps).
NUTEK (1995) marketed Eufor's Markus 2500 Kombi as a good option for homeowners with direct electric heating, while IVT’s Puls-Greenline was marketed towards homeowners with water-based heating systems. Direct expansion heat pumps were known for experiencing difficulty in steering the evaporation process in the ground collector, but this version had been tested thoroughly by Vattenfall, SP and KTH and showed good performance. In spite of this fact, the Markus product would face some severe challenges after the NUTEK competition.

In the middle of the NUTEK competition, the rules suddenly changed. The government’s decision to abolish ozone-hazardous refrigerants in Sweden ahead of other nations affected the competition, and a new requirement was added: winning competitors could not use the standard CFC refrigerant R12 (also called Freon 12).

Both IVT and Eufor had developed their products based on R12 and now quickly had to try to find a substitute. They contacted their compressor suppliers, which offered them new compressors that would work together with new ‘ozone-friendly’ refrigerant-blend R-407C. However, these refrigerants had other issues that were kept from both IVT and Eufor at first, as will be further discussed below.

8.3.5. Changed cross-network actor roles

Vattenfall had collaborated closely with SP in Borås during the entire 1980s and also in the NUTEK competition. After the NUTEK competition, Vattenfall eventually liquidated all its heat pump engagements. Vattenfall’s activity in the 1990s and 2000s was instead marked by efforts to expand internationally (Högselius 2009).

After the NUTEK competition, the collaboration between SP and Vattenfall concerning heat pumps also ended, but in 2003 the Swedish Energy Agency (which had adopted some of Vattenfall’s previous responsibilities since Vattenfall’s corporatisation) engaged SP in doing heat pump tests again (SP 2005). SP’s heat pump tests, on a commission from the Swedish Energy Agency, have included 50 air-air, 16 air-water, 14 ground-source and 3 exhaust air pumps (Nordsyn, 2015). The tests reveal the heat pumps’ SCOP, COP at different temperature levels, noise levels, investment costs and energy savings for different house types.

Since 2005, SP has also labelled heat pumps with the Swedish quality label called ‘P-marking’ (P-märkning). To get a P-marking, the heat pump manufacturer must pass SP’s CR130 certification rules concerning sound level, efficiency, safety and design, as well as documentation of quality assurance (Nordsyn 2015). The first heat pump to pass SP’s P-marking requirements was a Sanyo heat pump in 2005 (Eriksson 2005).
Two other labelling types are in use. One is the Swedish eco-label Svanen, which has been granted to heat pumps since 2005, with IVT Greenline becoming the first heat pump to receive it. The other is the European Heat Pump Association (EHPA) quality label. But the P-marking for air-air heat pumps has been most prevalent (Karlsson et al. 2013). With its vast knowledge of heat pumps, SP has also managed to become the headquarters of the IEA’s Heat Pump Centre.

SP’s work has also included conducting surveys on heat pumps as well as testing. In 2003, it distributed a survey with 251 responding households to investigate satisfaction and dissatisfaction concerning vertical ground-source heat pumps. SP also performed site visits to 25 of the respondents (SP 2005).

Most of the issues identified by customers concerned the installation and/or the installers, not the heat pump itself. The most frequent problems were noise from radiators and/or heat pumps, leakage in the collector circuit and the space where the heat pump was placed turning too cold (SP 2005).

Energimyndigheten (2006b) also notes that much of the overall dissatisfaction with heat pumps has come from customers with poorly installed air-air heat pumps.

### 8.3.6. Academic heat pump and refrigerant research programmes

The role of technological universities also changed during the 1990s. During the late 1990s and 2000s, the focus of heat pump research at technical universities was on incremental and environmental improvements, often involving improved system operations (cf. Forsén 2004; Granryd and Björk 2010; Energimyndigheten 2010). The personal mobility between industry and academia changed in character. Researchers and professors at technical universities rarely engaged in new start-ups or in product development for heat pump manufacturers, and there are few examples of heat pump–related spin-offs in this period. Instead the role of academia, in its relationship to the industry, was to supply knowledge and educate potential employees for the companies (see also Johansson et al. 2013).

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46 A study by Johansson et al. (2013) mapped the number of spin-offs from the refrigeration and heat pump research group at KTH Royal Institute of Technology, finding only two since 2000. One of them was Green and Cool, partly with roots at KTH, which had a business model that involved delivering cooling systems with environmentally friendly carbon dioxide (Björn Palm, personal communication, 25 January 2013).
The research programmes in which KTH’s heat pump research group was involved also included government agencies such as SP and the Swedish Energy Agency (Energimyndigheten 2006b).

Since the initiation of the alternative refrigerants research programme in 1994, a series of research programmes on both refrigerants and heat pumps have been in place. These programmes have received support from both SP and the Swedish Energy Agency, and universities such as KTH and Chalmers have taken part, along with much of the existing refrigeration and heat pump industry (Energimyndigheten 2006b). The first research programme on alternative refrigerants ran from 1994 to 1997 and also focused on developing heat exchangers and identifying lubricating oils for the compressors that would work together with the new refrigerants (Energimyndigheten 2006b; Martin Forsén, personal communication, 25 March 2013). According to Eric Granryd and Jan-Erik Nowacki (personal communication, 16 April 2012; Granryd, e-mail correspondence, 11 September 2014), large-scale testing was set up at KTH that helped manufacturers to find the right oils for their compressors with the new, non-ozone-hazardous refrigerants.

In a subsequent research programme from 1997 to 2000, called ‘Climate 21: More efficient refrigeration machines and heat pumps’, the research on environmentally friendly refrigerants continued (Gustafsson et al. 1999). For example, one study focused on how water-source heat pumps could be made resistant to corrosion when using brackish water (Energimyndigheten 2006b). Then in 2001, the so-called ‘effsys’ research series began, which ran in three different programmes through 2014. First came ‘Eff-Sys: The Swedish Energy Agency’s development programme for increasingly efficient refrigeration and heat pump systems’ (Forsén 2004). It was followed by ‘Effsys 2: More efficient refrigeration and heat pump systems’ and ‘Effsys+: Resource-efficient refrigeration and heat pump systems’ (Energimyndigheten 2010).

8.3.7. Technological developments leading to an increasingly standardised product

In the 1990s, ground-source heat pumps became increasingly standardised and the customers of these heat pumps became increasingly certain as to what type of product they could expect when they ordered a heat pump. In other words, a ‘dominant design’ for
ground-source heat pumps began to emerge\(^{47}\) (Anderson and Tushman, 1990), with increasingly standardised features such as size (a standard house appliance area base of 60 x 60 cm), exterior design of the indoor unit (see Figure 34), steering interface, noise level and installation procedures.

Although all heat pumps seen in Figure 34 are ground-source pumps, the same dominant design for indoor units applied to air-water and exhaust air heat pumps as well.

To a large extent, the emergence of a dominant design for ground-source heat pumps in the 1990s was made possible by technological advancements outside the heat pump industry. It was also facilitated by the work of Swedish academic researchers who had contributed to developing individual components and improved overall system performance.

![Illustration of ground-source heat pump indoor units of different heat pump brands. Source: Energimyndigheten, 2015a.](image)

The emergence of a dominant design also manifests the new phase into which the industry was entering. The increasing standardisation increased the focus on production, and the Swedish heat pump market was eventually dominated by only a few actors (Utterback and Suárez 1993; Klepper 1997).

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\(^{47}\) Since the heat pump market is fragmented between different types of heat pumps, there is no one dominant design that applies to all markets, as is common elsewhere (see e.g. Anderson and Tushman 1990; Utterback and Suárez 1993; Utterback 1994). Tushman and Murmann (1998) state that a dominant design is unlikely to appear if market volumes are small, customer preferences vary and government regulates and limits the production range – points that to a large extent are valid for heat pumps. Windrum (2005) furthermore suggests that a dominant design occurs only in a market where the majority of customers have similar needs and tastes and where there is a relatively large group of homogeneous customers.
Compact heat exchanger developments

There was a large interest in compact heat exchangers in the heat pump industry, especially after Thermia’s technological breakthrough in the late 1970s. In the late 1980s, compact plate heat exchangers began to gain market share as both evaporators and condensers in ground-source pumps (Björk et al. 2013, p. 20). The problem for plate exchangers had been that the high pressure on the condenser side – which could be up to 30 bars – would cause a standard plate heat exchanger to blow up into a balloon (Eric Granryd, personal communication, 5 February 2013). But eventually the manufacturers of plate heat exchangers were able to develop a technology in which the heat exchangers were soldered with correction plates. That innovation enabled them to withstand the high pressures that normal heat pump operation in the Nordic climate demanded.

Having small and efficient plate heat exchangers available made it possible for all manufacturers to produce smaller indoor units. Among the producers of plate heat exchangers in Sweden were Alfa Laval and SWEP, though these companies were traditionally more oriented towards the cooling side and the food industry. In 2009, Swedish companies had roughly 30% of the global market for plate heat exchangers (Braunerhjelm et al. 2009, pp. 115–116).

Compressor developments

Another part of the emerging dominant design was the entrance of scroll compressors. The technology behind the scroll compressor is almost as old as the heat pump itself, but it didn’t start to become used until the early 1990s; by the mid-1990s it had started to outcompete the traditional piston compressor in heat pump designs.

The scroll compressor had the advantage of compressing less amount of refrigerant in each compression cycle, which gives less pulsation and noise compared to piston compressors. Piston compressors, however, have a more even compression pressure output (Granryd 2011; Thermia 2012; IVT 2014).

A scroll compressor comprises two spirals – one fixed and the other moving – in which the moveable spiral runs in an oscillating orbit and creates ‘pockets’ of refrigerant that are compressed and driven towards the centre where the outlet is placed (Granryd 2011).

When Thermia launched its first scroll compressor in 1994, the company described it as having ‘high efficiency, great reliability and low noise level’ (Thermia 2012). Not until after the year 2000 did scroll compressors make a major impact in Swedish-based heat pump
manufacturing. The first scroll compressors constructed specifically for heat pump operation entered the market in 2002 (Thermia 2012; IVT 2014). In the following year, IVT launched a complete new model in its Greenline series with a scroll compressor, new refrigerant (R134a) and considerably increased water tank size (IVT 2014).

An incremental innovation that has spread in the industry in the last few years is speed-controlled scroll compressors, first introduced by Thermia for ground-source heat pump applications in 2005. With speed-controlled compressors it is possible to increase operational efficiency, since the compressor can run continuously during part-load operation instead of being switched on and off periodically (Thermia 2012).

**Systems performance developments**

The speed-controlled compressor was one step in the ongoing struggle to optimise heat pump system operation. Controlling the heat pump cycle – how the pump unit runs and operates in a system with its heat sources, heat sinks and heating demand – has been a main point for improved performance since heat pumps first came into use (Björk et al. 2013). After having faced considerable trouble with getting good control equipment to steer the cycle in the heat pumps, Thermia in 1984 launched a heat pump control computer that would enable fully automated steering (Thermia 2012).

With computerisation, it has become increasingly easy to optimise heat pump control. This advance has also contributed to the comeback of air-air heat pumps in the 2000s, after their very low sales volumes during the 1990s (see Figure 31). The new generation of air-air heat pumps could, with its improved steering, pick up heat from the outside air down to -20°C (Thermia 2012).

Another issue in optimising heat pump performance has been the trade-off between heating the hot tap water and the not-so-hot water for space heating. Two options mentioned previously involved using an immersion heater or a hot gas heat exchanger to heat the tap water. Another technique, water layering, is typically applied with hot water heaters. Layering the water in the heater makes it possible to partly separate the hot water needed for the tap from the colder water used for space heating. In 2004 Thermia patented such a technique, called Tap Water Stratificator (Thermia 2012), although the development of this technique has been ongoing since at least the 1980s.
8.4. **Horizontal value network integration and increased competition**

In the mid 1990s, having a borehole ground-source heat pump became increasingly popular and even served as a status symbol. According to Martin Forsén (2008) a phenomenon started to appear in Stockholm’s better-off suburbs called the ‘BBB syndrome’, which described the symbols of high status among the suburb’s homeowners: boat, BMW and borehole ground-source heat pump.

Swedish manufacturers were finally able to enjoy a market that showed positive signs of increased demand, and beginning in 1995 the demand in heat pumps would increase for more than ten years in a row. But the increased market shares also came with increased value network competition. The largest heat pump producers – Thermia, IVT and Nibe, later followed by CTC – all started to integrate their business offerings horizontally in this period, intensifying their competition against each other.

8.4.1. **Focus on getting added capital and market expansion**

Before the market turned around, both Thermia and IVT had needed added infusions of capital to survive. When the market started to expand, they again needed more capital, but now it was to invest in their production processes and facilities so that they could meet the increasing demand.

For Thermia, an addition to the company’s cash came when Bergslags Invest AB – which had been owned by Industrifonden (2013) since 1996 – acquired a large share of Thermia in 1998 (Thermia 1998).

Thermia increased both total turnover and its profits during the following years. In 2004, Procuritas Capital Investors III acquired all of Industrifonden’s shares in Thermia (26.4% of the total) for 100 MSEK (MyNewsDesk, 2004). Only a year later, Procuritas sold all its shares to the Danish industry group (and Thermia’s old heat pump competitor and rival) Danfoss.

IVT in Tranås had won the NUTEK heat pump competition in 1995 and had a growing backlog of ordered heat pumps. In 1994, the backlog had been valued at 3 MSEK; in 1995 it grew to 19 MSEK (IVT 2005). But IVT was still low on cash and therefore needed to mobilise liquid capital to buy components and resources from its suppliers – who often demanded direct payments – so that it could manufacture the ordered heat pumps.
In connection with this situation, the venture capital company Företagskapital entered as a shareholder in October 1995 and remained in possession of its shares of IVT until 2005 (IVT 2005).

With the added capital from Företagskapital, IVT was able to mobilise its resources. According to Kastengren (personal communication, 5 February 2015), IVT was, after 1995, finally able to employ people, provide the employees with better training, and ‘overall act more like a proper company’. With the cash and company in order, IVT also started to increase its focus on marketing. During the years following the NUTEK competition IVT captured half of the market for ground-source heat pumps.

Nibe was financially stronger than both IVT and Thermia in the mid-1990s. In 1994, Nibe’s executive board set the ambitious target of growing by 20% annually, of which 10% should be organic growth (Nibe, 2004). For the employees, the target was that ‘for every spent 100 SEK there should be 10 SEK in profit’ (Veckans Affärer 2007). During the following 15 years, the target was virtually met, with 19% total growth annually. Between 1996 and 2008, Nibe’s turnover grew almost tenfold.

In 1997 Nibe did an IPO, and it has since been a ‘rocket on the stock market’ and grown into a totally different company, according to CEO Gerteric Lindquist (Veckans Affärer, 2007). At the time of the IPO, Nibe was a relatively small company making tubular elements, heat pumps, water heater and wood stoves ‘without much fuss’. Ten years later, it was an international established heating company. The biggest owner of Nibe after the IPO was financier Melker Schörling, at about 20%, with Lindquist the second-largest shareholder at 8–9%.

8.4.2. Network reconfiguration through horizontal integration

The 2005 SP survey found that the three most common heat pump brands in Sweden in 2003 were Nibe, Thermia and IVT (SP 2005).

In the late 1990s the market was showing increasingly positive signs of increasing demand and both IVT and Thermia were able to refill their company treasury. Now the competition between the large manufacturers increased.

One step in this stepping-up of competition was the acquisition of Elektro Standard by IVT in 1998. Until then, Elektro Standard and Nibe

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48 At the time Företagskapital AB was 75% owned by A-listed Atle. Företagskapitel would later be renamed to ‘3i’.
had been the largest producers of exhaust air pumps. When IVT bought Elektro Standard, it was with the purpose of widening its customer segment into the home construction market, where Elektro Standard had established value networks.

Thermia a few years later also attempted to get into the exhaust air heat pump segment, but organically and not through acquisition. Unfortunately, Thermia lacked the distribution channels – which IVT acquired together with Elektro Standard – into the exhaust air market segment and didn’t get a foothold amongst home builders (Leif Olsson, personal communication, 30 March 2016).

As a response to IVT’s acquisition of Elektro Standard, the executives at Nibe decided to do a horizontal integration as well and enter the ground-source market segment. Only a few years earlier, IVT had been a customer of Nibe and now they were head-on competitors.

In 1998, CTC also decided to plunge into the ground-source heat pump arena. Since 1983, CTC had been a part of the heating conglomerate called Enertech Group, which also included Parca Norrahammar, and the two companies had some conflicts. In 1988 Saab sold the Enertech Group to the Trelleborg Group and concentrated its HVAC-oriented production on CTC in Ljungby. In 1993, the Trelleborg Group sold CTC to the international wholesaler company Wolseley.

In 1982, CTC had successfully launched an exhaust air heat pump model called CTC Master Success. CTC launched an air-water heat pump, CTC Rebel, in 1985 but it was a big failure, as a consequence of the failing market. In the 1980s, CTC had a strong share of the oil boiler market as well, with more sales in Germany and Switzerland than in Sweden. But there was no increase in the demand for oil boilers either during the 1980s. This market increased slightly during the early 1990s, only to decrease again shortly thereafter.

When the demand for oil boilers decreased, to the advantage of electric boilers and heat pumps, CTC decided to integrate into the ground-source pump market and launched a line of heat pumps in four different sizes in 1998. CTC’s greatest successes, however, would be with their reintroduced air-water heat pump (which they had removed from production for many years), as the company grabbed up to 50% of that market segment after launching its CTC Eco Air model in 2001.

As one sign of the increasingly intense competition, IVT was expelled from the industry organisation SVEP – for having ‘too good offerings’ according to an article in Dagens Industri (1999). IVT’s CEO, Johnny Wärnelöv, considered the expulsion a foul move by IVT’s competitors.
The high level of competition between the manufacturers and their partners spurred on further development of the heat pump offerings and market.

**8.4.3. The established manufacturers vs. direct expansion heat pumps**

While the established incumbents Thermia, IVT and Nibe profited from expanding markets in the 1990s, the smaller Eufor, with its direct expansion heat pump value network, had a harder time. This story deserves an extended description because it is an example of how the established manufacturers in the heat pump sector collaborated to outcompete alternatives, including innovative, environmentally friendly and possibly disruptive ones, eventually forcing Eufor to exit the sector during a time when the overall heat pump market was expanding.

In the early 1990s, the market for direct expansion grew in Sweden. The technology was not unique to Eufor; for example, it was the most common heat pump type in Austria for a long time (IEA, 2010). But since the 1970s, the typical ground-source heat pump in Sweden did not use direct expansion but a collector with a secondary refrigerant (brine).

Due to Sweden’s decision to abandon ozone-hazardous refrigerants before any other nation, the winners of the NUTEK heat pump procurement competition changed from refrigerant R22 to the ozone-friendly R-407C. As noted previously, the NUTEK competition rules changed in midstream, prohibiting use of ozone-hazardous CFCs including the standard refrigerants R12 and R22. These new directives came only six months before the winning contributions were to be selected – in spite of warnings that there would be insufficient time for testing (Jagemar and Fahlén 2007). All the remaining participants in NUTEK’s competition had to change refrigerants without time to test the new equipment.

The selected winners – Eufor's Markus 2500 Kombi and IVT's Greenline-Puls – had both been developed to run on R22 but converted to R-407C (NUTEK 1993; Rogstam 1997). The new refrigerant had some theoretical limitations compared to R22. It was actually a blend of refrigerants with the consequence that it had a temperature glide during the phase change, meaning that it did not change phase at a fixed temperature (whereas R22 changed phase at a fixed temperature without glide). But R-407C also had some advantages, such as stable operation even in situations of overheating (Rogstam 1997). So, the switch wasn’t all bad, at first.
The big problem was not discovered until later. The new refrigerant and the lubricating oil delivered by the supplier of the compressors were not compatible for longer operations. The new refrigerant reacted with the oil, slowly thinning it out until it stopped performing its lubricating function and the compressor malfunctioned. Since the compressor suppliers didn’t have the same laws as Sweden, they hadn’t tested their compressors with the new ozone-friendly refrigerant that they themselves were recommending (Martin Forsén, personal communication, 25 March 2013).

The problems with the malfunctioning compressors weren’t discovered until after a whole year of production, in 1996 and 1997. This meant that a lot of malfunctioning heat pumps had been sold (around 1,000 of Markus 2500 Kombi and around 1,300 of IVT Greenline-Puls) before Eufor discovered the problem (Bengt Sandström, personal communication, 21 March 2014). Today, both brands sit atop the statistics on failed heat pumps gathered by the insurance company Folksam (Wallberg 2011).

According to Anders Johansson (personal communication, 11 June 2013) – who did his PhD on heat pump refrigerants – the Markus 2500 Kombi could have run without problems on liquefied petroleum gas (propane or butane) instead of R22, but many customers would have felt uneasy about filling the ground around their homes with flammable gases, so it was decided not to continue with that solution.

Both Eufor and IVT took full responsibility towards their customers and exchanged the compressors in each reported malfunctioning unit, and the suppliers delivered new compressors (without charge) to both Eufor and IVT. This action helped to protect the whole industry against becoming tarred once again with a reputation of poor reliability (Energimyndigheten 2009c). The customers were also at least partly protected by the high standards set by SVEP.

The organisational structure of IVT gave it increased capacity to manage the task of changing compressors relative to Eufor. Eufor had a completely different network set-up, largely depending on Vattenfall for sales and even doing some sales by mail order, so it did not have a comparable service network. As Vattenfall had broken its collaboration with Eufor a few years earlier, Eufor was without partners when its customers started to report compressor failures.

Vattenfall’s break with Eufor was also related to the ban on the old refrigerants. Around 1994, Vattenfall received a directive that it needed to stop all handling of equipment with refrigerants hazardous to the ozone layer. At the time Vattenfall was a major retailer of Eufor’s heat
pumps. Vattenfall had also directly sponsored the development of Markus 2500 Kombi for the NUTEK competition. Before the directive came that Vattenfall had to stop selling any freon-related products, it had placed a big order from Eufor. Under the contract, Vattenfall had to pursue the order, but its owners were not allowing Vattenfall to sell the products. So Vattenfall was stuck with several hundred Eufor heat pumps that it was unable to sell (Bengt Sandström, personal communication, 21 March 2014).

The owners and entrepreneurs at Eufor worked hard to help all customers and to restore confidence in their products, but in the year 2000 they sold the company to Thoréns. During their last years, the management at Eufor had felt that the industry was working against them. Even though IVT had sold more heat pumps with faulty compressors than Eufor, the latter company was made the scapegoat in the heat pump sector. According to Bengt Sandström (personal communication, 21 March 2014), the other manufacturers and their partners spread untrue rumours about direct expansion and Eufor, such as that ‘the oil would get stuck in the ground’ and cause the compressor to fail. One example that backs up Sandström’s claim is an article in the newspaper Dagens Nyheter (Westmar 1999) that described the fate of the NUTEK competition winners, blaming Eufor’s heat pump for being of ‘faulty construction’ while not mentioning anything about IVT, despite the fact that IVT had more reported malfunctioning heat pumps.

8.5. Summing up the dynamics in the fourth phase of the heat pump transition

The structural tensions that had held development back started to be resolved as complementarities aligned and formed a complete development block after 1995.

Price developments during the 1990s had a positive effect on the economic benefits of converting to a heat pump for homeowners with either oil or electric boilers. The heat pump became an increasingly standardised product and an investment that increased the value of the house in which it was installed. An increasing number of homeowners, many with old heating boilers, now chose to install a heat pump. During this phase, the cross-network activities between value networks at the heat pump technology level were characterised by increased competition among heat pump manufacturers and their value networks. But the manufacturers also had a common interest in showing a unified front against other heating alternatives, and the increased dominance of the established heat pump manufacturers contributed to increasing the barriers to entering the developing industry.
8.5.1. Structural tensions and complementarities

The period after 1995 was characterised by increased structural stability of the heat pump industry. The radical configurations and reconfigurations of value networks that had been common in the prior phase became less common. Instead, the large established manufacturers started to widen their value networks by expanding horizontally through both acquisitions and organic growth.

Because the main components of the heat pump had been continuously developed in other industries, the theoretical performance potential of heat pumps had continued to increase despite of the minimal product development activities in the Swedish heat pump industry itself. During the 1990s, the steering of heat pumps improved and the heat pumps became quieter, due to use of a scroll compressor instead of a piston compressor but also due to improved products (e.g. rubber gaskets that didn’t vibrate off their place). With improved steering through computerisation (or ‘digitalisation’), the operational performance and reliability of air-air and air-water heat pumps improved significantly – making possible a comeback for the air-water heat pump segment. The design of heat pumps stabilised, and with this stabilisation and the appearance of a dominant design came decreased uncertainty associated with the technology among customers and government organisations (Anderson and Tushman, 1990).

With improved theoretical SCOP and increasingly beneficial energy prices for heat pumps, one of the largest challenges in opening up the potential of the heat pump market was to disseminate knowledge and information concerning the possibilities of heat pumps. The NUTEK competition helped in this regard.

Cross-network actors

NUTEK’s heat pump procurement competition in 1993–1995 was well timed. The competition was connected not only to financial support from NUTEK but also to marketing efforts for heat pump technology. Other stakeholders in the competition included BFR, Vattenfall and SP, which participated in various ways, such as by testing the heat pumps entered in the competitions. These tests also contributed to enhancing the learning process for heat pump actors. After the procurement competitions ended, SP - engaged by Energimyndigheten – continued to perform tests of heat pumps. The support from NUTEK and other government actors helped to finance new product developments and to market heat pump technology among the public in a period when the price of fuel oil was starting to increase again.
After 1995, there arose one structural tension that threatened to halt the market expansion of heat pumps if not overcome and that also affected the NUTEK competition: the ban on chlorofluorocarbons. Sweden’s decision to act faster than most of the signers of the Montreal Protocol on eliminating freon-based refrigerants had serious technological implications for the Swedish refrigeration and heat pump manufacturers. Changing the refrigerant in a heat pump was like changing a cogwheel in precision machinery – all the other components in the machinery needed to adjust accordingly. Therefore, changing the refrigerant required a lot of product adaptation followed by a period of serious testing. And all this was happening at a time when companies had little resources or time to spare. The consequence was large-scale technological malfunctions further down the road.

The Swedish technical universities played an active part in counteracting the troubles with changing refrigerants. In the 1980s, researcher Åke Melinder had conducted a series of tests with brines with different salt levels, which became increasingly important not only for industry but for researchers internationally as the interest in alternative refrigerants increased in the early 1990s. In 1994, several technical universities, including Granryd’s division at KTH, became involved in the alternative refrigerants research programme to contribute their academic expertise on the issue of substituting ozone-friendly alternatives for traditional CFC-based refrigerants. After much testing, along with product development of compressors and refrigerants outside Sweden, the tensions regarding refrigerants were resolved (for now).

**Financing – a complementarity**

In the early 1990s, the low and shrinking volumes of heat pump sales had emptied the treasuries of heat pump manufacturers. When market demand increased again, both Therma and IVT had the competence and resources to manufacture heat pumps (with their existing staff, production facilities and network of component suppliers) – but not at the rapidly increasing rate that the market demanded. Therefore, both companies needed to invest in their own production. But since their treasuries were virtually bare, they needed external capital to finance their investments.

From an individual value network perspective, this was one of the most pressing structural tensions after the NUTEK competition. From prior experience, these manufacturers knew the dangers of not being able to respond to market demand: opportunistic actors would enter the market space with subpar products that would taint the whole industry. And there was still the problem of poor competence among installers, at least
in other heat pump segments (such as the air-air heat pump market segment). There were no heat pump schools for air-air heat pump installers as there were for retailers of Thermia or IVT heat pumps.

**Horizontal integration and increased competition**

As the heat pump manufacturers’ treasuries grew again, they could start to launch new products and make acquisitions to widen their product range as they competed more intensely with each other. This process, which started with IVT’s acquisition of Elektro Standard in 1998, also caused the different value networks to become increasingly similar in structure. The main difference was that Nibe continued to supply through wholesalers while IVT and Thermia continued with their own affiliated networks of suppliers and installers. The competition between manufacturers became so heated that IVT was expelled from the heat pump association SVEP for having ‘too good offerings’ (Dagens Industri 1999).

**Coopetition against alternatives**

At the same time as the leading manufacturers competed against each other, they also collaborated to show a unified front against heating alternatives. That included opposing alternative heat pump products as well, as demonstrated by their ‘coopetition’ against the challenger Eufor.

The winners of the NUTEK procurement competition had ended up being technological failures because of the forced change in refrigerant in the middle of the competition. The results could have revived widespread public distrust towards heat pump technology in general. But the heat pump sector responded to the problem by taking full responsibility to their customers for failed pumps (both IVT and Eufor did), which was also ensured by the industry organisation SVEP. At the same time, the large incumbents tended to blame the direct expansion technology for the malfunctions, when there were just as many reports of failures of ground-source heat pump units.

**8.5.2. The situation before the next phase**

This chapter has described a period during which the heat pump sector formed a complete development block and started to grow with increasing market demand. By the end of this phase, the Swedish heat pump market had started to show signs of maturation and the developing European markets seemed increasingly attractive for Swedish heat pump manufacturers. Accordingly, the internationalisation of the Swedish heat pump industry is highlighted in the next chapter.

This chapter examines a time period when the Swedish heat pump value networks, having grown strong and stable in their domestic market, expanded geographically. Initially, Swedish firms were able to capture half of the ground-source heat pump market in Europe. In this process, when Swedish value network structures were transferred to other countries, similar application problems that had appeared in Sweden over 30 years earlier now occurred in the new markets where heat pumps were installed.

9.1. The societal and international context of heat pumps

After 2005, the European and international heat pump market became increasingly important for Swedish-based manufacturers, with growing heat pump markets in several European nations and an increasingly saturated Swedish market. The year 2008 witnessed an international economic crisis, and in 2008 and 2009 the growth of European heat pump markets halted, but it resumed its expansion a few years later.

9.1.1. Re-industrialisation of Swedish industries

Since 2000, the growing economies of India and China have been of increasing importance, with greater competition in the international market (Schön 2012). Most recently, Japan and Korea have been overtaken by China as the nation where the greatest number of heat pump–related patents are being filed (as can be seen from the Thomson Innovation patent database). However, no Swedish manufacturers moved their production facilities to East Asia. Instead, heat pump manufacturing in Sweden after 2005 can rather be characterised as a ‘re-industrialisation’. This phenomenon of renewed industrial production in Western Europe had emerged within manufacturing industries in the early 2000s. Its precise extent is unknown, but it involved some industries moving their manufacturing activities back from East Asia or Eastern Europe, possibly due to decreasing wage differences and the increased administrative and logistical costs of having manufacturing located far away from production development. It also had to do partly with the increase of digitalisation, which made production increasingly flexible and reduced the need for long assembly lines and standardised production facilities (Schön 2012).
9.1.2. The threat of climate change

Even though the US, Russia and several other prominent nations did not sign the Kyoto Protocol, the threat of climate change has remained on the international political agenda since the 1990s.

At Doha 2012 it was decided to prolong the Kyoto Protocol until 2020, and this protocol played an important role in determining the European Union’s 2020 targets, which require EU members to develop a strategy for achieving a 20% increase in energy efficiency, a 20% increase in renewable energy and a 20% reduction in emissions of exhaust gases, compared to 1990 levels (European Parliament 2009, 2012).

In Paris, on 11 December 2015, a global agreement was made that the global warming increase must be limited to 2°C, and that all nations will work towards keeping it from exceeding 1.5°C. Since the 2016 US presidential election, the future of US participation in the Paris agreement has been uncertain, but so far no other nations have threatened to leave the agreement.

9.1.3. The debate on marginal electricity as related to heat pumps

Between 2005 and 2015, there has been a stormy discussion on marginal electricity related to heat pumps in Sweden. The discussion on how to classify the heat taken up by heat pumps has also shifted. The results of both discussions have been in favour of heat pumps.

The first debate, as noted in previous chapters, surrounded whether the CO₂ emissions from heat pumps should be calculated based on the average electricity production mix or on the so-called marginal electricity (Sköldberg, Unger and Olofsson 2006; Barth et al. 2014). The CO₂ emissions from marginal electricity – the electricity produced ‘on the margin’ – can be as high as 750 g/kWh if it comes from coal. Proponents of heat pumps like to calculate the emissions of heat pumps based on the Swedish average (10 g/kWh) while opponents calculate it using marginal electricity coming from coal-burning power plants. Consequently, these two groups get very different results in their calculations of the CO₂ emissions attributable to heat pumps, as shown in a comparison made by Fröling et al. (2007, p. 24). The recommendations from the Swedish Energy Agency and Swedish Energy Markets Inspectorate state that the Nordic electricity mix should be used for these types of calculations (Granström et al. 2011; Forsén 2008a; Russell et al. 2009).

Because of this debate, some researchers and energy experts have stopped using the terms ‘marginal’ or ‘average’ electricity completely, instead discussing the consequences for the energy system of installing
heat pumps or other energy technologies (Wirtén 2015). This is in line with Laestadius’ (2013) discussion of how technologies such as heat pumps (referred to by Laestadius as a ‘blue’ technology) need to be placed in the context of the system of which they are a part before their environmental impact is assessed. However, irrespective of the conditions in initial assumptions, it is typically always beneficial from an environmental perspective to replace electric boilers and direct electric heating with heat pumps.

Discussions of the environmental aspects of heat pumps have also concerned whether the ambient heat that the heat pump takes up should be seen as renewable. This debate has been less stormy, but nevertheless the Swedish Energy Agency explicitly declared in 2007 that the energy that heat pumps absorb should be considered renewable (Russell et al. 2009). At the European level, it is now taken for granted that heat taken up by heat pumps from the air or ground should be categorised as renewable energy, but 10 years ago the situation was the opposite (Thomas Nowak, personal communication, 24 March 2016).

9.2. Energy system and energy policy developments

During this period, various types of support and legislation favoured heat pump technology, directly or indirectly. At the beginning of this period, there were direct subsidies; since 2008, only other types of policies favouring heat pumps have been in place. The changing energy systems and the so-called ‘new energy landscape’ also showed the potential of new complementarities for heat pumps at an energy system level.

There were no major changes in the electricity–oil price ratio, which has affected the heat pump market significantly in this period. The international crude oil price increased to new highs after 2005, comparable to those following the 1979 oil crisis, but since 2011 it has been dropping each year. Due to taxation and other costs, the drop in crude oil prices has had only a marginal effect on the price of heating oil, which is what homeowners with oil boilers use. The price of electricity in Sweden was relatively low in this period compared to that in most of Europe. These low prices can partly be explained by the low fuel and emission-related costs (Energikommissionen, 2017).

9.2.1. A ‘new energy landscape’

Between 2005 and 2015, the term ‘new energy landscape’ became common in the Swedish energy arena (Sköldberg and Rydén 2014; Svante Färnbo, personal communication, 10 October 2014). Sköldberg
and Rydén (2014) describe the new energy landscape’s relationship to heating actors as follows:

‘An increasing number of actors, renewables, small-scale electricity generation, demands for new solutions for energy efficiency improvements and proactive customers are all trends that rapidly are changing the conditions on the heating market. Altogether this calls for a new way of thinking from the actors on the market, if they want to stay competitive and maintain a profitable business.’

Since 2005, the development of energy supply in the Swedish energy system has been relatively stable in absolute figures for all means of production – in 2015 the Swedish electricity production mix still consisted of primarily hydropower and nuclear power – except wind power. Between 2005 and 2015, the electricity supply from wind power in the Swedish energy system increased from 1 TWh to 16 TWh. In the same period, electricity use in Sweden decreased slightly and the net exporting of electricity from Sweden increased (Energimyndigheten, 2017b). In 2015 solar power still constituted only a minor part of the Swedish energy system with a total electricity production capacity of 104 MW, whereas wind power had an installed production capacity of 6,029 MW in the same year (Energimyndigheten 2017b). But solar power continues to grow and is expected to play an increasing role in the Swedish energy system for the years to come (Energimyndigheten 2016; Energikommissionen 2017).

9.2.2. Energy policy developments

After heat pump subsidies were reintroduced in 1998, financial support from the government came intermittently over a 10-year period. Different sources assign different impacts to these subsidies. Some claim that they contributed strongly to market growth, while others point to the subsidies as highly market-disturbing.

In January 2006, a new subsidy was introduced for houses (single- or multi-family) that currently used electricity or oil to cover up to 30% of the total cost of converting to heat pumps, biofuel, district heating or solar heating (see Regulations SFS 2005:1255 and 2005:1256). The

49 With wide parliamentary support, Sweden’s Rikstad has set a target of 100% renewable electricity production by 2040 (Energikommissionen 2017), and the Swedish Energy Agency has suggested that 5–10%, corresponding to 7–14 TWh, of the total electricity production in the Swedish energy system could come from solar power (Energimyndigheten 2016c).
maximum subsidy was 30,000 SEK per house with direct electricity and 14,000 SEK for houses with oil burners (Boverket, 2011). The subsidy scheme was intended to continue to 2010, but within just a few months all the money for the project was gone, and the subsidy was ended in 2007 (Boverket 2007, 2008), hinting that Swedish authorities had little understanding of the state of the heat pump market.

No direct subsidies have been given to heat pumps in Sweden since 2008, but heat pump installations have benefitted from other types of support. So-called ‘ROT’ (renovering, ombyggnad, tillbyggnad) tax deductions for repair, maintenance, conversion and extension work, including heat pump installations, have been given since 2009. Originally, up to 50% of the labour cost of heat pump installations was deductible, and the deduction could be made directly by the installer on the invoice. Since 2016, the amount of total cost that could be deducted was cut from 50% to 30% for all homes under 65 years of age (Skatteverket, 2016).

Support other than subsidies has also been given to heat pumps, such as the above-mentioned information campaign ‘Heat in the Villa’ (Värme i Villan). In 2006, the building and planning agency Boverket introduced new demands on U-values for new built houses, regulating how much energy losses the houses were allowed to have. And in October of the same year, a law was introduced that demanded energy performance declarations for all buildings. In 2006, another law mandated that all prospective home buyers had the right to see the energy performance declaration before deciding on whether to buy the house (Swedish Parliament 2006). The energy declarations should be made by independent experts, and the energy declaration certificate contains information about energy performance, cost efficient measurements and reference values for comparison. Both of these new regulations have had a positive effect for heat pumps (Russell et al. 2009).

One regulation that hindered the installation of heat pumps increased the value of a property when a ground-source heat pump was installed, resulting in higher property tax. Therefore, the rules for property taxes were converted into a municipality fee, which would facilitate installations of heat pumps and other renewable energy technologies (Russell et al. 2009).

In 2009, Boverket introduced demands on energy efficiency for buildings using electricity for heating or cooling. This created increased demands for insulating houses as well as for more efficient heat pumps (Boverket 2012). As of 1 January 2012 (BFS 2011:6), the requirements
for all buildings that weren’t using electricity for heating were tightened as well (Boverket 2012).

Since 2008, EU legislation has had a bigger impact on heat pumps in Sweden than national legislation. The previously mentioned EU targets for 2020 – see the Renewable Energy Directive (2009/28/EC) and the Energy Efficiency Directive (2012/27/EU) – require EU member nations to develop a strategy to meet the targets of a 20% increase in energy efficiency, a 20% increase in renewable energy and a 20% reduction in emissions of exhaust gases by 2020, relative to 1990 values (European Parliament 2009, 2012). The efficiency measures taken by the EU should have an indirect positive effect for heat pumps (Karlsson et al. 2013).

On the EU level, two other directives directly affect heat pumps: the Ecodesign directive (2009/125/EC) and Energy Labelling directive (2010/30/EU). Ecodesign is a minimum requirement directive – all products not fulfilling the Ecodesign directives are removed from the market – and the Energy Labelling directive grades the remaining products so that they can be compared with each other (SKVP 2015). By September 2015 all new heat pumps in Sweden and the EU required energy labelling (European Commission, 2013).

Sweden’s system of electricity certificates was introduced in 2003, with the aim of increasing the share of renewable energy in the Swedish energy system (Russell et al. 2009). Though electricity certificates could not be given to heat pumps, the system increased electricity prices slightly, which in turn can be said to have had an indirect effect on the economy of heat pump investments. More significant, perhaps, is that the expansion of renewables with varying power output is creating new structural tensions in the energy system, which heat pump manufacturers have been trying to address over the last few years.

9.3. Heat pump sector developments

The Swedish heat pump industry underwent a period of strong economic growth from 1995 to 2005, mostly due to the rapidly growing domestic market. But after 2005 the Swedish market started to slow down and stagnate and the international market became increasingly important for Swedish heat pump manufacturers seeking to continue to grow.

Annual reports show that from 1996 to 2008, both Nibe and IVT increased their turnover tenfold (from 617 to 5,810 MSEK for Nibe and from 131 to 1,410 MSEK for IVT). Thermia also grew strongly, from 120 MSEK in 1996 to 658 MSEK in 2008. In 2008, CTC’s turnover was 810 MSEK. Since 2008, Nibe has continued its strong growth while the
turnover for all three of the large incumbents with international owners (IVT, Thermia and CTC) actually has decreased slightly.

9.3.1. Market stagnation

After the record year for Swedish heat pump manufacturers in 2006, the market stabilised for a few years and then declined somewhat from 2010 to 2012 before stabilising again in 2013 – see Figure 35. Heat pump sales statistics stopped including air-air pumps from 2012 on because of too-great uncertainties with the sources that the industry association SVEP used for its estimations.

Figure 35: Heat pump sales in Sweden, 2009–2015. Source: SVEP 2013 and SKVP 2017

Contributing factors to the drop in sales from 2010 – apart from the saturated market – according to Nibe (2012) were economic uncertainties related to the financial crises, loan restrictions, low energy prices and low rates of new building construction.

In 2012, the number of installed heat pumps in Sweden reached the one million mark (SVEP 2013; Energimyndigheten 2012b, p. 28; 2013). More than half of all small houses in Sweden now have an installed heat pump. The number of houses with oil burners has decreased drastically. In 2012, only 32,000 houses in Sweden used oil alone or in combination with electricity for heating. In the same year, biofuels supplied 35% and district heating 17% of the heating demand in small houses (Energimyndigheten 2009b, 2013).
Currently there are more than one million operating heat pumps in Sweden (SVEP 2013; Energimyndigheten 2012b, p. 28; 2013). The total number of heat pumps keeps growing, though the market has stabilised.

**9.3.2. The Swedish heat pump sector**

In 2010, SVEP estimated that Swedish firms controlled half of the entire heat pump market in Europe (not including air-air heat pumps) and that the Swedish heat pump industry in whole had a turnover of 9.1 billion SEK (Wenström, 2011). According to Finnish consulting firm Gaia Consulting, the Swedish heat pump industry had a turnover of about 6 billion SEK in 2007 and supplied 8,000 to 10,000 jobs (WWF Finland 2008).

The trend, based on annual reports from Swedish manufacturers, is that the Swedish manufacturers with international ownership (Thermia, IVT and CTC) have slowly decreased in annual turnover over the last few years while Nibe continues to grow steadily. This can partly be explained by the stagnating European market since 2008. According to Nibe (see the company’s annual report for 2012), the continued growth is due to several factors, including increased investments in marketing and product development even during the economic crisis. Nibe has also, according to CEO Gerteric Lindquist, continued to increase its share of the Scandinavian market through ‘good quality, consequent distribution strategy as well as high-performance products’ (Nibe, 2012).

But IVT, Thermia and CTC also claim in their annual reports that they are investing substantially in product development. They expect the export market to increase again during the coming years.

Swedish-based manufacturers have shown increased interest in expanding into other Swedish market segments besides the traditional small-house permanent residences, including holiday cottages, multi-family buildings and commercial buildings (Forsén 2008). The interest in increasing sales of larger-size heat pumps is also seen in the manufacturers’ product offers, with increased product offerings and marketing towards multi-family and commercial buildings; one example is CTC's (2014) launch of a new series of mid-size Eco Air heat pumps in 2008.

Since the ownerships have changed in the internationalisation process, venture capitalists are no longer part of the ownership structure of Swedish heat pump manufacturers.

Along with Nibe, IVT, Thermia and CTC, there are a number of much smaller heat pump manufacturers in Sweden, such as Euronom in Kalmar, Varmitek in Helsingborg, Sfinx Solar in Fjärås, Mecaterm in
Malmö, Octopus Energi in Sösdala and Thorén Värme pumpar in Ramvik. All these smaller companies have in some way chosen a specialisation and diversification strategy, separating them from the offerings of the big four firms.

The business model of Octopus Energi is very much centred on the aesthetics of its outdoor part, an outdoor convector\textsuperscript{50} called the ‘Ice-Stick’, and on the robustness of the model, which is based on direct expansion with only the compressor as a moving part in the whole heat pump system.

Mecaterm markets its heat pumps as ‘Swedish and stainless’ and Varmitek uses double compressors and has the slogan ‘higher heating factor at a higher price’. On their websites, these companies also display interest in reaching markets outside Sweden.\textsuperscript{51}

Thorén Värme pumpar has a long history in the Swedish heat pump industry, having manufactured heat pumps since the 1970s. It is located in the northern part of Sweden\textsuperscript{52} and has targeted customers in colder climates. In 2008, the company was juridically transferred to England, against the will of the Thorén family (Allehanda.se 2008). So the family started a new company called TRN Värme pumpar and continued their manufacturing. A few years later, the company’s turnover has increased fivefold, but compared to the bigger manufacturers the turnover of around 10 million SEK is relatively modest.

\textbf{9.3.3. Increasing exports}

When the Swedish home market showed signs of saturation in the 2000s, Swedish manufacturers increased their focus on international markets (Forsén 2008). As of 2003, Swedish heat pump exports were at 172 million SEK; five years later, the value of exports had risen to 1.2 billion SEK (roughly corresponding to 120 million €).

\textsuperscript{50} Wind convector technology which was under development during the 1980s (see Poppius 1984, pp. 30–31) but never achieved a major breakthrough in the heat pump market. The strength of the convector is that it lacks moveable parts and therefore is both more robust and consumes less energy than a fan. However, the output of the outdoor convector is limited and cannot be controlled.


\textsuperscript{52} On its website (thorenvarmepumpar.se, 2016) the company says that it exports to ‘Svealand, Götaland and other European countries’. Since Svealand and Götaland are in central and southern Sweden, this statement reveals (perhaps with intended humour) the firm’s northern identity.
Figure 36 shows the monthly value of heat pump exports from Sweden to the rest of Europe from 1997 until 2014. The export value was relatively stable until 2005, after which they grew rapidly, peaking in October 2008. In that month, IVT (i.e. Bosch) stated that 50% of its production in Tranås was going for export. After 2008, the effects of the international financial crisis dampened the European heat pump market as a whole and the exports dropped to slightly above 1 billion SEK per year.

Figure 36 also shows how the exports have varied depending on the season, with the greatest export values registered during autumn and the lowest levels in February and March. Also, the increase in exports from 2005 onwards coincides with the acquisition of IVT by Bosch and Thermia by Danfoss.

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53 In October 2008, the peak month, heat pump exports carried a total value of 190 MSEK according to the Statistics Sweden database (SCB – Statistics Sweden 2017).
54 The statistics on heat pump exports come from SCB (2017). From 1997 to 2005, heat pumps were registered under the code KN84186190; from 2006 onwards, the code was KN84186100.
9.3.4. The effects of subsidies on the heat pump sector

The 2006 heat pump subsidy partly explains the spike in sales that occurred during that year (Russell et al. 2009), as seen in Figure 31. Heat pump retailers and buyers registered their orders in 2006 to get the subsidy, but then waited for installation until the installers had time to deal with all the orders submitted in the same period.

Heat pump expert Jan-Erik Nowacki (personal communication, 4 April 2012), also active as a technological expert in the industry association SVEP, considered the subsidies ‘a poison to the industry’. When plans for the subsidy were first announced, heat pump orders stopped coming in – and manufacturers soon found themselves in a state of production over-capacity. When the subsidy then took effect, a flood of orders followed, leading to under-capacity. And when the subsidy ended, orders declined once again and over-capacity returned. Andersson (2005) similarly observed that real estate owners delayed their projects in 2005 to wait for the announced subsidies to begin in 2006.

When the established industry could not meet the sudden increase in demand, the situation provided an opportunity for unserious actors with imported heat pumps that did not meet the high Swedish standards, contributing to the poor reputation of heat pumps in Sweden (Jan-Erik Nowacki, personal communication, 4 April 2012).

The costs for end customers to install air-water and ground-source heat pumps have increased slightly in Sweden over the years, whereas prices have gone down in other countries such as Switzerland (Neij, Kiss and Jakob 2008; Karlsson et al. 2013). What effect the Swedish subsidies have had on this price development is difficult to say. Neij et al. (2008) speculated on why the purchase cost has gone up for Swedish customers while the production cost has decreased. Plausible explanations include the high installation cost, driven by the costs of education and ensuring high competence and expertise among the installers. Another reason could be the high market demand in combination with the fragmented nature of the subsidies.

In France, a national support scheme subsidised heat pump installations for a time, with a tax deduction based on the product cost; this is opposite to the current Swedish form of support, under which only the labour qualifies for a tax deduction. The result, according to Martin Forsén (personal communication, 27 November 2012), is that the price of installations has gone up in Sweden while prices on the technology itself have remained low. In France, the opposite situation prevails, with high product prices and lower labour costs.
9.3.5. International expansion

In 2005, the structure of Swedish heat pump value networks was largely the same as it had been for the previous ten years (see Figure 32 on page 190). The biggest changes concerned which government actors were involved in the industry. NUTEK had been replaced by the Swedish Energy Agency and SP had taken on much of the testing work previously performed (at least in part) by Vattenfall.

The internationalisation process amongst Swedish heat pump manufacturers had been ongoing ever since the 1990s, but when the international companies Bosch and Danfoss acquired IVT and Thermia, respectively, in 2005, these acquisitions marked a distinct switch from a Swedish to an international focus.

In 1998, BergslagsInvest AB had become a shareholder in Thermia (Thermia 1998) and in August 2005 all shares of Thermia were acquired by Danfoss (Thermia 2006). Danfoss is a Danish company concentrating on heating and refrigeration technologies, with its headquarters in southern Denmark. In 2005, IVT Holding and its affiliate IVT Industrier AB were acquired by the Bosch Group (IVT, 2005). IVT officially changed its name in 2008, from IVT Industrier AB to Bosch Thermoteknik AB (Bosch Thermoteknik AB 2009).

As of 2005, CTC was already part of an international consortium, having become part of the Enertech Group in 2001, and Nibe had focused on international expansion since the early 1990s. Of the large Swedish heat pump manufacturers, only Nibe remained under Swedish ownership. But in spite of this foreign ownership, all four large heat pump manufacturers kept their production facilities in Sweden and even increased their production capacity.

A contributing factor to this decision was the high competence concerning heat pump development that has developed in Sweden over the years. According to Nibe CEO Gert-Eric Lindqvist there is an

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55 In 1998, the same year as CTC once again started manufacturing ground-source heat pumps, CTC AB merged with its sister company Bentone AB and legally changed its name to Bentone AB, but with the heat pump production staying under the CTC brand. Bentone AB remained in the Wolseley Group until 2001 when it was sold to Enertech Limited, and CTC changed its name once more to Enertech AB. In charge of the Enertech Group was the Englishman Roger Hancox, who owns the holding company Inter Rested Ltd., which in turn owns 100% of the Enertech Group (Sunday Times 2009; Osby Parca 2015). Under Hancox, the production switched focus from traditional soldering to modern heat pump production. The production of oil burners has been phased out and the main production focus is on heat pumps and solid fuel boilers (CTC 2015).
advantage in having production and development in close relation to each other (Weibul 2014).

The location of production in Sweden can also partly be explained by the fact that Sweden is still – in absolute as well as relative figures – the biggest national market for ground-source heat pumps. However, of the 110,000 ground-source pumps sold in Europe in 2012 (EHPA 2012), only 25,000 were sold in Sweden (SVEP 2013). So even though Sweden still is the single largest market for ground-source heat pumps in Europe, the rest of the continent constitutes more than three-quarters of the total market.

According to Martin Forsén (personal communication, 27 November 2012), the Swedish market has some of the highest entry barriers in Europe. One way to gain access to the Swedish market is to do as Bosch or Danfoss did, acquiring an existing established Swedish manufacturer and brand.

### 9.3.6. Two different internationalisation strategies

Nibe and IVT represent two different approaches to internationalisation. Nibe chose to expand internationally through the expansion of many small to medium-size companies. As stated in the previous chapter, in 1994 Nibe set a target of growing by 20% annually (Nibe 2004). It completed a series of acquisitions from 1995 onwards, starting in Poland and Finland as well as in Sweden. It continued to expand through acquisitions in Denmark and Norway (to cover the whole Scandinavian market); in central and southern Europe (Italy, Czech Republic, Germany, Netherlands, Spain, France, Switzerland); and in Russia and the USA as well (Nibe 1997, 2004, 2010).

IVT instead chose first to partner with and then to merge with one of the largest corporations in the international market, Bosch. IVT had sold IVT-manufactured heat pumps under the Bosch brand name since 2003 in order to access Bosch’s distribution channels (IVT, 2004). Being acquired by Bosch allowed full access to all these distribution channels (IVT 2005), and this was one key motivation for Lars Kastengren’s (personal communication, 5 February 2015) decision to sell the company to Bosch in 2005.

Prior to the Bosch collaboration, IVT had tried to expand internationally through acquisitions as well. Three to four years after the NUTEK competition, after IVT had replenished its bank accounts with cash, IVT acquired the Swedish company Elektro Standard in Katrineholm as well as a company in Zürich, Switzerland. However, the Zürich-based company never became a success for IVT, according to Kastengren
(personal communication, 5 February 2015), and the company was sold in 2005.

IVT's acquisition of Elektro Standard was a way to tap into the exhaust air heat pump segment, but it also led to IVT's first contacts with the German market. Elektro Standard had been a supplier of heat pumps to Stiebel Eltron in Germany, which IVT continued with under the Stiebel brand. At the time, the German market was dominated by four companies: Stiebel Eltron, Vaillant, Viessmann and Bosch. After a few years, the collaboration between IVT and Stiebel Eltron ceased, as Stiebel Eltron wanted to start its own production instead of retailing for IVT. Lars Kastengren then initiated a conversation with Vaillant. But Vaillant sent the same signals as Stiebel had done, saying that it was not interested in retailing for IVT, so if it acquired IVT it would move production to Germany. Kastengren then approached Bosch, with which he established a better relationship, and IVT started to manufacture products with the Bosch brand for retail in Germany (personal communication, 5 February 2015).

Shortly before the acquisition by Bosch, the venture capitalist company Företagskapital, now part of the company 3i, wanted to sell its approximately 10% holding of shares in IVT, which it had acquired in 1995. The exit was financed partly with the help of Amrobank. Shortly thereafter, Kastengren sold all shares to Bosch, placing the company under an ownership better equipped than he was to help IVT continue to grow (personal communication, 5 February 2015).

Bosch described its acquisition of IVT as a step in its effort to develop energy-efficient products with a special focus on renewable energy (Bosch Thermoteknik AB 2016).

9.3.7. Heat pump production remains in Sweden

Since the Swedish heat pump manufacturers became part of international corporations the manufacturing activity has not, as one might have expected, been off-shored to a nation with lower labour costs. Instead, quite the opposite has happened.

In 2009, Bosch opened an education centre in Tranås and concentrated its production in Tranås (terminating production in Katrineholm) in a 'long-term investment’ (Bosch Thermoteknik AB 2009, 2010; IVT 2014).

In 2012, Danfoss announced that it would move all its production of heat pumps from five different sites in Europe to Thermia and Arvika (Thermia Värmpumpar, 2012). Most of Danfoss’ heat pumps had previously been produced in a Polish factory, which was shut down as
production moved to Sweden. According to Thermia CEO Magnus Glavmo, the move of production to Arvika depended on Thermia’s work with the Lean concept, which had increased productivity by 30% and reduced production time for each unit by half.

The CEO of Nibe has stated that he is passionate to develop the company and prove to all the know-it-alls who move industrial production to countries with low labour costs that it is possible to have cost-efficient production in Sweden (Elofsson 2015).

Other reasons for moving production to Sweden were the strong ties between production and development units and the fact that product development in the diversified heat pump market was still quite strong. Moreover, the Swedish and Scandinavian markets are still amongst the biggest in Europe (and the largest single ground-source pump market), and various benefits result from having production close to the customers.

9.3.8. Increasing district heating conflict

In recent years, both the Swedish heat pump market and expansion of the district heating grid have stagnated. However, if we are to believe heat pump expert Thomas Hallén (personal communication, 10 August 2016), district heating in Sweden is likely to face a period of shrinking, as heat pumps are already a cheaper alternative than district heating and the economic benefits of heat pumps are continuously improving. District heating, in Hallén’s predictions, will probably remain primarily in densely populated areas.

In the 1980s, over 100 large heat pumps were installed in district heating facilities across Sweden. At the time, most Swedish houses were using oil, biofuels, or electric boilers for heating. Heat pumps were not a major technological threat to district heating. As the new millennium began, the district heating industry association started to see things differently, as heat pumps became more and more of a threat to the continuous expansion of district heating (see e.g. Sköldberg et al. 2006; Barth et al. 2014; RO 2012).

Over the last few years, the competition between heat pumps and district heating alternatives have increased both in the detached small house segment and in larger industrial buildings and multi-family houses. The heat pump market has become increasingly saturated at the same time as the district heating expansion has stagnated (Bergman 2014, p. 101). Part of the reason for the stagnation of district heating is that newly built houses have greater amounts of insulation than existing houses, but the competition from heat pumps is also a factor.
Previously, only customers using oil or electric heating have switched to heat pumps, but there are more and more examples of customers connected to district heating who have chosen to disconnect from the grid and invest in heat pumps instead (see e.g. Akademiska hus 2013; Åslund 2011). The reason is often techno-economic (Thomas Hallén, personal communication, 10 August 2016), but another change driver may be that customers perceive the district heating monopoly as a concern and want to achieve increased autonomy through heat pumps (Bulut et al. 2014).

Some municipalities have been struggling to protect their district heating companies from heat pump competition, and their attempts have ended up in court several times. In 2013, the Swedish competition authority Konkurrensverket fined the municipality of Växjö 5 million SEK for requiring that customers who bought land in the municipality for building new houses also had to connect to the district heating grid (Konkurrensverket 2013). This decision was then appealed to a higher court (Stockholms tingsrätt) by Växjö, which ended in a ruling in favour of the municipality, allowing it to lock future homeowners into the district heating grid (Barth 2016).

Another example is the complaint filed by the Swedish heat pump association SVEP against the municipal energy company Ulricehamn Energi. Ulricehamn Energi had marketed district heating as 15 times better for the environment than heat pumps. For this statement, Ulricehamn Energi was held responsible for spreading misleading information (Reklamombudsmannens opinionsnämnd 2012).

9.3.9. Continued academic heat pump research

Academic research on heat pumps in Sweden has largely focused on system performance, substitution of refrigerants, and incremental improvements of the main heat pump components. KTH has remained a stronghold for heat pump research in Sweden and internationally. According to professor Björn Palm (personal communication, 25 January 2013), in 2012 there were about 10 research divisions and institutes in the world focusing on heat pumps, including research units in Padua, Italy and Valencia, Spain, as well as the Division of Applied Thermodynamics at KTH.

KTH has been part of all heat pump and refrigeration research programmes initiated by the Swedish Energy Agency since 1994. These research programmes have involved academia and government organisations as well as the Swedish heat pump industry.
In 2005, the first ‘Effsys’ (efficient systems) programme took place, later succeeded by ‘Effsys2: More efficient refrigeration and heat pump systems’, which ran until 2010 with a budget of 70 million SEK (Granryd and Björk 2010). Its successor was the programme ‘Effsys+: Resource-efficient refrigeration and heat pump systems’, from 2010 to 2014 (Energimyndigheten 2010).

Since the 1990s, academic research on refrigerants has shifted from reducing ozone hazards to the problem of greenhouse gases. Many HFC refrigerants that replaced the ozone-hazardous freons, such as R-134a, are powerful greenhouse gases (Martin Forsén, personal communication, 25 March 2013). As a consequence of the increased awareness of this issue, academic interest and research in ‘natural refrigerants’, such as ammonia (NH\textsubscript{3}), carbon dioxide (CO\textsubscript{2}), propane (C\textsubscript{3}H\textsubscript{8}) and isobutane (C\textsubscript{4}H\textsubscript{10}), has increased (Björk et al. 2013, pp. 17–18), and the heat pump researchers at KTH have adjusted their profiles to emphasise this research (Björn Palm, personal communication, 25 January 2013). In some ways, the challenges related to replacing current refrigerants are even greater now than when the freons were eliminated in the 1980s (Thomas Hallén, personal communication, 10 August 2016).

**9.4. The internationalisation of Swedish heat pump value network structures**

The formation of value network structures depends on the time and the context in which they are formed and configured. This thesis has shown that there are no optimal value network structures, but that the value network structure is typically adapted to the current business context when it is formed. After its formation, a value network can become relatively stable in structure, even though the context of the value network changes. This ‘value network structure path dependence’, or stability in a changing situation, can pose problems.

IVT and Thermia had focused at an early point on developing their own networks of dedicated installers and retailers. To establish a growing heat pump market, it had been important for the manufacturers to establish trust in heat pump technology among potential customers. They contributed to gaining this trust through forward integration with dedicated retailers and installers and by taking responsibility for the installation and service of the heat pump units sold. This commitment forced the manufacturers to educate their retailers and installers to make sure that they would carry out sound installations. As previously described, this model also sought to skip the wholesaler step.
Nibe, which entered the ground-source heat pump market at a later stage, has instead chosen to continue as previously and sell its heat pumps through wholesalers – without taking responsibility for the installations. This approach has the advantages that Nibe does not compete with its direct customers and does not limit its offerings to only a portion of all the available retailers and installers. It also means that Nibe has not needed to spend money on educating retailers and installers. Martin Forsén, who previously worked at the industry association SVEP but was later an employee of Nibe, claims that selling through wholesalers is one of Nibe's main advantages (personal communication, 27 November 2012).

But Nibe's strategy seems to be working better in Sweden – where the knowledge level among installers is generally high – than in other nations where heat pumps are still a new technology to many HVAC installers. In some reported cases, discontented homeowners have chosen to throw out their new heat pumps from Nibe and go back to gas-fired heating (BBC 2015). According to Nibe, the houses where these heat pumps have been installed were too poorly insulated for their exhaust air heat pumps to work. A competent installer would have noticed this issue in advance and avoided both the problem for the customers and the damage to the brand.

Since Bosch acquired IVT and Danfoss acquired Thermia, these two companies have once again started to sell their products through wholesalers. That has caused quite a stir among the dedicated retailers and installers associated with IVT and Thermia, who are forced to sell their IVT or Thermia heat pump at a high cost whereas competing retailers and installers can buy the same heat pump product, made in the same Swedish factory, but under a different brand (Bosch or Danfoss) and at a much lower price (Martin Forsén, personal communication, 27 November 2012). More recently, Bosch has stated that part of its strategy in Sweden is to create a ‘network of the best and most competitive subcontractors’ (IVT 2015b).

9.5. Summing up the dynamics in the fifth phase of the heat pump transition

In this phase, the Swedish heat pump development block was in a balanced situation and began to migrate to other markets. As Dahmén put it, ‘a “development block” ends up in a stable balance when the plant is capable of shedding seeds’ (1991, p. 139).

The other markets to which the existing heat pump value networks expanded included both foreign markets (e.g. the untapped UK market)
and new markets in Sweden (e.g. commercial buildings and multi-family houses). The latter has contributed to increased competition between heat pumps and district heating in Sweden.

The reason for the expansion into new markets is largely related to the Swedish domestic market being increasingly saturated. Both Thermia’s and IVT’s previous owners seem to have believed that an owner with an existing international network of suppliers of their products would be a better fit for an international expansion. While Thermia and IVT continued to develop along parallel tracks, Nibe expanded internationally through acquiring companies (instead of being acquired by an international corporation).

In the UK – an underdeveloped heat pump market with big potential – there have been many reports of problems with heat pumps. The problems have been almost identical to those reported in Sweden in the late 1970s and early 1980s: poor heat pump performance due to poor installations and system adaptations. When Nibe first joined the heat pump sector, it started with exhaust air heat pumps, which was a highly regulated market in which the home builders needed to take responsibility for the installations (so Nibe never had to). Years later, when Nibe entered the Swedish ground-source and air-water heat pump market segments it didn’t need dedicated installers because competence had reached such a generally high level amongst Swedish heat pump installers. In this period, as Nibe entered foreign markets in countries with lower competence levels amongst installers, it ended up with the same problems as those faced by Swedish manufacturers in the 1970s and 1980s. That is why the business logic that Nibe has followed since day one now presents new challenges as the company seeks to enter international markets such as the UK.

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This situation can illustrate the importance of taking local conditions into account in the transfer process of large technical systems, as described by Hughes (1983).
10. An outlook for heat pumps in Sweden and Europe

Over the last decade, expectations for heat pump technology have increased. Similar to when the interest in heat pumps grew after the 1970s oil crises, the threat of climate change now contributes to an increased international interest in heat pumps once again.

10.1. Environmental outlook

The high efficiency level of heat pumps provides strong potential to mitigate greenhouse gas emissions in building and service sectors around the world. The European Commission (2016) recently put heat pumps at the centre of a suggested EU strategy on heating and cooling, with the aim of replacing direct electric heaters and oil and gas boilers in Europe.

In recent years, the heat pump has received more and more attention as a potential key technology to achieve Europe’s environmental and sustainability targets (European Parliament, 2009; European Commission, 2016a) and decrease the total global emission of greenhouse gases (IEA 2008, 2013; IPCC-WG3 2008, 2014).

Buildings account for 36% of total CO₂ emissions in the EU (European Commission, 2016b). Improvements in this sector can thus make a major contribution towards reaching the greenhouse gas emission target set by the European Parliament (2009).

Heat pump technology’s potential to decrease dependence on fossil fuels in Europe’s building and service sectors has increased the political support for heat pumps in Europe (see e.g. Ofgem 2014). To meet the 2°C target (i.e. preventing average global temperature from increasing by more than 2°C), the International Energy Agency (2013) envisions heat pumps supplying 10% of all heating in the OECD region by 2020 and 30% by 2050. The IEA report claims that heat pumps are critical in creating thermal, low-carbon comfort in buildings. In a report by the IPCC (2008) the theoretical potential for decreased CO₂ emissions by using heat pumps is estimated at 1.2 billion tons of CO₂ per year, or 6% of the world’s total global CO₂ emissions.
10.2. Technological outlook

The final report from the Effsys2 research programme in 2010 noted that the potential performance development of heat pumps is still large. It lists the four most pressing points on how to further increase the efficiency and performance of heat pumps (Granryd & Björk 2010):

- Design systems so that small temperature increases are required
- Use efficient heat exchangers with the minimum possible temperature difference
- Use efficient electric motors, compressors, pumps and fans
- Design systems and steering so that parasite losses are avoided

Other recent heat pump improvements include the previously mentioned speed control of the compressor and improved heat exchange performance in boreholes (Björk et al. 2013).

In principle, these points are the same as those emphasised in the 1970s, 1980s, and 1990s, i.e. increase the individual performance of all components as well as increasing the system performance of the interaction of all components.

Heat pump expert Jan-Erik Nowacki (personal communication, 5 February 2013) calculated that the efficiency of small heat pumps has improved by around 1.5% each year since 1975 (see also Granryd 2011). There are no indications that the performance of heat pumps will not continue to develop.

The current era of computerisation and digitalisation has increased the practical possibility of increasing system performance of heat pumps even further, which can be noted in the market upswing for air-source heat pumps that can be steered more efficiently than before (Granryd 2010). Computerisation and digitalisation also offers new opportunities at an energy system level.

10.3. Potential heat pump complementarities

Heat pumps can help to balance variable supply from renewable energy sources through heat storage, depending on the capacity of available heat storage (size of water heaters, the thermal mass of the house, etc.). As the share of solar and wind power continues to grow, the European energy system also becomes increasingly favourable for heat pumps. Moreover, as heat pumps become increasingly efficient, their economic and environmental benefits compared to other alternatives increase.

Although there is some tension between district heating and heat pumps in Sweden, the situation in many parts of Europe – where both heat
pumps and district heating are in their early developmental stages – is quite different. For example, in Germany, the Swedish state-owned utility Vattenfall is experimenting with heat pumps as a means to store abundant electricity from renewable energy sources by heating water in the district heating grid, in a ‘smart grid’ set-up.

The positive effects of online steering of heat pumps were demonstrated in a field test conducted in Göteborg during 2007–2009. The results showed that customers who had their heat pumps steered by energy companies, to reduce the output when spot prices of electricity were high, barely noticed any difference in comfort. The test showed the theoretical possibility of letting heat pumps run during early afternoon when prices were low and storing the heat in the house so as to use less power at night when the outside air is cooler and the spot prices are higher (Fritz et al. 2009; Adsten et al. 2009).

Vattenfall’s tests of heat pumps within district heating grids have taken place under the name ‘Virtual Heat and Power Plant’ (VHPP). This VHPP is a cluster of decentralised renewable energy production and energy storages. For example, when there is an abundance of solar and wind energy, heat pumps can be used to store the energy in hot water storage sites in district heating grids, which can be used when the wind calms down or it becomes cloudy or dark (Vattenfall Europe Wärme 2012; Vattenfall 2011). Vattenfall has partnered with German heat pump manufacturer Stiebel Eltron in this project, and it has also developed an industrial standard for heat pumps that are ready to connect to a virtual heat and power plant called ‘VHP ready’. Currently Stiebel Eltron is the only heat pump manufacturer that has been awarded this industry standard.

A more common label, which has also developed recently, is the ‘SG-Ready’ label, which targets homeowners wanting to connect their heat pumps to the Internet and steer their operational time depending on electricity prices as well as on heating demand. At the ISH exhibition – Europe’s biggest exhibition for heat pumps – for 2013, almost all heat pump manufacturers had an ‘SG-Ready’ logo on their products (Martin Forsén, personal communication, 27 November 2012).

Another partnership between an energy company and a heat pump manufacturer in Sweden involves the energy company Skellefteå Kraft and Nibe (ERA 2015). In this partnership, a user of Nibe’s ‘Smart Price Adaptation’ gets access to Skellefteå Kraft’s predicted electricity prices for the coming 24 hours so that the Nibe heat pump can be set to run when the electricity cost is as low as possible.
These are just some examples of how heat pump technology is starting to align with other complementarities as the energy system is, once again, under increased transformation pressure.

10.4. Is time in favour of heat pumps?

Two of the most comprehensive international developments affecting the heat pump sector are the increased threat of climate change and the exponential growth of production from renewable energy sources, which is doubling roughly every five years (Rockström 2017).

Both of these changes offer new opportunities for heat pump technology. One of the major drawbacks for heat pumps in many European markets is the electricity mix, which is often still heavily based on fossil fuels (see the previous discussion on heat pumps and marginal electricity in this chapter). An increased level of renewable energy technologies (RETs) thus offers positive benefits from heat pumps. And the benefits go both ways, as heat pumps can actually be used to dampen some of the negative effects of increased renewable energy in the electricity mix.

The institutional and infrastructural setting is not yet aligned with heat pump technology in many emerging markets, and the joint heat pump–RET ventures between energy companies and heat pump manufacturers have not yet had a big impact on the European markets. But the development potential is there, and it may become realised through a series of structural tensions. As solar power and wind power increase, the tensions on the grid will call for complementarities to balance production, and heating water is currently one of the most cost-efficient ways to do so. This also opens up a window of opportunity for district heating power plants, which can utilise their big water storage facilities for short- to mid-term storage of abundant energy from solar and wind. Perhaps we will even see a renaissance for large heat pumps in district heating grids.

Tore Brandin’s statement in 1958 could be repeated now, almost 60 years later: time is working in favour of the heat pump.
11. Revisiting the study purpose and research questions

The purpose of this thesis has been to explore the early heat pump transition in Sweden and how Swedish industry has contributed to this transition.

Just as Denmark’s wind power industry has been deeply involved with the strong growth of that energy source in Denmark (IRENA-GWEC 2013), the Swedish heat pump industry has been tightly linked to the development of the Swedish heat pump market. Using the concepts of value networks, coopetition, and complementarities, an overall description of the interdependent co-evolutionary development of the Swedish heat pump sector and the Swedish heat pump energy system in this transition is given under heading 11.1 below.

After this recap of the ‘co-evolutionary dynamics’ in the Swedish heat pump transition, the lessons from this thesis relating to previous studies and to energy system and policy perspectives on the early Swedish heat pump transition are discussed under heading 11.2. Many factors and conditions have worked in favour of heat pumps in Sweden, starting with the country’s natural conditions – its cold climate and geological conditions (in most of Sweden) that are suitable for geothermal heat pumps. Policy and energy system developments have also benefitted heat pumps in many ways. Electricity has been relatively affordable with low levels of greenhouse gas emissions per kilowatt-hour due to large-scale hydro and nuclear power. The tax on carbon emissions has kept fossil fuel prices relatively high, and the 1980 building regulation formed a long-term market niche for exhaust air heat pumps.

However, this thesis has also shown that these conditions are not enough to explain the early and comprehensive market expansion and socio-technical transition towards heat pumps in Sweden. Two other aspects that this thesis has highlighted are the importance of the industrial context for the Swedish heat pump transition and the perseverance of the Swedish heat pump industry from the mid-1980s onwards.

First, the industrial context helps to explain the rapid formation of an advocacy coalition for heat pumps and the existing competence in Swedish industry that made it possible to adapt and develop heat pump technology and business models to Swedish conditions. These aspects are discussed more in detail under heading 11.3.

Second, the fact that the heat pump companies didn’t perish during a period of negative transformation pressure was an important
precondition for the establishment of a complete development block by the mid-1990s. The interest in heat pumps did not die out as the need for reducing oil dependence declined. Instead, long-term and tenacious efforts by a wide array of heat pump proponents – who had remained in the heat pump arena in spite of the dwindling market and gloomy outlook after the reverse oil crisis – contributed over time to the wide acceptance of heat pumps in Sweden. The industry’s perseverance has depended on several different conditions and factors, such as long-term regulations, support from cross-network actors (e.g. technical universities and Vattenfall), alignment of energy system complementarities (e.g. heat pumps and district heating), reconfiguration of value networks, and balanced heat pump sector coopetition dynamics. These aspects are partly discussed under heading 11.2 but primarily under heading 11.4.

### 11.1. A summary of the interdependent development of the Swedish heat pump sector and the Swedish energy system during the heat pump transition

This thesis has shown how closely coupled industrial development has been to the energy system’s transition towards heat pumps in Sweden. I have described how the Swedish heat pump sector developed interdependently, or co-evolved, with the Swedish energy system in the transition away from oil and electric heaters towards heat pumps. These co-evolutionary dynamics could be summarized as follows.

The negative transformation pressure on the Swedish energy system in the late 1970s forced a search for heating alternatives to oil. ‘Oil incumbents’, such as manufacturers of oil boilers, were as much part of this search as any other actor. The involvement of a diversity of actors and the intense coopetition dynamics between newly formed heat pump value networks following the 1970s oil crisis contributed to creating alignment between heat pump–related complementarities in the early stages of the transition. Even though many factors contributed to the Swedish recession (Schön 2012), oil dependence was seen as the number-one cause of the economic crisis. Virtually no one favoured retaining a high level of oil dependence in Sweden in the late 1970s. The industrial context helped to guide search heuristics towards heat pump technology, and a coalition formed quickly in support of heat pump technology.

In the 1970s, both knowledge development and knowledge diffusion concerning heat pumps increased amongst industry, academia and
government organisations. After the second oil crisis, the pressure on the Swedish energy system increased even further, intensifying the positive pressure on this now-established technology. At this time, both the ground-source and air-air heat pump technologies were perceived as mature – which in hindsight can be seen as an incorrect perception. The demands from both policy makers and early customers exceeded what the heat pump industry could deliver in quality. In spite of the increasing problems of low quality heat pumps, the negative pressure on the energy system kept exerting positive pressure on the heat pump technology.

When the negative pressure on the energy system was relieved in the mid-1980s, demand for heat pumps collapsed. Several heat pump value networks, of different structures and business logics, had developed during the period of the energy system’s transformation pressure. When the heat pump demand collapsed, the immature heat pump industry went into a state of crisis, leaving only a few value networks remaining. But the period from the first oil crisis to the reverse oil crisis had created structural changes in the energy system and heating industry that remained even after the transformation pressure was alleviated. These changes included changes in regulations and heuristics, strong complementarity connections between district heating and heat pumps, formation of a heat pump interest organisation, positive coopetitive relations between different value networks, and a positive path dependence on heat pump research at technical institutes. All these changes contributed to the perseverance of heat pump value networks in the following years.

But the industry could not persevere without restructuring and maturing during the period after the reverse oil crisis. Therefore, the value networks’ ability to adapt and reconfigure their business models and value networks was essential to the industry’s survival. These renewal processes and reconfigurations in external value networks sometimes required new ownership. Largely due to developments outside the heat pump industry, the efficiency, performance and reliability of heat pump technology also matured during the ten-year period following the reverse oil crisis.

In the mid-1990s, the potential latent in the heat pump development block started to become realised as energy system complementarities came into place and general trust in heat pump technology was regained with help from policy support. Because the value networks in the Swedish heat pump sector had retained competencies and resources relating to production and service of heat pumps, the sector could still influence and respond to increased demand. In the following ten years, the heat pump market grew with remarkable speed, this time not
because of negative transformation pressure on the energy system but because the heat pump development block was in a complete stage.

In the 2000s, an internationalisation process began for Swedish heat pump companies, featuring the changes in ownership from Swedish to foreign owners of both Thermia and IVT in 2005. The early Swedish market development and growth of the Swedish heat pump industry had given Swedish companies a comparative advantage over their European competitors, which contributed to the high production competence in Sweden. As a result, the manufacturing of heat pumps was concentrated in Swedish manufacturing facilities even after the industry became internationalised around 2005.

During the last decade, the heat pump market reached maturity. The sector’s value networks have shifted their relationship with district heating from cooperation to competition for the same market segments in more densely populated urban areas. But in Sweden, as in Europe, there are now signs of new complementarities being formed in the energy area amongst solar power, wind power, heat pumps, district heating, and storage technologies. When Sweden’s heat pump industry was aligned with the Swedish energy system, the energy system complementarities were missing in many fossil-dependent European electricity systems, e.g. Germany. But the rapid growth of renewables is now leading to new tensions and possibilities in the heating sector in these European nations, as well as in other areas such as North America. The world has yet to follow Sweden’s footsteps in undergoing a large-scale transition towards heat pumps.

11.2. Reviewing policy and energy system perspectives on the Swedish heat pump transition

The results of this thesis make it possible to extend and, in some cases, add nuances to the discussions in previous studies, which have presented primarily energy system and policy-related perspectives on the Swedish heat pump transition.

Although industry has played an important part in the Swedish heat pump transition, this is by no means the only perspective that needs to be considered. For example, Germany also had a relatively strong domestic heat pump manufacturing industry that had survived the reverse oil crisis and that allied with electric utilities to promote heat pumps in the 1990s (Zimny, Michalak and Szczotka 2015). But the German heat pump market developed much more slowly and later than the Swedish market. The contrast proves that other factors beyond the
industrial context and development must be considered to understand the Swedish heat pump transition, such as policy and energy system developments regarding heat pumps. To study one part without including another is to conduct an incomplete study of the Swedish heat pump transition.

In this section, I will review the previously discussed policy perspectives and energy system perspectives on why the Swedish heat pump transition occurred so early.

11.2.1. Policy perspectives

Policy support for heat pumps has been largely uncoordinated during the whole transition period, from the early 1970s until today. That is not surprising, considering the changes in context and political constellations that have transpired over 45 years. What is more surprising is that policy support aimed directly at heat pumps has not necessarily had the biggest positive impact on the transition. Two examples of direct government support that have had ambiguous results are direct subsidies and procurement competitions.

It is difficult, if not impossible, to measure the effect of the procurement competition support schemes on long-term heat pump market demand, e.g. to determine to what extent the 1993–1995 NUTEK procurement competition contributed to the increase in market demand during the second half of the 1990s. The NUTEK competition is often routinely pointed to as the reason for increased market demand during the 1990s (cf. Nilsson et al. 2005), but since the competition coincided with increased prices on fuel oil (see Figure 6 on page 40) and advancements in technological complementarities (e.g. introduction of the scroll compressor) and increased standardisation, the long-term effects are difficult to discern. The two heat pump types that won the procurement competition in 1995 also started to malfunction en masse a year after the competition had ended. And the main reason for these malfunctions was the last-minute addition to the NUTEK competition of a requirement to use new and untested refrigerants – following the Swedish government’s decision to ban chlorofluorocarbons ahead of the Montreal Protocol’s time plan – without allowing long enough time to test these new refrigerants. The sum of the positive effects from the NUTEK competition may outweigh the negative ones, but there is good reason for scepticism with regard to giving this competition credit for the realisation of the Swedish heat pump transition.

It could even be argued that the NUTEK competition serves as a classic example of poor policy coordination. As the banned refrigerants were tightly integrated in current heat pump products and as Swedish heat
pump manufacturers were dependent on partners and suppliers outside Sweden that were not bound by the legislation, the sudden decision to ban current refrigerants in the middle of the competition became a major issue for the manufacturers. The competitors could have been given increased support to meet this challenge and longer time for testing the new products, thus perhaps averting the epidemic of malfunctions eventually suffered by both winning entrants.

The policy support mechanism of financial subsidies aimed at heat pumps has also had both positive and negative effects on the transition. The financial subsidy schemes for heat pumps (as well as for other technologies) have been characterised by their short-term nature and by lack of coordination at the government level. One would not expect long-term policy coordination in the frequently changing political realm, but the lack of short-term coordination is more surprising. From a manufacturing point-of-view, the on-and-off short-term subsidies have caused forward ordering followed by periods of low demand. Such conditions make it difficult for manufacturers to match their production capacity to the volatile market demand. It is also possible to speculate, as Neij et al. (2008) have done, that the Swedish subsidies have contributed to the slightly increasing (rather than decreasing) cost of installing heat pumps for Swedish customers.

Both of these forms of governmental support – financial subsidies and procurement competitions – have in some ways been outright counterproductive from a heat pump supplier’s perspective, increasing the volatility of market demand and making it possible for untested and unreliable products to enter the market (when established actors have not been able to meet the sudden increase in demand). This tendency has in turn contributed to other problems for heat pump suppliers, namely distrust and poor rumours about heat pumps among potential customers.

These bad rumours have had to be countered with increased quality assurance measures, which were not commissioned at the government level but did involve government authorities such as SP, Konsumentverket, etc. They have also largely involved key industry stakeholders, and a large part of the responsibility for quality assurance has been shouldered by the heat pump manufacturers themselves.

Nilsson et al. (2005) argues that the Swedish heat pump transition can be seen as a case in which a ‘winner’ was selected at an early stage, which would counteract the generally strong arguments against picking winners in transition management. But although heat pump technology was indeed picked as a winner at an early stage, it was not selected by the
government itself but by the state-owned energy company Vattenfall (which had its own agenda). Already in the 1970s, Vattenfall decided to focus substantial effort and resources on heat pumps instead of solar technologies. This may in turn have influenced the increased focus on heat pumps that becomes apparent when one compares the Swedish government’s 1975 and 1979 energy plans. But the Swedish government did not explicitly pick heat pumps as a winner, and thus it can be argued that this transition should not be described as a clear case of pick-the-winner.

Related to this issue, we can also note that some of the most important policy decisions that have favoured heat pumps were not of a ‘pick-the-winner’ character. Carbon taxation is one example of an indirect policy measure that had a positive effect on heat pump market development. Another even more evident example is the 1980 building regulation, which specifically targeted energy efficiency and energy recovery in newly built houses. The importance of this regulation was highlighted by Kaijser et al. (1988) but has not received sufficient attention in later studies. The 1980 building regulation was originally aimed at decreasing moist and mould more than at supporting heat pumps, but one result of the regulation was that exhaust air heat pumps made a quick entrance into the market for newly built houses. The exhaust air heat pumps quickly became much more stable and standardised in design and function compared to other heat pump types, possibly because of the relatively few customers (constructors of single-family houses) and relatively few manufacturers of exhaust air heat pumps (Kaijser et al. 1988, p. 88). The R&D and learning activities, supported by the Swedish government (mainly through its corporate agency Vattenfall), likely influenced the quick deployment of exhaust air pumps in 1981 and 1982 by companies that had not manufactured heat pumps at all prior to 1980.57

Nilsson et al. (2005) proposes that the perseverance of key actors was an important contributor to the Swedish heat pump transition. The unforeseen consequences of the 1980 building regulation were one important factor that made this perseverance possible. The demand on the relatively homogeneous exhaust air heat pump market has to a large extent been decoupled from the price of fuel oil, and sales have instead tended to follow the housing market’s trajectory instead. As a result, the

57 It is possible to say that Vattenfall’s choice of heat pumps as a ‘winner’ laid the groundwork for the changes in building regulations, which resulted in heat pumps becoming the winner in a new market segment where it was not ‘picked’.
exhaust air heat pump segment, being independent of both oil prices and subsidies, did not suffer from the mid-1980s reverse oil crisis. The exhaust air heat pump brought stability to the Swedish sector when other segments were under strong negative transformation pressure – thereby helping to keep heat pump technology alive in the minds of both customers and policy makers.

11.2.2. Energy system perspectives

Heat pumps have become established in the Swedish energy system without acting in a system-disturbing way relative to either the Swedish electrical energy or heat energy systems. Heat pumps have not directly required or forced any large-scale investments in the electricity grid. And, in spite of a recent increase in conflicts, heat pumps contributed to strengthening the position of district heating in Sweden during the 1980s.

The oil crises in the 1970s made a big impression not only on the Swedish energy system but on those in many other countries as well. Other European governments that invested in and supported heat pumps after the second oil crisis, such as Austria, Switzerland and Germany, did so to mitigate their oil dependence. But none exceeded Sweden’s high level of oil dependence. Reducing the amount of oil in the heating sector was an important target, and the forthcoming expansion of electricity production offered a promising opportunity for concrete success.

The development of hydro power plants followed by the expansion of nuclear power in Sweden in the 1950s–1970s set the stage for the processes of mitigating oil consumption (for both heating and electricity production) in the 1980s and onwards. The abundant electricity production from Swedish hydro and nuclear power plants made heating with electricity a competitive option to oil and other alternatives, even in district heating systems with their grid losses.

As Granryd (2011) points out, from a system perspective district heating and heat pumps have strong synergies. When combined heat and power plants in district heating systems fire up to respond to the heating demand in the grid, then the plants also produce electricity, which can run heat pumps that heat buildings outside the densely populated areas that the district heating grid covers. The same logic is not applicable when district heating systems use large heat pumps to supply heating in their grids. But in this case, there are other synergies. As Kaijser et al. (1988) pointed out, the development of heat pumps contributed to strengthening the position of district heating in the Swedish energy system, e.g. by facilitating the replacement of oil in the heating plants.
Conversely, when district heating companies chose to install heat pumps in their district heating systems, they bestowed credibility on heat pump technology. Because of their relatively large investments in heat pumps, the district heating companies were locked in to using them, as long as they were profitable to operate. Many of the large heat pumps installed in the 1980s are still in operation in district heating grids around Sweden today.

Since the 1980s, electricity production from wind power has increased substantially, now supplying roughly one tenth of the Swedish electricity demand. More recently, the development of solar power has also begun to increase strongly, although as of 2017 it is still quite small in absolute figures. The tensions that arise from the increase of variable electricity production currently seem to be in favour of heat pumps, which can utilise abundant electricity from renewables – as they once used the availability of abundant electricity from nuclear power to enter the Swedish market – not only to supply heat but also to store it for later use. Newly formed partnerships between energy companies and heat pump manufacturers indicate an increase in the integration of heat pumps in energy systems to complement the increasing electricity production from wind and solar sources.

11.3. How did the industrial context contribute to the early Swedish heat pump transition?

The energy system factors and policy factors described in this chapter have been foundational to the Swedish heat pump transition, but to understand how the Swedish heat pump market became one of Europe’s earliest and largest, it is also important to consider the industrial context.

Many of the companies that first engaged in the heat pump arena were incumbents in other areas, and so they brought with them competencies and contacts from their previous activities. The existing heat pump–related competence in Sweden in the 1970s contributed to the formation of an early advocacy coalition for heat pumps, to the adaptation of heat pump technology to Swedish conditions, and to the development of new value networks and increased quality of installations. The industrial context also played a part in the Swedish heat pump sector’s perseverance during the reverse oil crisis and in its retention of heat pump production competence, which also contributed to the early Swedish heat pump transition.
The two aspects of the industrial context featured in this section are the existing heat pump–related competence in Sweden in the 1970s and the early formation of an advocacy coalition.

11.3.1. Adapting the heat pump to Swedish conditions

The technological development of heat pumps in Sweden has focused primarily on system performance, i.e. the performance of the interconnected heat pump components and the functioning of the heat pump unit with the heating system and environment where it is installed. Some of the development and manufacturing of the main components has taken place in Sweden (e.g. heat exchangers) whereas other components had to be imported (e.g. small compressors). The technological development of heat pumps in Sweden has therefore depended partly on technological developments elsewhere. But much of the work in adapting heat pumps to Swedish conditions has taken place in Sweden. And the capability for Swedish actors to adapt and develop heat pumps was dependent on the existing established industry in the 1970s.

Prior to the 1970s, Sweden had an internationally competitive refrigeration industry. The level of knowledge and competence concerning compressors (which constitute the ‘heart’ of the heat pump) and refrigeration cycles were relatively high. The same can be said for Switzerland, which also formed a heat pump industry ahead of its time (Zogg 2008). The Swedish refrigeration industry had the competence to design and produce heat pumps, but in other ways it lacked required capabilities to supply the housing market with affordable heat pumps.

In the 1970s there was also a network of companies with equipment and competence to drill fresh-water wells. This sector had the potential for branching into drilling energy boreholes for geothermal heat pumps, but these companies did not pursue this path until the potential of vertical ground-source heat pumps was considered and there were established ground-source heat pump manufactures in Sweden.

Moreover, by the 1970s Sweden had an established industry that manufactured heating products for the growing number of Swedish houses and buildings and for the retrofit market. These companies, with roots in the HVAC industry, had the practical capabilities for assembling and manufacturing, but refrigeration-cycle technologies were alien to them. The knowledge of how to design, configure and adapt heat pumps as reliable systems had to be sourced from external partners or recruitments.
To sum up the situation in the 1970s: there was existing knowledge and competence on how to adapt, develop and produce heat pumps in Sweden, but it was scattered and spread out among different actors. The potential for a heat pump development block was therefore present but needed increased knowledge flow to be realised.

Both technical universities and energy companies played important parts in increasing the knowledge flow concerning heat pumps in the early phases of the Swedish heat pump transition by acting as ‘cross-network actors’. The engagement of Swedish technical universities in heat pump-related research and education can be dated back at least to the early 1900s, when Edvard Hubendick was encouraged and supported by the Swedish refrigeration industry to conduct research on refrigeration technologies (Almqvist et al. 1992). Over the years, academia has collaborated with Swedish compressor, refrigeration and heating industries. The build-up of heat pump-related knowledge in Swedish academia played an important role from the 1970s and onwards in the development and diffusion of knowledge regarding heat pumps.

From this, it can be argued that the industry and academic context set conditions for the development and diffusion of knowledge as well as guiding the search (cf. Hekkert et al. 2007) during the period when the Swedish heat pump industry first started to form. The industrial and academic background was foundational for the cooperation and increased knowledge flow that transformed the various heat pump-related value networks into a heat pump industry in the 1970s, and this was in turn foundational for the learning processes related to heat pumps that would occur later.

### 11.3.2. An advocacy coalition without opposition

By the early 1980s, there was wide support for heat pumps in the energy system. The advocacy coalition for heat pumps ranged from private to public – from municipal district heating companies to state-owned Vattenfall, from individual inventors and fortune-seeking entrepreneurs to some of Sweden's largest corporations. This advocacy coalition faced little opposition and contributed to early heat pump market expansion in the first half of the 1980s.

The early formation of a heat pump advocacy coalition can partly be explained by looking at the industrial context and extending the previous discussions on the energy system and broader societal context in Sweden at the time. Decreasing oil dependence was one of the big tasks at hand in the late 1970s. This task was not limited to energy system actors alone, as energy-related issues had been previously. Instead, the ‘energy situation’ was a national issue with wide societal engagement – not least
because of the sharply divided opinions and public polemics concerning nuclear power. The robust debate over nuclear power in Sweden stands in stark contrast to the widespread societal consensus concerning oil at this time. The question was not whether but how to reduce dependence on oil. The opposition to this imperative was almost non-existent.

Both Kaijser et al. (1988) and Nilsson et al. (2005) have pointed out how strikingly little conflict has arisen around heat pump technology. But as previously discussed, the heat pump was seen as a non-disturbing technology in the energy system. It was suitable to use as a substitute for oil boilers (decreasing oil dependence) or as a substitute or complement to direct electric heating (decreasing the electricity demand and thus the need for nuclear power).

During this period, the energy corporate agency Vattenfall was a central actor in the emerging heat pump area. Vattenfall, with Head of Staff and Planning Director Bengt Nordström leading the way, had identified the heat pump as a promising technology very early and was one of its main supporters in the 1970s and 1980s. Vattenfall’s first solar programme, in conjunction with the municipally owned electric utility Sydkraft, was followed by the even more comprehensive Solar Project aimed towards heat pumps. Both of these programmes acted as platforms for Swedish heat pump–related industries, increasing the development and diffusion of knowledge in the Swedish heat pump arena. Vattenfall also took an active part in guiding the search for alternatives to oil, steering the Solar Project away from actual solar technology projects towards heat pumps. In fact, Vattenfall used the solar norm of the time, i.e. the general positive attitude towards solar technologies, in favour of heat pumps, by directing large investments towards heat pumps instead of solar technologies.

There are different interpretations as to why Vattenfall engaged in heat pumps – whether it was simply following its directives and acting for the good of society or pursuing its own long-term interests. By supporting the substitution of direct electric heating with heat pumps, Vattenfall actively acted to decrease the total electricity demand (though not the capacity demand) amongst its customers, resulting in less kilowatt-hours sold. But at the same time, the heat pump customers remained dependent on electricity for heating in the long term, rather than switching completely to another type of heating, e.g. solar panels or a biofuel boiler. As Kaijser et al. (1988) point out, through its orientation towards heat pumps Vattenfall strengthened the position of electricity in the heating sector for the long term.
It seems that the position of heat pumps in the energy system – being part of both the heating and electricity systems – has made it possible for the heat pump to gain support from key stakeholders in both segments of the energy system, as they viewed heat pumps as a satisfactory means to replace both oil and electric boilers.

The adoption of heat pump technology in the district heating grid is an example of this pattern. Not only has this expansion strengthened the position of electricity, but it also had (at least at the time) synergies for both district heating and heat pumps, as described above. The expansion of heat pumps in Swedish district heating can to a large extent be attributed to the close collaboration between STAL-Laval and Vattenfall, which resembles the characteristics of a so-called ‘development pair’ (Fridlund 1999). STAL-Laval’s existing contacts with Vattenfall and district heating companies and Vattenfall’s early procurements of large heat pumps strongly contributed to the rapid expansion of large heat pumps in the Swedish district heating grids.

11.4. How did the Swedish heat pump sector survive the reverse oil crisis?

The industrial context must also be considered with regard to the survival of the Swedish heat pump industry through hard times. To understand its perseverance through and beyond the reverse oil crisis of the mid-1980s, we must take into account developments at the value network and sector levels during this time of negative transformation pressure.

Nilsson et al. (2005) suggested that the perseverance of key actors was one of the most important factors in the early and comprehensive Swedish heat pump transition. I am in full agreement. The fact that there was a Swedish heat pump industry at all – though not as strong as it once was – by the mid-1990s played a big role for the Swedish heat pump transition.

The number of heat pump suppliers dropped significantly from its peak years around 1983–1984. Ten years later, there were only a few active heat pump manufacturers left, and the conversion market for heat pumps was in a weak state. But the perseverance of manufacturers through this period meant that key manufacturing knowledge was retained and that the continuous knowledge development that had been ongoing outside the industry (e.g. regarding compressors and ozone-friendly refrigerants) could be absorbed by the remaining participants when the heat pump market showed positive trends again. The long-
term presence of heat pump actors also strengthened overall trust in heat pump technology.

The importance of energy system complementarities and long-term policies, specifically the 1980 building regulation, for actor perseverance has already been discussed. Other aspects that remain to be discussed include stability and long-term support provided by cross-network actors, reconfigurations of value network structures and changed external partnerships to adapt to changes in the business environment, changes in ownership of heat pump manufacturers, and coopetition between heat pump value networks, which contributed to the build-up of industry-sector capability to produce and service heat pumps.

11.4.1. Stability from cross-network actors

The fact that much of the technological development of heat pumps has taken place in Sweden has been important in the development of long-term learning concerning heat pump technology.

Technical universities have played an especially important role in this long-term learning process. Technical universities have contributed to developing knowledge as well as retaining already-developed knowledge in periods when the competence in industries has stagnated or even started to regress. Through the projects and efforts undertaken at technical universities, knowledge concerning heat pumps continued to advance in Sweden after manufacturers shut down their R&D units. One example of the importance of the role of academia is Eric Granryd’s work for AGA and Thermia in developing compact heat exchangers and innovative heat pumps. Another example is the work done on replacing ozone-hazardous refrigerants with ‘ozone-friendly’ ones.

Vattenfall and SP are two governmental organisations that also contributed to the long-term stability of the Swedish heat pump sector. Both have been engaged in testing, labelling and certifications concerning heat pumps.

Vattenfall’s biggest engagement in the heat pump area was during the period of the Solar Project between 1979 and 1986. In the late 1980s Vattenfall, for many reasons, abandoned its role as a platform for heat pump suppliers. That position was instead taken on by the heat pump interest organisation SVEP. SVEP’s advocacy helped to counter the threat of ‘unserious’ heat pump suppliers that gave the heat pump technology a bad reputation, as well as lobbying government for increased support of heat pumps (e.g. the procurement competitions).

The role of the cross-network actors changed as the industry matured and the need for these actors’ work decreased. By then the structure of
the heat pump industry – which Vattenfall, SP and SVEP had helped to foster – was so stable that it on its own could ‘outcoopete’ any threats, as exemplified by the fate of Eufor in the late 1990s, described above in sub-section 8.4.3.

In short, the stability provided by cross-network actors contributed significantly to the survival of the Swedish heat pump sector after the reverse oil crisis.

11.4.2. Vertical forward integration

Heat pump technology was old and internationally established by the 1970s, but to Swedish heating firms it was radical, requiring a radically different business logic and value network structure than what they were used to.

The radical nature of the heat pump resided not in its novelty, but in the fact that the competencies and resources required to produce and service heat pumps were situated between two existing industries: the refrigeration industry (which understood heat pump technology but not the heating market) and the heating industry (which knew the heating market and its heating systems but which had no experience with refrigeration-cycle technologies). Swedish manufacturers of heat pumps primarily had a background in the HVAC industry, just as the contemporary German heat pump manufactures did (Zimny, Michalak and Szczotka 2015). The HVAC industry’s installers of heating appliances lacked competence concerning refrigeration cycles, just as many early heat pump manufacturers did, leading to the poor quality and reliability of many installed heat pump units, which in turn contributed to setbacks for heat pump technology in the late 1980s in Sweden. This problem wasn’t unique to Sweden. Zogg (2008) describes one of the main problems in Switzerland as there having been ‘too many competitors with insufficient know-how’.

In the Swedish context, it seemed more difficult to develop new networks than to internalise heat pump construction and installation knowledge. One example of this tendency arose when Thermia first tried to enter the exhaust air heat pump market. The performance of the heat pump stood well against its competitors, but as Leif Olsson (personal communication, 30 March 2016) at Thermia explained, the company seemed to have lacked ‘access to the right networks’ to make its heat pump a market success.

The organisational and competence problems of the heat pump industry were partly overcome by two measures. One was increased education efforts aimed at the entire sector of heating product installers. Second,
individual manufacturers took increased responsibility for the installation of their own heat pumps by reconfiguring their value networks, following the logic of the refrigeration industry’s typical business model of turn-key solutions.

Since the poorly conducted installations in the home heating market reflected negatively on heat pump technology in general, manufacturers of heat pumps – who were not used to having direct contact with the end users of their products – were encouraged to take action. Thermia, followed by IVT, applied the business model used by suppliers of medium- and large-size heat pumps in the refrigeration industry and, through soft forward integration in the value chain, tied a network of retailers and installers to their brands. This action enabled them to take measures to guarantee the quality of their heat pump installations.

This serves as an example of how coopetition dynamics benefitted the heat pump sector. The manufacturers of small heat pumps benefitted from adopting the business model of their competitors in the refrigeration industry, and the improved performance of heat pumps created increased interest in heat pumps (e.g. from Vattenfall), which also opened up new heat pump markets for refrigeration companies.

The issue of poor installations nudged manufacturers to reconfigure their value networks in the early 1980s so that they could continue expanding in the home heating conversion market. In the late 1980s, the same manufacturers faced a declining market and needed to reconfigure and trim their value networks in order to survive. These reconfigurations in turn contributed to the sector’s survival. They were also closely associated with changes in ownership of the largest heat pump manufacturers.

11.4.3. Changing ownerships and acquiring venture capital

The profitability problems of the heat pump sector in the second half of the 1980s spurred on increasingly fast changes in ownership. Eventually both IVT and Thermia ended up in the hands of owners with the capability to reconfigure the companies’ value networks both internally and externally, to adapt to existing conditions and to try to influence those conditions to their advantage.

For example, IVT’s new owner, Lars Kastengren, brought with him contacts and competence that helped IVT to form new external partnerships and mobilise external resources to manage a tough market situation. Examples of these new capabilities included the ability to find investors and acquire capital for IVT, to acquire new partnerships based
on the business context need (e.g. partnerships with air-air heat pump suppliers when the air-air heat pump market was at a temporary peak while the ground-source heat pump market was declining), and to use existing competencies within the company to fully apply component improvements achieved in other industries to the development of new heat pump products.

When Kastengren owned IVT and Gustafsson owned Thermia, they were both able to attract governmental venture capital funds. These investors had directives to invest in technologically oriented small- and mid-sized companies with growth potential, and their investments contributed to both IVT’s and Thermia’s ability to reinvest in their production facilities and increase both the rate of product development and production capacity. All these advances contributed to the professionalisation of the Swedish heat pump industry and the build-up of industry-sector heat pump capabilities.

The changes in ownership at IVT and Thermia in 2005 were partly based on the same logic that had contributed to the ownership changes after the reverse oil crisis, when new owners had brought new capabilities and new network connections to the heat pump manufacturers, which meant that they were better equipped for the coming challenges. In 2005, the existing owners (regionally located real-estate owners and company leaders) of Thermia and IVT did not have the capacity to expand into Europe in the same way as the already internationally established corporations Bosch and Danfoss would do.

The changes in ownership to stable owners who brought new capabilities and established networks were an important reason why the Swedish ground-source heat pump manufacturers survived until 1995 and why the necessary competence concerning ground-source heat pumps was retained within the sector.

11.4.4. The development of heat pump sector capabilities

In the Swedish heat pump transition, there have been varying levels of coopetition intensity between value networks. In the long term, this coopetition has contributed to the build-up of industry-sector capabilities in producing and servicing heat pumps.

There are several examples of ‘healthy coopetition’ leading to increased sector capabilities during the Swedish heat pump transition. In the early 1970s, there was an intense level of coopetition between different types of heating alternatives, e.g. between heat pumps and either district heating or solar technologies. There has also been coopetition between manufacturers of heat pumps with different backgrounds, e.g.
refrigeration-based and HVAC-based suppliers. In the early periods of the Swedish heat pump transition, there was coopetition between value networks offering different types of heat pumps (e.g. exhaust air and ground-source), and as the heat pump industry consolidated there has been coopetition between different heat pump manufacturers and individual value networks.

It is evident that the sector has developed through close relations (with varying levels of coopetition intensity) between the different major heat pump manufacturers: Thermia, IVT, Nibe and CTC. When Nibe started manufacturing ground-source heat pumps they were technologically similar to IVT’s existing heat pumps, and IVT’s ground source heat pumps were technologically similar to Thermia’s heat pumps. And Thermia had based its own first heat pump, the JBC-400, on a Danish design.

The healthy coopetition dynamics, first between Thermia and IVT and later encompassing Nibe and CTC, have contributed to creating what can be called a manufacturing cluster (cf. Porter 1991; Nuur 2005) around heat pumps in Sweden, with an increased overall level of relevant competence and the ability to recruit experienced personnel and disseminate knowledge on best practices across the industry. The relatively early growth of the Swedish heat pump industry gave Swedish companies a comparative advantage over their European competitors, which partly explains why the development and production of heat pumps has remained in Sweden even after international corporations with headquarters located elsewhere purchased some of the largest manufacturers.

The coopetition dynamics within the Swedish heat pump industry also contributed to the build-up of competencies and capabilities – and also to the internal momentum, or path dependence, of the heat pump sector – that facilitated the industry’s survival during the period after the reverse oil crisis.
12. Implications of this thesis

The Swedish heat pump transition has been a silent revolution with a big impact in many areas. The annually supplied heating from heat pumps can be measured in TWh, their environmental impact can be measured in mega-tonnes of saved CO₂ emissions, and their export values and the economic growth of the heat pump industry can be measured in billions of SEK. Over the past decades, few energy-related developments have had such an enormous societal, environmental and industrial impact in Sweden as the heat pump transition. Creating knowledge about this development and transition is a part of documenting modern Swedish energy history.

The Swedish heat pump case and the results of this thesis hold lessons that can be applied to many other areas. From a strategic management and industrial dynamics perspective, the observed dynamics in the Swedish heat pump sector offer potential insights on the changes of coopetition intensity during socio-technical transitions, with implications for how firms manage external partnerships and relations during technological transitions.

From a transition study perspective, the combination of the value network, coopetition, and complementarity concepts used in this thesis could be conceptualised further in descriptive and exploratory studies on the role of firms and industries in socio-technical transitions, thereby complementing existing dominant frameworks in transition studies.

From a policy perspective, the lessons from the Swedish heat pump transition indicate the importance of coordinating policy measures – not only within the energy policy area but also between the industry policy and energy policy areas.

From an energy system perspective, lessons from the Swedish heat pump transition could be applied to other European heat pump markets now undergoing similar developments that the Swedish transition has already experienced. Lessons could also be applied to other energy technology areas in Sweden. For example, the current stage of the Swedish solar power sector has similar characteristics to the early stages of the Swedish heat pump transition. Both of these comparisons could be further pursued in future research projects.
12.1. Coopetition dynamics in relation to structural tensions

One of the main findings of this thesis is that cooperative activities and cooperation dynamics are closely connected to structural tensions. When the structural tensions are numerous and hard to overcome, cross-network and cross-technology cooperation increases. But in a balanced situation, the incentives to cooperate decrease.

This study found a higher level of collaboration both within and between sectors (i.e. technological regimes) before a dominant design emerged and a lower level of collaboration after it emerged. This is partly counterintuitive to the competition dynamics in and between technological regimes described by Anderson and Tushman (1990), who indicate that the period before a dominant design emerges is typically characterised by a high level of competition between and within technological regimes. This thesis has found instead that the overall coopetition dynamics were more intense before a dominant design emerged. This means that, while there is competition between actors prior to the emergence of a dominant design, there is also a greater effort to seek potential cooperations and collaborations. After a dominant design appears, the industry becomes more dynamically stable and the intensity of coopetition decreases, with less searching for new external partnerships and increased focus on the core business model of the value network.

This thesis shows that when a structural tension arises that an individual organisation cannot resolve by itself, the level of networking and cooperative relationship activities increases. Consequently, when a development block is in a complete state, the level of competition increases.

Hynes and Wilson (2012) propose that an industry life cycle is characterised by coevolutionary dynamics (involving both cooperation and competition) in early and late stages of the life cycle, while the middle stages of an industry life cycle (the period of growth after a dominant design has been established) is characterised by ‘survival of the fittest’. Looking at the value network dynamics over the 50-year period of the Swedish heat pump transition may give some insights as to the microfoundations of Hynes and Wilson's findings. Perhaps what they observed is that coopetition intensity increases in periods with high level of structural tension (which occur around the time of a technological discontinuity, i.e. in the early and later stages of an industry life cycle), whereas when the industry is in a more stable state (after a dominant
design has emerged) there are typically few structural tensions needing new cooperation or new alignment of complementarities.

12.1.1. Exploration and exploitation

The implications of the characteristics of coopetition dynamics discovered in this thesis, in relation to structural tensions between complementarities, can be discussed by relating to Arvidsson and Mannervik’s (2009) discussion on the processes concerning organisational learning. This discussion is based on the concepts of exploration and exploitation in organisational learning as developed by March (1991).

The exploration process of organisational learning is dependent on networking, which is clearly visible in the heat pump transition, but when firms go into the exploitation process the amount of networking decreases. A depressive pressure on the whole heat pump sector forced the value networks to undergo more exploration processes to find new areas to profit from. They also networked to increase government funding aimed at the heat pump area. The ambition was always to move towards the exploitation process, in which the firm can grow.58

This perspective on exploration and exploitation processes is consistent with the findings on coopetition dynamics in relation to structural tensions – namely, exploration processes require increased exploration, which means increased external cooperation activities. A dynamically stable state, on the other hand, invites an increased focus on exploitation with less need to develop new external partnerships.

12.1.2. Managing external partnerships

This thesis has found that the characteristics of coopetition and incentives to collaborate are dependent on the type of structural tension at hand and the type of complementarity required to alleviate or resolve the tension. For example, the incentive to cooperate or compete is connected to whether the structural tension is of an institutional, organisational or technological character. The incentive to cooperate or compete also relates to the business model or value network level of the

58 The exploration process of organisational learning is also related to finding and forming new connections between existing complementarities. It could be argued that Apple, since Steve Jobs became CEO in 1997, has built its fortune on managing complementarities rather than managing innovations. Apple has been most proficient in exploration activities to find new ways of combining already-existing technologies, i.e. complementarities, into radical and innovative products.
structural tension. For example, two manufacturers that compete over the same market segment may be in fierce competition over increased shares in that market while cooperating with each other against threats from alternatives to their common business model.

For a company to efficiently manage its external relations, it can be useful to implement this ‘coopetition management’ knowledge so that the cooperation activities with a certain external actor are kept separated from the competition activities related to the same partner (cf. Bengtsson and Kock 2000). Conducting a complementarity analysis can be useful to understand the foundations of the coopetition dynamics and thus make changes where needed in external partnerships in relation to changes in complementarities and structural tensions.

The role of value networking dynamics in relation to structural tensions is consistent with the theories concerning dynamic capabilities and sensing, seizing, and reconfiguring capacities put forward by David Teece (2007). A value network reconfiguration is similar to the reconfiguration capacity that Teece (2007) describes as a foundation of the dynamic capabilities that firms must develop for ‘superior long-run business performance’.

The business model–centric value network can act as a tool to illustrate both the possibilities and rigidities entailed in reconfiguring competencies (especially external ones). Analysing the value network that a company is part of and identifying a company’s capacity to reconfigure this or other value network(s) may give insights to the microfoundations of the organisation’s ‘dynamic capabilities’.

Combining value network, coopetition and complementarity concepts provides a potential venue to operationalise the process of analysing and managing an organisation’s external relations and partnerships in order to improve its flexibility and capability to manage ongoing comprehensive technological transitions.

12.2. The usefulness of value network and coopetition perspectives in transition studies

The combination of the value network, coopetition, and complementarity concepts can be conceptualised for descriptive and exploratory studies on the role of firms and industries in socio-technical transitions, thereby offering a complement to existing dominant frameworks in the transition area.

Markard and Hoffmann (2016) state that current transition literature has yet to explore and fully implement the dynamics of interdependent
elements such as organisations, technologies, institutions and infrastructure (i.e. complementarities) in socio-technical transition studies. This thesis argues that using a value network and coopetition perspective together with a complementarity analysis offers a promising approach to study the dynamics of interdependent complementarities in socio-technical transitions. Since complementarities depend on the chosen perspective (i.e. a ‘complementarity’ to what?), the researcher must first define the analytic perspective, which is a contributing factor to why the value network is useful to combine with a complementarity analysis. The value network perspective offers a division of actors into networks that are relatively easily to delimit, and that does not divide actors into niche- or regime-level actors.

The value network–coopetition–complementarity framework is both consistent with and complementary to current dominant frameworks in the transition studies area, e.g. the multi-level perspective (Geels 2002) and technological innovation system (Markard, Hekkert and Jacobsson 2015) approaches. The complementary aspects include the increased actor perspective and the different aggregates of networks, based on business models, that the value network–coopetition–complementarity framework offers.

### 12.2.1. Value networks instead of niche- and regime-level actors

In relation to the MLP, this would mean a complementary way of dividing actors into groups than to sort them by system levels.

The Swedish heat pump transition is an example of a transition in which technologies and innovations developed within the existing regime, rather than in a niche where it would be protected from market mechanisms. Instead of being developed by niche actors outside the dominant regime, heat pump technology was picked up and supported by incumbents at an early stage, long before it had been proven as a reliable technology. In the Swedish heat pump transition, the stakeholders in using oil for heating provided very little to almost no resistance to the transition away from oil. On the contrary, many oil incumbents directly engaged in and supported the development of heat pumps. For example, manufacturers of oil boilers were among the first to start manufacturing biofuel boilers and heat pumps, and district heating companies made large investments to convert their oil plants to other fuels. This makes the Swedish heat pump transition an interesting contrast to many other socio-technical transition cases. Unlike Hughes and Schumpeter, who point to the system builders and entrepreneurs in transformation processes, the Swedish heat pump transition was
characterised by collective efforts and widely established consensus amongst governmental, academic and industry actors regarding the importance of reducing oil imports. In such settings, there is little value in distinguishing niche-level from regime-level actors. It is instead more useful to discern which actors are stakeholders in which business models and value networks.

12.2.2. Analysing incumbent ambiguity in transition studies

Bakker (2014) showed that companies can act ambiguously in socio-technical transitions, and the value network–coopetition–complementarity approach can offer some insight into company ambiguity in such situations. Connecting to the reasoning made in 12.1, the unexpected behaviour that company incumbents can exhibit during socio-technical transitions is based on the simultaneous exploration and exploitation activities that incumbents can undertake when managing comprehensive socio-technical transitions. To find new business models and complementarities, companies may act counter-intuitively to their core business model (which they fear may become obsolete in the near future) but without having abandoned the ‘old’ core business model as long as it generates revenue.

To understand the behaviour of incumbents during socio-technical transitions, it is also important to include contextual factors. As shown by Vermeulen (2012), value networks are highly context-dependent and lack life-cycle patterns. To understand changes in the roles of companies in their value networks, the institutional, societal and industrial context of the studied company must be included. In the Swedish heat pump transition, Vattenfall is a good example of this. The societal liberalisation trend, the changed policy directives, and the industrial context of the European energy markets all contributed to Vattenfall’s decision to abandon its long-term efforts and investments in the Swedish heat pump sector. Vattenfall’s responsibilities were partly, in conjunction with this shift of role, moved to other government actors, creating a new type of government-industry relationships in the Swedish heat pump transition. So, to understand Vattenfall’s actions, the inclusion of context is clearly important. And that is also true, I would argue, for studying companies and changes in company roles during socio-technical transitions in general: context is king.

12.3. Policy implications

The policy-related developments that have had an unambiguous long-term positive impact on the Swedish heat pump transition include the
1980 (and 1975) building regulations, the taxation of carbon emissions, and the venture capital allocated to Swedish heat pump manufacturers. The effects of energy policy initiatives aimed directly at heat pumps have often been more ambiguous in their impact. For example, heat pump subsidies have caused forward ordering and attracted opportunistic actors to the market when the established suppliers have not been able to meet the sudden changes in demand.

Industry policy measures taken in Sweden have had a significant effect on the Swedish heat pump industry. One example is the decision to invest in technologically oriented companies with growth potential during the 1990s (Giertz 2016), which benefitted both IVT and Thermia. These two companies both went through bankruptcies and multiple changes in ownership during the late 1980s and early 1990s, but emerged with new owners, cleared balance sheets and relatively high competence in efficient heating technologies, which contributed to attracting state-owned investors.

This thesis is consistent with previous studies in that policy measures have had a big impact on the Swedish heat pump transition. The implications of this thesis include the observation that when one studies the effects of policy changes, the scope needs to be wider than just energy policies and should include changes in industry policy as well. The thesis also highlights the importance for policy makers of coordinating policy measures – not only within the energy policy area but also between different policy areas, e.g. the industry policy and energy policy areas.

### 12.4. Suggested further research

This thesis, though quite comprehensive, should not be the last word in research on the transition towards and developments relating to heat pumps in Sweden. Hopefully, the opposite will be true, as several areas deserve further research. For example, future research could more fully incorporate the demand side and customer perspectives on the Swedish heat pump transition (and perhaps develop some points of critique of the supply-side perspective of this thesis).

Other possible future research projects could include a comparative study of the heat pump transition in Sweden and other countries, such as Finland, to expand our understanding of the specific contextual conditions of the Swedish heat pump transition.

It would also be possible to conduct a cross-technology study based on this thesis, e.g. comparing the expansion of solar power in Sweden with the heat pump transition. The Swedish solar power transition is in a formative and early phase and shows many resemblances to the early
stages of the Swedish heat pump transition – for example, the active involvement of both large electric utilities and local municipal energy companies, the search for successful business models, and the combination of imported products and experimental Swedish development and production (though on a much smaller scale than for heat pumps). From this point of departure, another possible study could focus on what lessons concerning business model innovation and value network dynamics could be transferred from prior Swedish socio-technical transitions in the energy area to the ongoing transition processes.

12.4.1. Developing a value network–coopetition–complementarity framework

When new complementarities align and create new business conditions, this puts increased pressure on organisations to adapt. One potential approach for companies to mitigate uncertainties and prepare for organisational change in relation to socio-technical transitions could be to combine a complementarity analysis with a scenario analysis. Such an approach could help a company to develop the potential to allocate and adapt external competencies and resources.

Although a company’s long-term strategy should dictate its core competencies, the company can prepare for different outcomes of various conceivable scenarios in a technological transition by preparing to be able to allocate central competencies and resources for each scenario amongst external partners. Compared to developing internal dynamic capabilities, this approach allows for cost-efficient mitigation of uncertainties associated with technological transitions.

I do not mean to imply that maintaining a large network of external contacts is cost-free. The trade-off concerning the extent to which external contacts are maintained should be assessed by managers in relation to the scenario analysis and risks that accompany the transition process. A big advantage of such tactics in managing technological transitions is that they allow the company to focus on its core competencies and still prepare for profound changes in the business environment. When the business environment has reached a point of relative dynamic stability, then the next step can be taken by analysing, depending on the transaction costs at hand, which external competencies and resources that have been engaged previously should now be internalised.
12.4.2. Analysing the timing of investments

Finally, this thesis could possibly, by building on previous knowledge from Teece (2007), provide the basis for an analytical framework that helps companies to plan investments. Whereas Teece largely focuses on strategy as a process, the value network–coopetition–complementarity approach allows for increased inclusion of a focus on strategy as a plan. The difference is the approach to the question of timing, seen as a set of aligned complementarities the timing of which managers, by way of value network reconfiguration, may influence. The aspect of timing is of course not new to strategic management scholars (e.g. Mitchell 1991; Teece 2007), but further research based on this thesis could potentially offer a practical analytical tool for analysing the alignment potential between internal and external complementarities of a value network and its business context, thereby guiding managers to the identification of structural tensions and necessary ‘value networking’ processes (internal as well as external) so that they can properly time their investments.
13. Personal final remarks

This thesis represents likely the most in-depth research that I will ever do on a single topic. I have learned a lot from the journey, and I think that I have also managed to highlight some interesting aspects of the Swedish heat pump transition.

During this work, I have been struck by the seemingly widely anchored and tenacious belief in the potential of heat pumps. I have interviewed several people who participated in all periods of the Swedish heat pump transition (e.g. Jan-Erik Nowacki, Eric Granryd, Enno Abel, Leif Olsson). I would tend to describe this belief in the heat pump – which has survived many setbacks – as a Swedish heat pump norm. The trust in heat pump technology as means to reduce CO$_2$ emissions and gain indoor comfort has been sincere. Looking back, these believers seem to have been right. And perhaps they are right looking ahead as well.

The need to address CO$_2$ emissions due to threat of climate change has manifested itself in many different ways over the last few years. The level of CO$_2$ in the atmosphere reached 400 ppm during 2013, which is 43% higher than in the pre-industrial era. The whole of Greenland suffered snow melt during summer 2012, and in the same year the ice-covered surface in the Arctic Ocean was only half its normal size (Laestadius 2013). The halt in the increase in energy-related global CO$_2$ emissions since 2014, as confirmed by the IEA (2016), has given some hope in the hour of need. But much work remains to mitigate the threat of climate change, not least in the heating and cooling sectors. It is thus more important than ever to consider what measures are most effective in decreasing greenhouse emissions.

Here we must look towards heat pumps. I believe that the development we have seen in Sweden is only a taste of what is yet to come, especially considering the emerging complementarities to heat pumps discussed in Chapter 10.

Currently, many countries have an emerging or underdeveloped heat pump market. With technological advancements happening continually (cheaper material, faster and cheaper drilling, etc.) and the synergies with renewable and variable energy sources growing ever stronger, the potential for heat pumps in these markets continues to increase.

I recently listened to a podcast from the US (The Energy Gang, 21 July 2017) in which the hosts discussed the potential of geothermal heat pumps in the US and asked: ‘can geothermal heating and cooling follow the path of solar [in the US]?’ In the ears of a Swede, the question
sounded surprising. A Swede would have expected it to be formulated in reverse: ‘can solar power follow the path of geothermal heat pumps?’

In the US, buildings account for 39% of all CO2 emissions, and in New York state alone, over 2 million households depend on fuel oil and propane for heating. The potential to reduce greenhouse gas emissions is huge. So why have geothermal heat pumps not made a bigger impact in the US? Without knowing the specifics of the US context, I dare say that the answer does not lie in matters of technological and economic performance alone. The development of heat pumps should and must be viewed holistically (e.g. as a development block).

Context is king. There are perhaps no general recommendations that can be drawn from this thesis and applied directly to the US. Nevertheless, this thesis may hold potential answers to questions asked by heat pump proponents in the US.

We should all do what we can to mitigate the risks of climate change. There remain many oil boilers yet that need to be replaced. I hope that this thesis will be consulted widely for insight as to how heat pumps – and other technologies with a sustainability potential – can best be managed and supported in untapped and developing markets, where great environmental gain can still and must be achieved.
References


Axell, M. (2006) *Kommentar till debattinlägg om värmepumpars bidrag till koldioxidutsläpp*, sp.se. Available at:


Dahmén, E. (1950) Svensk industriell företagarverksamhet. Ph. D.
Industriens Utredningsinstitut, Stockholm.


Eskilstuna: Swedish Energy Agency.


IVT (2015b) ivt.se. Tranås: Bosch Thermoteknik AB. Available at:


Karlsson, F. et al. (2013) Nuvarande status och framtidsutsikter för
värmepumpar, solvärme och pellets på den svenska värmemarknaden, *SP Rapport 2013:45*. Borås: SP.


Katrineholm: Svenska Värumpumporganisationen.


Värmepumpsföreningen.


Thermia (2010) *Thermia-veteran tackar prästen och miljörörelsen för


Vattenfall (2011) *The Virtual Power Plant; Wind power meets heat*. Berlin: Vattenfall Europe Wärme AG.


Wenström, E. (2011) ‘Försäljning av värmepumpar ökar’, *Anbud24* (7 February 2011) Available at: https://anbud24.se/forsaljning-av-
varmpumpar-okar/


Appendix I: How heat pump technology works

A heat pump moves heat from a cold side to a warm side. This procedure at first seems contrary to the laws of thermodynamics. This appendix explains the thermodynamic principles and technical details of a heat pump so that the reader can better understand its functions and product characteristics. I also seek to explain why the technology has been and still is somewhat difficult to grasp for non-technical experts.

Heat pumps can vary with regard to their size, heat sink, heat source, and drivers of the compression cycle (Björk et al. 2013). But the same scientific principle applies to all heat pump types. Amidst this wide variation of types, dominant designs have arisen in some application settings, such as small houses with water-based heating systems.

A.1 Heat pump diagrams

The heat pump principle is illustrated in both an s,T diagram and an h-log(p) diagram in Figure 37. The s,T diagram at left shows the Perkins refrigeration cycle with entropy (s) on the x-axis and temperature (T) on the y-axis. The h-log(p) diagram on the right shows the same cycle but with enthalpy (h) on the x-axis and logarithmic pressure (p) on the y-axis. Entropy is a means of measuring disorder, or alternatively a measurement of how much heat energy can be converted to work. Enthalpy (h) is an energy measurement of the inner energy (U) of the system and the product of pressure (p) and volume (V) of the system according to the law \( h = U + pV \). For an ideal, incompressible gas, the enthalpy measurement is – unlike entropy – not dependent on pressure.

Understanding innovations in heat pumps depends on understanding these basic heat pump principles, which were also introduced in Fact Box 4 on page 48.

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59 In real processes, the sum of entropies in all participating bodies always increases according to the second law of thermodynamics. To put it more simply, heat always flows from the warm side to the cold side.
A.2 Coefficient of performance

The efficiency of a heat pump is given by its coefficient of performance (COP). If the COP of a heat pump equals 3, then the heat pump supplies three times as much energy as it consumes.

This process may seem counterintuitive, but no new energy is being created; it is simply a matter of energy conversion. In the heat pump process, electric energy with high exergy (meaning high level of possible conversion to useful work) is converted to heat with low exergy (or low possibility to convert the energy into work). It is also important to understand that the net heat supplied by a heat pump – if the heat from the cold and warm sides of the heat pump are blended – corresponds to direct electricity heating, as the two sides negate each other. We can understand this better by looking at how to calculate the COP of the Perkins refrigeration cycle.

To achieve a high COP, it is important to have as low a temperature lift as possible. That is, the theoretical COP increases with higher temperatures at the heat source and lower temperatures at the heat sink.

This relation can be deduced by some basic equations. The COP for heating is referred to as COP₁ (with COP₂ referring to cooling) and is calculated by dividing the heat effect \(Q₁\) from the heat pump by the drive power \(E\) required for the heat pump process:

\[
COP₁ = \frac{Q₁}{E}
\]

The uptake of heat on the cold side \(Q₂\) is called the cooling effect. The theoretical heat output \(Q₃\) is as big as the sum of the cooling effect and
driving power input \((E)\). From this the following relation can be deduced: \(COP_1 = COP_2 + 1\).

The French officer Nicolas Léonard Sadi Carnot was the first person to describe the direct proportional relation for an ideal working cycle between the two temperatures \(T_1\) (hot side) and \(T_2\) (cold side) (Björk et al. 2013, pp. 12–13). The heat cooling factor \(COP_2\) can be described using only these temperatures:

\[
COP_2 = \frac{Q_2}{E} = \frac{T_2}{T_1 - T_2}
\]

The temperatures \(T_1\) and \(T_2\) are here given in Kelvin. From these equations, it is possible to deduce the heating factor \(COP_1\) in relation to temperatures \(T_1\) (hot side) and \(T_2\) (cold side):

\[
COP_1 = \frac{T_2}{T_1 - T_2} + 1
\]

And from this we can see that the theoretical heating factor increases with smaller differences between \(T_2\) and \(T_1\).

As an example, the theoretical heating factor \(COP_1\) of a heat pump working between temperatures \(T_1 = 55°C (\approx 328 \text{ K})\) and \(T_2 = 0°C (\approx 273 \text{ K})\) gives a theoretical heating factor of 5, but lowering the \(T_1\) to 20°C while keeping \(T_2\) at 0°C drastically increases the \(COP_1\) to 14.6. In reality, modern heat pumps achieve a much lower COP, with losses at compressors, pumps, fans, heat exchangers, etc. But with the increasing efficiency of heat pumps the gap between ideal theory and reality decreases (though it can never disappear). The main thing to remember from these equations is that heat pumps working across smaller temperature intervals have higher efficiency.

Since the coefficient of performance changes with varying temperatures of the heat source and heat sink it is common to discuss the average COP over the course of a whole year, called the Seasonal Coefficient of Performance (SCOP).

### A.3 Heat pump sources and sinks

The most common heat sources for heat pumps are air and the ground. In the early experimental days, water was also a common heat source.

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60 The European Standard EN 14825 states how to calculate the SCOP.
Air is easily accessible everywhere but has the drawbacks of low density and typically being cold in winter, when the demand for heating is at its peak. The ground is a more stable heat source that can provide higher efficiency. Many factors determine the efficiency of the uptake of heat from a ground-based collector, however, and technological advancements are continuing in this area.

Currently, the most common ground-source heat pump in Sweden is the closed-loop vertical ground-source heat pump. This type does not require much land area for its installation, unlike the horizontal ground-source heat pump, which require large land areas next to the house.

Another efficient type is the open-loop vertical ground-source heat pump. This type uses groundwater directly and is similar in design to the horizontal ground-source pump. But although groundwater heat pumps can have a higher efficiency by not having any heat transfer losses in a collector, they also have a more limited heat extraction capacity, as the horizontal ground-source pump can extract heat from the borehole even after the borehole has frozen (Björk et al. 2013, p. 23; Vattenfall 1989, p. 23). There are also some legal restrictions concerning circulation of groundwater, as water streams and water quality at different levels in the ground can be affected (Eric Granryd, personal communication, 11 September 2014).

The theoretical COP of a heat pump is dependent on not only the heat source but also the heat sink. Commonly used heat sinks include indoor air, hydronic heating systems, and tap water heaters. In Sweden, water-based (hydronic) heating systems are typically used both for space heating (using radiators and/or underfloor heating) and heating tap water.

The difference between heating tap water and space heating is that tap water must be heated to much higher temperatures. In Sweden, tap water must be heated to over 60°C to avoid hazardous legionella bacteria (Poppius 1984, pp. 45–47). But space heating in modern facilities can require much lower temperatures, sometimes only 30°C or even 25°C. Many heat pump units that handle both tap water and space heating are fitted with a technology that layers the hot water in the water heater to separate the hot tap water from the colder water used for space heating.

61 The density of water is 1 tonne per m³, whereas the corresponding density of air at normal atmospheric pressure is about 1.2 kg per m³.
A.4 Heat pump components

In this section, the main and the regulating components of the basic heat pump compression cycle are presented and briefly discussed.

A.4.1 Condenser

The two heat exchangers in the heat pump cycle, i.e., the evaporator and condenser, can be quite similar in their design (depending on the intended application). But as far as the heat transfer process goes, they are inherently different. For example, in the condensation process it is advantageous if the floating condensate runs away as quickly as possible to avoid an isolating effect on the internal heat exchanger surface. It has therefore been common to have condensers with small tube diameters positioned in an angle in heat pumps (STU 1988, pp. 20–22).

The condenser can also be used to sub-cool the refrigerant, in order to gain extra energy efficiency. If the condenser is designed to have the condensed refrigerant run away, there can be another heat exchanger after the condenser — or an extension of the condenser itself — to sub-cool the refrigerant (STU 1988, p. 22). The gain from sub-cooling involves utilizing the ‘free heat’, though it is at a lower temperature than the condensing temperature.

A.4.2 Evaporator

Just as the condenser can be used to sub-cool the refrigerant, the refrigerant can be overheated in the evaporator. But overheating in the evaporator means that part of the surface of the evaporator is used for heating gas, which is less efficient than using the evaporator to heat the fluid refrigerant for boiling. A way to make sure that the evaporator always works with fluids is to have incomplete evaporation, split the gas and fluid after the evaporator, and lead the fluid back to the evaporator inlet (STU 1988, pp. 16–18).

A.4.3 Expansion or pressure valve

The expansion (pressure) valve is an important part of the heat pump that regulates the flow and pressure in the compressor cycle. It lowers the pressure coming from the high-pressure side to the low pressure that is to be maintained in the evaporator. It can be difficult to design a suitably sized expansion valve to manage all possible operation modes, especially for air-source heat pumps with great variation in temperature at the heat source.

The expansion valve can be mechanically (thermostat) or electrically regulated. In a low-budget version, mechanical capillary tubes can be
used as an expansion valve instead of thermostatic valves (Poppius 1984, p. 22).

A.4.4 Refrigerant

Many types of substances can act as refrigerants, but there are many requirements of a good refrigerant. A refrigerant should have both good thermodynamic properties for heat transfer as well as being safe for the environment, i.e. non-toxic, not hazardous to ozone, not having greenhouse gas properties or in other ways causing harm to the environment. These requirements limit the list of potential refrigerants for heat pumps (Björk et al. 2013). For a long time, the HCFC refrigerant R-12 (or freon-12) was commonly used as a refrigerant in heat pumps, before the ozone hole and the ozone-depleting effects of R-12 and other chlorofluorocarbons were discovered.

The chlorine atom in HCFC refrigerants was responsible for the harm to the ozone layer, so HCFC products were mainly replaced by HFC compounds, such as R-134a, and HCF blends. The problem with refrigerant blends is that they have a temperature glide during the phase change transition of the refrigerant (unlike R-12), which gives other (often less efficient) thermodynamic properties.

A.4.5 Compressor

The compressor is the heart of the heat pump and the only main component that needs to have movable parts. A heat pump compressor is typically driven by an electric engine. The type of compressor used varies depending on the intended power output and operation modes. For small to medium-size heat pumps, the piston, rotary, and scroll compressor been popular options. Screw compressors have been used for larger ranges of power output; for the largest heat pump types, the most economical choice has typically been turbo-compressors (Granryd 2011; Vattenfall 1989).

Though rarely used for commercial and standardised heat pumps, there are other alternatives to electrically driven heat pumps, such as gas-driven heat pumps and absorption heat pumps. Gas-driven pumps are used when it is not desirable or possible to run a heat pump on electricity, but they are otherwise normal compression-cycle pumps. Heat pumps driven through an absorption process are more fundamentally different. These heat pumps have the advantage that they can, in some cases, operate completely without moving parts. The refrigerator invented by Carl Munters and Baltzar von Platen is a famous example of an applied absorption cycle. This silent refrigerator later became a big success for Electrolux (Almqvist et al. 1992). However, the
theoretical efficiency limit for an absorption heat pump is lower than that for compression-cycle heat pumps.

A.4.6 Control equipment

The regulation of a heat pump is of great importance to achieve efficient operation and reliable heat pump systems. The control equipment runs the heat pump system to steer the heat output depending on the temperatures of the heat source and heat sink. Regulation of heat pumps has most certainly been challenging for heat pumps that rely on outside air as a heat source in the cold Swedish climate. On colder days, the heat pumps are forced to have gaps in operation and it has also been necessary to include a smoothly functioning regulator to defrost the outdoor unit of the heat pump. During breaks in operation, such as during defrosting, the stop must be compensated with increased power. The control equipment in some cases also controls possible auxiliary heating, such as an immersion heater or oil boiler.

Heat pumps are also equipped with safety equipment that is supposed to protect against too great a pressure level or too high a temperature. For this purpose, switches and thermostats can be used (Poppius 1984, p. 22).
Appendix II: Example of an interview form

This sample interview form was used as a template for interviews with Vattenfall employees who had been involved in that company’s heat pump projects. Note that this form was designed specifically for a cross-network energy company. The interview templates varied somewhat depending on the interviewee. The form is translated from the original Swedish.

- Concerning employment
  * What is your background?
  * For how long and during what time period(s) have you worked with heat pumps?
  * What role did you have in your work with heat pumps?
  * What heat pump projects have you been involved in at Vattenfall?
  * Did you mostly work with small, medium-size or large heat pumps?
  * Who were your colleagues in the project? Are some of them still active?
  * Which managers did you work for while working with heat pumps?
  * What typical background did those who worked with heat pumps within Vattenfall have?

- Concerning technical developments
  * What technical progress was made while you worked with heat pumps?
  * Which component in the heat pump was considered most critical for heat pump development?
  * How did production costs change while you were active in this work?
  * What type of heat pump did Vattenfall focus on most?
  * Which technologies competed most with the heat pump?

- Concerning business models and the energy system
  * How did Vattenfall profit from heat pumps? What types of business models were used? What were the economic drivers?
  * What was considered more important: the price of electricity or oil prices?
  * What did you consider the biggest advantages of heat pump technology?
  * What did you consider the biggest challenges for heat pump technology?
  * How did you work to reduce installation costs?
  * What did you think about service on heat pumps? How was it done?
- Concerning collaboration
* How did you choose which companies to cooperate with? Did Vattenfall have any strategy regarding partners? Which partnerships were most important to Vattenfall?
* What was the purpose of cooperating with heat pump manufacturers?
* How extensive was the collaboration with KTH, Chalmers or any other academic institute?
* Did you cooperate with SVEP or other associations?

- Concerning Vattenfall’s heat pump projects
* Were you involved in the heat pump programme that took place from 1973 to 1979? What do you know about this programme?
* Were you involved in the Solar Project that lasted from 1979 to 1986?
* Were you involved in the Mission 2000 project that ran from 1986 to 1992? If so, how did you work with heat pumps in this project?
* Were you involved in the NUTEK procurement of heat pumps during 1994 and 1995? Are you familiar with the cooperation with Eufor and the production of the heat pump called Marcus?
* Vattenfall invested in heat pump technology from 1973 to 1995; why did this investment continue over such a long period? And why did you pull out after 1995?
* Was the government’s directive indicating that Vattenfall should invest in heat pumps, or was that Vattenfall’s own interpretation of the government’s directive? Why did you focus so hard on heat pump technology and not on other similar technologies?

- Concerning the Solar Project
* What was the overall goal of the Solar Project? What directives did you get with regard to who worked on the project?
* How was Bengt Nordström’s leadership?
* Was Bengt Nordström more an entrepreneurial or a classical project manager?
* How did you deal with the approach to small, medium-size or large heat pumps? Which of these was most prominent in the Solar Project?
* What was the Solar project’s impact on the heat pump industry and the market?
* What was the biggest success of the Solar Project? What was the most successful thing, from your perspective, about the project?

- Other: * Are there other questions that I haven’t asked but that you think I should ask?