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Excess heat supply collaborations within the district heating sector: Drivers and barriers

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This article combines the theoretical field of Industrial Symbiosis (IS) with a business model perspective to increase the knowledge about drivers and barriers behind the emergence of excess heat supply collaborations between district heating companies and industrial firms. The increased knowledge is gained by identifying and examining drivers and barriers associated with collaborative efforts to funnel excess heat produced by industrial firms into district heating grids in Sweden. An increased recovery of excess heat has the potential to reduce the primary energy demands of district heating systems. This study examines both existing and potential developments of industrial collaborations of excess heat-based district heating systems. The focus of the study consists of two Swedish cases of existing collaboration between district heating companies and pulp and paper industries as well as 16 industrial firms that all produce unused excess heat as a by-product. Confirming earlier research results, this study shows that financial issues are both the main drivers and the main barriers behind the emergence and development of inter-organisational collaborations. In addition, this study confirms earlier research that found the trust, joint problem solving, and fine-grained information transfer are important elements of successful collaboration. This study complements and clarifies these three features by including honesty and shared visions on common goals as important qualities needed for well-functioning collaborations. Combining the IS and the business model perspective has made it possible to examine more factors related to collaboration. The business model perspective has contributed with knowledge about central components of the business agreement between the collaborating parties, and the IS-perspective has contributed knowledge of the important organisational factors behind the emergence and development of long-term sustainable business agreements between firms. © *2015 AIP Publishing LLC*.
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I. INTRODUCTION

As a result of the growing global concern for climate change, countries all over the world are striving to lower their energy use and their emissions. Excess heat is used worldwide (especially in cold climates) to lower the primary energy demand for heating (Hirvonen *et al.*, 2014). Large energy-intensive industries produce a significant amount of excess heat. This type of industrial excess heat can be used in several areas, both internally within the industry's own activities and externally. How this excess heat can be used is largely determined by its form and temperature (Persson and Werner, 2012). Industrial excess heat with sufficiently high temperatures can be used in large-scale systems that distribute heat, such as district heating. Industrial excess heat can be used as a source of energy to heat water that serves as the heating medium for heating villas, apartment buildings, and public buildings. These buildings are connected to the system via two heat exchangers: at the heating plant the excess heat is transferred to a central distribution system and this heat is delivered to the end users where it is transferred to the buildings via radiators. The cooled water is then returned to the heating plant where it is

heated again. This set-up provides a resource-efficient source of heat that generates a low environmental impact (Werner, 2004). Compared to other external uses, excess heat recovery by district heating grids is currently one of the most cost effective ways of using excess heat as a source of heating (Fahlén *et al*., 2012).

An increased recovery of excess heat from industrial processes and thermal power generation has great potential to reduce primary energy demands (Persson and Werner, 2012). District heating systems based on industrial excess heat are generally considered resource-efficient as long as these systems provide heat for customers using energy that would otherwise be wasted (Werner, 2004). Recovery of industrial excess heat could also lead to the development of new district heating systems.

The use of excess heat is also relevant when it comes to the industrial development at the regional level. Actors, such as an industry selling excess heat to a district heating company, can benefit from such heat supply collaboration. In addition to the environmental benefits, this approach can bring financial benefits and improved competitiveness for the companies involved (Gebremedhin and Carlson, 2002), as the industries are paid for a heat that they otherwise would have been forced to find ways to cool, yet another expense. In some cases, district heating companies are given the opportunity to buy excess heat at a lower price than the market price of primary energy.

Sweden, the focus of this study, has a tradition of large energy intensive manufacturing industries—such as paper mills and steel mills—that generate large amounts of excess heat (Cronholm *et al*., 2009). Although collaboration around heat supply in Sweden has increased, its use is low compared to the supply of excess heat produced as the result of industrial processes (County Administrative Board, 2011). Although previous research on the development of excess heat-based district heating mainly focuses on technical solutions, it often highlights organisational aspects as important in the development of inter-organisational collaborations (Arnell *et al*., 2012). However, Difs *et al*. (2009) argue that the district heating literature contains a knowledge gap regarding the impact of organisational aspects concerning the development of inter-organisational collaborations.

Previous studies of collaboration on excess heat often have been conducted within Industrial Symbiosis (IS). IS, developed as a subset of Industrial Ecology (IE), is a cluster of operational agreements between normally unrelated industrial companies or other organisations that lead to resource efficiency (Jensen *et al*., 2011). The agreements, for example, can involve reuse of one company's by-products as raw material for another company as well as the sharing of manufacturing capacity, power, water, and steam supplies as well as logistics and expertise (Jensen *et al*., 2011). IS research provides examples of similar cases of companies and other organisations successfully exchanging resources to improve financial and environmental outcomes for the involved organisations and for society at large (Doménech and Davies, 2009). However, the previous studies of collaboration on excess heat within the research field of IS mainly concern excess heat collaborations as part of a larger symbiotic context of multiple actors and flows of resources. This study differs in the way of using IS, by studying isolated collaborations between industry and district heating sector. Compared to previous studies, this study also differs in the way it addresses IS combined with a business perspective. This combination is in line with Coelho and Ruth (2006) as well as Woodard (2001) who mean that one weakness with IS is that it mainly considers factors related to the inputs and outputs of collaboration and not the collaboration process *per se*. It is important to also consider the business model of the collaboration where the actors are involved (Coelho and Ruth, 2006 and Woodard, 2001).

The business perspective contributes knowledge of the business model behind the collaboration (Ehrenfeld, 2007; Hopwood *et al*., 2005; and Lombardi and Laybourn, 2012). According to Chertow (2007), the most successful cases of collaboration have arisen spontaneously; however, Chertow (2007) concludes that collaboration between companies does not always occur even though the physical conditions for it exist.

Given the discussion above, this article investigates drivers and barriers behind the development of excess heat-based systems for district heating. Increased knowledge of these

important aspects could mean greater opportunities to develop excess heat-based systems for district heating. This study examines both successful and potential collaborations between industrial producers of excess heat and users of excess heat, specifically district heating systems. The focus of the study consists of two Swedish cases of existing collaboration between district heating companies and pulp and paper industries as well as 16 industrial firms that all have unused excess heat as a by-product. Combining both realised and potential cases of excess heat collaborations, this study identifies the prerequisites for successful collaboration between industrial firms that produce excess heat and district heating companies that use excess heat.

II. EXCESS HEAT COLLABORATIONS FROM AN INDUSTRIAL SYMBIOSIS AND BUSINESS MODEL PERSPECTIVE

From an organisational perspective, we analysed the on-going and potential collaborations between industrial firms and the district heating sector to understand the essential mechanisms behind the formation and development of inter-organisational networks in which actors collaborate. The article's theoretical foundation is based on IS. Although earlier studies recognize the importance of the business side of IS, it is important to consider the business model of the collaboration in addition to considering the factors related to IS, such as inputs and outputs (Ehrenfeld, 2007; Hopwood *et al.*, 2005; and Lombardi and Laybourn, 2012). Therefore, a business model perspective complements IS theory. These complementary approaches focus on factors necessary for the development of business agreements. However, as mentioned above IS does not deal directly with the business perspective and thus is isolated from business studies and industrial investments (Coelho and Ruth, 2006 and Woodard, 2001). The link between IS theory and the business model perspective within the framework of this study builds on previous IS research that shows the importance of well-designed business agreements between the actors involved in collaboration. The agreements, for example, can involve reuse of one company's by-products as raw material for another company as well as the sharing of manufacturing capacity, power, water, steam supplies, logistical expertise, and other company expertise (Jensen *et al.*, 2011).

When it comes to collaboration between different actors, profitability and competitiveness are the main drivers behind IS synergies (Ehrenfeld and Gertler, 1997). The drivers, however, can also be social, environmental, or regulatory (Chertow, 2007). Perceived benefits for all actors involved need to be considered (Palm and Ramsell, 2007). Inter-organisational collaborations can result in significant financial and environmental benefits both for the companies involved in the given synergy as well as for society at large regardless of the driving forces behind the development of the synergies (Doménech and Davies, 2009).

For a successful collaboration, all actors must believe that they have something to gain and that their collaborative efforts will move them closer to their own goals and closer to the interests they share with their collaborators. To achieve these common interests, collaboration and co-ordination are required (Börzel, 1998). Embedded relations based on trust and personal ties rather than explicit contacts are important preconditions for a successful collaboration around exchanges of energy and resources among organisations (Uzzi, 1997). Uzzi describes embeddedness as "the process by which social relations shape economic action in ways that some mainstream economic schemes overlook or miss to specify when they assume that social ties affect economic behaviour only minimally or, in some stringent accounts, reduce the efficiency of the price system" (1996). Embeddedness, for Uzzi (1997), requires three important organisational preconditions: (1) trust, (2) fine-grained information transfer, and (3) joint problem solving abilities. These preconditions allow companies to adapt more quickly and to be more flexible to environments characterized by continuous change and complexity. All these features have also proved to be important preconditions in the decision-making process for joint collaboration projects where knowledge through participation of relevant stakeholders within the collaboration is required for understanding and translating the common goals and objectives into practice (Albrechts, 2006). Companies and other organisations involved in embedded networks tend to have a greater chance to gain advantages compared to other forms of governance (Uzzi,

1996). The main problem, which is widely held to be one of the primary barriers behind the development of these kinds of inter-organisational collaborations, involves difficulties generating intercompany interaction, a relationship that is required for companies to link production processes (Gibbs, 2003).

Since the late 1990s, the business model concept has been used extensively in academia and in industry to describe how organisations create and capture different values. The business model concept is an emerging concept (Boons and Lüdeke-Freund, 2013). Central to any business agreement is a business model, which can help create collaboration and co-ordination in the first place. The main challenge for any business model is to make it simple, relevant, and intuitively understandable without oversimplifying how the enterprises function. A business model should simplify and clarify the importance of value creation and increase understanding of the companies' often complex realities (Osterwalder and Pigneur, 2010). Boons and Lüdeke-Freund (2013) describe the generic business model using four concepts: value proposition, supply chain, customer interface, and a financial model. In our study, we use the canvas business model, which according to Boons and Lüdeke-Freund (2013) includes all four of these elements. Yet this study does not look into these elements in detail, it rather uses the model in a more general way in order to get a more generic understanding of the business model perspective and how it contributes to a deeper understanding of the drivers and barriers behind the studied collaborations. The business model is a strategic management tool mainly used in the development of new, or for documenting of existing business models. Through a visual chart, this model assists firms in aligning their activities by illustrating potential trade-offs and by describing the firm's value proposition, infrastructure, customers, and finances (Osterwalder and Pigneur, 2010).

Osterwalder and Pigneur (2010) describe the canvas business model using nine basic building blocks. Table I, which is based on the description by Osterwalder and Pigneur (2010), contains a compiled description of these nine building blocks. These building blocks reveal that the canvas model can be seen as a concretising complement to IS theory as the canvas model goes deeper into the basic steps behind companies' and organisations' business strategies and business agreements with other actors. The model is widely used to analyse businesses, such as the potential cases in this study, and to clarify actors' needs. Such clarification then can be used to

TABLE I. Description of the nine basic building blocks described by Osterwalder and Pigneur (2010).

The nine building blocks	Descriptions
Customer segments	The heart of any business model since no company would survive without profit.
Value propositions	Products and services that create value for a specific customer segment by solving a customer problem or satisfying a customer need.
Channels	Communication, distribution, and sales channels describe how the company reaches its customer segments. These channels play an important role in the customer experience.
Customer relationships	Can be both automated and of a more personal manner. Different customer relationships are often driven by different motivations, such as upselling and customer acquisition and retention.
Revenue streams	Covers the revenue a company generates from each customer
Key resources	A precondition for the value proposition, the market, the relationship with customers and the revenues.
Key activities	Define the important activities behind a successfully operated company
Key partnerships	Partners and suppliers that make the business model function well. For example, companies enter collaborations as a way to acquire resources, reduce risk, or optimise their business models.
Cost structures	Describes all the costs involved within the operation of a business model.

improve communication and relationships between actors. For this study, parts of the canvas model that are compatible with IS and the objective concerning drivers and barriers behind the development of excess heat collaborations are used.

The concept of business model covers the entire field of business (i.e., pricing, relationships, marketing, strategy, marketing, channels, etc.). These nine blocks help explain the important factors behind a sustainable business model. It is difficult to determine which of these blocks best explain the phenomena studied within the framework of this article as all the blocks more or less include and depend on organisationally important factors related to both internal and external communication.

III. METHODOLOGY

This study examines 18 Swedish cases associated with excess heat. The first two cases—case 1 and case 2—are characterized by excess heat collaborations between district heating companies and pulp and paper industries. By studying two existing cases of excess heat collaborations (i.e., the entire development process), we were able to uncover important factors for successful collaborations. Moreover, as the two studied cases are active in the same sector (Table II), the prevailing conditions are relatively similar, a factor that facilitated a comparison. The cases are further described in Sec. IV.

The 16 remaining cases (case 3 though case 18) consist of single industrial firms that all produce unused excess heat as a by-product of their main production but are not currently part of any heat supply collaboration with the district heating sector. These 16 industrial firms vary in size and include many industries—pulp and paper, steel, chemical, hazardous waste, recycling, and bio-fuel. Table III provides the basic technical information for these 16 cases: the type of industry (branch), number of employees, amount of excess heat, and proximity to district heating grid. The amount of excess heat these companies differs—some produce very small amounts of excess heat and some produce very large amounts of excess heat. In addition, seven of the industries did not provide estimations of their excess heat production. A third of the industries are located a considerable distance from a district heating grid, which means that the remaining two-thirds of the industries have considerably better technical advantages to start with when it comes to heat collaboration with the district heating sector.

The study builds on interviews with relevant actors. For cases 1 and 2, respondents from the district heating company, the industrial firm providing the excess heat, and local authorities are represented. The selection of respondents, representing different businesses, captures both the industries' and district heating companies' perceived drivers and barriers of such a collaboration. To provide an understanding of the experienced drivers and barriers behind the development within the two cases, five respondents from each case were contacted—two respondents representing the industry in case 1 and one respondent from case 2 and two representing the district heating company in case 1 and three in case 2. One respondent represented the local authority from each case.

For cases 3–18, one respondent from each industrial firm is represented. All of the participating respondents for cases 3–18 have a broad knowledge of the company organisation combined with some form of environmental and/or energy responsibilities. The participating respondents are not identified by name. Analyses of the technical aspects have not been made within the framework of this study. Table IV presents number and types of respondents from each case.

The study builds on the two realised cases (case 1 and case 2). These cases gave input to the continued studies of the 16 industries (cases 3–18). The different cases complement each other by highlighting different aspects of the studied heat collaborations, both from the district heating companies' and the industrial firms' perspectives. The interviews, conducted via telephone during the spring and fall of 2012, were semi-structured. As a semi-structured interview is based on open-ended interview questions that allow respondents to speak freely on specific themes, it allows for follow-up questions that encourage the interviewees to expand on their responses (May, 2001). An interview guide with basic questions was formulated in advance.

TABLE II. Technical case description of case 1 and case 2 (investigated in 2012).

	Case 1	Case 2
On-going collaboration since	2006	1999
District heating company	Local authority owned	Local authority owned
Provider of excess heat	Paper mill. The heat is from the mill's bleach plant. The energy is used to heat nearby villas, apartment buildings, and several public buildings.	Carton board mill. The heat is from the mill's plant. The energy is used to heat nearby villas, apartment buildings, and several public buildings.
District heating grid	Owned by the energy company	Owned by the energy company
Amount of energy delivered	20 GW h/yr	87 GW h/yr
Energy balance (mill)	88% of the mill's combustion consists of renewable fuels. The remaining 12% is fossil-based fuels. Combustion of oil is only used at peak load.	95% of the mill's combustion consists of renewable fuels. The remaining 5% is fossil-based fuels. Combustion of oil is only used at peak load.
Energy balance (grid)	50% excess heat and 50% steam produced to raise the temperature of the excess heat	87% excess heat
Responsibilities for delivery guarantees	The district heating company is responsible for the delivery guarantees to customers and, if necessary, provides additional energy	The mill is responsible for the delivery guarantees to the district heating company and thereby obliged to compensate for loss of supply
Breakdown of investment costs	The district heating company is also responsible for the heat exchanger located at the paper mill	The district heating company is responsible for the pipes, and the mill is responsible for the heat exchanger inside the factory
Investment grant	A government investment grant called Klimp (climate investment program) was awarded to the district heating company and the municipality. They were granted approximately 16% of the total investment cost of the project.	A government investment grant called LIP (Local Investment Program) awarded to the district heating company and the municipality
Environmental effects	Decommissioning of several oil-fired boilers: approximately 2500 m^3 of oil have been replaced by the excess heat from the mill	A heat pump has been taken out of operation, resulting in a savings equivalent to approximately 4200 tonnes of Liquefied Petroleum Gas (LPG) and 200 m^3 of oil. Hence fossil fuel consumption has been reduced by 96%.

The first interview guide, used during the empirical data collection for cases 1 and 2, was based on conclusions from previous research that shows that financial incentives are important drivers behind these types of collaborations (Ehrenfeld and Gertler, 1997). In addition, organisational aspects such as embedded relations based on trust and personal ties (described as important aspects of a well-functioning collaboration (Uzzi, 1997)) were also included in the questionnaire. Preliminary results from cases 1 and 2 indicated that industrial firms were often unwilling to operate outside their core business. To account for this perspective, the interview guide used for cases 3–18 was redesigned. For all the cases (cases 1–18), the questions addressed perceived drivers and barriers behind excess heat supply collaboration between industrial firms and the district heating sector.

The choice of qualitative method and semi-structured interview studies has clarified the overall characteristics of the studied collaborations. This approach also contributed to a deeper understanding of the different stakeholders' active within the inter-organisational collaborations. The use of semi-structured interviews created good opportunities to gain a deeper understanding

TABLE III. Technical case description of the 16 industries: cases 3–18, investigated in 2012.

Industry/case	Branch	Number of employees, approximately	Amount of excess heat (MW h/yr)	Proximity to district heating grid
3	Chemical industry	70	No estimation from industry	Yes
4	Chemical industry	35	No estimation from industry	Yes
5	Recycling	25	200	No
6	Mining	20	No estimation from industry	No
7	Chemical industry	250	No estimation from industry	Yes
8	Biofuels	90	200 000	Yes
9	Paper mill	300	27 000	Yes
10	Mining	330	10 000	No
11	Paper mill	550	13 000	Yes
12	Manufacturing—industrial components	3000	No estimation from industry	No
13	Manufacturing—industrial components	20	No estimation from industry	Yes
14	Paper mill	190	330 000	No
15	Recycling and landfill	150	No estimation from industry	Yes
16	Manufacturing—building materials	45	62 000	Yes
17	Paper mill	630	600 000	Yes
18	Steel industry	215	95 000	Yes

of the respondents' answers by asking follow-up questions, which, in turn, contributed to this objective. A quantitative method would not have provided the same opportunities.

The interviews were recorded and transcribed. Except for inaudible sounds, repetitions, and other words or sounds from the respondents, the interviews were transcribed word-for-word. According to Kvale (1997), a transcribed interview can be seen as an interpretation by the person transcribing and as a way to make the information more manageable. The study of different cases was meant to capture the process behind the development of the excess heat-based district heating systems and thereby drivers and barriers for the development and the collaboration between the district heating company and the industry. In addition, this study examined written documents such as articles and reports.

The investigated key concepts—drivers and barriers—involve aspects of potential positive and negative consequences of collaboration. The drivers are the factors that encourage collaborations. A driver, for example, could be the potential for financial gain from the collaboration in the long term. Thollander and Ottosson (2008) argue that driving forces for increased energy efficiency are different types of factors that stress investments in technologies that are both energy efficient and cost effective. The barriers are the circumstances or obstacles that prevent collaboration. For example, a barrier could be significant investment costs; that is, barriers can be seen as the opposite of drivers (Thollander and Ottosson, 2008). Barriers, in this context, can be defined as "any factors that may account for the existence of the energy efficient gap" (Jaffe and Stavins, 1994).

TABLE IV. Number and types of respondents from each case: cases 1–18.

Case	Industrial firm	District heating company	Local authority	Total
1	2	2	1	5
2	1	3	1	5
3–18	1	0	0	1, for each case

The results from the interviews and the additional documentation are divided into themes that emerged from the interviews. These themes—financial, technical, and organisational—were identified by analysing the respondents' answers about the drivers and barriers behind excess heat collaborations. As mentioned, a combination of IS and a business model perspective has been used to analyse the results.

IV. RESULTS

Section IV contains results from the semi-structured interviews with all respondents from all 18 cases. The same section summarizes the results from the interviews and is based entirely on the respondents' own experiences and perceptions of the progress of each case. The results are presented according the perceived drivers and barriers in all 18 cases. The presentation of the results is based on the themes that emerged from the interviews.

A. Drivers and barriers

As mentioned, the results from the interviews in all 18 cases have been categorized into the three themes—financial, technical, and organisational. Subsections IV A 1–IV A 3 below present the results according to these themes.

1. Financial aspects

One respondent representing the district heating company in case 1 described the collaboration as effective when "both parties have something to gain." All of the respondents from cases 1 and 2 believed that an investment grant contributed to the project's relatively fast-paced development (Table II). In case 1, the respondents from the district heating company did not know whether they would have expanded the grid to the extent they did without the investment grant. According to one of the respondents, the investment grant led to a greater confidence to invest and expand than they perhaps would have done without it. The respondent from the local authority in case 2 summarized the situation as follows: "It would have been difficult to succeed in persuading the politicians to implement the project without the grant." The financial aspects behind the project have been strong drivers for all parties and all parties believed that the project had been financially profitable.

At the same time, the financial aspects of the developments in both cases were also important barriers. In case 1, respondents were concerned about the breakdown of the investment costs. One respondent from the mill described this concern as follows: "This is not our core business; we put our investments in improving our products, and we cannot start building district heating systems with our relatively small investment budget." This view is strengthened by the results from cases 3–18: financial concerns were the most common reason why the cases did not supply waste heat to a district heating grid. As one respondent noted, "the investment costs for the new technology required to heat the low-temperature water into the district heating grid is too high for it to be considered economically viable." All respondents noted that collaboration must be seen as economically viable before entering into any agreements.

One of the respondents from the district heating company in case 1, however, recalled that one representative from the mill stated the following condition: "You [the district heating company] have to take the cost and all risks if you are interested in our excess heat." Because both parties in case 2 were faced with significant financial investments to solve their initial problems, it seemed natural to share most of the investments. As the district heating company is a local authority-owned company and the project required a major investment, the decision had to be made by the local authority, the City Council. The respondents from the district heating company noted that they initially felt that it was difficult to convince the politicians of the financial sustainability of the project.

Another aspect that emerged during the interviews is the importance of a clear and transparent business agreement between the industry and district heating company. All respondents consider a good business agreement on equal terms as important for a development and long-

term sustainable excess heat collaboration with the district heating sector: "A good business agreement is when we get just as well paid what we deserve for our delivered excess heat. It must be done on our terms too, and not just on the district heating company's; they cannot just decide what to pay us." One of the respondents also believed that there may be factors other than financial that finally determine the decision to invest in a heat supply partnership. These can include environmental considerations, environmental profiling, and energy strategies: "These "softer" aspects can in some cases lead to the investment assessed differently in the end. In normal cases, we may have a payback period of 3 yr, but in this case, where one can count these reasons, perhaps we can extend the payback period to 5, 7, or 10 yr."

2. Technical aspects

Another identified precondition for collaboration dealt with technical issues. The necessary technical preconditions—such as heat demand, availability of technical solutions, and reasonable distance between the industry and the district heating grid—had to exist for both excess heat collaboration projects (cases 1 and 2) to be feasible. One of the respondents from the mill in case 1 noted this concern: "One reason that there often is a scepticism about this type of collaboration that involves connections to society, especially from the industries point of view, is that we are very afraid of breakdowns in the production […] if one is a large heat supplier to a society these stops can be very damaging […] then there must be a back-up system."

In case 2, the main technical barrier was securing permission from all landowners affected by the pipeline from the district heating company to the mill. One of the respondents from the district heating company described the barrier: "Some were very sceptical and had comments on the project. There were two who felt that the financial compensation was too low and protested, but eventually they gave in as well."

For five of the industries without on-going heat collaboration, the main technical barrier was identified as the absence of an existing nearby district heating grid (Table III). These five industries are all located outside urban areas. A lack of knowledge about the amount of excess heat as well as small amounts of excess heat are other technical barriers behind heat supply collaboration with the district heating sector. The fact that Sweden is a country with large seasonal temperature differences is described as another problem that complicates collaboration with the district heating sector: "We have a larger amount of excess heat during summer than we have during winter. We sometimes even consider buying heat ourselves during winter […] then we often use all excess heat within our own facility."

3. Organisational aspects

A clear business plan and mutual agreements are described as essential. One respondent from case 1 described the difficulties related to organisational aspects: "It is a lot about chemistry at the personal level; I believe that is very important […] that there are people speaking the same language and get along well." The same respondent also believed that one of the most basic preconditions is about "[a] willingness to do something innovative and daring—to go for something new." Yet another respondent claimed, "it is important that this type of collaborative project is channelled the right way through the company." The same respondent also concluded "it is often also that the top-management thinks that it is more fruitful to talk to someone at the same professional position who should not be ignored."

The basis for a well-functioning collaboration is described as an open relationship with mutual trust and understanding of each other's activities. This relationship should be based on honesty, willingness, an open mind, and a clear and fair business plan. One respondent in case 1 summarised his belief: "You have to be open and honest to each other. If you get the feeling that the other one earns more from the deal than you do yourself, it will not be good." Similarly, a respondent in case 2 concluded, "the same technical possibility has existed in many other places as well, but without being a success."

In case 2, the agreements about the financial issues are described as essential. Obviously, both parties must trust one another when dealing with financial responsibilities and rewards:

"From the energy company's side, they often see excess heat and think that it is just waste and something they should not pay for. The industry, on the other hand, sees it as prime heat that should cost full price. This difference places the energy company and the industry far from each other and often makes it hard for them to agree" (respondent, case 2).

For the respondents from cases 3 to 18 (cases without on-going heat collaboration), the perceptions of the importance of personal contacts and relationships in the development of excess heat collaborations differed. Some believed that personal contacts and relationships have no significance, but others believed that it might be significant. However, most of the respondents believed that personal contacts and relationships at a professional level are beneficial in terms of exchange of information. Some felt that transparency and openness contributes to a greater consensus and better understanding. However, this is also described as something that requires communication and sharing of information, a time intensive commitment.

Another respondent believed that personal contacts with anyone from the other company could provide insight into their business, leading to access of informal information: "It can be about anyone who knows of someone who might be of interest and thereby provides a valuable contact. In this way, information can be more easily available which also makes it easier to exchange information. It may as well be that important information can be missed out of without some more personal contacts." Another respondent put it this way: "It [personal contacts] could be important and have a relatively large impact. It may be about getting information that you would not otherwise have received." The respondents had varied opinions about who should initiate collaboration: some believed that the district heating company should contact potential industries and some believed that industries that have excess heat should initiate collaboration.

V. ANALYSIS AND DISCUSSION

Subsections V A–V D contain an analysis and discussion of the results based on previous research on drivers and barriers behind the development of IS collaborations. Through the use of parts of the canvas business model, the results are also analysed and discussed from a business model perspective. As mentioned, this study does not look into these elements in such a detailed form, it rather use the canvas model in a more general way in order to get a more generic perception of the business model perspective and how it contributes to a deeper understanding of the drivers and barriers behind the studied collaborations.

A. Success factors for collaboration

In both of the realised cases (cases 1 and 2), the collaboration on heat supply developed spontaneously. However, in case 1 the district heating companies had a more proactive role. They drove the development forward and had a clear vision of what they wanted to accomplish. The fact that the collaboration did not take off at the beginning of the development process could have been the result of the lack of a shared vision on common goals. In the beginning, the communication between the two parties was poor as the district heating company initially entered the business organisation hierarchy at the mill on the wrong level.

According to Albrechts (2006), interactions and exchanges of knowledge are important preconditions in the decision-making process. Exchange of knowledge through mutual participation is required in order to understand the goals and objectives and to translate these into practice. Initially, the mill from case 1 did not see any potential gains from collaboration. They only saw a number of potential risks by allowing the district heating company into their industrial park. However, when the right representatives from both organisations came into contact with each other, they started to share information. When they started to formulate common goals and objectives, the collaboration took off.

In case 2, the two parties had a common goal and a clear vision from an early stage of the collaboration. They both faced significant financial challenges, and they both had much to gain from the collaboration. There is a clear difference between how the collaboration within the two cases began. In case 2, the two parties were more equal in terms of driving forces behind

the project, so their collaboration quickly developed towards common goals. Chertow (2007) and Ehrenfeld and Gertler (1997) view this type of similarity in drivers and the timing of such needs as important aspects of collaboration. They believe that collaborations that evolve spontaneously and with common interests seem to be more durable and functional than collaborations that are planned. In addition, the significant financial investments in developed technology, established roles, new standards, continuous contact, and cognitive routines within the new widened system, as described by Geels and Kemp (2007), lead to the dynamic stability of systems.

B. Financial

The main drivers behind both collaborations in cases 1 and 2 have been financial, although the respondents also described environmental aspects as important drivers. The respondents from other cases (cases 3–18) expressed that financial issues can be both drivers and barriers behind collaboration on heat supply with the district heating sector. Nevertheless, all respondents consider the financial aspects as strong driving forces. For cases 1 and 2, the collaboration never would have taken place if it had not been financially viable. This view supports Ehrenfeld and Gertler's (1997) belief that financial driven actions are the main reasons behind IS collaborations. Applying a business model perspective further shows that the financial aspects are strong drivers when it comes to inter-organisational business collaborations (Osterwalder and Pigneur, 2010).

Potential financial benefits for the district heating companies include access to cheap energy. For the cases studied in this article, the heat certainly is waste for the industrial firms, yet it is also an important resource for district heating companies. As for the financial conditions, it is not given that the industry should finance the construction associated with extracting heat from its premises. Case 2 is a good example where the industry and district heating company split the costs. However, the district heating company that financially invested the most was also assigned the largest share of the profit. Case 2 is a good example of when the potential financial risks reflect the potential benefits of collaboration. The breakdown of investment costs is another financial aspect that needs to be addressed. For example, it is not obvious how the investment costs should be allocated between the parties. It is important that the financial risks and investments reflect the potential benefits of the collaboration.

From a business model perspective, sufficient financial resources are required for any collaboration to develop (Osterwalder and Pigneur, 2010). This economic reality and the fact that the respondents identified financial aspects as important suggest that public investment subsidies could encourage heat supply collaborations.

C. Technical

Concerning the technical conditions for some of the industries (3–18), the absence of an existing district heating grid is seen as a significant technical barrier. These types of technical preconditions can be described in terms of technical key resources necessary for development (Osterwalder and Pigneur, 2010). However, an existing district heating grid does not necessarily have to be a precondition. In case 1, the supply of heat from the local paper mill was the basis for the development of the new district heating grid. Case 14, which also is a paper mill, lacked access to an existing district heating grid, but the mill produces a large amount of excess heat. Assuming that there is a demand for heat in the surrounding area, it might be interesting to investigate the opportunities of developing an excess heat-based district heating system as in case 1. According to Osterwalder and Pigneur (2010), the financial drivers of these cases could overcome the lack of essential technical key resources.

The other four cases—5, 6, 10, and 12 (Table III)—also lack access to an existing district heating grid; however, these cases produce considerably less excess heat, perhaps making them less suitable as heat providers. Another example of a technical barrier is found in case 4. Case 4 produces an excess of 230 MW h/yr, and does not consider heat supply collaboration with the district heating sector to be a viable idea because of their small amount of excess heat. In these cases, it is likely that the financial drivers do not overcome the technical barriers, essential

technical key resources (Osterwalder and Pigneur, 2010). This designation, however, does not mean there could not be another use for the excess heat from this specific industry. Because seven of the cases could not provide information about the size of their excess heat production (Table III), it is difficult to say anything about the potential of these industries. The cases that can be identified as having the best technical preconditions or best technical key resources (Osterwalder and Pigneur, 2010) for developing heat supply collaborations with the district heating sector are cases 8, 9, 11, 16, 17, and 18. All of these cases have a relatively large excess of heat, from 13 to 58 GW h/yr (Table III). In addition, they also have access to an existing district heating grid.

D. Organisational

In addition to the basic financial and technical preconditions, organisational preconditions are necessary for collaborations to overcome the main barriers. Previous research on embedded relations based on trust and personal ties are described as important aspects of a well-functioning collaboration (Boons and Baas, 1997; Gibbs and Deutz, 2007; and Uzzi, 1997). Both cases met the characteristics of an embedded network of collaboration involving the three features identified by Uzzi (1997): trust, joint problem solving, and fine-grained information transfer. Our results support Uzzi's theory that these three features along with honesty and shared visions on common goals are important for developing well-functioning collaborations.

Uzzi (1996) further noted that companies and organisations involved in embedded networks that exhibit these three features tend to have a greater chance to gain advantages compared to other forms of governance. Such collaboration can provide positive financial and environmental outcomes for the organisations involved as well as for the community as a whole (Burström and Korhonen, 2001). As in the previous study by Uzzi (1997), all our respondents noted that these three features, along with honesty and shared visions on common goals, made it possible to overcome both financial and technical barriers. In addition, collaborations involving actors with exchanges of resources and shared goals are regarded as the best way to achieve common interest (Börzel, 1998). Therefore, a better understanding the social mechanisms that shape the decision-making process of companies and relevant actors such as policy makers will encourage and improve sustainable industrial systems (Doménech and Davies, 2011).

These organisational conditions have also been important when it comes to the financial issue concerning investment grants in cases 1 and 2. In both these cases, all respondents believed that the investment grant was important for developing collaborations. Some respondents even believed that development would not have happened without the investment grant. Both the Local Investment Program (LIP) and the Climate investment program (Klimp) (see Table II for an explanation) are based on collaborations between different actors in the community to improve environmental performance: LIP promotes measures to increase ecological sustainability and Klimp promotes long-term investments to reduce greenhouse gas emissions and to increase local participation and initiative. It is the local authority that is responsible for the program and its implementation (Swedish Environmental Protection Agency, 2012). Clearly, the goals of the LIP and Klimp require well-functioning collaborations.

When it comes to fine-grained information, cases 1 and 2 both show that effective communication, exchange, and integration of knowledge are crucial. In case 2, the respondents noted that they had been working closely together through continuous discussions to learn about each other's businesses. The information transfer between the actors involved resembles a feedback loop between the realm of knowledge and the surrounding environment (Peschl, 2007) The feedback loop of learning between the actors involved in each case made it possible for them to learn about each other's businesses and to see outside their own system's boundaries (Peschl, 2007). This new perspective led to a greater effectiveness and environmental and financial gains for the companies involved as well as for the society at large. Collaboration in terms of interaction and exchange of knowledge are important preconditions in the decision-making process (Albrechts, 2006 and Boons and Baas, 1997). These conditions are also important for building

trust and shared visions on common goals, interactions that require time and frequent contact (Doménech and Davies, 2011). Knowledge through the participation of relevant stakeholders is required to understand common goals and objectives and to translate these into practice (Albrechts, 2006).

Personal and emotional relations have also shown to be important for the excess heat supply collaboration in the two cases (cases 1 and 2). All respondents noted that personal and emotional relationships played an important role in the collaborations. The importance of these relationships is particularly evident in case 1: the district heating company initially came into contact with the wrong representatives from the mill and this led to misunderstandings and a delay in collaboration. This poor communication resulted in the management feeling insulted, so the professional relationship was damaged before the project even started. As Doménech and Davies (2011) noted, good personal relationships in business are extremely important.

As for joint problem solving, shared visions and goals (cf. Domenech and Davies, 2011 and Baas and Boons, 2004) were important for the development of embedded collaborations based on trust. Domenech and Davies (2011) further concluded that embedded relations develop opportunities for more risky and innovative projects.

The not yet realised collaborations (cases 2–18) would probably benefit by developing a joint strategy before a business agreement concerning the value of both parties is developed. For these cases, the organisational preconditions are primarily about well-functioning communication along with a business agreement that benefits both the industrial firms and district heating company. According to the canvas model, each one of the involved parties must first have a clear idea of what it wants to achieve by collaborating, a prerequisite for a business agreement to develop on equal terms (Osterwalder and Pigneur, 2010).

In the case of trust, it was important to show humility with respect to the other partner's business from the beginning so that both parties felt equally important to the success of the project. This seems to be especially important for the energy companies, as heating issues do not belong to their core business. Acknowledging the right pricing of the excess heat and not seeing the heat as a free good should be central for these business agreements. This understanding means that both parties, the district heating company as well as the industrial firm, need to develop a business agreement where they both are able to generate profits from selling and buying the excess heat. Information sharing and collaborative efforts are the two major concerns in enabling these kinds of supply chain performance between companies (Uzzi, 2007). It is important to take these aspects into account early in the process, as they are crucial to how the collaborations eventually develop. The role of trust in building and realizing a well-functioning collaboration has been widely recognized (Chertow *et al*., 2008; Gibbs, 2003; Hewes and Lyons, 2008; and Jacobsen and Anderberg, 2005).

To develop a business agreement on equal terms, each of the involved parties' individual business plans is important as these plans constitute important building blocks for the joint business agreement (Osterwalder and Pigneur, 2010). It is important that the joint business agreement is clear about what is expected from the parties involved in the collaboration and the conditions under which it is applicable (Osterwalder and Pigneur, 2010). For the cases in this study, this would mean that a clarification of the financial risks and potential benefits would be important at an early stage of the process so a mutually beneficial agreement on the allocation of the investment costs could be determined. The results show that these issues are especially important for industries to be willing to enter a partnership for excess heat exchange, as excess heat exchange does not belong to the core business of the industries. The heat certainly is a waste by-product for the industry, but at the same time it is an important resource for the district heating company. Therefore, it should also be priced accordingly. The energy company in case 2 believed that this is a key issue for gaining and maintaining the trust. The respondents believed that it was important to be open about what they gained from the collaboration and to price the heat accordingly. It is also important that all parties within the collaboration are open about their financial gains, as the role of trust in building and realising well-functioning collaborations has also been widely recognised (Chertow *et al*., 2008; Gibbs, 2003; Hewes and Lyons, 2008; and Jacobsen and Anderberg, 2005).

Honesty, which is one of the two features described as the basis for a well-functioning collaboration within the framework of this study, is identified as an important aspect of trust, which in turn leads to both parties having the courage to invest in these types of inter-organisational collaboration projects. Shared visions on common goals, which is the second important feature identified in this study, have proved to be of great importance in the beginning of the development process. Without a shared vision on common goals on equal terms, there is a risk of failure. This understanding is an important lesson because often one actor is more proactive than another actor. This difference, as in case 1, may lead to the more proactive actors making their own visions and goals, a situation that could result in the loss of important knowledge. In addition, this inequality in collaboration could make an actor feel undervalued, further exacerbating communication issues.

Much of the previous research within the field of IS supports our results by highlighting the importance of certain organisational conditions (Uzzi, 1997; Domenech and Davies, 2011; Chertow *et al*., 2008; Gibbs, 2003; Hewes and Lyons, 2008; and Jacobsen and Anderberg, 2005). Additionally, previous social science research also highlights organisational conditions such as participation, communication, exchange of knowledge, understanding, trust, and problem solving as important for well-functioning inter-organisational collaborations (Börzel, 1998; Powell, 1991; Kenis and Schneider, 1991; and Volpe and Cannon-Bowers, 1996). However, the results from this study show that the parties involved in the collaborations are largely controlled by the substantial financial investment associated with the technical solutions. As mentioned, it is often the financial aspects that are the main drivers behind the development of collaboration projects (Ehrenfeld and Gertler, 1997). However, these substantial financial investments are also barriers. Based on this, we believe investment subsidies can encourage investments and help all parties involved see the long-term benefits of collaboration.

VI. CONCLUSIONS

This study confirms that trust, joint problem solving, and fine-grained information transfer are important elements in the development of collaborations. In addition, the results from this study complement and clarify these three features by adding honesty and shared visions on common goals as important for the development of well-functioning collaborations. All these features have proved to be central in the decision-making process for joint collaboration projects where knowledge through participation of stakeholders is required to understand the common goals and objectives and to translate them into practice. Financial aspects are the main drivers and the main barriers both when it comes to the emergence and development of long-term sustainable excess heat supply collaborations.

By combing IS and the business model perspective with the actors' perspectives, our study has focused on collaboration as an interaction across business boundaries. Table V highlights how the different perspectives used complement each other and in which ways they contribute to the analysis. This summarising table (Table V) shows important preconditions behind the development of heat supply collaborations, both from an IS and a business model perspective.

The canvas model has proven to be a useful analytical tool that complements the IS perspective. The business model perspective has led to an increased understanding of the interactions for higher durability. As shown in Table V, supplementing IS theory with a business model perspective has generated an increased understanding of important factors behind the fundamental cornerstones that form the basis of a business agreement between actors. While the IS perspective identifies and recognises a phenomenon, the canvas model identifies underlying important factors behind the development of the business arrangement, which has shown to be an essential factor behind the development of inter-firm heat supply collaborations. The analysis has thus strengthened the knowledge of the important drivers and barriers behind the emergence of collaboration and thus has further verified the analysis of the results. In addition, the canvas model has also contributed more in-depth knowledge concerning basic components that contain a company's business model as well as knowledge of important drivers and barriers from the companies' and organisations' perspectives.

TABLE V. Preconditions from both an IS and a business model perspective and divided into the three themes: financial, technical, and organisational.

	Financial	Technical	Organisational
IS perspective	• Financial gain is an important driver • Investment subsidies can be important for the development	• Technical conditions are important. A technical barrier, however, can be overcome with certain financial or organisational conditions.	• Important that the collaborations are not top-down • The business agreement is of great importance • Personal relationships are somewhat important
Business model perspective	• Profitable business agreements are an important pre-condition • Investment subsidies can be seen as an important key resource	• Technical conditions can be seen as important key Resource	• The business model structures the business agreement • The joint business agreement should be clear on what the agreement is about, what is expected from the parties involved in the collaboration, and the conditions under which it is applicable • Personal relationships are somewhat important

What also makes this study interesting is that by focusing on only one exchange it examines in more detail the factors behind the emergence of the collaboration. This focus makes a large portion of the findings from this study useful for other studies where inter-organisational collaborations across business boundaries are central. These other studies may involve exchanges of other resources or more complex clusters of numerous companies involved in collaboration. The results from this study could therefore be used to improve the understanding of important success factors for other forms of collaboration as well. As a next step for future research, it would be interesting to apply this model to empirical data with a greater focus on the formation of the business agreements.

Although this study was conducted in Sweden during the current Swedish conditions, the results should still be applicable even in an international context. The findings on central drivers and barriers should be applicable on inter-organisational collaborations both where the prerequisites for similar types of collaborations between industry and district heating sector occur, as well as for other types of inter-organisational business collaborations concerning other exchanges except excess heat.

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