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Abstract

The EU target on energy efficiency implies a 20% reduction in the use of primary energy by implementation of energy efficiency measures. Not all potential cost-effective measures for improved energy efficiency are implemented. This energy efficiency gap is explained by market barriers. Policy instruments can be used to overcome these barriers. The target could, for example, be obtained through industrial excess heat recovery; but there is a knowledge gap on factors affecting excess heat utilization. In this study, interviews were carried out with energy managers in order to study excess heat utilization from industry's perspective. The study seeks to present how excess heat recovery can be promoted or discouraged through policy instruments, and several factors are raised in the paper. The interviews revealed that excess heat recovery is generally referred to in terms of heat deliveries to the district heating network. One may need to look for innovative recovery solutions and policies are needed to bring these solutions into action. Due to inefficient conversion for heat driven electricity generation, a system favoring this implementation could favor an inefficient system. Beyond external instruments, internal goals, visions and the importance of energy as a priority were shown to be important in the work with improved energy management.

Keywords: industrial excess heat, industrial waste heat, energy efficiency, energy policy, heat recovery, interviews

1. Introduction

Increasing industrial energy efficiency has emerged as a key to reduce the climate impact and to maintain competitive industrial sector. In 2010, energy end-use among Sweden's industrial companies amounted to 149 TWh/year, corresponding to 36% of Sweden's energy end-use. The energy-intensive industries (pulp and paper industries, iron and steel industries and chemical industries) used the largest share (approximately 70%). (SEA 2011) To fight climate change, increase the region's competitiveness, and guarantee energy security, the European Union (EU) has decided to convert itself into a highly efficient, low carbon economy. As a result, the EU launched the "20-20-20" objectives in 2008. One of the main targets is to reduce primary energy use by 20% from the 2005 level by implementing energy efficiency measures (EC 2010). One of the major means to improve energy efficiency is through the use of excess heat recovery. In the EU's Energy Efficiency Directive (EED), the recovery of industrial excess heat is raised as one important measure for reaching the EU target (EC 2012). Industrial excess heat is heat generated as a by-product of industrial processes. The heat is not used today, but could be used to create benefits for the industry and/or the society. The heat can be carried in either liquids, gases or as heat in material. But it should be noted that there is no clear definition of excess heat, and several definitions have been proposed (see e.g. SEA (2008b) for a discussion regarding possible definitions). Excess heat can be used in several ways and can be recovered internally or externally. Internally, the heat can e.g. be used for pre-heating of air, water, and material through heat exchanging; externally, e.g. it can be used through recovery and deliveries to a district heating (DH) system or for generating electricity. (Thekdi and Belt 2011) Delivery of excess heat is generally not the industries' core business, but is often peripheral.

It has previously been stated that not all potential cost-effective measures for improved energy efficiency are implemented. This gap between the cost-effective measures (i.e. the energy efficiency potential[1]) and the energy efficiency measures actually implemented is referred to as the energy efficiency gap (see for example Jaffe and Stavins (1994)). This gap is explained by market barriers. Jaffe and Stavins (1994) refer to two types of market barriers. Market failures are deviations from the assumption of a perfect market. Market barriers that are not embraced by market failures are referred to as non-market failures and one such example is the uncertainty of future energy prices (this uncertainty can be taken into account when making investment decisions). (Jaffe and Stavins 1994) Backlund et al. (2012) argues that the energy efficiency potential is higher than the energy efficiency gap and introduces the extended energy efficiency gap. The extended energy efficiency gap looks beyond the energy efficiency potential associated with the diffusion of energy efficient technologies and includes the efficiency potential associated with energy management practices. (Backlund et al. 2012)

Policy measures can be used to overcome market failures and improve the resource allocation (Gillingham et al. 2009; Jaffe and Stavins, 1994; Morvaj and Bukarica, 2010). Morvaj and Bukarica list four pillars for improved energy efficiency: using regulations to avoid unnecessary energy use; implementing energy efficiency measures and technologies to reduce energy losses (this can be done e.g. through excess heat recovery); improve knowledge on energy use through monitoring; and managing energy use by improving operational and maintenance practices - hence: avoiding, reducing, monitoring and managing. The authors state that in the process of policy making, these pillars have to be taken into account. (Morvaj and Bukarica 2010) The EED has not yet been implemented in Sweden and is currently at proposal level; however the proposal raises the issue of industrial excess heat recovery (Ministry of Enterprise, Energy and Communications 2013). The EED aims to promote energy efficiency and establishes a framework for this purpose. (EC 2012)

[1] The energy efficiency potential may be viewed upon from three different perspectives: the hypothetical perspective (i.e. the total potential if all available technological measures are implemented), the technologist´s economic potential and the enonomist´s economic potential (Jaffe and Stavins 1994; Backlund et al. 2012). Hence, the actual magnitude of the energy efficiency potential depends on the perspective used. For a further description of the different perspectives, see e.g. (Jaffe and Stavins 1994; Backlund et al. 2012).

Gillingham et al. (2009) discusses market failures related to energy efficiency and policy measures that have been or could be implemented to overcome these failures. For example, energy prices that do not reflect the actual cost of energy use, e.g. the cost of greenhouse gas emissions that are not internalized by the energy users, lead to an overuse of energy and underinvestments in energy efficiency, if policies are not used to correct the energy market failure. Information problems are another example of a reason for underinvestments in improved energy efficiency. (Gillingham et al. 2009) Lack of information regarding the savings from energy efficient technologies and cost of information, i.e. the costs associated with obtaining information, are examples of information problems and hence barriers to energy efficiency. (Sorrell et al. 2000) Information programs are a policy measure that could be implemented to overcome this barrier. For a more thorough description of barriers to energy efficiency see for example (Gillingham et al. 2009; Sorrell et al. 2000; Thollander and Ottosson 2008). Morvaj and Bukarica (2010) raise policy dynamics as a key to efficient policy making. Implementing energy efficiency policy needs to be looked upon as a learning process. Policies need to be designed, the instruments developed and implemented but they also need to be evaluated following implementation. This evaluation can be achieved using statistics and indicators, and also qualitative and quantitative evaluation of the impact of the policy instruments. (Morvaj and Bukarica 2010)

From a resource use perspective, improved energy efficiency through excess heat recovery is attractive because it reduces the use of primary energy and might also reduce carbon dioxide (CO_2) emissions and result in economic gains (Thekdi and Belt 2011). Although there are examples of excess heat recovery trough deliveries to, for example the DH system, it is argued that there is still a large heat recovery potential (see e.g. Broberg et al. 2012; Broberg Viklund and Johansson 2014; Campana et al. 2013; Cronholm et al. 2009; Persson and Werner 2012). Unused industrial excess heat is consequently a large untapped resource that could be used to increase energy efficiency. Thollander et al. (2010) examines factors that promote or inhibit DH cooperation between industries and utilities. This is studied in three types of collaborations; DH supply to industry from the energy utility, boiler cooperations, and cooperation where DH deliveries to industry would enable the building of a new combined heat and power (CHP) plant. However excess heat deliveries were omitted from the study. (Thollander et al. 2010)

Due to the importance of excess heat as a resource for improved energy efficiency, and the knowledge gap on factors affecting excess heat utilization, the aim of this study is to examine and elucidate how energy policy instruments affect or might affect the industry incentives for excess heat recovery. The study seeks to present how policy instruments can be used to promote or discourage excess heat recovery. This is done by using research interviews to study how the actual stakeholders of industrial excess heat, the Swedish industrial companies, respond to and reason about excess heat recovery in the light of policy measures. To the author's awareness, no previous paper has been published studying excess heat utilization from the perspective of Swedish industry. Swedish industry is affected by a number of climate and energy policy measures and the main policy means studied in this paper are: taxes, electricity certificates, investment grants, Third- Party Access (TPA), the environmental code, municipal energy planning, the programme for improving energy efficiency in energy-intensive industry (PFE) and information and expert support. The outline of the paper will be as follows: Section 2 serves as an introduction to excess heat recovery research followed by a brief description of the main policy instruments studied. Section 3 presents the method used in this paper. Section 4 provides the results retrieved from the interviews, and Section 5 contains discussion and conclusions.

2 Background

2.1 Excess heat utilization

There are examples of external heat recovery through cooperation between DH companies and industries, and several Swedish DH systems already accept industrial excess heat for heat deliveries (Swedish District Heating Association 2010). In 2011, excess heat accounted for approximately 7.2% of the heat deliveries in the DH networks in Sweden (Swedish District Heating Association 2011). Several studies investigated the use of industrial excess heat (see for example Jönsson et al. 2008; Svensson et al. 2008; Wolf et al. 2007). Jönsson et al. (2008) and Svensson et al. (2008) used a system boundary approach to study whether excess heat should be used internally or externally in Kraft pulp mills. Wolf et al. (2007) developed an approach for local industrial ecosystems and identified several possibilities for improved energy and material use when increasing the integration between the actors being studied (forest industry, municipality, and energy service company).

The CO_2 emission consequences resulting from excess heat recovery are hard to predict. Depending on which model is used for CO_2 emissions evaluation, the results may vary. Some factors that affect the systems' emissions are the heat producing technologies in the heating system and the emissions associated with electricity use. Broberg and Karlsson (2013) studied excess heat recovery using modeling and consistent energy market scenarios, which made it possible to study excess heat recovery and associated CO_2 emission changes under different conditions. The six different energy market scenarios studied all showed a reduction in CO_2 emissions when industrial excess heat was introduced in the system. Broberg Viklund and Johansson (2014) maps different options for excess heat recovery and applies the recovery technologies to the untapped excess heat potential in Gävleborg County in Sweden. It is shown that when the heat was used for electricity generation the CO_2 emissions were reduced whilst when the heat was used for deliveries to the DH network the CO_2 emission consequences depended on e.g. the heat production technology in the DH system. (Broberg Viklund and Johansson 2014) Johansson and Söderström (2013) studies electricity generation from low-temperature industrial excess heat within the steel industry, showing reduced CO_2 emissions.

2.2 Review of energy policy instruments studied

Since resources are scarce, choices have to be made about what these resources should be used for. The use of industrial excess heat may release resources that could be used for other purposes. Different types of policy instruments can control the use of resources, and this paper has studied the effect of several economic, administrative, informative and voluntary policy instruments. Economic policy instruments can be viewed as performance-based because they state that the goal should be reached but not how to reach it. Administrative policies are method-based because they demonstrate how to reach the goal. (Brännlund and Kriström 2012) To distinguish information from other administrative policy instruments, these are usually called informative policy instruments. Voluntary policy instruments are those implemented by companies on a voluntary basis. Below are descriptions of the main policy instruments studied in this paper.

Taxes: There are taxes on electricity, fuels, carbon dioxide and other pollutants. Starting in the 1990s, the environmental profile of the Swedish energy taxation system was strengthened and taxation aims to contribute to more efficient energy use, promote the use of biofuels, create incentives to reduce the environmental impact of companies, and create favorable conditions for domestic electricity production (SEA 2011). Energy taxes include taxes on fuels and electricity (none on biofuels). Generally, the taxes are imposed on the users and not the producers. The tax rate is higher in sectors with low price sensitivity and lower for sectors exposed to external competition. The carbon dioxide tax is assessed depending on the fuel's carbon content. Some sectors are entitled to a reduced CO_2 tax. The CO_2 taxation level within industry has been reduced since the 1990s, as a result of international competition. The EU trading scheme (EU ETS) constitutes a major climate policy in this sector. (Mansikkasalo et al. 2011)

Electricity certificates: The electricity certificate system seeks to increase renewable electricity generation. Electricity producers meeting the requirements receive certificates for each MWh of renewable electricity they produce. The producers of renewable electricity can then sell their certificates and receive an extra income, which stimulates the expansion of renewable electricity generation. (SEA 2012) The demand for electricity certificates occurs because electricity suppliers and some electricity users are required to buy certificates that correspond to a certain share of the suppliers'/users sale/use. This share is raised incrementally, resulting in an increased demand for certificates. (Mansikkasalo et al. 2011) Excess heat can be used for electricity generation in several technologies, for example, in the Organic Rankine Cycle (ORC) and Kalina Cycle (Broberg Viklund and Johansson 2014). Companies generating electricity from excess heat (with renewable origin) are also entitled to receive electricity certificates (SEA 2008a).

Investment grants: Government grants, in the form of investment grants, have been offered in Sweden for different energy-related measures. The Local Investment Programme (LIP, running between 1997 and 2002), and the Climate Investment Programme (Klimp, running between 2003 and 2012) have offered stakeholders the opportunity to receive funding for e.g. excess heat-related measures. One aim of the programs has been to reduce Sweden's impact on the climate and expedite the transition to a sustainable society. Investment grants have the advantage of providing companies with a reliable picture of the costs of long-term investments (SEA 2008a).

TPA: In accordance with current Swedish regulations, new heat producers have no right to access the DH network; only the owner of the DH system does. To create a more efficient DH market, allowing third-party access (TPA) to DH systems has been proposed. The aim of TPA was to open the DH networks to new heat producers and let them compete in the heat market. Markets under competition would be divided into three parts: production, distribution, and trading. (SOU 2011) TPA has not been introduced, and current work focuses on the implementation of the EED and the directive's recommendations regarding excess heat utilization (Ministry of Enterprise, Energy and Communications 2013).

Environmental code: The environmental code coordinates the environmental targets in Sweden. One of its objectives is to require those running an operation to economize with energy and raw materials and utilize opportunities for reuse and recycling. The objective should be taken into account in the licensing process of industries and when providing guidance. Several environmental targets may be incompatible, and the decision regarding measures has then to be based on what best promotes sustainable development. (Mansikkasalo et al. 2011)

Municipal energy planning: By law, municipalities in Sweden are required to develop energy plans; in other words, each municipality should have a plan for the supply, distribution, and use of energy. This allows a municipality to strategically influence development and to control energy use and supply in the municipality. The law also requires municipalities to look at the possibility of excess heat collaborations. Hence, the law on municipal energy planning and the energy plan could serve as an incentive for excess heat collaborations. (Ministry of Enterprise, Energy and Communication 1977; SEA 2008a)

PFE: The programme for improving energy efficiency (PFE) in energy-intensive industries is a voluntary policy instrument intended for energy-intensive companies and focuses on electricity use. It aims to increase awareness of untapped energy efficiency potentials in Swedish companies. The program was first introduced in 2005 and the second five-year program period is running. The incentive for a company to participate is a tax rebate on electricity use. Technology and management measures are combined in the program. During the first two years, a company has to perform an energy audit and identify electricity saving measures. In the following three years, the company must implement the measures identified and a standardized energy management system. (Stenqvist and Nilsson 2012)

Information and expert support: Information campaigns are used to reach many people with material on energy efficiencies, such as examples of successful excess heat collaborations. Excess heat collaborations may involve several parties (politicians, industry or DH companies), and various types of information may be relevant for different parties. The use of a competence center to support different stages of an excess heat collaboration process is another example of a measure that can affect excess heat recovery. The center could offer help in various issues and stages of the process, for example, technology, economics, laws and agreements. (SEA 2008a)

3. Method

To explore how the industry views excess heat recovery in the light of energy policy, interviews were conducted. The interviews provided the opportunity to gain a deeper understanding of the way Swedish companies and their energy managers look on excess heat recovery and on energy policy measures. It is difficult, or even impossible, to reach a solid and multifaceted understanding of how industry reasons about, and looks on these issues from their own perspective using approaches other than qualitative research methods, such as interviews. The interviews were semi-structured and the interviewer used a guide containing the questions following the main themes of the interview; background information (e.g. companies' work on energy and excess heat recovery), the main energy policy instruments studied, and the need for new instruments. The semi-structured format allowed freedom to change the order of questions and how they were asked. It also allowed for asking additional questions to clarify or follow up on interesting answers or new themes emerging during the interview which would not have been possible if using e.g. questionnaires or a closed format interview. (Kvale and Brinkmann 2009)

In total, eight interviews were conducted during the autumn of 2012. Since no similar study has previously been done, this exploratory study offered the opportunity to study the companies reasoning, identify key aspects and collect data from several different production areas. A week before the interview, the respondents received a short pre-interview questionnaire, designed to give the author a better picture of the company in advance of the actual interview. The questionnaire included questions about the company, its energy use, and its excess heat potential and current excess heat recovery situation. The interviews were conducted at the companies' conference rooms or in the respondents' offices and lasted for approximately one hour. All the interviews were recorded digitally and then transcribed word for word.

The interviewed companies are all multinational and the production sites visited are geographically distributed in Sweden. None of the companies are located in the same municipality. If local conditions were identified or highlighted, these are reported in connection to the results. The companies were selected because they currently recover excess heat, and therefore had likely reflected on their conditions for heat recovery. The companies were identified using contacts within the Division of Energy Systems at Linköping University. The companies belong to the following production areas: pulp and paper, iron and steel, chemical, food, foundry and the non-ferrous industries. These industries account for most of the industrial energy use in Sweden. Since the aim of this study was not to compare companies or industries, the results were not analyzed in relation to type of industry.

The respondents were the persons responsible for energy issues at the company. For a summary of the companies, their yearly energy uses, and the respondents' positions, see Table 1. The interviews were all conducted in Swedish and therefore all the quotes presented in this paper have been translated into English by the author. Since the aim of this study did not require the companies to be mentioned by name or type of industry, the respondents have been anonymized in this paper.

The transcribed interviews were sorted into overall categories to identify data of interest for this study, and thus the empirical material was reduced. The categories were based partly on the questions and themes used in the interview guide while others emerged from the analysis of the transcribed material. The goal of developing the categories and themes was to identify the respondents' views on how policy instruments affect excess heat recovery. (Ryan and Bernard 2003) Some categories are energy prices, use, impact on quality and production processes, and investments. Several themes overlap each other and the results are therefore presented in this paper using six main categories: use of excess heat; alternatives to DH deliveries; awareness, commitment and legitimacy; knowledge development; internal- and external-based control; and investments and economic factors.

Table 1 Summary of companies, energy use (approximate numbers) and respondents' positions.

Industry	**Energy use (GWh/year)**	**Respondents position**
Pulp and paper	6 720	Energy Controller
Pulp and paper	2 400	Manager Recovery and Energy
Iron and steel	130	Quality and Environmental Manager
Chemical	5 200	Energy Specialist
Foundry	350	5 respondents[a] (two working for another group company): • Energy Manager • Energy Manager • Regional Manager • Environmental and Quality Director • Technical Specialist
Foundry	50	Energy Controller
Non-ferrous	2 040	2 respondents[b]: • Environmental Manager • Electricity Manager
Food	8	Environmental Manager

[a]The main respondent invited four people to join the interview for educational and supportive purposes, making it resemble a focus group interview (Wibeck 2010). One of the additional respondents was the r respondent's manager, which might have affected the outcome of that interview. However, the main respondent brought up his own weaknesses in some subjects, indicating that he felt comfortable in the situation even in the presence of his manager.

[b]The main respondent invited the electricity manager to the interview. This probably did not affect the main respondent's answers in this case.

While the interviews and the results in this study do not represent Swedish industry as a whole, they can still contribute to an understanding of how policy instruments affect excess heat utilization.

4. Results and analysis

Interviews with energy managers at eight Swedish production sites revealed that when they talk about excess heat recovery they generally refer to heat recovery through deliveries to the DH network. This is reflected in most of the results presented in this paper.

4.1 Use of excess heat

The respondents raised the issue of the lack of use of the heat as a major factor that prevented the recovery of excess heat; the lack of a nearby DH network was mentioned as an example. These problems have been raised in previous research. Walsh and Thornley (2012) found among others two important barriers to energy efficiency improvements in the process industry; location (mismatch between the heat source and the possible heat sink) and availability of infrastructure (existence (or non-existence) of piping for heat transportation). Proximity to a DH network for heat deliveries from industries seems to be a prerequisite for large-scale heat recovery. “I cannot see where we could use it otherwise,” one respondent said.

The heat demand in the DH system can be covered using different technologies, for example, waste incineration and bio-fuelled combined heat and power plants (bio-CHP). Waste incineration has become popular because of the pricing of waste. Households and industries pay for waste disposal while waste incineration plants are paid for receiving and treating the waste (Avfall Sverige 2005). Electricity generation from bio-based CHP entitles companies to green electricity certificates, providing additional income for electricity and heat producers using renewable fuels (SEA 2012). Previous research has shown that the profitability of investments in new CHP plants increased significantly with the introduction of green electricity certificates (Knutsson et al. 2006). The competition between CHP, waste incineration and excess heat in the DH system has previously been discussed in e.g. (SEA 2008a; SEA 2008b). In line with this, several respondents pointed out waste incineration and bio-CHP as factors that counteracted the use of excess heat. One respondent said, “The world can see that the competition is obvious.” Another respondent said, “Even if they (note: the DH company) got the heat for free, they do not want it.” One respondent believed that excess heat utilization would increase if it were regulated so that the use of excess heat was given priority over waste incineration and bio-CHP. One company had appealed the establishment of a bio-based CHP plant by referring to the principle in the environmental code of economizing on energy, but the CHP plant was still built. One respondent however expressed that waste incineration was needed because of the current waste generation. Another respondent however thought that the expansion of waste incineration and bio-CHP facilities may have led to an increased expansion of DH infrastructure, which, in turn, may create opportunities for excess heat utilization. Large industries are often located near cities and areas with limited heat demand. One way to increase the heat load is to integrate several DH networks and one company interviewed is involved in an initiative trying to develop a regional DH network. The initiative has met opposition as it affects local electricity generation and the ability to incinerate waste. There is also a problem with who would lead such a border-crossing DH network. In addition, a large proportion of the unused excess heat is at lower temperature levels. Two means mentioned for increasing the use of these heat resources were lowering the supply temperature in the DH network and using low-temperature networks. Despite the belief that waste incineration and bio-CHP affects opportunities for industrial excess heat deliveries, none of the respondents expressed a wish to introduce a constraint for use of excess heat. In their opinion, excess heat should be used in the DH system only if it is the best solution.

Several respondents addressed the concept of risk, in other words, the risk of reduced heat availability due to the shutting down or relocation of the company or production site holding the excess heat or changes in the production processes. The risk of closure of the industry has also been brought up as a key factor in a study of factors that promote or inhibit DH collaborations between industries and utilities (Thollander et al. 2010). This risk must be managed to facilitate excess heat collaborations. One respondent exemplified risk reduction; they offered to let a DH company buy their boilers (for less than 1 Euro) if the company had to close down, to make the necessary investments including a thermal storage tank to guarantee delivery despite uneven production. Still, the DH company was not interested in taking excess heat deliveries. Trygg et al. (2009) points out heat cooperation as a way to reduce the risk of a company closing down, i.e. it could be a strategy for e.g. a municipal owned DH company to retain the jobs associated with the industrial site.

The majority of the companies interviewed deliver part of their heat to the DH network. One company had tried to initiate collaboration with the DH company but they were not interested due to uneven access of excess heat. The companies currently supplying heat to the DH system have had various experiences regarding cooperation with the DH companies. Some described it in positive terms, and as resulting from the DH company’s initiative. During the interviews, respondents mentioned several success factors: long-term contracts, municipally owned DH company, open dialogue regarding profitability requirements, investment grants and solutions concerning dependability (e.g. having several heat suppliers). Respondents with negative experience associated it with the following factors: uneven production, non-municipally owned DH companies, an alternative heat production facility and the risk that the producing companies will close down. The proposed policy instrument TPA and the implementation of the EED have recently been discussed as ways to increase the amount of excess heat in the DH network (Ministry of Enterprise, Energy and Communications 2013; Optensys 2012; SOU 2011). The companies with negative experiences were positive about a TPA and believed the instrument could enable or increase their excess heat deliveries. One respondent even believed that opening up the heat monopoly would result in a more competitive product and, hence that a TPA would increase the market share for DH. One respondent believed an introduction of TPA would allow market forces to solve the heating supply in the cheapest way, and that excess heat would then be introduced in the cases where it was part of the best solution. Several respondents, however, said that the investments, work load, and responsibility associated with a TPA were beyond their interest since it is too far from their core business. Previous research states and discusses that, due to the increased focus on core business among manufacturing industries, the companies have fewer resources for non-core business activities and hence issues regarding improved energy efficiency are often not fully prioritized (Möllersten and Westermark 2001; Thollander and Ottosson 2010). The proposal for implementation of the EED states that a cost-benefit analysis should be performed, in connection with certain investments[2], to evaluate use of available industrial excess heat with the aim to promote an efficient energy supply (Ministry of Enterprise, Energy and Communications 2013). One respondent emphasized that implementation of new policies as a result of the EED could offer a way to increase the use of industrial excess heat in the DH network, i.e. an opportunity for excess heat utilization.

4.2 Alternatives to DH deliveries

The electricity certificate system allows certificates to be given for excess heat-based electricity generation if the heat has renewable origin (SEA 2008a). Several respondents thought it was wrong to value excess heat based on its origin, referring to the importance of using available resources. One respondent said, "It´s just politics." In talking about having to cool fossil-based excess heat, one respondent said, "Society does not benefit from that." It was discussed that electricity certificates from excess heat, independent of origin, might increase use of excess heat due to new economic opportunities for investing in electricity generation technology. Two advantages of excess heat-driven electricity generation were brought up. First, using the heat for electricity generation could increase the use of the available heat and offer the possibility of using it year-round. This could offer an application beyond the current situation where the utilization depends largely on the heat demand in the DH network and the DH companies' willingness to introduce excess heat in the heating systems. Second, it would reduce the external dependence on electricity supply. Seven out of eight companies had looked at a possible investment in heat-driven electricity generation technology but none saw profitability in the investment, mainly due to the inefficient conversion. One respondent said: "I would argue that the systems (note: the heat driven electricity generation technologies) are financed as a shortcoming in the electricity certificate system, since you receive certificates for gross production." The respondent argued that the systems use large amounts of energy combined with low efficiency, resulting in inefficient systems. Johansson and Söderström (2013) studied electricity generation from low-temperature industrial excess heat using different heat driven technologies. They showed that investment in such technologies could be profitable; however, not all associated costs were included in the calculations in this study, i.e. the cost of piping and pumping of excess heat and cooling water.

The respondents discussed examples of other means and technologies for recovering industrial excess heat. One company is looking into the possibility of producing biogas from food waste resulting from their production; the process requires low-temperature heat and thus may allow for use of available heat flows. The use of low-temperature excess heat in biogas production processes has previously been discussed in e.g. (Ammar et al. 2012; Ellersdorfer and Weiss 2014) and Ammar et al. (2012) emphasize it as an opportunity,

[2] A cost-benefit analysis should be performed when planning for: a new thermal electricity generation facility (>20 MW), a new DH/district cooling (DC) network, a new "energy production facility" (>20 MW) in an existing DH/DC network, an industrial facility (>20 MW) that would generate excess heat or when an existing energy generation facility is being reconstructed (Ministry of Enterprise, Energy and Communications 2013).

particularly in the food industry, to reduce the environmental impact. Another company has invested in a thermal storage system that allows meeting of internal heat demands. Several respondents highlighted opportunities provided by heat collaborations and the importance of using a system perspective, emphasizing that energy systems, including industrial energy systems, must be seen as a whole. This is in line with what is stated in Ammar et al. (2012), that a holistic view would increase the opportunities for low-temperature excess heat (Ammar et al. 2012). The respondents pointed out that it is important to have available industrial excess heat in mind when planning new residential areas, to plan for excess heat recovery through deliveries to the heating systems. They also pointed out that splitting responsibility for energy issues into different parts of the organization, such as real estate and processes, makes it difficult to see the potential for energy recovery and systems integration and so may disadvantage heat recovery. They addressed the importance of owning their own properties in increasing motivation for implementing energy efficiency measures. This barrier, associated with split incentives, is further discussed in Thollander et al. (2010). Advantages with industrial collaborations such as the possibility of sharing infrastructure and the use of industrial excess heat were discussed. However, the difficulty for two parties with matching needs to find each other to initiate collaboration was brought up. Gertler (1995) states the importance of knowing the inputs and outputs from each member in a collaboration. This however requires the companies to be aware of their by-product streams, and e.g. energy audits can be used to provide a picture of the industrial energy flows.

4.3 Awareness, commitment, and legitimacy

All companies interviewed that participated in the voluntary energy efficiency program, PFE, brought up several perceived success factors associated with the policy instrument or with an introduction of a revised policy instruments. Although PFE primarily focuses on electricity saving measures, it contains other activities for participating companies to commit to (Stenqvist and Nilsson 2012). The PFE was described as making it legitimate to work with, and prioritize energy issues (in respect of the company management), since participation forced the participating companies to commit time to energy-related work and energy efficiency. Previous research has highlighted the importance of support from top management in order to succeed in energy efficiency and energy management (McKane et al. 2008; Thollander and Ottosson 2010). In addition, several studies point out lack of time as a barrier to energy efficiency (Johansson 2013; Rohdin et al. 2007; Thollander and Ottosson 2008). PFE was described to lead not only to electricity efficiency measures but also to energy efficiency measures in general. The energy audit performed within the program was described as providing a picture of the energy flows in industry. It was stressed that since PFE made energy visible, it has resulted in positive effects regarding excess heat utilization. Rudberg et al. (2013) shows that participation in PFE increased the company's awareness of energy and put energy management on the strategic agenda of the company. While some respondents said the set-up of the program and its obligations offered opportunities to initiate excess heat measures, others believed that, despite what the program offered, companies would implement measures when they saw value in the heat.

Several respondents said their company would like to participate in a program that focused on energy issues and energy use from a broader perspective. They believed that by including e.g. thermal energy and fuels, the move from electricity to total energy use could create incentives to reduce the energy use at several levels and improve energy efficiency, including excess heat use. The importance of including PFE's economic incentives in a revised comprehensive program was emphasized, as was the importance of not favoring recovery of excess heat in an unsustainable manner.

4.4 Knowledge development

All the companies interviewed requested information or education regarding excess heat recovery. Needs, ideas and positive effects of current activities emerged during the interviews. The importance of benchmarking or the ability to participate in networks, internally and/or externally, was highlighted. Networking within the company or within the same industrial sector, as well as benchmarking, has previously been found to be a driving force and an effective way to improve energy efficiency (Amundsen 2000; Apeaning and Thollander 2013; Palm and Thollander 2010; Thollander and Ottosson 2008; Worrell et al. 2009). Palm and Thollander (2010) discusses that innovative and new ideas and new technologies have problems breaking through due to existing energy efficiency values and are more likely to come through when introduced from external actors. (Palm and Thollander 2010) Respondents described their exchange of ideas via networks as being organized either by business associations (or similar) or as gatherings at industrial actors' initiative. They said that smaller gatherings usually occur at the initiative of the company. Through field trips and seminars they present good examples, share experiences and ideas, such as energy efficiency solutions, or the network meetings were described as serving as a platform for acquiring new contacts. Palm and Thollander (2010) also highlights sharing good examples as a way to improve energy efficiency. One respondent referred to good examples saying, "I think it is really important to show concrete examples. So that it´s not just theory." These get-togethers were described by the respondents as inspiring and they wished for more externally initiated gatherings. Another example that came up during the interviews was through the introduction of a measure database to spread energy efficiency and excess heat recovery measures. Several respondents believed it could serve as an aid for investments because they could take advantage of other companies' experiences.

The importance to raise the awareness of energy issues within the organization, e.g. through education and benchmarking, were emphasized. Lack of awareness about energy has previously been highlighted as a barrier to energy efficiency, and increased awareness may result in a more energy efficient behavior (Johansson 2013; Sorell et al. 2000; Thollander and Ottosson 2008). The companies interviewed, which had several production sites, highlighted their ability to share experiences and ideas in-house. The idea of sharing efficiency solutions, however, led to a discussion of competitive issues. One respondent said it was advantageous to discuss energy issues with companies in the same industry sector but with different products, because they do not compete. Another respondent emphasized the general fear of sharing ideas due to competition, but stressed the relative openness regarding energy saving measures. Monitoring and visualization, two recurring concepts in the interviews, were also said to create an awareness of energy use and lead to the discovery of excess heat recovery solutions and more efficient energy solutions in general. “To measure is to know”, said one respondent. Using monitoring, one can also study the effect of implemented measures. It was described as making it possible to demonstrate positive effects of an investment or implemented measure and, thereby, establish management´s trust hence making it easier to receive approval for other energy efficiency investments.

Related to information and education, the respondents described the difficulty in using external expertise due to the complexity of their production processes. The respondents seemed to agree that they knew their own processes well: excess heat potentials (overall) and the ability to create internal process solutions. However, they mentioned the need for external expertise for new technological solutions, such as heat driven electricity generation. Respondents believed experts, such as energy consultants, could possess great knowledge from their experience in several projects within industry and in addition, a consultant they had previously worked with might also be knowledgeable about their specific company processes. They emphasized the need to have external support in the initial phase of larger excess heat utilization projects, such as in taking the project from concept to management approval. Several respondents pointed out that the company´s personnel resources for energy issues are not large enough for major innovative projects. The importance of a well prepared pre-study for energy efficiency investments was stated in Johansson (2013), and lack of time and personnel was brought up to be a problem that sometimes prevented these pre-studies and hence investments in energy efficient solutions (Johansson 2013). Besides technical expertise, respondents raised the need for support with administrative procedures and soft issues, such as contractual processes and the application process for investment grants. It is discussed that collaboration projects may require the involvement of an independent actor to avoid questions of trustworthiness. This is linked to the increased need for different types of research, which several respondents emphasized. It is needed both on the technology level and on the system level (e.g. exploration of when it is good to use excess heat on behalf of other heating technologies).

4.5 Internally and externally based control

Due to limited resources, different job assignments are described as competing with each other. Several respondents expressed frustration that lower priority was given to energy issues. In regard to excess heat recovery, respondents emphasized that they primarily work with internal heat recovery and that they have been or are picking the low-hanging fruits. External excess heat recovery is often associated with larger projects that require more resources. The respondents provided several examples of how internal support, goals and policy instruments have affected their work on energy efficiency. One respondent said environmental and energy issues were given higher priority after the introduction of concrete goals, such as a figure on CO_2-emission reduction requirements. Another respondent said the internal environmental goals and the company core values had driven their environmental work forward: “For our part, we have had internal company goals; they have been our policy instruments so to speak.” They had placed great internal demands on monitoring, reporting, and CO_2 emissions reduction, and, at the same time, increased the possibility of investing in energy efficiency measures. The increased focus on reducing the environmental impact was said to have led to an increased awareness within the company of new energy efficiency and cost saving opportunities. Again, management support was shown to play a major role in the work with energy efficiency and excess heat recovery (see also McKane et al. 2008; Thollander and Ottosson 2010). In addition, the importance of a long-term energy strategy for improved energy efficiency was stated in (Thollander et al. 2007) and the importance of identifying energy as an important part of the business has been discussed as a factor for successful energy management (Johansson 2013). The introduction of the EU emission trading scheme (EU ETS) resulted in the introduction of a new position at one of the companies (the position that the respondent from that company holds), providing more resources for the work with energy issues. The respondent believed that the introduction of the position was one main factor that led to their excess heat collaboration with the local DH company, since it aimed to e.g. work with strategic energy issues. One company pointed out that their company environmental targets do not contain any requirements for energy use, but believed that energy use is strongly associated with the production and profitability of the company, and it is therefore covered by these goals. At the same time they expressed great frustration and stressed that the issues are not sufficiently prioritized within the company and they had far from enough time to work on energy efficiency and excess heat recovery. The respondent said, “...they (note: the management) probably expect me to have time for that too.”

The respondents believed that the municipality has an important role in the municipal heating systems, and thus the ability to influence the choice of heating system and excess heat utilization in this system. Several respondents said they do not have any contact with the municipality and that they are probably not aware of the company’s heat flows. Generally, the respondents wanted more active dialogue with the municipality regarding the possibilities of using industrial excess heat. One respondent thought the municipality should ascertain the possibilities of industrial excess heat collaborations and have excess heat in mind when planning new infrastructure. While municipal goals and energy plans can benefit excess heat utilization, a concern was raised that municipal borders can counteract the work of excess heat recovery across these borders and, thus, regional DH networks.

Respondents described a good environmental profile as leading to good publicity, which was hard to value in monetary terms. At several of the companies, excess heat recovery investments had led to positive publicity and created an external interest in the company. Also, customers were described as being able to affect the companies through their demands. One respondent said: “Customer requirements mean much more than policy instruments. They are concrete.” The respondent argued that increased customer demands affect company management and thus the possibility of working with energy issues. The respondent believed that increased customer demand would increase use of excess heat. The importance of customer requirements in the work with company sustainability has previously also been raised in Lieb and Lieb (2010). In addition, it was raised that companies can increase their competitiveness and may win new market shares by working with energy issues and becoming more environmentally friendly.

4.6 Investments and economic factors

The interviewed companies pay-off criteria for excess heat recovery investments is 1–3[3] years. In addition, the annual investment opportunities are limited. Investments in excess heat recovery, and other energy efficiency investments, were described as competing with production-related investments. The latter were generally prioritized because they were described to be necessary to keep the companies in the market. One respondent said, "The actual investment is almost always the Achilles' heel when it comes to excess heat recovery." In line with this statement, in a study of barriers and drivers for energy efficiency in the foundry industry, limited access to capital was ranked as the largest barrier to energy efficiency (Rohdin et al. 2007). The barrier was also highly ranked in Thollander and Ottosson (2008) together with the barrier of other priorities for capital investments. However, several respondents pointed out the opportunity of excess heat recovery in connection with other investments or reconstructions. Reconstructions were described as e.g. creating opportunities for cost-effective process integration, such as internal heat recovery. One respondent illustrated the benefits (related to heat recovery) of combining investments: When the company invested in a new boiler, the processes were at the same time changed to further extract excess heat. As a result, the boiler could be designed with lower power, creating an opportunity for excess heat recovery investments due to the reduced cost of boiler investment.

Several of the companies have received investment grants, directly or indirectly, for excess heat recovery projects, mainly for investments in transmission lines to connect the industry to the DH network or for heat storage solutions. In all cases, the investment grants were said to have affected their heat recovery; either the grants had been crucial for actually making the investment or allowed the investment to be made much earlier than would otherwise have been possible. "The grant was like the icing on the cake, there was no more questioning", one respondent said. The investment grants enabled companies to make investments with longer payback times than the industry normally accepts. One respondent said, "The investment grants serve as a risk reduction and enable collaborations." It was exemplified with that an investment in a thermal storage would enable companies to make steady deliveries to the DH network despite uneven production.

Several respondents had noticed that as a result of increases in energy prices or reductions in subsidies on fuels and energy, their company had an increased interest in excess heat recovery measures and other energy efficiency or energy-related issues. Energy prices and taxes were believed to act as an incentive for energy efficiency but may also affect the companies' competitiveness. They stressed the risk of the policy instrument only serving as a financial burden that ultimately forced the company to close. Respondents highlighted the alternative cost for heating; if excess heat is the cheaper alternative, this could favor use of excess heat.

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[3] Not all companies were able to disclose this information.

One example given was that a tax on electricity could be beneficial for excess heat recovery because it makes the use of heat pumps a more expensive option. One respondent said, “You could say that it is money that governs the development.” Several respondents believed that current energy prices and taxes are not high enough to affect excess heat recovery and hence tax reduction may also counteract excess heat utilization. The interviews revealed that in companies exempted from taxation, the saving resulting from energy efficiency was lower, i.e., the savings per MWh_{fuel} is worth less to the company. “At the margin, the value of the savings was smaller, the result being that fewer ideas have the profitability that they otherwise would have.” said one respondent. On the other hand the respondent said that, due to the tax reduction, the company had more money left, which could be used for investments such as excess heat recovery or other energy efficiency investments.

Excess heat deliveries to the DH network require resources from the industrial companies. In addition to the actual investments, the cooperation was described as requiring employees’ time and involvement. One respondent spoke about the importance of employees’ work generating revenues due to competition for the employees’ time. Respondents viewed being paid for the heat as a prerequisite for making heat deliveries, and thought heat recovery should be profitable for all stakeholders, both industry and the DH company. The realization that excess heat can be valued had affected their work with excess heat recovery. “It is when excess heat is priced that the organization begins to work,” said one respondent and another respondent said, “You do not recover the heat just for fun.” This created an incentive to control the production processes to extract the excess heat in its most useful form. However, several respondents felt they are not paid enough for the heat. One respondent believed that if it was possible for them to sell their heat to DH customers at a competitive price, the heat demand would increase, and hence the DH market share.

The importance of long-term policy instruments was also stressed, reducing the risk-taking in investments. If the e.g. subsidy could only be guaranteed for a couple of years, it would affect the profitability calculations of the investment and whether the investment would be realized.

5. Concluding discussion

The aim of this paper was to elucidate how current and future policy instruments promote or discourage industrial excess heat recovery. The need for increased heat use was identified a prerequisite for excess heat recovery. Not knowing how and where to use the heat flows was repeatedly identified as a problem. Several recovery options for increasing the use of available excess heat were however discussed during the interviews indicating that the respondents are aware of the breadth of possible recovery solutions. Nevertheless the industry seems to limit their actions or thoughts of action to heat recovery in the DH network. To increase the recovery of industrial excess heat, one may need to look for new innovative recovery solutions. Uneven production was discussed as a barrier to heat deliveries, but this could be overcome by the use of e.g. a thermal storage tank or through industrial cooperation to eliminate the mismatch between supply and demand. Synergies to match excess heat to external users, together with innovative recovery technologies, such as heat driven cooling or electricity generation, could be introduced to increase the use of industrial excess heat. The fact that the industries are aware of these solutions, but still they are not being implemented, indicate that policies are needed to bring these solutions into action. The awareness of recovery opportunities within the industry needs to be further increased, and also, support is needed to evaluate the opportunities to implement the solutions in their specific production processes. This could e.g. be achieved through the use of information, support during the initial phase of the project through taking the project from idea to decision support or mapping of heat flows to build up information about available options. A more holistic approach could promote mutually beneficial cooperations through increased use of excess heat. Industrial collaborations could create use for untapped heat resources and collaborations regarding industrial infrastructure systems. However, finding suitable collaboration partners where excess heat supply and demand match is recognized as a problem. An external function, e.g. the municipality, could support the industry in finding collaboration partners to promote these collaborations.

The interviews revealed a difficulty in entering the DH network. A TPA has previously been discussed as a way to create a more efficient DH market (SOU 2011) but the opinions regarding a TPA differed. TPA as an opportunity for increased use of excess heat was discussed while others believed it would lead to work far beyond their interest and core business. Introducing a TPA would shift the work load regarding (excess) heat supply from the DH companies to the industries. In line with previous research showing that industry has fewer resources for non-core activities (Möllersten and Westermark 2001; Thollander and Ottosson 2010), this setup would probably not affect the heat deliveries from the majority of industries holding the heat.

The study revealed that industries believe in the municipalities' ability to increase the share of excess heat in the heating systems. The municipality has the potential to affect the heating systems and infrastructure investments in the municipality through e.g. the municipal energy plan (Ministry of Enterprise, Energy and Communication 1977; SEA 2008a). Increasing the awareness of the available heat resources at the municipal level could create an opportunity for heat recovery and as a result, prompt the municipality to take action. Using their awareness they could contribute in initiating heat collaborations within the municipality and work towards increasing the share of excess heat in the heating systems, e.g. when planning new residential areas. Connecting several DH networks was described as a way to create an increased heat load in the heating system and consequently may increase the potential for industrial excess heat recovery. The author believes it is important to keep in mind, when developing and using the energy plan, that the municipal borders should not stand in the way of the work towards the national goal in decreased use of primary energy.

Favorable conditions for competing heat sources, such as bio-CHP and waste incineration were identified as working against excess heat deliveries to the DH network. On the other hand, it was also discussed that the expansion of bio-CHP and waste incineration may have led to an expansion of the DH infrastructure. An expansion of the DH infrastructure could be favorable for excess heat recovery in the long run. Excess heat driven electricity generation with renewable origin allows companies to earn electricity certificates (SEA 2008a). Even though the majority of the companies had looked at a possible investment in heat-based electricity generation, none saw profitability in the investment due to the inefficient conversion. This indicates that a system aiming to increase the share of excess heat based electricity generation, similar to the electricity certificate system, could favor the development of an inefficient system.

All respondents participated in some kind of networks and these gatherings were highlighted as important for inspiration and for seeing possible measures for improved energy efficiency. Networking and benchmarking have previously been discussed as ways to increase energy efficiency (Amundsen 2000; Apeaning and Thollander 2013; Palm and Thollander 2010; Thollander and Ottosson 2008; Worrell et al. 2009). The interviews reveal that this type of information/education was requested in different forms, e.g. through network meetings and seminars. Today these network gatherings or benchmarking originated, in many cases, from company initiatives. Where this is not possible (due to e.g. resource scarcity or lack of drive), there is a risk that this feature disappears. Large companies or company groups can internally offer the opportunity for idea sharing, however this feature is not possible at all companies. Including network meetings in the context of other policy instruments could be one example of increasing external inspiration and implemented measures. The compilation of a database covering excess heat recovery measures and experiences from implemented measures could be another example.

Beyond external policy instruments, internal visions and goals were shown to work as internal policy instruments and thus impact excess heat recovery. Having management prioritizing and highlighting energy issues may thus create a foundation for energy efficiency through implementing internal goals that strive towards increased energy efficiency. The interviews showed the importance of having management support in the work with energy efficiency, showing that the work was improved and got a higher priority when internal goals were introduced. Also, one company lacking goals regarding energy use expressed great frustration due to lack of time working with energy efficiency issues. This is in line with previous research where lack of awareness of energy was found to be a barrier to energy efficiency (Johansson 2013; Sorrell et al. 2000; Thollander and Ottosson 2008). The obligations within the voluntary agreement PFE affect many of the prerequisites that emerged in this study. Knowing the existing heat flows should be a prerequisite for heat recovery and similar instruments as PFE, favoring this information gathering, are therefore to be desired in order to increase the awareness of the industry opportunities. However, the study found that awareness of the heat flows is not enough for excess heat recovery to be realized - although the PFE was identified as having made energy visible and provided a picture of the energy flows, hence increasing the awareness of energy. By having agreed to participate in the program, it became, as regards management, more legitimate to work with improved energy efficiency. Based on the positive experience around PFE, the author believes that a comparable policy instrument, one with a broader perspective (including e.g. heat and fuels) and a similar economic incentive may promote other energy efficiency measures, such as use of excess heat.

Investment was described as the Achilles´ heel when it comes to excess heat recovery, and the importance of seeing a value in the investment was emphasized. This may primarily be related to internal decisions and priorities, in line with company core business, however economic incentives can be used to affect the outcome. Investment grants were revealed to have made an impact on excess heat recovery investments in the companies studied. Investment grants may create economic security since, unlike other economic policy instruments, the policy conditions will not change over time. Overall, the companies asked for long-term policy instruments because they create a better picture of the investment possibilities and reduce the associated risk. The interviews revealed the importance of the investments creating a value because of competition for company resources; hence, being (sufficiently) paid for the heat is a prerequisite for recovering heat. Access to an independent party during negotiations and the contractual process could facilitate the process of reaching a solution that is profitable for both stakeholders. The interviews also reveal that taxes, subsidies, and energy prices can work as an economic incentive for energy efficiency measures. For example increased taxation on primary energy may result in increased interest in resource efficiency and thereby excess heat recovery.

The goal determines the policy instruments that should be implemented and must therefore guide the development of these instruments. Mandatory requirements could be used to force recovered excess heat in to the system but despite the difficulties identified with industrial excess heat recovery, none of the respondents expressed a willingness to introduce a mandatory requirement on excess heat utilization. The proposal for implementation of the EED is one example of a policy instrument that could be used to promote excess heat recovery in the cases where it is instead part of an efficient energy supply. In order to develop policy instruments for improved energy efficiency it is important to have an understanding of factors affecting this development. Factors that promote or inhibit heat cooperation have previously been studied but excess heat deliveries were then omitted. This paper studies heat utilization from the industry perspective, filling in a gap in knowledge, and therefore the results presented in the paper represent a great contribution to the work with energy policy development that will promote energy savings in the industry.

It is important to note that the results of this study are the outcome of the interviews with the chosen companies. Factors such as the choice of and number of companies, choice of respondents and geographical location (due to local circumstances) may have affected the retrieved results. The purpose of this study is not to draw general conclusions on how the industry sector, or even the Swedish industry sector, reason about excess heat recovery in the light of policy instruments. The purpose is rather to take the first step towards an understanding of how policy instruments affect or might affect the industry incentives for heat recovery. Hence, part of the results may also put light on the international industrial sector. Also, since the aim of this study was not to compare companies or industries, the results were not analyzed in relation to this factor. However, the interviews indicate that there may be differences in how companies' reason about the issues discussed in this paper, and it would therefore be interesting to complement this study and investigate these possible industry related differences.

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