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District heating as a flexibility service: Challenges in sector coupling for increased solar and wind power production in Sweden

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ABSTRACT

With expanding solar and wind power production, the topic of flexibility services attracts increased attention in the Swedish energy system. In this context, the potentials in using thermal storage capacities in district heating (DH) systems have been brought forward, primarily by academic scholars. Using a 'grounded' approach, this study investigates if professionals assigned to Swedish DH companies and electricity distribution system operators utilise, or plan to utilise, DH systems as flexibility services for the electricity grid. Original data was collected through semi-structured interviews, held with fourteen individuals affiliated to different actors in the Swedish energy system. These individuals were identified as being experts, or practically engaged, in using DH utilities as flexibility services for the electricity grid. The findings show that although technologies for coupling between DH systems and the electricity grid are already in place, initiatives for using DH systems as flexibility services for the electricity system are rare in Sweden. Coupling challenges stem from ownership and operation legislation frameworks, marginal incentives and a widespread focus on firm benefits rather than energy systems benefits. Identified initiatives for using DH systems for flexibility services are primarily run on a local scale, designed and propelled by small groups of engaged individuals.

1. .Introduction

The installation of wind- and solar power is growing rapidly around the world (Outlook, 2020). Sweden, for example, has a policy objective of 100% renewable electricity production by 2040 (Government Office of Sweden, n.d.). With expanding sources of variable energy production, the Swedish energy system is increasingly pressed to find flexibility solutions for balancing intermittent electricity production with electricity demand, in place, time and quantity (Sovacool et al., 2018).

In the EU, large variation in wind and solar power production is primarily managed through cross-border interconnections. Thus, it is argued that to cope with forthcoming increased intermittent electricity production, also the Swedish transmission grid must be expanded by cross-border connections in the Nordic region and/or throughout Europe (Wangel, 2015). Expanding electricity transmission networks is however associated with expensive long-term processes which risk delaying the transition to renewable energy production. Yet, there are several other options for increasing electricity system flexibility, including demand side management, supply side flexibility, system services and storage (Lund et al., 2015; Paiho et al., 2018) that can be supportive in this transition.

In the light of an increased need for flexibility services for the electric grid, power-to-heat has gained increased attention, (see e.g., (Böttger et al., 2014; Mathiesen and Lund, 2009; Paiho et al., 2018; Paiho and Saastamoinen, 2018)). Technologies such as heat pumps, electric boilers and thermal storage are examples of power-to-heat solutions that can be used to compensate in times of high and low electricity production from wind and solar (Lund et al., 2010).

Denmark, for example, is one of the frontrunners in installing solar and wind energy power production and has thus faced increased needs for balancing intermittent production. In their case, district heating (DH) systems and thermal storages have been key in the ability to increase intermittent power production with retained energy system efficiency and low total CO_2 emission (Lund et al., 2010). This is relevant for Sweden as, there is a lot of DH systems already in place. Also, large heat pumps were installed in Swedish DH systems during the 1980s in order to utilise the surplus electricity production from nuclear power (Averfalk et al., 2017). It has been estimated that the majority of the Swedish DH systems have as much as 64% available of short-term thermal storage capacity, only in the DH distribution networks

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(Hennessy et al., 2019). This thermal storage capacity is a potential to use for flexibility services to the electric grid.

Based on this, the purpose of this study is to investigate if professionals within Swedish DH companies and electricity distribution system operators (DSO) utilise, or plan to utilise, DH systems as a flexibility service for the electricity grid. And if not, to discuss why this does not happen and what conditions are needed for realisation. Focusing on professionals within DH companies and distribution system operators (DSO), as opposed to politicians or citizens, as drivers for change is important as previous research show that professionals, affiliated to different actors, understand key challenges and envision the future in different ways (Horsbøl and Andersen, 2021). To address our purpose, this paper takes a 'grounded' approach, in the sense that conceptual accounts and possible explanations are developed from the data, in contrast to logical deduction from a priori assumptions (Cunliffe, 2011). The paper contributes to the understanding of barriers for using power-to-heat to increase solar and wind power production in Sweden.

2. Background

2.1. Increasing needs for flexibility services

Sweden has set the goal to reduce the amount of greenhouse gas emission by 75% by 2040, compared to 1990s levels (Government Offices of Sweden, 2017). Above steering towards increased renewable electricity production, this ambitious climate policy goal also steers towards an electrification of the industry and transport sector, expecting to result in an increased electricity demand. One example of the industrial electrification is the HYBRIT initiative, aiming towards a fossil-free steel production. HYBRIT uses a process that requires large amounts of electricity, approximately 10% of the Swedish use (Swedish Energy Agency, 2020a).

Simultaneously to the ongoing electrification of society and growing metropolitan areas, the Swedish nuclear fleet is facing an uncertain future. As a result, this also puts pressure on increasing the amount of renewable electricity production in Sweden. Wind power production has extensively increased from 2010 and forward (Swedish Energy Agency, 2020a). An increasing power production can also be derived from solar power during the same period, however, solar power still stands for less than 1% of the Swedish electricity production (Swedish Energy Agency, 2020b).

Taken together, this changing energy landscape, and the problems that arise in association to it, is currently a hot topic in Sweden. The importance of power balance and flexibility services have consequently increasingly gained attention (see e.g., (Karlsson et al., 2020; Öman et al., 2020; Sonnsjö et al., 2020; The County Administrative Board of Stockholm, 2020)). Unlike Denmark and Germany, where grid congestion has increased with the increase in variable renewable production (Chaves-Ávila et al., 2014), Sweden has historically not been as sensitive to fluctuations in solar and wind power, due to the large amounts of balancing power from hydropower and the base load nuclear power provides (Svenska kraftnät, 2019). However, the reduced power production from nuclear and increasing power demand due to electrification in the industry and transportation sector is already causing increasing problems with lack of power supply, especially in the southern parts of Sweden (Sonnsjö et al., 2020).

2.2. District heating systems as a potential flexibility service

In the light of an increased need for balancing and flexibility services in the Swedish electricity grid, the opportunities offered by DH systems are interesting to look further into. DH systems have inherent energy storage capacity in the DH grids themselves as well as the buildings connected to the grids. They are also already connected to the electricity system which means that DH systems can provide flexibility both in terms of electricity consumption to reduce production peaks, for example via heat pumps and electric boilers, and in terms of electricity production through CHP plants. In 2018, DH had almost 60% of the market share for heating in Swedish residential buildings and premises (Swedish Energy Agency, 2020b) and there are currently approximately 500 DH systems in Sweden, which means that the potential for providing local flexibility is large (Ericsson and Werner, 2016; Werner, 2017). In 2021, the CHP peak electric generation capacity was 2875 MW (Swedenergy, 2022a).

Despite a wide use of large heat pumps in DH systems during the 1980s (Averfalk et al., 2017), current electricity prices have led to a decrease in electricity-based heat production technology, such as heat pumps and electric boilers (Swedish Energy Agency, 2020b). Still, many of the large heat pumps and electric boilers are functionable and an average of 7.6% of the heat production was based on heat pumps and electric boilers between the years 2017 and 2021 (Swedenergy, 2022b). The estimated potential power-to-heat capacity in the Swedish DH systems is about 0.2–8.6 TWh, assuming that electric boilers are used as power-to-heat technology (Schweiger et al., 2017). According to Bollander (2018), 72 out of the 305 largest DH systems in Sweden have heat pumps or electric boilers installed. The total installed capacity in these DH systems is 1207 MWth and 1151 MWth for heat pumps and electric boilers respectively, with a combined maximum electrical power draw of 1540 MW.

As previously mentioned, DH systems are also interesting as a flexibility resource duet to their heat storage capacity. For example, heat accumulators and increase of DH network supply temperature could be used to provide day-long heat storage which in turn could enable flexibility services and cross sectoral energy system benefits. In total, Swedish DH systems were estimated to approximately provide 150 TJ in 2016 (Eriksson, 2016), suggesting some 96 TJ available for additional load variations. This did not include the additional contents of the pipeline network.

While an existing body of literature is lacking for accurate calculations of national flexibility potentials, there still appears to be large potentials in utilising DH systems as flexibility services for the electricity grid. However, scholars investigating this potential claim that in comparison to, for example, Denmark and Germany, this opportunity has not yet been fully exploited in Sweden (Askeland et al., 2019; Cominola et al., 2018; Hennessy et al., 2019; Ma et al., 2020).

2.3. Roles, regulations, and responsibilities in the Swedish electricity and DH market

Sweden's electricity network consists of transmission networks and distribution networks. The transmission network, owned and managed by the state-owned enterprise Svenska Kraftnät, transfers electricity from the large national electricity producers to the distribution network (local and regional networks). In addition, it connects the Swedish electricity network with other European networks (SKV, 2021). The regional network, owned by large electricity network companies, transfers electricity from the transmission network to the local networks. Large electricity users as well as medium-sized producers are normally connected directly to the regional network while small producers are connected to the local networks (SKV, 2021). The local networks are owned by one of the more than 150 different electricity networks companies in Sweden (SKV, 2021; Swedenergy, 2018). Sweden is a net exporter of electricity and has transmission connections with Norway, Finland, Germany, Poland and Lithuania, and further connections are planned (Swedish Energy Agency, 2020b). Electricity within the Nordic, Baltic, Central Western European and UK are traded on the power market, Nord Pool.

In 1996 the Swedish electricity market was deregulated. Regulations on trade in electricity are given in the Swedish electricity law (Government offices of Sweden, 1997). The law was updated because of the structural change resulting from the deregulation, with the aim of clearly introducing a division between electricity suppliers and electricity network operators, i.e., on one hand production and sale of electricity and on the other hand transmission of electricity (ibid). As a result of the deregulation, the Swedish electricity market was exposed to competition. It is however socio-economically inefficient to have parallel electricity grids, thus the electricity grid is deemed a natural monopoly, and is thus regulated and monitored separately (The Swedish Energy Market Inspectorate, 2015). In response to regulatory changes decided at EU level in 2016, the Swedish Energy Markets Inspectorate (EI) has brought forward a proposal for national legal changes within the electricity market. These changes are not decided on, but a proposal is being made, among other things, for the introduction of civic energy communities and energy communities for renewable energy. The civic energy communities aim, among other things, at the possibility of production, transmission, use and storage of electricity limited to the members of an economic association. The energy communities for renewable energy would enable for an economic association to, toward its members, conduct activities within renewable energy (The Swedish Energy Market Inspectorate, 2020).

Since 2011, Sweden has been divided into four different electricity price areas. The division intends to reflect where there is a need to expand the transmission network and where there is a need to increase electricity production. The purpose is to reduce the need for long distance electricity transmission by steering the expansion to the parts where the need is the greatest. Electricity prices therefore vary between different areas in Sweden with usually higher prices in the southern parts (The Swedish Consumer Energy Market Bureau, 2020). The Swedish electricity prices have fluctuated widely in recent years due to e.g., weather conditions affecting renewable production, changed energy demand due to the Covid-19 pandemic, ongoing nuclear audits and increased fuel prices on the world market. These effects culminated in the summer of 2020 and led to volatile electricity markets with electricity prices varying from very high to negative and with large price differences between the four electricity price areas. Although negative electricity prices are common in e.g., Germany and Denmark (Rintamäki et al., 2017), it has previously not before occurred in all four of the Swedish electricity price areas (Swedish Energy Agency, 2020c). Several large projects to increase the transmission capacity are currently ongoing between the Nord Pool area and the rest of Europe, which will increase the market connection between these areas (ibid).

As with electricity grids, it is inefficient to have several parallel DH grids, thus DH is also considered a natural monopoly (Bonev et al., 2020). Unlike the electricity market, DH can however only be traded locally. Approximately 72% of the DH companies are municipally owned, whereas 6% are owned by the private sector. The rest is mainly owned jointly by municipalities, state and private actors (Magnusson, 2016). District heat production is, in Sweden, mainly covered by combined heat and power (CHP) plants using biofuels and municipal waste. As such, the Swedish DH systems are often highly integrated in the local waste infrastructure. Industrial excess heat stands for approximately 8% of the production (Swedish Energy Agency, 2020b).

3. Research approach and methods

3.1. Research approach

This study investigates what actions are taken by established Swedish energy actors to address present and future electricity grid challenges resulting from increased renewable variable electricity production. The research was conducted using grounded approach, in the sense that our research did not start by proposed hypotheses (Glaser et al., 1967). Instead, we applied an inductive discovery method to developing understanding of a phenomenon from findings rather than starting from a theoretical preconception (Cunliffe, 2011). The grounded approach is widely used in organisational studies, focusing on organisational behaviour and features of the organisational world (Martin and Turner, 1986), and has previously also been used in relation to energy systems studies (e.g., (Edberg and Tarasova, 2016; Muench et al., 2014; Paiho and Saastamoinen, 2018; Sovacool et al., 2018)).

To find out what was going on in terms of ongoing or discontinued initiatives, and experiments (here after referred to as initiatives), for using DH utilities as flexibility services for the electricity grid in Sweden, we relied primarily on original data. Original data was collected through semi-structured interviews. The first part of the interview was structured around questions addressing the company's existing energy production and storage technologies; geographical areas of activity, ownership structures and information about the person(s) being interviewed (i.e., role, responsibilities and time of employment at the company). In the second part of the interview the interviewee was encouraged to give extensive answers and make 'think-aloud' contributions (De Fina et al., 2019; Kvale et al., 2009). Open ended and follow up questions, such as "What do you think about the development towards an increased share of renewable electricity production?"; "What are the biggest challenges for your organisation, linked to increased intermittent electricity production?"; "Are your organisation engaged in any flexibility initiatives today?"; "How do you think the need for flexibility services will develop in the future?"; and "Why are your organisation working with flexibility issues?" were used to encourage the interviewee to speak freely and 'think aloud'. During the second part of the interview different topics could take up different amount of time depending on if the interviewee found some topic extra engaging or important.

3.2. Research method

To identify individuals to interview, we started in a registry of established actors in the Swedish energy system. This registry included all major private and municipality owned energy companies, energy agencies and industry organisations in Sweden. Using this registry, we entered actors' webpages and searched for information, such as published reports, debate posts or presentations of initiatives, related to the topic of this study. Specifically, we searched for initiatives coupling the electricity grid to DH systems for balancing or flexibility services.

In addition to this desktop search, the members of the reference group assigned to this research project were engaged in identifying initiatives and individuals who could be considered experts in the field. The reference group consisted of individuals from the energy industry, research institutes and academia. They were invited to the reference group as they were knowledgeable in flexibility issues for the electricity grid, DH and energy storage. Together, the members of the reference group had a large and well spread network within the Swedish energy sector.

In total, 10 organisations, represented by 14 individuals, holding different roles in the Swedish energy system were identified when studying the engagement in utilising DH systems as flexibility services for the electricity grid (interviewees presented in Table 1). The listed DH companies represent a wide array regarding network size, geographical distribution, and ownership structure. Together these companies deliver 31% of Swedish DH in 2021 (Swedenergy, 2022b). It is important to note that for qualitative research it is often preferable to employ 'theoretical' sampling of small numbers of people chosen for their special attributes (Cunliffe, 2011). In our case, it was thus most important to find professionals knowledgeable in flexibility issues for the electricity grid, DH and energy storage. The individuals found in the initial search were contacted via e-mail or telephone and asked to participate in an interview study about using DH facilities as flexibility service for the electricity grid. They all agreed to be interviewed. At the end of each interview, we asked about other initiatives or persons, within or outside their own organisation that could be relevant for us to talk to. With this 'snowballing technique', we were able to identify two additional individuals, one working for a DSO and one working as an expert at an industry organisation. This snowballing technique was not only useful for identify additional individuals but was also a way for us to ensure that we had identified key initiatives and the individuals engaged in this

Table 1
Interview sample. Heat production: small <1 TWh, large > 3 TWh (based on annual firm activity reports).

Role of person being interviewed	Type of organisation	Organisational characteristics
Head of Sustainable City Development	National energy distributor. Privately owned.	Heat and energy solutions. Regional and local electricity grids. Large DH distribution in regional grit.
Specialist District Heating	National energy distributor. Privately owned.	Next generation low tempered district heating systems.
Project Manager, Business Development	Regional energy distribution. Jointly owned by four municipalities.	Heat and energy solutions. Small DH distribution.
Business Developer	Regional energy distribution. Jointly owned by four municipalities.	Heat and energy solutions. Small DH distribution.
CEO, DH and Cooling	Regional energy distribution. Jointly owned by a local industry and the municipality.	Heat and energy solutions. Bio energy production. Large DH distribution.
Market Developer	Regional DH and cooling distribution. Jointly owned by a larger energy company and the municipality.	Large DH distribution.
Regional Director	DH company, owned by foundation.	DH operation in twelve municipalities.
Head of Power Technology Development	National electricity distributor. Privately owned.	Regional and local electricity grids.
Investigating Engineer District Heating and Cooling	Regional energy distributor. Jointly owned by two municipalities.	Regional and local electricity grids. Gas, heating and cooling distribution. Recycling, water and sewage. Small DH distribution.
Electricity Market Analyst, Operational department.	Svenska kraftnät (The Swedish agency responsible for the national electricity grid).	Responsible for Sweden's transmission system for electricity. State-owned enterprise.
Senior advisor, Operational department.	Svenska kraftnät (The Swedish agency responsible for the national electricity grid).	Responsible for Sweden's transmission system for electricity. State-owned enterprise.
Senior advisor, DH, energy and CHP	Swedenergy, Industry organisation	A non-profit industry and special interest organisation. Representing 400 Swedish companies that supply, distribute, sell and store energy.
Professor of Energy Technology	Researcher, university (from reference group).	Public university.
Director, Electric Power Systems	Researcher, Technical research institute.	State-owned research institute.

issue in Sweden.

3.3. Data and method of analysis

The interviewees represent a mix of privately and publicly owned energy distribution firms, ranging in size and in heat/cooling/electricity operation. Professionals affiliated to The Swedish agency responsible for the national electricity grid, an energy industry organisation, and researchers within the field are also represented in the data. The role of the interviewees and the characteristics of the organisation they worked for are presented in Table 1. All data is presented anonymous as respondents were ensured confidentiality. The reason for ensuring confidentiality to the responders was to make it easier for them to speak freely about the company's future strategies and make personal reflections upon potential challenges for coupling between electricity and DH systems. All interviews were made between May and November 2020 and by at least two, often all four of the authors. Interviews lasted between 30 and 90 minutes. Due to Covid-19 restrictions all interviews were made digitally, using Microsoft Teams. Interviews were recorded and transcribed verbatim.

Interview transcripts were analysed using a thematic analysis to inductively identify and analyse patterns of meaning (themes) in the data (Braun and Clarke, 2006). Thematic analysis is foremost a tool, used for interpretation. Its results shall thus not be thought of as descriptive, or in effectively summative, ways. Our aim was to present a coherent analysis while also preserving the nuances in the data so that readers can evaluate the credibility and transferability of the results. The analysis was thus set out to present the practitioners' perception of practical issues, challenges and enablers related to using DH systems for flexibility services in the electricity grid. This, however, does not mean that the analysis was done in an 'epistemological vacuum'. Previous knowledge, theoretical and epistemological values will always be present when data is extracted into patterns and themes are established (Braun and Clarke, 2006).

First, all authors read interview transcripts multiple times to identify sections of salient topics relating to using DH systems for flexibility services in the electricity grid. All sections were extracted from the transcripts. Under workshop like conditions, the authors extracted duplicates of selected sections and arranged the remaining into issues. Issues evolved during the workshop and was eventually settled to 21 issues (see Table 2). For example, the sections: "There are several regulatory barriers for this [integration]. For example, when property owners declare purchased energy, they do not need to report at what time of the year, day or hour the energy was bought. And the energy declaration is not technology neutral – district heating always has different emissions than electricity […] We must allow these reports to be adjusted to local conditions [in the energy system] in order to make it attractive for property owners to contribute to an energy system optimisation" and "The same electricity price for all customers in one and the same electricity area means that local problems may affect everyone, or no one", were two of the sections that were arranged into the issue 'Strict legislation'. Third, issues were grouped according to meaning and each group of issues formed a theme (see Table 2). Coding of interview transcripts was done using NVivo software.

Table 2
Issues related to using DH systems for flexibility services in the electricity grid grouped into themes found in the collected data. The themes and issues are further explored in the sections below.

Technologies for coupling	Market and business models	Roles, regulations and responsibilities	Beliefs and future trends
• Heat pumps	• Firm focus	• Strict legislation	• Future changes in policy of waste incineration
• Cogeneration plants	• Lack of incentives	• Initiatives are manually operated and with informal communication	• Deep geo-thermal heating
• Thermal accumulator tanks	• High alternative risks	• Complex relations with adjacent sectors	• Complex to explain green energy and energy systems benefits
• Remote control of heat pumps	• Production optimisation	• Lack of energy systems perspectives among individual actors	• Future waste situation and heating needs
• Combined control systems	• Heat as a service		
• Excess heat	• Local energy market		
• Next generation district heating systems			

4. Results and analysis

The most striking result in this study is that although Swedish DH systems constitute a large potential flexibility recourse in the national energy system (Hennessy et al., 2019; Lund et al., 2010) and that there are many large-scale power-to-heat solutions already in place (Averfalk et al., 2017), initiatives for utilising DH as flexibility services for the electricity system are rare in Sweden. The findings in this study suggest that the reasons for why there is such a low mobilisation around using DH as flexibility services in Sweden primarily relate to ownership and operation legislation frameworks, marginal incentives and a widespread focus on firm benefits rather than energy systems benefits. These findings are based on data collected among individuals affiliated to actors such as established DH companies, DSOs, national agencies, industry and research organisations. Although our findings do not display any particular differences in how professionals form different actors understand key challenges and envision the future (c.f., (Horsbøl and Andersen, 2021)), our interviewees have provided a comprehensive range of contemporary issues related to using DH systems for flexibility services in the electricity grid.

When analysing our data, four themes stood out: (1) technologies for coupling between the electricity grid and DH system; (2) market and business models; (3) roles, regulations and responsibilities in the energy system; and (4) beliefs and future trends. Each theme and its associated issues are presented in Table 2, and further explored in detail in the sections below. We close this article by presenting our conclusions and policy implications.

4.1. Technologies for coupling between the electricity grid and DH systems

There are numerous technologies already in place in the Swedish energy system that enable couplings between the electric grid and DH systems. For example, our interviewees referred to cogeneration plants and large-scale heat pumps. These are directly connected to the electricity grid and can be controlled both in relation to demand and overproduction in the electricity grid.

Large-scale heat pumps (1 MW heat and above) were installed in DH systems during the 1980s due to national electricity surplus from increased nuclear power production (Averfalk et al., 2017). Many of these heat pumps are still in operation, although, with reduced capacity due to 'internal competition' from waste and biomass cogeneration plants. The potential in steering these large-scale heat pumps to providing flexibility services to the electricity grid has previously been brought forward by Averfalk et al. (2017). However, our findings show that larger heat pumps in the Swedish DH system are seldom steered depending on situations in the electricity grid, and we will return to some of the reasons for this in the themes below.

Instead, our findings show a tendency for using smaller heat-pumps (below 1 MW) when experimenting with flexibility services. For example, DSO professionals involved in an initiative using a software solution for remote control of small heat pumps in villas and residential houses argued that it is possible to shave electricity usage peaks by steering a lager set of small heat-pumps in one district or a city block. On the same token, another initiative merged bought energy, i.e., electricity, heating and cooling, and local solar electricity production into one and the same control system. This control system allowed for optimising the total energy usage for a set of larger buildings in one and the same district. This specific initiative integrated different forms of local data, such as the buildings' thermal inertia, how the buildings are used and local energy production. Although there are practical challenges in collecting and interpreting local sensor data from different energy carries, such data can allow for more dynamic timespan of heating and cooling. However, both these initiatives were primarily arrangements between DSOs and houseowners and not the local DH company.

Focusing on flexibility capacities in the DH systems, our interviewees pointed out that thermal accumulator tanks with a storage capacity between 1 and 2 days are relatively common throughout the Swedish DH systems. However, we found no intention for utilising these storage capacities beyond the local DH system. Although, experts interviewed in this study were positive about the potentials in the existing storage capacities for flexibility services, practitioners within DH systems rather referred to thermal storages as short-time storage capacities, primarily useful for day storage to handle the daily DH production. Other storage capacities with longer time span, such as thermal or battery storage, were thought of, by the practitioners, as difficult to obtain economy feasible or in need of further technical development.

In one of the metropolitan areas, a larger energy firms explored the flexibility potentials in introducing low tempered district heating systems (LTDH). In contrast to standard DH designs, LTDH operate using temperatures between 10 and 70 °C and excess heat, such as from industries or renewable energy sources, with temperature levels as low as 5–40 °C can be efficiently integrated into the schemes. Although, a LTDH system is only relevant when building a new district, because older DH systems, including older buildings, require higher flow temperatures (e.g., ca 86 °C), establishing a LTDH system can lowering the total energy demand in a larger energy system (Li et al., 2017).

In sum, our findings show that there are established DH technologies that can optimise energy usage and provide flexibility in an energy system perspective. However, we found surprisingly few ongoing initiatives in Sweden using, or even exploring the potentials in using, DH (including LTDH) as flexibility services for the electricity system. Nor did we find many discontinued initiatives. A lot of discontinued initiatives could have indicated invincible challenges related to coupling between the electricity grid and DH systems. The following themes thus points towards the most salient challenges perceived by our interviewees for using DH systems as flexibility services to the electricity grid.

4.2. Market and business models

Besides technology, all our interviewees talked about market and business models. Interviewees working at energy firms, first and foremost focus on their own organisations' business rather than taking an 'energy system at large' perspective: "The most important is to find a business model that is profitable for the costumers and for us" says the Head of Sustainable City development at a national energy distributor and who engaged in initiatives for including energy issues earlier in the city development process.

A major challenge, for engaging in flexibility services is, according to our findings, related to a lack of incentives and high alternative risks. "There is a will to act on a flexibility market, but the uncertainties are too great, and the gains are too small" says the Market Developer at a regional DH and cooling distribution company, situated in one of the metropolitan areas in Sweden. And (s)he continues: "For commercial property owners, there is a huge risk for deteriorated indoor climate when heat pumps are turned off to avoid peak electricity pricing. If their tenants get unhappy because of lost comfort, it can turn out to be much more expensive than what their potential gain is from providing energy system flexibility services".

Likewise, a lack of incentives for engaging in electricity flexibility also relate to how storage capacities in DH systems are used. "Day long storages, such as heat accumulators, are relatively common throughout the Swedish DH systems. Primarily, they are used for providing production optimisation and day-long storage flexibility services in the DH system, rather than for cross sectoral energy system benefits. Our only use [of thermal storage] is really for avoiding peak electricity price during our [DH] production" says the Investigating Engineer District Heating and Cooling.

Some of the interviewed experts did speak about the potentials in utilising different sized storage capacities for flexibility services. "We have seen a lot of short-term storage, for a day or two, been built in Sweden during the last couple of years. But no seasonal storage. They have not really rooted here" says the Senior advisor at the national industry organisation. However, storage capacities with longer time span, such as seasonal geo-thermal or battery storage, were thought of by interviewees working in energy firms as difficult to obtain economy feasible. Again, the focus among our interviewees is not surprisingly first and foremost on their own organisations' business rather than on the 'energy system at large'.

Although DH systems in Sweden are integrated with the electricity grid, from a technical point of view, the interconnection between these two systems is currently primarily managed by the electricity price. From an electricity system perspective, the electricity price is a blunt and partly also the 'wrong' signal. Primarily this is because the electricity price is set to national energy areas and does not account for local lack of power and/or capacity. In addition, DH companies generally purchase electricity for longer timespans to avoid exposure of high price fluctuation. The motives for DH companies to engage, based on electricity price alone, as a balancing service to local electricity systems are thus limited.

Some of the initiatives found in this study explored new business models to enable increased flexibility. For example, in one initiative, a DSO explored the potentials in taking control of small heat-pumps in villas and residential houses and offered 'heat as a service' via comfort agreements. In this way it was possible for the DSO to adjust heat-pumps to avoid peak loads in the electracy gird. In another case, a large regional DSO introduced peak-hour pricing of distributed electricity (kWh) to encourage behavioural changes in energy usage among end-users. In this new pricing model, the monthly distribution price to costumers is set based on the three highest hours of use during the previous month. Flexible energy consumption agreements are somewhat more common between DSOs and larger process industries, who, if incentivised can adjust production and energy usage for regional peak shaving, but in the time of writing this article it is new in Sweden to also apply this price model for households.

A 'sub-issue' within this theme was to discuss how to achieve flexibility via local energy markets. In a local energy market, multiple energy carriers and local power production can be merged into one and the same market. This provides flexibility benefits as the energy price can be adjusted in relation to local power and/or capacity conditions. By market clearing mechanisms, the electricity price, set for national energy areas, becomes less important and synergies between the different energy carries has a potential to increase efficiency in the use of existing resources (Brolin and Pihl, 2020).

4.3. Roles, regulations and responsibilities

As outlined in section 2.3, ownership and operation are strictly legislated within the energy system. It is thus not surprisingly that the initiatives we found, involving both DSOs and a local DH system, are often run by a small group of people who know each other well and who communicate directly and informal to act on each other's flexibility issues. For example, in the only initiative found, utilising large heat-pumps in DH systems, the demand-response adjustment was primarily made manually. "Currently we do this manually. For the future, we must get this to a higher automation […] For example, we need to get the revenue opportunity into our production optimisation systems, so that it becomes another parameter that we can consider in our DH operation" says the Project manager on a regional DH company.

Another dimension of this theme is that energy transcends a number of different socio-technical systems and in the current era of grate challenges, actors in the energy industry have started to become involved in the transition of adjacent sectors. For the energy industry, such engagement opens for new roles and responsibilities and creates need for new competences and constellations of skills. Likewise, these challenges also open up the energy sector to the entry of actors from adjacent sectors. One such actor, often discussed in our interviews, is property owners due to increased interests in using small heat pumps and buildings as thermal storage.

In the metropolitan areas, we found that larger energy firms recently have started to become engaged earlier in the city development process. "We now have three project managers who are energy system experts and also very knowledgeable in urban development processes. They are involved in various urban development projects, both here in Sweden and abroad" says the Head of Sustainable City Development at one of the major energy firms. And he continues "In general, Swedish DH systems are integrated with the municipality's sewage treatment and waste incineration. In some cases, DH systems are also integrated with private industries, such as paper mills and chemical plants. We are often asked about the use of excess heat from new industrial establishments or other new infrastructure. However, efficient use of excess heat is often complex to achieve, especially in already established DH systems. It is much easier to include excess heat as a resource in the heating system when planning for new districts, which includes expansion of new DH or LTDH systems."

Although there are ongoing discussions with larger energy firms in urban planning processes, our finding shows that both DH companies and DSOs still struggle with finding their role in the incumbent city development process, especially in the metropolitan areas. All too often, they claim, they still get involved too late in the planning process which leaves them with a reduced set of energy solutions and alternatives to provide flexibility services.

In smaller regions, sector transcendent collaboration appears somewhat easier to operate than in metropolitan areas where more actors typically are involved. "Our energy system has been developed in symbiosis between the city and the local industry for decades […] When we build new things in our region, we usually get all of us involved already in the early planning process. We know each other well. But we have experiences of when new actors, not knowing any one here, establish their business without involving us from the start. In these cases, it was more difficult to, for example, take care of residual heat" says the CEO of DH and cooling in one of the regional energy distribution firms.

Regardless of regional size, common challenges for the DH sector are regulations in the building sector such as energy declarations and low energy housing. "The focus on bought energy, which is reported in the energy declarations, does not account for when during the day the energy was bought, and it does not necessary accounts for any aspects in the local energy system. Bought energy has only focus on price and origin" says the Market Developer at a regional DH and cooling distributor, pointing at the lack of an energy system perspective in these policies.

4.4. Beliefs and future trends

The fourth theme is a cluster of issues brought up by the interviewees regarding technology development trends and possible future policy changes. One issue, primarily brought up by DH professionals, related to CO2 tax and potential future changes of policy for waste and biofuel use in CHP plants. Changed policy of waste incineration can have large impact on the Swedish DH heat production. These uncertainties have already had direct effects on some investments in the DH system: "We use a 20-year perspective, and sometimes even longer. Now it is very uncertain. Should we build a waste plant, or a cogeneration plant? We try to propound this decision as long as possible" says the Marked Developer on a regional DH and cooling distribution firm. However, as the Director, Electric Power Systems pointed out: "If we stop burning stuff for heat production, we will see more heat-pumps in the DH system. And then, the DH system will automatically constitute an even better flexibility source for the electricity grid".

Some future trends in adjacent sectors were also brought up by the interviewees. For example, the tendency among houseowners to choose 'green' heating solutions. "Reducing the CO2 emissions is important. It is much easier for house owners to choose heat pumps than DH because they understand green electricity. The energy system benefits when choosing DH are more difficult to explain" says the Marked Developer on a regional DH and cooling distribution firm. And reduced access to waste and increased energy efficient houses: "In the future, we will probably have less waste and future houses will probably have much lower energy needs. So, perhaps we can use low-temperature DH systems that are connect to the return of established DH network and distribute that as prime heat" says the Senior advisor at Swedenergy.

Although we see scepticisms regarding business opportunities in seasonal storage among the interviewees, there are also positive references to seasonal storage of municipal waste for incineration. However, as pointed out by the Senior advisor, at Swedenergy, "previously stable access to waste for energy production is becoming more and more uncertain and potentially something that is becoming more and more difficult to obtain".

In sum, although there is some uncertainty among the interviewees about the future of today's DH systems, there is also a widespread hope for the next generation DH systems. LTDH is one example, but also DH systems powered by geo-thermal heating which is a future technology with potentially large disruptive effects in the DH system: "When in use, such system would only use small amounts of electricity. However, this system will not strictly be coupled with the electricity system so its ability to provide flexibility service will only be limited to reduced electricity needs for heating" says a Specialist District Heating at a national energy distributor.

5. Conclusions and policy implications

Alongside an ongoing increased solar and wind power production in the Swedish energy system, the topic of flexibility services in the electricity grid attracts increased attention. In this context, the thermal storage capacity in DH systems have been brought forward by energy systems scholars. Large thermal storage capacity allows DH systems to run their heat production in such way that they can provide flexibility services to the electric grid. For example, they can adjust their heat production to reduce electricity usage peaks, switch to large heat pumps or electric boilers in times of electricity surplus or they can switch to electricity production in CHP plants in times of electricity shortage. This study shows that although Swedish DH systems, from a technical point of view, already can provide such flexibility services to the electricity system, there is still no clear resource mobilisation around this issue in the Swedish energy system.

The findings in this study bring forward three salient conclusions. First, upholding a DH system as a flexibility resource is currently associated with risk because the potential gain is considered low and unpredictive. Our analysis shows that this is because there is no clear signal on which DH system operators can act on flexibility. A common notion is that flexibility needs in the electric grid are associated with the electricity price on the day-ahead and intraday electricity markets. But from an electricity system perspective, the electricity price is a blunt and partly also the 'wrong' signal as the electricity price is set to national energy areas and does not consider local lack of electricity power and/or capacity. Moreover, Sweden's electricity tax is static. This means that the electricity tax is a set price per kWh (0.36 SEK/kWh in June 2022), independent of the electricity price. In a scenario with very low or even negative electricity price, for example during windy and sunny days, a dynamic electricity tax would make it more attractive for DH actors to provide flexibility services, for example by producing heat for storage or use large heat pumps. The implication here is thus that a dynamic electricity tax together with robust and predictive flexibility market conditions would support the use of DH system as flexibility resources for the electricity grid.

Second, establishing couplings between the DH sector and the electricity sector challenge ownership and operation legislation frameworks as there is a division between electricity suppliers and electricity network operators in Sweden. However, in the current era of great challenges, boundaries between energy and adjacent socio-technical systems are already being blurred. Representatives for energy actors are increasingly being brought into situations where they, despite their affiliation, must take 'an energy system at large' perspective. One such example is urban planning. As metropolitan areas expand and become more densely populated, energy actors have become increasingly involved in the urban planning and development processes. Not only does this put the energy system at large in new perspectives, it also brings forward needs of new competences, such as combining knowledge about energy systems and urban development. However, energy systems in metropolitan areas are often complex and include many actors. And our findings show that in metropolitan areas, there is a general lack of collaboration and understanding between actors in the energy sector and actors in the urban development process.

The initiatives found in metropolitan areas were typically run at block or city district level and involved no more than a handful of actors. This was similar, regardless of where in the country initiatives where arranged. Initiatives were commonly designed and propelled by small groups of engaged individuals who knew each other and who could trespass organisational boarders.

The key element for strengthening collaboration between energy system actors and planning for urban development is to spark cross sectoral collaborations and support engaged individuals who can organise initiatives in complex environments that include many actors. Early collaboration between urban planning and energy system actors can provide a wide range of alternative energy system solutions to enable sustainable urban development. In larger cities, for example, enabling already existing DH systems as flexibility resources can alleviate problems with transmission capacity when planning for a new city district.

Our third conclusion is that DH systems play a larger role than merely heating houses. Transformative energy policy extends beyond the energy sector and the societal aspects of DH should therefore be considered in adjacent policy frameworks. One example is the real estate sector's reporting of purchased energy. In this reporting, only carbon dioxide emissions form the purchased energy is declared. However, it is not possible to consider other societal benefits of cogeneration or any other energy system perspectives (such as flexibility services) in this reporting, which makes it difficult for customers to choose energy types that also can function as flexibility resources and that can be used to contribute to a sustainable energy system. It is also important to consider the future technical development, as, for example, geo-thermal powered DH systems will not strictly be coupled with the electricity system and will therefore probably provide less flexibility functionalities for the electric grid. Thus, the roles of future DH systems need further attention.

CRediT authorship contribution statement

Niklas Fernqvist: Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition. **Sarah Broberg:** Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition. **Johan Torén:** Conceptualization, Investigation, Writing – original draft. **Inger-Lise Svensson:** Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Anonymous data will be available on request

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