Barriers to and enablers of district cooling expansion in Sweden

Palm, Jenny; Gustafsson, Sara

Published in:
Journal of Cleaner Production

DOI:
10.1016/j.jclepro.2017.10.141

2018

Document Version:
Peer reviewed version (aka post-print)

Link to publication

Citation for published version (APA):
Palm, J., & Gustafsson, S. (2018). Barriers to and enablers of district cooling expansion in Sweden. *Journal of Cleaner Production*, *172*, 39-45. https://doi.org/10.1016/j.jclepro.2017.10.141

Total number of authors:
2

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Barriers to and enablers of district cooling expansion in Sweden

Jenny Palm[ab]*
[a] Lund University
International Institute for Industrial Environmental Economics (IIIEE)
Box 196
SE- 221 00 Lund, Sweden
+46 (0)46 2220242
Jenny.palm@iiiee.lu.se

[b] Linköping University
Department of Thematic Studies – Technology and Social Change
581 83 Linköping, Sweden
+46 13 285615
jenny.palm@liu.se

*Corresponding author

Sara Gustafsson
Linköping University
IEI/ Environmental Technology and Management
581 83, Linköping
Sweden
Sara.gustafsson@liu.se
+46 13 28 66 02

Barriers to and enablers of district cooling expansion in Sweden

Highlights

- District cooling (DC) growth can benefit from increased inter-actor collaboration.
- A barrier to DC expansion is that information is not adapted to broader audiences.
- DC pricing is not transparent and is perceived as “black-boxed”.
- DC business models need to be developed.

Abstract

Although Sweden is a northern country with fairly low outdoor temperatures most of the year, its district cooling (DC) systems are expected to expand. Some actors claim that there is potential for at least a doubling of DC in Sweden. One reason for this is that demand for cooling increases with the increased use of electronics such as computers, resulting in higher indoor temperatures from waste heat production. Although DC should have considerable growth potential based on its convenience and climate benefits, its growth has been surprisingly slow.

This article discusses the barriers to and enablers of DC expansion. We examine how energy companies, property owners, and tenants perceive the barriers to and enablers of installing and using DC. How do these actors view the present and future need for cooling? What would make DC more attractive according to these actors? These questions were studied using surveys and in-depth interviews.

The results indicate that lack of information is the most important current barrier to DC expansion, a barrier that could easily be addressed, making information an enabler of DC. Earlier grid-based energy systems in Sweden were established through public–private collaboration, and such collaboration could promote the ongoing expansion of DC. For example, municipalities played an important role when district heating was built, but this has not been the case for DC. Another possible enabler is the eco-labelling of DC, which has so far played a minor role in the Swedish system.

Keywords: District cooling, Barriers, sustainable energy, Large technical systems, Urban

1. Introduction

The increasing temperatures accompanying climate change and the greater use of electrical equipment that produces waste heat will together increase the need to cool indoor environments such as shops, offices, industrial facilities, and hospitals in order to maintain comfortable indoor temperatures (Fahlén et al., 2012; Rodriguez-Aumente et al., 2013; SOU (Swedish Governments Official Reports), 2007; Werner, 2016). This applies not only to countries in warmer areas, but also to those in the northern hemisphere. Although Sweden is situated in a geographic zone where, most of the year, the outdoor temperature is relatively low, cooling has become an issue (SOU (Swedish Governments Official Reports), 2007; Werner, 2004). There are various technologies for cooling premises, among which district cooling (DC) has been identified as effective for reaching overall strategic energy goals (EU Directive 2009/28/EC; Gang et al., 2016a). This paper considers the enablers of and barriers to the expansion of DC, based on the Swedish experience.

The first known DC systems were built to serve the Rockefeller Centre in New York and the U.S. capital buildings in Washington, D.C. in the 1930s. The expansion of DC in Sweden took off in the early 1990s (Abrahamsson and Nilsson, 2013) and today there are about 30 DC-producing energy companies in the country. DC delivery in Sweden increased by 63% between 2004 and 2015, with around 1 TWh of DC being delivered in 2015 (vs. around 55 TWh of district heating delivered per year) (Svensk fjärrvärme, 2015, 2016). DC can be produced in various ways, for example, using compression chillers, absorption chillers, or deep lake water cooling. Earlier studies on DC focus mainly on technical aspects of the system and for example the latest major comprehensive review article (Gang et al., 2016b) about DC do not include a customer perspective. Here we do not analyse DC technologies, but rather consider the various aspects and preconditions for expanding the use of DC as such. Few residential or other buildings in Sweden use this type of cooling system, and as the cooling of premises seems to be the main DC market in Sweden (Abrahamsson and Nilsson, 2013), this study will focus on premises.

DC systems in Sweden, as in Europe, have considerable expansion potential, and a doubling of the Swedish DC capacity in the near future is often said to be realistic (Svensk fjärrvärme, 2016; Werner, 2016). Various development paths support an increase in the demand for cooling. DC is generally regarded as sustainable, especially when it replaces electricity-based cooling (see e.g. Ameri and Besharati, 2016; Fahlén et al., 2012; Gang et al., 2015; Lake et al., 2017; Werner, 2004; Werner, 2016). Although DC should have expansion potential based on its convenience and climate benefits, its growth in Sweden has been surprisingly slow.

The overall aim of this paper is to discuss the barriers to and enablers of DC expansion. The results are based on the Swedish experience, though we will address these issues in a wider context as well. In this paper, we will examine how energy companies, property owners, and the tenants of premises perceive the barriers to and enablers of the installation and use of DC. How do these actors view the present and future need for cooling? What would make DC more attractive according to these actors?

2. Theory: large technical system and barriers

In Sweden, state and municipal governments have traditionally been key actors in building and operating major public works systems, such as water and sewage, electrical, and district heating (DH) systems. One frequent argument for this has been that the profits from such enterprises should not accrue to private interests, but rather benefit the Swedish citizenry, for example, in the form of lower tariffs. This is also one reason why most DH companies were run as municipal services up until the 1980s (Palm, 2006). Over the last 25 years, most of these services have been converted into municipal corporations. Most Swedish DH corporations are still under municipal ownership, although there has been a trend towards increased privatization in the DH industry (Magnusson, 2012; Magnusson and Palm, 2011).

DC is similar in many ways to DH, as it involves the centralized production and distribution of energy, but in the form of cooling. In DC, chilled water is delivered via underground pipelines to cool the indoor air of buildings within a district. Each building connected to the system has a heat exchanger, which uses the chilled water to lower the temperature of air passing through an air conditioning system (Werner, 2004). In Sweden, a big difference between the systems is that DH is well established, widely distributed, and regulated by law, while DC is a more recently introduced concept still in an expansion phase. Furthermore, over the years, several governmental investment programmes have contributed significantly to the pace and extent of DH expansion in Sweden (Byman, 2004). Municipalities in collaboration with local energy companies have played a key role in this (Palm, 2004; Summerton, 1992). So far, there have been no similar initiatives to promote DC expansion. This makes DC interesting to study from the perspective of the enablers of and barriers to introducing new large technical systems in a country.

The development of infrastructural systems such as DC has often been analysed through the lens of the large technical system (LTS) framework. This framework, developed by Thomas B. Hughes (Hughes, 1983), has mainly been used to analyse the establishment of systems in phases, i.e. the invention phase, expansion phase, technological transfer phase, and, finally, the momentum phase, when a system acquires autonomy from its environment and becomes difficult to change. This study focuses on the expansion phase.

Large technical systems can be viewed as natural monopolies. What characterizes a natural monopoly is that one firm can supply a market's entire demand for a good or service at a lower price than two or more firms. In a DC system it is for example more cost effective for an existing DC company to expand its operations than it is for a new company to establish itself in the same area. The entrance of yet another company into the local market does not have the healthy regulatory effect associated with an optimal competitive situation (Palm, 2007). The DC industry's character as a natural monopoly implies that there is room for only one company within a geographically delimited area. In DC, it is the *distribution* of chilled water that is considered to constitute a natural monopoly; the *production* of chilled water could, in theory, be open to competition. The ideas about where competition can and cannot work in DC (and DH) is ongoing discussions among policymakers and practitioners and how the arguments develops dependence where, who and when a discussion takes place. Customers who choose DC today are referred contractually, technically, and financially to a single seller, so that DC also exerts a certain "lock-in" effect. Changing cooling sources is an option, but the costs associated with such a switch make it financially infeasible or, in any event, difficult to accomplish, which is why there is a lock-in effect.

DC can at the same time sometimes be viewed as a near monopsony, as the market may effectively comprise only one customer for whose business the sellers must compete (Jonsson, 1999). One example in relation to DC is that, for example, a hospital can have such a dominant role that the seller's financial situation is dependent on retaining it as a purchaser of DC. The DC company's bargaining chip in this context is, of course, its power to shut off the supply of DC (Palm, 2007).

From earlier research into grid-based systems (e.g. gas, DH, electricity, railways, and broadband) we know that there are five key issues to be solved when establishing a new large technical system:

- technical uncertainties concerning, for example, the risks of the technology in terms of, for example, reliability and interference with the environment and plant life;
- inertia in the system, meaning that it takes time from system initiation until the system is ready for use; The distribution grid has a lifespan of up to 100 years. If doubt occurs about the system's expansion potential, that will be one of the major threats to the system.
- economic conditions characterized by large initial investments in production and distribution facilities and the significant uncertainty of future profitability;
- the organizational form of the business and, in particular, the question of whether cities should be responsible for construction and operation or should transfer the systems to private contractors; and
- the legal relationship between supplier and customer. There is substantial uncertainty about subscriber behaviour and there are strong interdependencies between subscribers and their suppliers. Summerton (Summerton, 1992) has demonstrated the importance of having a major customer on board when initiating a grid system. Historically, municipally owned housing companies in Sweden have played a major role in ensuring an initial market for district heating.

These five issues apply to more or less all grid-based supply systems. From barrier theory, it is possible to identify and specify further hindrances to the establishment of DC.

2.1 Barriers and enablers relevant to DC

When barriers are discussed in relation to energy efficiency, and in this context a barrier is defined as a postulated mechanism that inhibits investments in technologies that are both energy efficient and economically efficient (Sorrell, 2004; Sorrell et al., 2000; Thollander et al., 2010). Here, we will examine some of the barriers that can be relevant to the expansion of DC, barriers that, when addressed, have the potential to give rise to enablers.

Information imperfections: A large body of research states that consumers are often poorly informed about market conditions, technology characteristics, and their own energy use. The lack of adequate information about DC can mean that DC is not even on the decision agenda. Information does not always receive as much attention as warranted, because people are often not active information-seekers but rather selective about attending to and assimilating information. Research identifies some characteristics of how information is assimilated; some people, for example, are more likely to remember information if it is specific and presented in a vivid and personalized manner and comes from a person similar to the receiver (Aronson and Stern, 1984; Gyberg and Palm, 2009; Palm, 2010).

Insufficient information is one information imperfection. Another is excessive cost of information, here referring to the costs associated with searching for and acquiring information about DC. Yet another form of information imperfection concerns the accuracy of information, meaning that the information provider may not always be transparent about the product being offered. Information imperfections are likely to be most serious when the product is purchased infrequently, the performance characteristics are difficult to evaluate either before or soon after purchase, and the rate of technology change is rapid relative to the purchase intervals (Sorrell et al., 2000). Issues related to information imperfection may be countered with various information campaigns that, if conducted properly, can enable DC.

Another factor that may inhibit DC adoption is the perceived credibility of and trust in the information provider on the part of the receiver. Energy users cannot always easily obtain accurate information about the ultimate comparative cost of different investment options; they must rely on the most credible available information (Thollander and Palm, 2013).

Split incentives: A split incentive may occur when the potential adopter of an energy-efficiency investment is not the party that pays the energy bill. If so, information about available cost-effective DC in the hands of the potential adopter may not be sufficient; adoption will only occur if, for example, a tenant can recover the investment from the real estate owner (Jaffe and Stavins, 1994). This aspect of the landlord–tenant relationship restricts the adoption of energy-efficient technologies, particularly those with higher initial costs but lower lifecycle costs than conventional technologies (Hirst and Brown, 1990).

Hidden costs: Hidden costs include the high costs associated with information-seeking, meeting with sellers, writing contracts, and other activities (Thollander et al., 2010).

Limited access to capital: Investing in DC can be more expensive than investing in other technologies. Moreover, low liquidity and limited access to capital may also be problems, and sometimes such restrictions may be self-imposed (Palm and Thollander, 2010).

Risk: Even though, for example, managers may know the capital cost of an investment, uncertainty about the long-term operating costs means that the investment still poses a risk. Such concerns have been found to be very important to decision-makers (Hirst and Brown, 1990). It can be difficult to accurately estimate the net costs of an energy-efficiency investment, which depend on future economic conditions in general as well as on future energy prices. Energy prices have fluctuated as long as there has been a market for energy, leading to perceptions of uncertainty about future prices. Studies among small and medium-sized enterprises have found that some may even be unable to reduce this uncertainty to a calculated risk due to a lack of time and money to make the required estimates (Aronson and Stern, 1984).

Bounded rationality: Another explanation of why cost-effective energy-efficiency measures are not undertaken is bounded rationality (Simon, 1957). Organizations, like individuals, to some extent do not act on the basis of complete information but rather make decisions according to rules of thumb (Sanstad and Howarth, 1994).

Below, we analyse which of the above barriers the studied actors believe are central to the expansion of DC. First, we will provide an overview of the methods used to collect data.

3. Method

The paper is based on an explorative study, and takes its point of departure in experiences of DC in Sweden. The study was carried out in 2015–2016 in two steps. The purpose of the first step was to gain insight into various actors' attitudes or approaches to DC. To obtain this insight, interviews were performed with representatives of energy companies, municipalities, and national real estate owner organizations. The main themes of these initial interviews concerned the (potential) market for DC, customer demand for DC, and the DC technology used.

Reflections on the results of the first step were fed into the second step, in which we developed and sent an online survey to around 900 members of a national real estate owner organization. In total, 176 responses were received, for a fairly low response rate of 20%. One reason for the low response rate could be that that many potential respondents simply did not know enough about DC, which we also observed in the interviews (we return to this point below). Lack of relevant knowledge may have caused them to put the survey aside. We nevertheless think that the survey identifies certain tendencies in the perceived barriers to and enablers of DC in Sweden. We also triangulated the survey results with those of the interviews conducted both before and after the survey, increasing the reliability of the overall results (Yin, 2009). The survey asked respondents about the following topics: type of premises owned, assessment of their indoor comfort, need for cooling, type of cooling used, opinions about DC, and why DC is or is not used.

The same themes were addressed in a second round of interviews, though the interviews let us obtain more in-depth responses to the themes. In total, we conducted 42 interviews in this step, interviewing representatives of six municipalities, eight energy companies delivering DC, five umbrella organizations for real estate owners, one umbrella organization for energy companies and one for businesses, 14 real estate owners, and six corporate tenants. We have anonymized the respondents and, when quoting interviews, refer to them as follows:

- municipality: M (1, 2, etc.),
- energy company: EC (1, 2, etc.),
- umbrella organizations for real estate owners: UREO (1, 2, etc.),
- umbrella organization for energy companies: UEO,
- umbrella organization for businesses: UB,
- real estate owners: REO (1, 2, etc.), and
- tenants: T (1, 2, etc.).

The interview and survey results were compiled and categorized before analysis. The results were validated in two workshops with practitioners, one with energy companies that produce DC and one with real estate owners.

4. Results and discussion

Earlier research identified five key issues as important to address for the successful establishment of grid-based systems, for example, technical uncertainties, economic conditions, and the legal relationship between suppliers and customers. Historically in Sweden, these key issues have been dealt with through collaboration between the government/municipalities and public or private companies. However, this has not been the case for the introduction of DC in Sweden, which has mainly concerned energy companies. When asking the municipal representatives about their lack of engagement in DC, their answers indicate a lack of knowledge of DC in municipal administrations and that DC is simply not on local authority agendas (Interviews M1 and M2). One municipal representative did say, however, that DC might become of increased interest to the municipality in the near future. Many local responsibilities, such as elderly care premises, already need cooling systems, and DC could play a much more important role in these premises than it does today (Interview M1). We also find that DC has found its way into two local energy and climate strategies. In Sweden, local energy and climate strategies are developed is a political document, adopted in the city council, which guide local authorities when managing the local energy system (Fenton et al., 2015; Gustafsson et al., 2015). Hawkey et al (2013) also show the importance of supportive local policy framework when establishing district heating and cooling in the UK. Thus, that DC is beginning to be included in local energy and climate strategies may indicate an increase importance for the system in the future.

One interviewed real estate owner said that the development and expansion of DC grids should be a municipal responsibility or interest (REO6). The energy companies also noted the importance of expanding the DC grids so that they can connect more buildings, making it easier to negotiate costs, etc. (EC1, EC4). Currently, one of the represented energy companies does not actively promote DC to new customers, but only discusses it with potential customers who make contact. In this case, the active involvement of local authorities, for example, would be needed to expand the system further.

The four energy companies in the studied municipalities justified their investment in DC in several ways. The energy companies already produce DH and have excess heat in the summer that could profitably be used to produce cooling. In Sweden, the DH market is stagnant and the energy companies see the opportunity to offer their customers DC as a way to retain their DH customers. The energy companies found that it was difficult to find profitable DC solutions: initial investment costs are large and DC is more expensive to produce than DH. One energy company representative said that it takes at least 15 years before profits are earned from DC (Interview EC1). All companies seem to have used the same strategy of starting at a small scale and letting expansion happen organically over time. At the same time it seems like the view from the energy companies are that the small start with organic growth has made DC more expensive compared to if the DC had started with a more extensive system in mind where potential future customers were approached and contracted early. Then the DC could have benefit from economies of scale already in the establishment phase.

As discussed above, large technical systems are often natural monopolies, and we discussed this aspect with the interviewees in relation to DC. The energy companies did not perceive DC as a monopoly market in the same way as the DH market, because they needed to compete with existing individual cooling systems every time a new deal was discussed. DC is an immature market in Sweden, meaning that the prices are not fixed but are negotiated individually with the customers depending on “how much cooling the customers want, what they need, what the alternative price is, and what we can offer” (Interview EC1).

The lack of fixed prices also means that a contract could take years to negotiate (Interview EC3). The customers easily understood DC as a monopoly, and several cited lock-in effects as a reason why they did not want to connect to the DC system.

As mentioned above, large technical systems can develop into near monopsonies if there is one dominant customer that buys a large share of the supply. From our material, it is clear that large customers that buy a lot of cooling are more satisfied than are small customers. The large customers also feel that they have been able to influence their contracts, something that the small customers could not do. The representative of one major real estate owner stated that they could negotiate the purchase contract with the local energy company, meaning that the price could be set in favour of the real estate owner: “I know that we pay much less than other customers do, because we issued an ultimatum to the provider” (REO2).

Still, in none of the studied cases did a single customer completely dominate the market; rather, several larger customers were all able to influence factors such as price and service levels.

4.1 Barriers to DC

The survey of real estate owners found divergent results regarding the importance of cooling their premises: about half of them thought cooling was important, while half considered cooling less important than heating or unimportant. However, most of them (82%) cooled at least some of their premises, compression chilling being the most common cooling method, followed by free cooling. Just over one third of the respondents believed that the demand for cooling would increase in the future, while 20% thought that the demand would remain stable. Only 2% foresaw decreased cooling demand.

Of the 176 survey respondents, only 15 have installed DC. The main reasons for choosing DC were a need for cooling along with that it was deemed a maintenance-free system (because other actors handle servicing, etc.) (see Table 1). Other reasons for using DC were that investment costs perceived as reasonable and it provides a good indoor environment (e.g. silent operation and good indoor climate control).

Reasons for installing district cooling	No. of answers
Need for cooling	8
Convenient maintenance	7
Reasonable investment costs	5
Gives good indoor climate control	4
Silent operation	3
Value for money	2
Easy to install	2
Low operation costs	2
TOTAL NO. OF ANSWERS	**33**

Table 1. Survey responses regarding reasons for installing district cooling (note that it was possible to give more than one answer to this question).

In the follow-up interviews to the survey, most respondents confirmed that they had installed DC in response to tenant demand and that they observed increased demand for cooling in general, especially in shops where lighting produces excess heat and warmer indoor temperatures. The interviewees all emphasized the environmental advantages of DC and its user-friendliness (e.g. no need for users to conduct system maintenance) as main arguments for installing it.

Most respondents in the real estate owner survey said that they did not use DC in their premises. Their reasons varied greatly, though the most common reason for not using DC was the lack of a grid (see Table 2).

Reasons for not installing district cooling	No. of answers
No district cooling grid	40
Requires significant building adaptations	14
High investment costs	13
Lock-in effect	12
Flexible operation costs	11
Uncompetitive pricing	10
Fixed operation costs	9
Maintenance is demanding	1
TOTAL NO. OF ANSWERS	**110**

Table 2. Survey responses regarding reasons for not installing district cooling (note that it was possible to give more than one answer to this question).

The high cost of adapting existing buildings in order to install DC was the second most common reason for not choosing DC (also compare Gang et al., 2016a). Some respondents mentioned the lock-in effect as a reason for not installing DC, as they did not want to be dependent on a single supplier. This reason was also discussed in an interview with a customer who needed a lot of cooling and was highly dependent on it for their business. The local energy company could not guarantee that it would meet the cooling demands of the company (in terms of amount of cooling and timeliness of supply), which led to one part of the company being cooled with DC while the other, more sensitive part was cooled using a local cooling system (Interview REO14).

Lack of knowledge was also mentioned as a reason for not investing in DC (Table 2). When it comes to *information* about DC in Sweden, the available information is technically oriented. Customers that have energy managers or personnel dedicated to working on DC can relate to such information and understand how to interpret it. Small customers without this competence struggle to find information that makes sense to them. These customers have a difficult time understanding the technology and assessing the environmental impact of the system, and must therefore trust that the supplier is giving them accurate information. In Sweden, it is difficult to find objective information on DC, i.e. information disseminated by a party not producing or distributing DC. We quickly noted that it was difficult even to find informants who were able to answer our questions. Many simply said that they did not know anything about DC or only had a vague idea of what it was. Even the question of whether the respondents had access to DC was difficult for them to answer: “I don’t know exactly, but I think there is good availability of DC” (REO9).

Compared with DH, there is much less knowledge of DC and such knowledge is less widespread. Big umbrella organizations such as the Swedish Trade Federation had no one working on cooling (or even on energy), the Swedish Association of Public Housing Companies said that DC was not an issue on their agenda, and the Property Owner Association thought it would be an interesting issue for the future, but that DC was not of current interest. During the interviews, the real estate owners said that the energy companies could do better at informing and marketing DC. One real estate owner pointed out that to attract more DC users, the energy companies needed “to make contact themselves, to promote DC to various actors and thus contribute to an increased demand for DC” (Interview REO11).

One energy company representative was self-critical, saying that DC was not marketed well enough and that customers simply did not know that DC existed (Interview EC4).

Split incentives as a barrier occur when an adopter of an investment is not the party that pays the bill. In our material, this barrier was related to information. The real estate owners said that their tenants did not demand DC; on the other hand, no one informed the tenants that DC was an option. The tenants were not always aware of whether or not they had DC in the premises: “If it is district heating in [to the building], then it is district heating [that we use]. If it is district cooling in, then it is district cooling we use … we must use what is installed” (T1).

Those who had invested in DC justified doing so by claiming that the investment cost of DC is reasonable. In contrast, several respondents who did not use DC argued that the investment cost was a barrier and that DC operation is expensive (see Table 2).

Both the factors *split incentives* and *hidden costs* could give rise enablers if business models were taken into account. Previous research into DH expansion finds that organizational aspects, such as business models, are important enablers of expansion (Päivärinne et al., 2015). Knowledge of the importance of business models for developing the DC market is limited, though it is reasonable to believe that it would be as important for DC as it is for DH. This was also indicated by the online survey and the interviews in this study. To expand the use of DC, it could be important to understand the underlying economic mechanisms, to be able to develop an attractive offering for potential customers. In this paper, we treat business models as organizational and strategy-oriented tools (as discussed by Boons and Lüdeke-Freund (Boons and Lüdeke-Freund, 2013)), with the business model being seen as a strategic management tool and market competition as a driver of organizational performance.

The energy companies regarded low electricity prices as a barrier. In relation to that, they said that *bounded rationality* was a problem, They meant that the customers did not really compare the different alternatives available on the market. The energy companies found that customers have no knowledge of, for example, how much electricity their existing cooling equipment uses, making it difficult for suppliers to convince them that DC is a good deal. The customers only see how expensive DC is, but have nothing with which to compare it (Interviews UEO, EC1). The customers that ultimately chose DC were the ones capable of comparing the operating cost, because they often realized that DC would be cheaper in the long run (Interview E3).

Hidden costs were not mentioned by the customers, but the energy companies said that these costs are high. It takes time to reach agreement with a customer and, as mentioned above, it can take years to negotiate a contract.

Limited access to capital is another barrier mentioned by the energy companies rather than the customers. In Sweden, DC is such a small part of an energy company's total business that it is difficult to have DC prioritized by company management.

When reflecting on what would make DC more attractive, the main factors specified by the online survey respondents concerned economic aspects and increased access to DC grids (see Table 3). These, followed by tenant demand and better knowledge of the environmental performance of DC and of DC as such, seem to be the factors enabling real estate owners to install DC in their premises.

What would make district cooling more attractive	**No. of answers**
Lower price	16
Access to grid	13
Develop working business model	5
Tenant demand	7
More environmentally friendly	3
More competitive than its alternatives	2
Lower installation costs	2
More information/knowledge of district cooling	2
Warmer summers	1
If it were easier to install	1
TOTAL NO. OF ANSWERS	**52**

Table 3. Survey responses regarding what would make district cooling more attractive (note that it was possible to give more than one answer to this question).

Several interviewees mentioned pricing and said that DC would be more attractive if it were cheaper in terms of both installation and operation costs. Furthermore, several stressed the challenge of developing reasonable pricing and business models in which the costs are paid by those using the DC. DC pricing is often individually set by the energy companies, resulting in different prices for different customers and prompting uncertainty among customers. They simply could not assess the value of DC: “I have no idea about the financial aspects, because I don’t know the price of DC” (REO8).

Three of the studied energy companies were municipally owned, and their representatives emphasized that their local roots, and the facts that they are locally known and trusted, are important reasons why customers choose DC. All the companies otherwise highlighted values such as comfort, reliability, simplicity, and no space needed for equipment as important factors contributing to the choice of DC.

5. Conclusions

In Sweden, DC is an emergent but still immature market developed solely by market actors, in sharp contrast to how earlier grid-based large technical systems were developed, i.e. through collaboration between public and private actors. The municipal representatives we talked to have no aversion to DC; it is simply not an issue on their agenda. When discussing DC, they believed that it might have an important role to play in the future, not least to reach the ambitious climate targets set in many Swedish municipalities. That we found DC mentioned in local energy and climate strategies also indicates an increased interest for the system in a climate perspective. Increased collaboration between public and private actors such as energy companies, real estate owners, and municipalities could be a future enabler of DC system expansion. On a liberalised energy market the establishment of new large technical systems as DC might need new public private partnership to evolve. Another way is in line with the development seen now where DC is starting in a small scale, with organic growth and individualised contract solutions. The problem is if the costs initially will be too high with an organic development, which will result in DC systems without any potential to grow.

However, the Swedish District Heating Association believes that DC systems have the potential to grow to at least double their current capacity within a few years, if only barriers to this can be overcome. Inadequate information was one of the barrier most discussed during the interviews and perhaps the most important barrier to DC expansion; if this problem is addressed, however, appropriate information could become an important enabler of expansion. If the expansion of DC is desirable, it would likely need to be preceded by a major promotional campaign highlighting the major advantages of DC, such as comfort and convenience. Such a campaign would probably be difficult for a single company to manage, but the industry umbrella organization, the Swedish District Heating Association, perhaps working in collaboration with several energy companies and municipalities, would have the required capacity.

The present DC market seems to serve large real estate owners who have many similarities to early adopters, i.e. they are interested in the technology as such and do not hesitate to discuss how the system operates. The energy companies seem satisfied with targeting customers who already understand the technology and have not really adapted their information to reach a broader audience. In our interviews, we found it difficult to talk about DC because this technology is unknown to many real estate owners and their tenants. Disseminating knowledge to users unfamiliar with or uninterested in the technology is a big challenge for the sector if it wants to expand the systems.

Also noticeable is that the arguments for and against DC are the same. For example, the price is used to justify both investing in and rejecting DC. As mentioned above, however, it is not that easy to compare the prices of different cooling options, because many DC companies do not have fixed prices but negotiate the price individually with each customer.

One way to expand DC systems is as mentioned above to integrate DC more into municipal planning and into local climate and energy strategies. This might however be hard on a liberalised market where the discourse mainly is dominated by values as competition, freedom of choice, and profit. More in line with the ongoing discourse would be to develop functional business models that could work as “market devices” (as defined by Doganova and Eyquem-Renault (Doganova and Eyquem-Renault, 2009)) in order to make DC attractive to real estate owners, tenants, and energy companies. This would drive the innovation process by promoting both competition and cooperation between DC actors. From a sustainability perspective, this is important because new ways of competition and collaboration might be needed in order to market sustainability solutions. This would be an important and interesting field for future research. Furthermore, it would also be interesting to explore the eco-labelling of DC in depth, to consider whether this could represent a way forward for DC.

Acknowledgement

This work was supported by the Swedish District Association and the Swedish Energy Agency through grant number 39607-1.

References

Abrahamsson, K., Nilsson, J., 2013. Kartläggning av marknaden för fjärrkyla. Energimarknadsinspektionen, Eskilstuna.
Ameri, M., Besharati, Z., 2016. Optimal design and operation of district heating and cooling networks with CCHP systems in a residential complex. Energy and Buildings 110, 135-148.
Aronson, E., Stern, P.C., 1984. Energy use : the human dimension. W. H. Freeman and company, New York.
Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. Journal of Cleaner Production 45, 9-19.
Byman, K., 2004. Bättre miljö med utbyggd fjärr- och närvärme : en utvärdering av LIP-finansierade fjärr- och närvärmeprojekt. Naturvårdsverket, Stockholm.
Doganova, L., Eyquem-Renault, M., 2009. What do business models do?: Innovation devices in technology entrepreneurship. Research Policy 38(10), 1559-1570.
EU Directive 2009/28/EC, on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
Fahlén, E., Trygg, L., Ahlgren, E.O., 2012. Assessment of absorption cooling as a district heating system strategy - A case study. Energy Conversion and Management 60, 115-124.
Fenton, P., Gustafsson, S., Ivner, J., Palm, J., 2015. Sustainable energy and climate strategies: Lessons from planning processes in five municipalities. Journal of Cleaner Production 98, 213-221.
Gang, W., Wang, S., Augenbroe, G., Xiao, F., 2016a. Robust optimal design of district cooling systems and the impacts of uncertainty and reliability. Energy and Buildings 122, 11-22.
Gang, W., Wang, S., Gao, D., Xiao, F., 2015. Performance assessment of district cooling systems for a new development district at planning stage. Applied Energy 140, 33-43.
Gang, W., Wang, S., Xiao, F., Gao, D.C., 2016b. District cooling systems: Technology integration, system optimization, challenges and opportunities for applications. Renewable and Sustainable Energy Reviews 53, 253-264.
Gustafsson, S., Ivner, J., Palm, J., 2015. Management and stakeholder participation in local strategic energy planning - Examples from Sweden. Journal of Cleaner Production 98, 205-212.
Gyberg, P., Palm, J., 2009. Influencing households' energy behaviour-how is this done and on what premises? Energy Policy 37(7), 2807-2813.
Hawkey, D., Webb, J., Winskel, M., 2013. Organisation and governance of urban energy systems: District heating and cooling in the UK. Journal of Cleaner Production 50, 22-31.
Hirst, E., Brown, M., 1990. Closing the efficiency gap: barriers to the efficient use of energy. Resources, Conservation and Recycling 3(4), 267-281.
Hughes, T.P., 1983. Networks of power : electrification in Western society, 1880-1930. Johns Hopkins Univ.Press, Baltimore.
Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap What does it mean? Energy Policy 22(10), 804-810.
Jonsson, B., 1999. Elements of the Asia Pacific gas market : market power and efficiency. Luleå University, Luleå.
Lake, A., Rezaie, B., Beyerlein, S., 2017. Review of district heating and cooling systems for a sustainable future. Renewable and Sustainable Energy Reviews 67, 417-425.
Magnusson, D., 2012. Swedish district heating-A system in stagnation: Current and future trends in the district heating sector. Energy Policy 48, 449-459.
Magnusson, D., Palm, J., 2011. Between natural monopoly and third party access - Swedish district heating market in transition, Monopolies: Theory, Effectiveness and Regulation. pp. 1-33.
Palm, J., 2004. Makten över energin : policyprocesser i två kommuner 1977-2001, Linköping studies in arts and science,; 289. Linköping University, Linköping.
Palm, J., 2006. Development of sustainable energy systems in Swedish municipalities: A matter of path dependency and power relations. Local Environment 11(4), 445-457.
Palm, J., 2007. District heating as a secure heat supply - A question of regulation. Energy and Environment 18(6), 747-760.
Palm, J., 2010. The public-private divide in household behavior: How far into home can energy guidance reach? Energy Policy 38(6), 2858-2864.
Palm, J., Thollander, P., 2010. An interdisciplinary perspective on industrial energy efficiency. Applied Energy 87(10), 3255-3261.
Päivärinne, S., Hjelm, O., Gustafsson, S., 2015. Excess heat supply collaborations within the district heating sector: Drivers and barriers. Journal of Renewable and Sustainable Energy 7(3), 033117.
Rodriguez-Aumente, P.A., Rodriguez-Hidalgo, M.D.C., Nogueira, J.I., Lecuona, A., Venegas, M.D.C., 2013. District heating and cooling for business buildings in Madrid. Applied Thermal Engineering 50(2), 1496-1503.
Sanstad, A.H., Howarth, R.B., 1994. ‘Normal’markets, market imperfections and energy efficiency. Energy policy 22(10), 811-818.
Simon, H.A., 1957. Models of man : social and rational : mathematical essays on rational human behaviour in a social setting, New York.
Sorrell, S., 2004. The economics of energy efficiency : barriers to cost-effective investment. Edward Elgar, Cheltenham.

Sorrell, S., Schleich, J., Scott, S., O'malley, E., Trace, F., Boede, E., Ostertag, K., Radgen, P., 2000. Reducing barriers to energy efficiency in public and private organizations. SPRU Science and Technology Policy Research, Brighton.

SOU (Swedish Governments Official Reports), 2007. Sverige inför klimatförändringarna : hot och möjligheter : slutbetänkande. Fritze, Stockholm.

Summerton, J., 1992. District heating comes to town : the social shaping of an energy system, Department of Thematic Studies - Technology and Social Change. Linköping University, Linköping.

Svensk fjärrvärme, 2015. Statistik fjärrkylaleveranser. (Accessed 01/12/2015 2015).

Svensk fjärrvärme, 2016. Om fjärrkyla. (Accessed 04/04/2016 2016).

Thollander, P., Palm, J., 2013. Improving energy efficiency in industrial energy systems : an interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs. Springer, London.

Thollander, P., Palm, J., Rohdin, P., 2010. Categorizing Barriers to Energy Efficiency-an Interdisciplinary Perspective, in: Palm, J. (Ed.) Energy Efficiency. INTECH Open Access Publisher, Croatia, pp. 49-62.

Werner, S., 2004. District Heating and Cooling A2 - Cleveland, Cutler J, Encyclopedia of Energy. Elsevier, New York, pp. 841-848.

Werner, S., 2016. European space cooling demands. Energy 110, 148-156.

Yin, R.K., 2009. Case study research : design and methods. SAGE, London.