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Risk assessment of industrial excess heat recovery in district heating systems

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ABSTRACT

The recovery of industrial excess heat for use in district heating systems can be characterised by great political interest, high potential, low utilisation and often high profitability. These characteristics reveal that barriers are present for its greater utilisation. One identified barrier is the risk that industries with excess heat can terminate their activities, resulting in the loss of heat recovery. Excess heat recovery investments are therefore sometimes rejected, despite them being viable investments. The risk of termination of industrial activities has been assessed by a study of 107 excess heat recoveries in Sweden. The analysis verified that terminated industrial activities are one of two major explanations for terminated heat delivery. The other major reason is substitution by another heat supply. These two explanations correspond to approximately 6% of all annual average heat recoveries. The identified risk factors are small annual heat recovery and the use of heat pumps when low-temperature heat was recovered. The main conclusion is that a small proportion of industrial heat recovery has been lost in Sweden because of terminated industrial activities. The risk premium of losing industrial heat recovery for this specific reason should be considered to be lower than often presumed in feasibility studies.

1. Introduction

1.1. International context

District heating companies provide heat to consumers through heat distribution networks. The heat supplied is mainly recycled from external activities, such as thermal power generation, waste incineration and energy-intensive industrial processes. The fundamental business idea is simply to reuse existing heat sources [1]. This reuse of heat is complemented with direct heat generated by boilers or large heat pumps. Internationally, the most common form of heat supply to district heating systems is in synergy with thermal power generation [2], when heat is supplied from combined heat and power (CHP) plants. Most of these CHP plants still use fossil fuels, however. With respect to lower emissions of carbon dioxide, this fossil-based heat recovery should be substituted with a combination of renewables and further heat recoveries, such as recovery from industrial excess heat.

This possible reuse of existing excess heat streams has been identified by the European Commission: “In its 2016 impact assessments for the reviews of the Energy Performance in Buildings Directive, the Energy Efficiency Directive, the Renewable Energy Directive and for the new Market Design Initiative, the Commission will analyse different options to help buildings and industry shift to efficient, decarbonised energy systems based on renewable energy sources and the use of waste heat” [3]. The background to this heightened political interest is that industrial excess heat recovery can contribute to overcoming the energy efficiency gap, i.e., the gap between identified cost-efficient energy efficiency measures and their implementation rates [4]. By closing the energy efficiency gap, primary energy would be saved, greenhouse gas emissions would be reduced, and heat could be utilised that otherwise would be lost.

The potential for industrial heat recovery is high in Europe. According to a survey of various estimated potentials for different countries [5], the EU technical potential, without any restrictions, could be 2.7 EJ/year. This corresponds to about one-quarter of the European heat demands for buildings of about 10 EJ/year [2]. It is known that the most suitable heat to be recovered comes from industrial sites having excess heat from high-temperature processes [6]. A systematic heat cascading concept for an integrated industrial-urban system was presented in Ref. [7]. Internationally, the high potential for further use of industrial excess heat in district

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heating systems has been verified and assessed for the United Kingdom [8], Spain [9], Germany [10,11], Denmark [12], China [13–15] and the European Union [16,17].

The current utilisation of recovered industrial heat is low, compared to the total heat supply in national district heating sectors. A brief survey is provided in Table 1 for some countries with developed district heating systems. This information was mainly obtained from national sources from Denmark [18], Finland [19], France [20], Germany [21], Russia [22] and Sweden (this study), since the International Energy Agency energy balances do not report these heat supplies properly because these regular energy balances do not track heat deliveries between different end-user groups. The total volume of industrial heat recovery in the EU can be estimated at about 30 PJ/year, which is about 1% of the full technical potential reported in Ref. [5].

In the literature, some studies have indicated the typical static payback periods for industrial excess heat recovery investments, concerning connections to existing district heating networks. Interviews with some Swedish industrial companies in Ref. [4] revealed payback periods of one to three years for excess heat recovery investments. The connection of the second oil refinery in Gothenburg, Sweden in 1997 was reported in the local newspaper as having a total payback period of about four years [23]. One plate-exchanger manufacturer communicated the case story of Helsingborg, Sweden as an example of a successful industrial heat recovery. This cooperation initially had an overall payback period of less than one year [24]. A recent UK study estimated that some initial industrial heat recoveries could be commercially implemented with payback periods of less than two years [25]. An Italian case study of a small industrial heat recovery was reported as having a payback period of five years [26]. A recent paper [27] reported that payback periods of around three years could be achieved for a number of cases concerning a petrochemical cluster in Stenungsund, Sweden.

These payback periods for industrial excess heat recovery investments do not appear to be substantially longer than for other alternative investments in energy supply. An indicative conclusion is that most suitable industrial excess heat recoveries could be connected to existing district heating systems with payback periods of between one and seven years; however, shorter payback periods should be expected in countries with developed policy instruments for the substitution of fossil fuels, such as carbon taxes or emissions trading.

Internationally, the identified combination of high potential, low utilisation and often high profitability reveals that major barriers exist for investment in excess heat recovery.

1.2. Current knowledge concerning barriers to industrial excess heat recovery

Barriers to industrial excess heat recovery investments have been identified in several scientific articles and reports. Barriers external to the investment decision are the absence of a district heating network, cost-competitive heat supply alternatives, and current policy incentives for other forms of heat supply, such as bio- or waste-fuelled CHP plants [4,28–32].

Table 1
Survey of annual volumes of recovered industrial excess heat supplied to national district heating sectors during 2014, and the corresponding proportions of the heat supply to these national district heating sectors. Sources for this information are referenced in the text.

	Industrial heat recovery, PJ	Proportion of total heat supply
Denmark	2.6	2.1%
Finland	2.9	2.3%
France	2.2	2.4%
Germany	4.0	1.6%
Russia	330.8	6.0%
Sweden	17.8	9.0%

Barriers to making the investment decision are many, and their assessment is complex. The technical circumstances of the investment are sometimes linked to the barriers. Examples are technical solutions that are more complex than were foreseen, profit erosion from too low temperature levels of the excess heat [29] and too costly transmission pipes [4,28–30]. Other barriers are less tangible, and are linked to the interaction between the local district heating company and the excess heat provider.

The provider and the district heating company often hold different views of the quality of the excess heat. The industry tends to claim that the available heat is of premium quality, which should be reflected in the price, whilst the district heating company may disagree. Another level of complexity concerning excess heat recovery investments is the asymmetric information about the inputs and outputs of each party in the collaboration [4,33]. Furthermore, to arrive at a profitable excess heat recovery investment, energy efficiency competency from the district heating company and the excess heat provider is imperative [28,34], as are shared incentives., Split incentives, when implementing energy efficiency measures, are common, however [30]. Finally, the investment in excess heat recovery competes with alternative uses for investment capital [4,31,32,35].

Apart from the external barriers to excess heat investments, and barriers to arriving at an efficient investment decision, there is one important additional barrier often mentioned. That is the risk that the excess heat provider will terminate its industrial activities. In one study [4], several respondents addressed the risk of reduced heat availability because of the industry shutting down, relocating, or modifying the local production process that creates the excess heat. The risk of closure of the industry was also mentioned as a key factor in a study of factors that promote or inhibit district heating collaborations between industry and utilities [30]. A reduced risk was presented in Ref. [36], wherein heat recovery cooperation can actually offset, or at least reduce, the risk of a company closing down, since remuneration for the recovered heat can become an additional revenue stream to support the industrial process.

The external barriers, and barriers linked to the investment decision mentioned above, can rationally be accounted for in the investment decision by adding a risk premium. The barriers can be contrasted with the benefits of the excess heat recovery investments for the district heating company in terms of reduced carbon dioxide emissions, less need to provide capital in fixed assets (the excess heat recovery investment is often less capital intensive than alternative heat supplies), and a local partnership with the excess heat provider. The cognition of risk associated with the excess heat provider going out of business is difficult to quantify in an objective manner, however. No scientific information is currently available about how high this termination risk is, or why the transfer of recovered excess heat into district heating systems is terminated. Consequently, the risk premium in investment assessments is somewhat exaggerated, due to this uncertainty.

1.3. Research questions

In this study, a novel analysis has been provided for estimating the magnitude of the risk associated with termination of industrial excess heat deliveries. Industrial excess heat recovery investments are built on the rationale of a synergy that creates an economic win-win situation between the excess heat provider and the district heating company. The risk of terminated industrial excess heat delivery is interpreted as the risk of losing the heat recovery synergy, especially from terminated industrial activities. The risk assessment was addressed through three research questions:

(i) What characterises industrial excess heat recovery cooperations that are terminated, with respect to lost volumes and risk factors?
(ii) What typical explanations can be found for terminated industrial excess heat recoveries?
(iii) What characterises the terminated industrial activities and the corresponding magnitude of the risk?

The purpose of the first research question was to identify the main characteristics of terminated heat recoveries, while the purpose of the second question was to separate out terminated industrial activities among all explanations for terminated heat deliveries. Information about the characteristics of terminated industrial activities was expected from the third question.

These three research questions together provided a perspective on how the existing recovery of industrial excess heat developed after it started. This perspective is different from that provided by most contemporary scientific articles about this issue, since those are predominantly looking for opportunities to get these heat recoveries started.

Answers to the three research questions were provided by a unique input dataset, composed of almost all of the Swedish industrial excess heat recovery cooperations between 1974 and 2014. A preview of some early results were presented in a conference paper [37], but no quantitative results concerning the risk for termination of industrial activities was communicated in that. These early results were based on a preliminary database that later was extended to a higher number of cooperations.

2. Industrial heat recovery in Sweden

Since Sweden was chosen as the target area for this analysis, some additional information is provided in this chapter as a complement to the international context provided in the introduction. Sweden is one of the countries in the world that has a high proportion of recovered industrial excess heat in its district heating systems. Even so, this heat only corresponds to 9% of the total heat supply in those district heating systems, according to Table 1. The country has a long tradition of transferring recovered excess heat to the district heating networks from industrial processes and recovered gases, such as blast furnace gases, and these are currently in operation at about 70 locations.

The first excess heat recovery investment for a district heating system was undertaken in Helsingborg in 1974. This heat recovery from a chemical company has evolved over time, and is currently the final stage in a large industrial symbiosis of chemical processes. Another example of an early, large excess heat recovery investment was that made by one oil refinery in Gothenburg with the municipal district heating company [38]. This city has further developed its heat supply using various external excess heat resources [39]. Early heat recovery activities in the 1970s provided inspiration to some early national inventory projects concerning the future possibilities for recovery of industrial excess heat to be used in district heating systems [40–43].

One major reason for the historical great Swedish interest in industrial heat recovery was that fossil fuel taxes increased during the 1980s. Pure power stations could deduct all this tax for electricity generation, but CHP plants were obliged to pay the tax for the heat generation part. Hence, the energy tax legislation did not acknowledge the excess heat character of heat obtained from CHP plants, since this heat was taxed in the same manner, as it was used in fossil fuel boilers. This reduced the competitiveness of the existing CHP plants, which provided a window of opportunity for industrial heat recovery.

In spite of the long-held Swedish tradition of excess heat recovery from industry, several potential studies [4,34,44–52] have shown that the potential for reuse of industrial excess heat is still higher than the actual recovery.

Concerning the role of industrial heat recovery in the Swedish district heating context, a general survey of past and current Swedish district heating situations, concerning six different contexts, was provided in Ref. [53].

3. Methods

The analysis considers almost all identified Swedish industrial heat recoveries fed into district heating systems for the 41 years between 1974 and 2014. A majority of the cooperations were still in operation in 2014, while a minority had terminated.

3.1. Methodology

This kind of retrospective analysis of existing and terminated heat recoveries of industrial excess heat has never been performed before. Hence, it was difficult to find a developed method that could serve as a model for the analysis. Designing a method for a new research situation is always an iterative process, since methods are always further elaborated when more information is available about the nature of the problem or situation. Hence, it was difficult to design a perfect method, since we did not know what to expect in obtaining the first analysis. The method applied was divided into four phases: data gathering, quality assurance, screening and analysing.

The purpose of the data-gathering phase was to get information about the operational statistics, use of heat pumps, industrial actors, the corresponding industry branches, and locations where heat recovery had occurred. Temperature levels, load profiles, or other project details, were not gathered. This first phase is described in section 3.2.

With respect to quality assurance, time-series of aggregated heat volumes from the data-gathering phase were compared with two official time-series, for identification of, and explanations for, discrepancies between the different time-series. This second phase is reported in section 3.3.

The purpose of the screening phase was to assess the aggregate number of cooperations and operational years, together with average heat deliveries and operational years. Also, the historical development of the number of cooperations, and the proportions of lost heat volumes were assessed. The latter was defined as the lost volume share of all heat deliveries with no terminated cooperations. Lost annual volume was estimated for each terminated cooperation as the average heat delivery during the years that the cooperation was active. This third phase is presented in chapter 4.

The results from the analysis phase are reported in, concerning the first research question. The proportions of lost heat volume in section 5.2 follow the same definition as used in the screening phase. The results associated with the second and third research questions are presented in, respectively.

3.2. Information sources

Three main information sources were used, in order to identify the industrial heat recoveries, together with their annual heat deliveries, starting years and termination years. First, the Swedish District Heating Association have, each year, reported the composition of the heat supply in each member district heating system, and this information is available from 1974 onwards. Before 2003, this information is available in printed statistical reports, but latterly is digital, as Excel files on their website [54]. Second, the annual supply compositions, concerning fuels used and heat supplied in district heating systems by municipality, are available from Statistics Sweden from 2005 onwards, on their website [55]. Corresponding national aggregated heat deliveries are available in annual statistical reports from 1974 [56]. Third, annual heat supply compositions by each district heating company are available from the Swedish Energy Market Inspectorate, since 2007, on their website [57]. Further information about local cooperations was obtained from personal interviews, articles in newspapers and trade magazines, and various research reports about Swedish industrial heat recoveries, such as [28,58–60].

In recent years, some excess heat has also been recovered from large data centres for use in Swedish district heating systems. Three of these heat deliveries are listed in Ref. [61]; however, these heat recoveries are not included in the available Swedish statistical reports about excess heat recoveries, and are not part of the dataset for this study.

When several industrial heat recoveries were in operation in the same system, the heat delivery for each recovery was not available from the three main information sources, since annual heat deliveries were reported by system, municipality or company. In these cases, the reported annual heat deliveries were split into each delivery, based on correspondence with each district heating company.

Sometimes, annual heat deliveries were not reported, by mistake, in the statistical reports from the Swedish District Heating Association. In these cases, the missing years were estimated using corresponding information from Statistics Sweden or the Swedish Energy Market Inspectorate. If still unavailable, the missing years were estimated by interpolation between the preceding and following years.

Since industrial heat deliveries were not properly defined in the basic questionnaires from the three different organisations, some deviations appear between different time-series. External suppliers using primary energy resources as biomass were sometimes also reported as industrial heat recoveries. Recovery of blast furnace gases from steel mills, and the corresponding heat recoveries, were also considered as industrial heat recovery in this study. By tradition, low-temperature industrial heat recoveries have been reported differently when heat pumps have been used. In these cases, annual heat deliveries were reported as being supplied by heat pumps in the annual statistics from the Swedish District Heating Association. In this study, these low-temperature industrial heat deliveries were included with the corresponding electricity input.

3.3. Comparison of different time-series

In order to assess the annual heat deliveries included in this analysis, a comparison is provided (Fig. 1) of five different time-series. All three times-series relating to heat delivery in this study have, in general, higher heat deliveries than the two official time-series from the Swedish District Heating Association and Statistics Sweden, except for in 2004, when the large waste incineration plant in Gothenburg was erroneously reported as industrial heat recovery in the two official time-series. The main reason is that the low-temperature heat recoveries with heat pumps are included in this study and excluded from the two official statistical time-series. When excluding the heat pumps in this study, as a fourth time-series, a higher correlation appears, but some discrepancies remain because of reporting mistakes and the lack of proper definition of industrial heat recoveries. The fifth time-series reveals the total expected industrial heat recoveries when all terminated heat recoveries are included. All of the time-series show lower heat deliveries during 2009, since many industrial activities were reduced because of the financial crisis that prevailed in that year.

4. Input data collected

In the data-gathering phase, 132 industrial heat recoveries were identified from the available statistical sources; however, 23 of these cooperations were identified as conventional external heat providers, using mostly biomass boilers that cannot be considered to be recovered heat from industrial processes, since biomass is

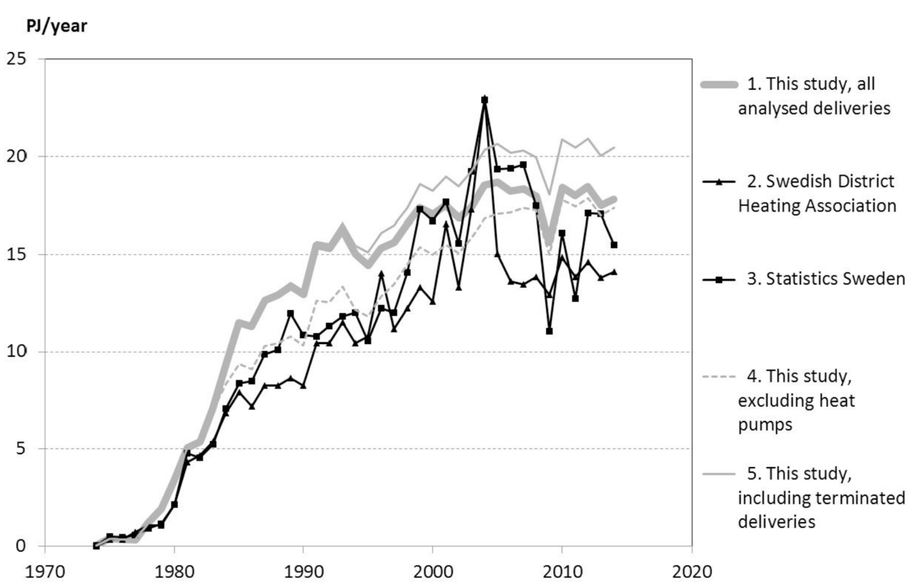

Fig. 1. Annual heat volumes obtained from industrial excess heat and delivered into Swedish district heating systems since 1974, according to the Swedish District Heating Association, Statistics Sweden and three estimations provided by this study, concerning all analysed deliveries, exclusion of heat-pump-based deliveries, and inclusion of all terminated deliveries. These three time-series are based on the aggregated actual annual heat recoveries from all locations included in the analysis. In the fifth time-series, the added terminated deliveries are based on annual average heat deliveries from when the terminated cooperations were in operation.

Table 2
Survey of input data concerning number of cooperations, annual average heat deliveries to district heating systems, number of operational years and average number of operational years. A large delivery considers annual average heat deliveries above 300 TJ/year, while a small delivery had annual average heat deliveries of below 55 TJ/year.

	Total	Without heat pumps	With heat pumps	Large delivery	Medium delivery	Small delivery
Number of cooperations	107	88	19	16	46	45
still in operation in 2014	74	69	5	16	32	26
terminated before 2014	33	19	14	0	14	19
Annual average heat delivery, PJ	19.9	17.3	2.6	12.8	6.0	1.1
still in operation in 2014	17.3	16.2	1.1	12.8	3.9	0.7
terminated before 2014	2.6	1.1	1.4	0.0	2.2	0.4
Number of operational years	1788	1460	328	458	828	502
still in operation in 2014	1348	1231	117	458	609	281
terminated before 2014	440	229	211	0	219	221
Average number of operational years	16.7	16.6	17.3	28.6	18.0	11.2
still in operation in 2014	18.2	17.8	23.4	28.6	19.0	10.8
terminated before 2014	13.3	12.1	15.1	–	15.6	11.6

considered to be a tradeable primary energy source. These omitted cooperations were found by the company name, and the corresponding activity for each heat provider. The most typical omitted activity was sawmills that exported heat from their own biomass boilers.

From the remaining 109 cooperations, two cooperations were also lost from the analysis. One industrial heat source could not be identified (Västerås), and the time-series of annual heat deliveries could not be restored properly for another cooperation (Umeå). These exclusions left 107 deliveries of industrial excess heat to analyse. Terminated heat deliveries constituted 33 of all of the identified industrial heat deliveries. A survey describing the input data for analysis is provided in Table 2.

In the following screening phase, the identified cooperations were analysed with respect to annual average volumes of heat recovered, commissioning years and proportions of remaining industrial heat recovery by calendar year.

In Fig. 2, the magnitudes of each industrial heat recovery are presented by annual average heat recovery. An early observation is that none of the 16 largest heat recoveries have terminated, indicating that size is important for survival.

In Fig. 3, the number of cooperations are reported by commissioning year. Between zero and six cooperations started every year, except in 1984, when 15 cooperations started. Thus, new cooperations were continuously starting during the analysed period. The oldest terminated cooperation started in 1978, and the newest terminated cooperation started in 2008. Ten of the cooperations that started in 1984 have terminated. Characteristic of the 1984 energy situation was high oil prices that decreased considerably two years later. This indicates that the profitability of these cooperations were not as high as expected at the point of the investment decision.

In Fig. 4, the proportions of lost annual heat volumes from industrial heat recoveries are presented by calendar year. These proportions were estimated as the lost heat volume share of all heat deliveries, excluding terminated cooperations, as defined in the methodology section. By this definition, the proportion of lost heat volume decreased when new cooperations were implemented.

The first termination of a cooperation happened in 1986. Up to 2014, 13% of the total heat delivery volumes were lost through terminated cooperations. This figure verifies again that the magnitude of the industrial heat recovery is important for the survival of cooperations, since no large delivery was lost in this period, but for small and medium-sized heat recoveries, 38 and 34% were lost, respectively.

Fig. 2 also shows that the presence of a heat pump for using low-temperature industrial excess heat poses a high probability of termination. In these cases, the industrial heat recovery must cover

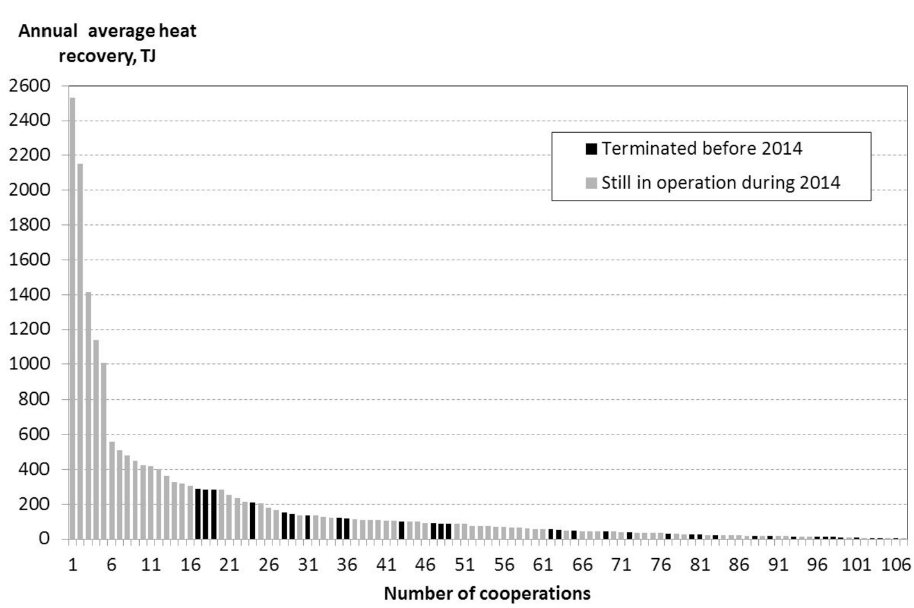

Fig. 2. Annual average industrial heat recovery for each cooperation, sorted by descending order and operational status during 2014 (still in operation or terminated).

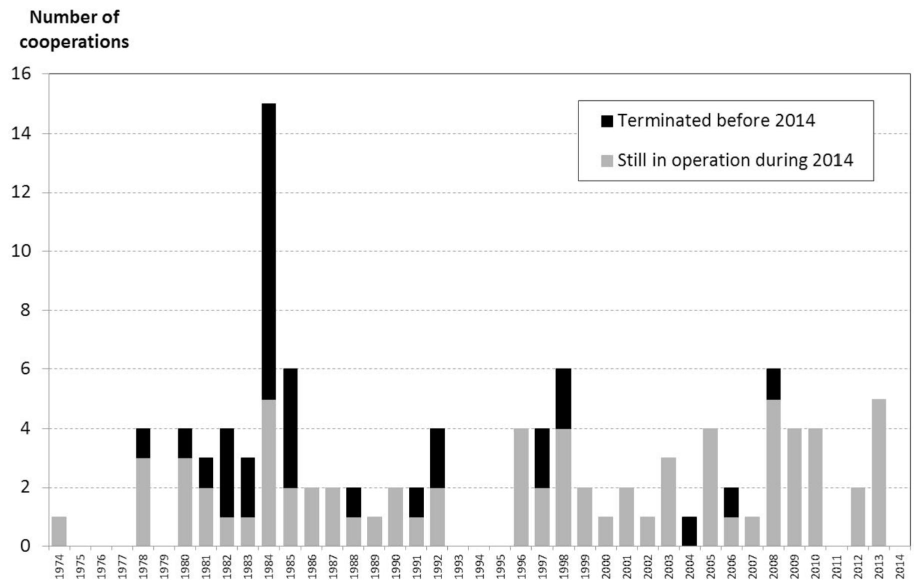

Fig. 3. Number of cooperations by commissioning year, and operation status during 2014 (still in operation or terminated).

the remuneration for the industrial excess heat recovered, the heat pump investment, and the electricity used in the heat pump. So, use of a heat pump can be identified as a risk factor for termination. Concerning heat pumps, 76% of the heat deliveries were lost, giving only 6% of losses when heat pumps were not used. This high proportion of lost heat deliveries for heat pumps was also influenced by a significant decrease in heat delivery volumes from heat pumps in operation.

5. Results

Based on indications from the screening phase, the results focus on the importance of the magnitude of the cooperation and the presence of heat pumps in the cooperation. In order to reflect the investor perspective for these two aspects, the historical time perspective of calendar years in the screening phase were changed to a more pronounced project perspective, concerning the operational years, following the initial commissioning year.

Furthermore, the industrial branch affiliations for the industrial excess heat utilised, explanations for all terminated cooperations, and the characteristics of the terminated industrial activities were analysed.

5.1. *Cooperations by operational years*

By redesigning Fig. 3, the project perspective concerning number of operational years is presented in Fig. 5. The grey bars reflect the number of operational years for all ongoing cooperations during 2014. These vary between 2 and 41 years, with an average of 18.2 years. The black bars consider the number of operational years during the termination year for all terminated cooperations. These vary between 3 and 34 years, with an average of 13.3 years. Hence,

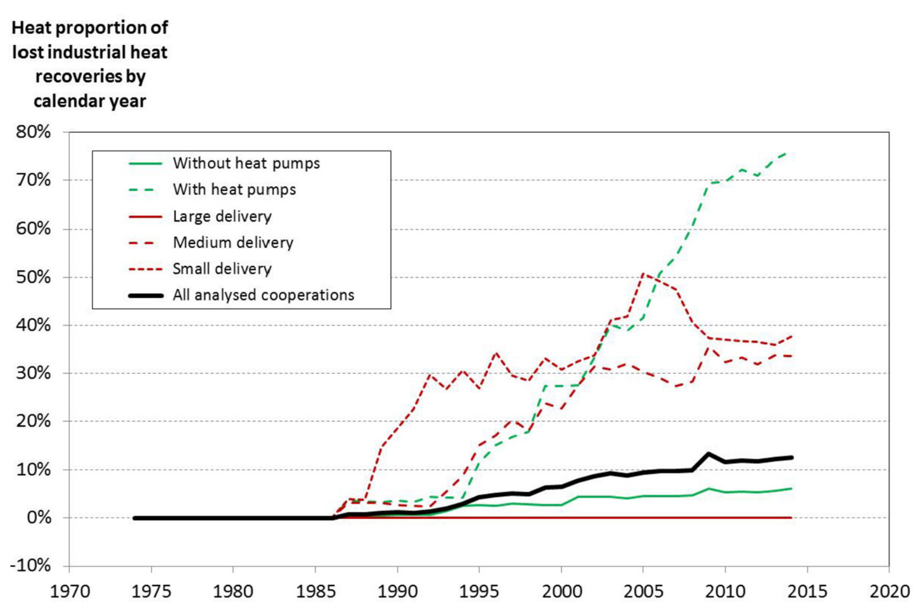

Fig. 4. Proportions of lost annual heat volumes from terminated industrial heat recoveries, by calender year, with respect to with and without heat pumps, together with the extent of cooperation (from large to small deliveries), with respect to the threshold volumes defined in Table 2.

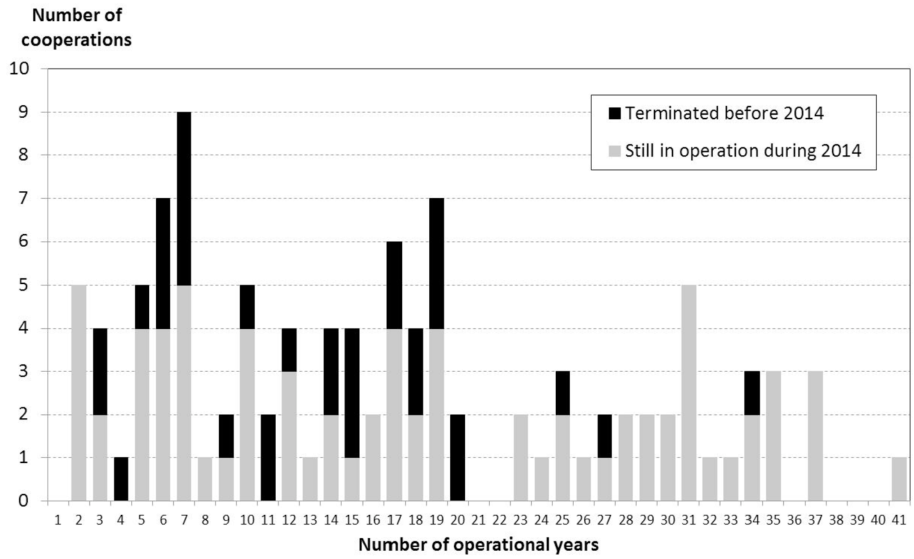

Fig. 5. Number of cooperations by number of operational years, and operational status during 2014 (still in operation or terminated).

most terminated cooperations had more operational years than the indicative time interval of one to seven years for expected payback periods previously identified in the introduction. Only 11 out of the 33 terminated cooperations had final operational years within the identified time interval of the indicative payback periods. From a retrospective perspective, some of these 11 terminated cooperations may have become unprofitable. The remaining 22 terminated cooperations reached more operational years, and many of them probably became profitable. Most existing industrial heat recoveries have also reached operational times beyond these threshold years.

5.2. Cooperations by typical groups

By redesigning Fig. 4, the project perspective concerning lost annual heat volumes by operational years is presented in Fig. 6. These annual proportions were estimated as the lost heat volume share of all heat deliveries without any terminated cooperations, as defined in the methodology section. By this definition, the proportion of lost heat volumes decreases when new cooperations are implemented.

After 10 years of operation, the total heat volume loss was only 1% of all possible annual heat deliveries. Only small heat deliveries show a significant loss (26%) of annual heat delivery volumes.

After 20 years of operation, the total loss had increased to 13%. Concerning magnitude, no heat delivery was lost for large deliveries, while 46% was lost by medium-sized heat volume deliveries, and 70% were lost by small deliveries. Concerning heat pumps, the lost heat volumes were 46%, while cooperations without heat pumps only lost 7% of the annual heat delivery volumes.

Low proportions of lost heat volumes were kept for the oldest

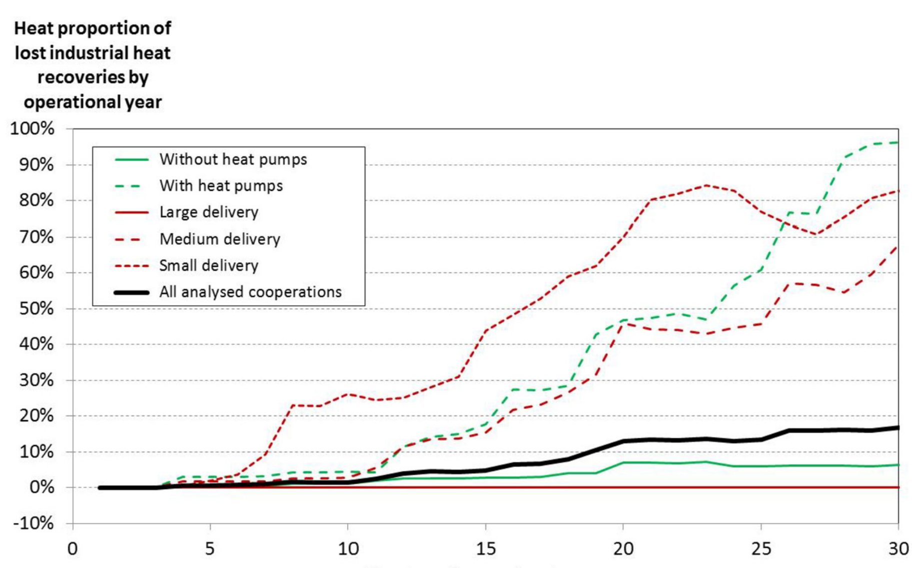

Fig. 6. Proportions of lost annual heat volumes from terminated industrial heat recoveries by operational years, with respect to with and without heat pumps, together with the extent of cooperation (from large to small deliveries), with respect to the threshold volumes defined in Table 2.

Table 3
Number of cooperations by industrial branch codes, according to the NACE classification, with respect to operational status during 2014, without or with heat pumps, and the extent of cooperation (from large to small deliveries), with respect to the threshold volumes defined in Table 2.

Industrial branch	Total	Terminated before 2014	Without heat pumps	With heat pumps	Large delivery	Medium delivery	Small delivery
07 Metal ores	1		1			1	
10 Food products	9	4	7	2		3	6
11 Beverages	2	2	2			1	1
16 Wood products	4		4			3	1
17 Pulp and paper	27	4	23	4	8	12	7
18 Printing	2	2	2				2
19 Coke and refined petroleum	5		5		2	3	
20 Chemicals	14	6	10	4	2	10	2
21 Pharmaceutical	3	2	2	1		1	2
22 Rubber and plastics	2	2	1	1			2
23 Non-metallic mineral product	10	3	10		1	3	6
24 Basic metals	6	1	5	1	3	3	
25 Metal products	18	5	13	5		5	13
28 Machinery	1	1	1				1
35 Energy supply	1	1		1			1
38 Waste management	2		2			1	1
	107	33	88	19	16	46	45

cooperations, since only two cooperations terminated, out of the first nine cooperations that started between 1974 and 1980. Probably, these pioneer cooperations were obvious and very profitable, since they started early.

5.3. Cooperations by industrial branches

The number of cooperations are presented in Table 3 by industrial branch, according to the current NACE classification, defined in Ref. [62]. The corresponding annual average heat volumes are presented in Fig. 7. The pulp and paper industry is the largest Swedish industry branch, with respect to total energy use, since it constitutes about half of the total industrial energy balance.

Both numbers of cooperations and volumes of heat recovered are dominated by four industrial branches: pulp and paper, chemical, basic metal, and fuel refineries. These industrial branches are considered to be suitable for recovery of industrial waste heat, since they use high-temperature heat in their industrial processes [6]. These four branches include 52 cooperations and 83% of all annual average heat deliveries. Almost all large deliveries belong also to these four industrial branches.

In Fig. 7, the proportions of terminated cooperations can be seen to vary by branch; however, the numbers of cooperations are too low in each industrial branch to allow identification of significant risks, with respect to terminated cooperations.

5.4. Reasons for terminated cooperations

Reasons for the 33 terminated cooperations were researched and verified from available literature sources and statistics. These identified explanations can be divided into four different groups. In 14 cases, the heat supply ended because the industrial activities terminated, while substitution with another heat supply was identified in 11 cases. Technical problems were reported for one small heat pump and one small cooperation, concerning heat recovery from a lime works. No obvious explanations could be identified from the available information concerning the six remaining cases.

Out of the total 2575 TJ of annual average heat delivery volumes lost up to 2014, from terminated cooperations, most deliveries were lost from terminated industrial activities (1175 TJ/year), and substitution from other heat supply (1193 TJ/year), according to Fig. 8. Both corresponded to about 6% of all annual industrial heat recovery volumes. Technical problems only caused heat delivery volumes of 30 TJ/year. Unknown reasons caused heat delivery volumes of 176 TJ/year, including one medium-sized delivery and two heat pumps. These two minor categories of explanation correspond to only 1% of all industrial heat recovery volumes.

Terminated industrial activities were dominated by cooperations without heat pumps. These lost heat recoveries were caused by closure decisions by the industrial partners, and gave no further heat deliveries to the local district heating companies.

Substitution with another heat supply was dominated by cooperations using heat pumps, giving an indication that heat pumps were primarily substituted, rather than the basic industrial excess heat recoveries. These terminated heat recoveries were caused by decisions taken by the local district heating companies, who gave no further remuneration to the industrial partners for heat delivered. Direct substitution of existing heat recoveries without heat pumps was very low, since these lost heat volumes were only 155 TJ/year, or 1% of the total sum of annual heat recovery volumes. This was only about one-seventh of the heat lost from terminated industrial activities. Concerning these heat supply substitutions, explanations that are more detailed are beyond the scope of this analysis, since more information is required for obtaining such explanations.

5.5. Characteristics of terminated industrial activities

Information about the 14 terminated industrial activities is of relevance in identifying risk factors for terminated industrial activities, and quantifying the corresponding risk magnitudes. More details about these terminated cooperations are provided in Table 4.

With respect to location, some district heating systems were more affected than others. Closing years are relatively well distributed between 1986 and 2013, so terminated industrial activities were not concentrated in a certain narrow time period. But this is the case for starting years, where two-thirds of the terminated cooperations started in the first half of the 1980s. The numbers of operational years before the termination of heat recoveries were also relatively well distributed between 3 and 34 years. Hence, both new and old cooperations were terminated. No industrial branch dominated among the terminated cooperations. Only two heat pumps were utilised, and both were located in Trollhättan. Half of the terminated cooperations were small deliveries (between 9 and 48 TJ/year), while the other half were medium-sized deliveries (between 89 and 212 TJ/year). The most

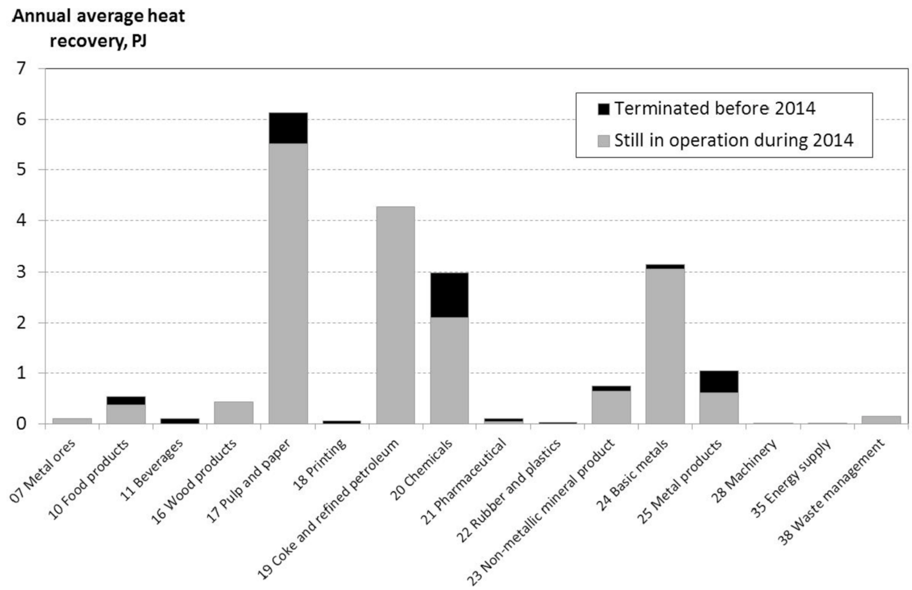

Fig. 7. Annual average industrial heat recoveries, with respect to industrial branch, according to NACE classification, and operational status during 2014 (still in operation or terminated).

significant fact is that no large heat delivery was terminated because of terminated industrial activity.

By combining information from Fig. 6 and Table 4, risk magnitudes for terminated industrial activities can be estimated, if assumed equal to the proportion of lost heat deliveries from terminated industrial activities. This estimation becomes then 0.6% after 10 years, and 6.9% after 20 years. When omitting cooperations associated with the two identified risk factors (concerning small deliveries and heat pumps), the estimate will be reduced to 0.0% after 10 years, and 4.9% after 20 years.

6. Discussion

The Swedish context has been that industrial heat recovery has been more prevalent than in other parts of Europe. This situation can be understood in the light of strong national policy instruments. In the aftermath of the two oil crises in the 1970s, fuel oil usage was 'punished' by taxes that benefitted new industrial excess heat recoveries in the 1980s. The carbon dioxide tax was later introduced in 1991 for fossil fuels, and several pronounced incentives have also been introduced to promote the use of other fuels over fossil fuels. The Swedish energy and climate change mitigation policies have also supported the expansion of bio- and waste-fuelled CHP plants. Industrial excess heat recovery has thus become exposed to competition from these CHP plants, reducing the explicit incentives for new cooperations. Few existing heat recovery cooperations without heat pumps have terminated, however, when the industrial activity has remained untouched.

Concerning terminated industrial activities, it is evident that the results show that larger heat deliveries are more robust and reliable

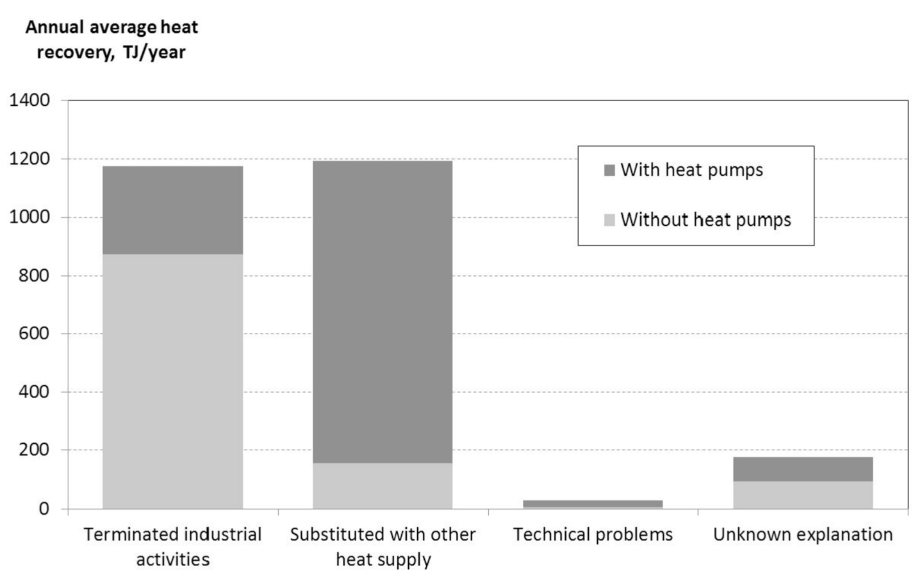

Fig. 8. Identified explanations for lost annual average heat delivery volumes due to terminated cooperations, with respect to the use of heat pumps or not in the cooperations.

Table 4
Overview of identified terminated heat recovery cooperations caused by terminated industrial activities.

Location	Closing year	Starting year	Number of operational years	Industrial activity	Annual average heat delivery (TJ/year)
Trollhättan	1986	1983	4	Graphite plant	15
Trollhättan	1986	1984	3	Ferroalloy furnace with heat pump	90
Skinnskatteberg	1988	1982	7	Cardboard plant	48
Burlöv	1992	1982	11	Sugar refinery	117
Falun	1993	1984	10	Sulphur acid plant	122
Trollhättan	1994	1984	11	Chlorate plant with heat pump	212
Staffanstorp	1995	1981	15	Development laboratory	9
Stockholm	1996	1978	19	Distillery	89
Landskrona	2000	1982	19	Artificial fertiliser plant	286
Göteborg	2002	1997	6	Brewery	25
Huddinge	2004	1991	14	Printing works	42
Kungsbacka	2010	2006	5	Printing works	13
Halmstad	2013	1980	34	Float glass plant	92
Huddinge	2013	1997	17	Brewery	16
Total			175		1175

than small heat deliveries. The lower risk of cooperating with larger excess heat providers reflects also the long-term structural transformation of the Swedish industry. Over time, smaller industrial units have been closed due to competition with fewer, larger and more competitive units.

The implemented industrial heat recovery reflects the aggregated result of many investments decisions, where less suitable and unreliable cooperations have been rejected. The low proportion of lost heat volumes from terminated industrial activities could reflect that the Swedish district heating companies have been successful in choosing suitable and reliable cooperations. The analysis showed also that two-thirds of the cooperations that ended as a result of terminated industrial activities were started in the first half of the 1980s, when the international oil price was high. Maybe these feasibility assessments overlooked the latent risks associated with unreliable heat providers, when the benefit of substitution of expensive fuel oils was high.

Concerning substitutions of heat supply, heat pumps appear to have played a large role in decisions taken to substitute industrial excess heat recovery. One reason for this could be that heat pumps are reliant on electricity, which links the profitability of the investment to the price of electricity. Adding an external factor that the investment is dependent on increases the risk of the investment. This study considered historic data, and reviewed a period when the electricity price varied, and the electricity tax increased. Higher electricity costs can be an explanation for why heat pump cooperations were more risky, based on this retrospective study.

The higher risk with heat pumps is also associated with the current high temperatures applied in the heat distribution networks. Future lower temperature levels could make it possible to recover low-temperature excess heat without the use of heat pumps. Thus, the risk of using heat pumps can be eliminated.

Concerning profitability, strong conclusions cannot be identified without closer profitability analyses of the actual heat recovery cooperations implemented; however, some indications can be identified. The combination of longer operational years, lower proportions of lost heat volumes, and the scale effect of lower supply costs for large-volume cooperations provides a motivating argument for allocating a lower risk premium to large-scale industrial excess heat recovery cooperations, compared to small cooperations.

The results also show that the district heating companies are economically rational actors that are in business for profit, and heat supply options that do not yield sufficient profit are terminated. Hence, the explanation of substitution with another heat supply is also a reason for terminated excess heat recoveries beyond terminated industrial activities.

In the investment context, the risk adjusted discount rate of the net present value calculation of an excess heat recovery investment needs to account for known barriers to heat recovery investments. Because of the specific circumstances of each excess heat investment, it is not possible to provide one single number for an appropriate risk premium for excess heat delivery termination; however, the risk of terminated excess heat delivery can be offset by close cooperation, and removal of information asymmetries between the excess heat provider and the district heating company. Accounting for the known barriers to excess heat recovery investments in a more precise way could increase the accuracy of profitability calculations made for investment decisions. Increased accuracy will attract additional investment capital, and will support the market of excess heat recovery in becoming more efficient.

Further research to be performed includes tracking of more sources of detailed information concerning the terminated heat recoveries. This information can then provide input to closer analysis of backgrounds for terminated industrial activities and explanations for the high proportion of heat pumps in substituted heat recoveries.

7. Conclusions

Concerning the first research question, and the characteristics of terminated heat recoveries, two risk factors were identified——small heat deliveries and the use of heat pumps for recovering low-temperature excess heat. Total annual lost heat delivery volumes correspond to about 13% of the sum of all annual existing and terminated heat delivery volumes. About one-third of the terminated heat deliveries had final operational years within the indicative payback time interval of between one and seven years. Two-thirds of the terminated cooperations were then probably profitable, since they had operational times longer than these indicative payback times. Most existing industrial heat recoveries have also reached operational times beyond this threshold.

Identified explanations for terminated heat recoveries, according to the second research question, were mainly the termination of the industrial activity creating the excess heat, and business decisions for the substitution of the excess heat recovery with another heat supply. Together, these corresponded to about 6% of all annual industrial heat recovery volumes. Substitution with another heat supply was highly associated with the use of heat pumps, indicating that heat pumps, rather than heat recoveries, were substituted. Technical problems with heat recoveries were only reported from two very small heat recoveries.

Finally, the most typical feature concerning terminated industrial activities, according to the third research question, was that no large delivery had terminated because of this reason. No systematic explanation could be found, associated with the closing year, the number of operational years, or the industrial activity; however, two-thirds of these terminated cooperations started in the first half of the 1980s. Concerning the risk magnitude for terminated industrial activities, it can be assumed to be equal to the proportion of lost heat delivery heat volumes. With this assumption, the risk of losing a heat recovery because of terminated industrial activity can be estimated to be only 7% after 20 years. By omitting the two identified risk factors (concerning small deliveries and heat pumps), this risk estimation was reduced to 5% after 20 years. The main conclusion is, then, that a small proportion of industrial heat recovery has been lost in Sweden because of terminated industrial activities.

Beyond the answers to the three research questions, further answers can be provided in future research concerning explanations to terminated heat recoveries, if information that is more detailed is gathered.

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