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RESEARCH

Bridging the energy efficiency gaps: Lessons from the Swedish PFE programmes

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Abstract Sweden implemented a unique policy instrument over two consecutive five-year periods aimed at promoting industrial energy efficiency: a voluntary agreement programme (VAP) known as the Programme for Improving Energy Efficiency in Energy-Intensive Industries (PFE). This paper evaluates the second programme period using process and impact evaluation approaches. The impact evaluation revealed that the programme generated numerous benefits beyond the implementation of energy efficiency measures. The second programme period demonstrated impacts comparable to the first, underscoring the pivotal role of energy management within policy frameworks. Moreover, the findings suggest that VAPs may be among the few policy instruments capable of achieving substantial impact within industrial production processes. The process evaluation identified two critical gaps: a policy gap and a knowledge gap. Many of the positive elements present in the evaluated programme are currently absent from Sweden's industrial policy mix. The role of the policy operator—as facilitator or intermediary—proved essential, particularly in the context of policies involving energy audits and certified energy management systems. In this case, the Swedish Energy Agency played a central role. The study concludes that continuous energy management, when integrated throughout the entire organization, significantly enhances companies' capacity to identify and implement energy efficiency measures. This approach not only deepens internal knowledge but also fosters the development of more structured and effective routines. Furthermore, the findings suggest that financial incentives may be essential to ensure the long-term persistence of energy efficiency practices. Consequently, future policy design should include a strong facilitator and incorporate mechanisms that both reinforce organizational knowledge of energy end-use processes and promote sustained engagement over time, preferably involving a financial incentive.

Keywords Programme for Improving Energy Efficiency in Energy-intensive Industries (PFE) · Energy efficiency policy · Industry · Policy facilitator · Voluntary agreement · Impact evaluation

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Introduction

With increased demand for climate change mitigation, one of the largest policy challenges is to develop and deploy energy policy programmes, while maintaining strong economic growth. Economic growth, in turn, relies on a country's industrial production, which inevitably drives energy demand—often with adverse environmental consequences. The challenge for the policymakers is to find pathways to improve energy efficiency, without negatively affecting the country's industrial production and growth. The two foremost energy efficiency policy programmes for industry are energy audit policy programmes (Anderson & Newell, 2004) and voluntary agreement programmes (VAPs) (Price, 2005). In Sweden, the manufacturing industries' final energy use accounts for 39% of total energy use in industry, domestic transport and residential and services (Swedish Energy Agency, 2023), which is higher than in the EU as a whole. Efficient energy use in the industrial sector is an important challenge for Sweden, the EU and globally. Even though previous and current energy efficiency policy instruments have been deployed and evaluated (Johansson, 2022; Johansson et al., 2022), there is still a potential for improved energy efficiency. This is known as the energy efficiency and energy management gaps (Backlund et al., 2012; Jaffe & Stavins, 1994), and several studies have demonstrated the existence of these gaps, in, among other areas, the Swedish industrial sector (Paramonova et al., 2015). Industrial energy behaviour also influences a company's energy use (Rotzek et al., 2018), and energy management systems have been identified as an important tool in reducing the energy efficiency gap (Liu et al., 2021). Energy management systems can also influence enterprise and economic performance, as shown by Liu et al. (2021).

The foremost industrial energy efficiency policy programme in Sweden was the Programme for Improving Energy Efficiency in Energy-intensive Industries (PFE), and this study evaluates the second programme period of that programme. The programme, a combination of an energy audit programme and a VAP, was initiated as a result of the EU Energy Tax Directive 2003/96EG, and the purpose of the instrument was to improve electricity efficiency in the Swedish manufacturing industry, and at the same time offer companies a way to avoid paying the new electricity tax that came from the EU directive (The Swedish Government, 2004). The PFE involved around 100 companies, which together accounted for a quarter of Sweden's energy use, and more than half of the industrial energy use domestically. To be eligible to take part in the programme, the companies had to be electricity intensive.

The programme was carried out in two five-year programme periods, of which the first was evaluated in 2010 by Stenqvist and Nilsson (2012). The second period, however, has not yet been evaluated. Evaluating the second programme period of PFE would provide valuable insights for policymakers into how to design and operate future policy programmes in the areas of improved industrial energy efficiency and climate change mitigation. The aim of the PFE was to improve electricity efficiency, but the programme may also have given rise to other non-energy-related benefits (NEBs), which are currently unexplored in industrial energy efficiency policy with the exceptions of the work of Johansson and Thollander (2019) and Nehler et al. (2018). An evaluation of the PFE could provide knowledge about both the policy's impact and the functioning of the processes, as well as possible NEBs. The aim of this study is to evaluate, *ex-post*, the second programme period of the national Swedish industrial VAP programme. The aim is formulated into four distinct research questions:

- What was the impact of the second programme period?
- How did the processes within the programme function?
- What are the major NEBs from the programme?
- How should a future policy instrument for improved energy efficiency in industry be designed?

The aim and the research questions were answered through both a process and an impact evaluation inspired by Stenqvist and Nilsson (2012), as well as in-depth interviews. In the analysis, the subsequent industrial energy efficiency policy instruments are included in relation to the results of the PFE.

This paper concentrates on large energy-intensive industrial companies in Sweden, as these were the primary participants in the PFE. Measures aimed at small and medium-sized enterprises or companies with low energy use fall outside the scope of this study. The evaluation of the PFE focuses solely on its positive outcomes, acknowledging that negative aspects may have existed but are not explored here. Additionally, the study is restricted to companies that took part in the second phase of the PFE. Other large energy-intensive companies, which may hold different views on both the PFE and current policies, are not considered in this paper.

The structure of the paper is as follows: it begins with an introduction, followed by two chapters that explore policy programmes and non-energy benefits associated with industrial energy efficiency. This is succeeded by a methodology chapter and a presentation of the results. The paper concludes with a discussion and final conclusions.

Industrial energy efficiency policy programmes

There is large potential to improve energy efficiency and reduce CO2 emissions in industry, such as in the pulp and paper industry (Lipiäinen et al., 2022). Policy instrument and regulation are important tools for promoting environmental performance and energy efficiency (Shi et al., 2023), and with careful design these can create both environmental and economic benefits (Weiss & Anisimova, 2019). Often, a combination of different policy instruments is more successful in promoting energy efficiency improvements (Wiese et al., 2018), and the choice of policy approach can have a significant impact on the degree to which the intended results are achieved (Chai et al., 2023). The energy cost is one of the most important factors influencing energy intensity. Higher energy prices lead to a higher degree of energy efficiency potential, and in turn, increased rates of improvements and practices (Dahlqvist & Söderholm, 2019; Lawrence et al., 2019a). In this section we present the PFE programme, describe previous and current Swedish policy programmes and conclude with an international outlook.

The PFE programme

The PFE was a voluntary policy instrument. Such instruments can be divided into fully voluntary agreements, agreements with threats of taxes or fees in the future as incentives to participate, or agreements initiated in relation to existing taxes or fees (Price, 2005). In the first programme period of the PFE, which was held from 2005 to 2009 and was evaluated by Stenqvist and Nilsson (2012), approximately 100 companies participated, which together had around 250 production sites in Sweden. The participating companies represented less than 10% of the companies that met the requirements for the programme, but as argued by Ottosson and Petersson (2007), the participating companies' total electricity use represented 84% of the electricity demand that could be made tax-exempt by joining the programme. So, even though 10% may seem low, Stenqvist and Nilsson (2012) also argued that the original goal of the programme was that 60 companies from the traditional energy-intensive industries would participate, and that goal has been achieved and even exceeded.

All measures implemented during the first period were estimated to provide total improvements of 1450 GWh annually. However, all these measures may not provide full additionality, i.e. being a direct result of the programme. A free-rider coefficient, i.e. the share of energy efficiency improvement that would have been achieved during the same period without support from the PFE programme, was estimated to be 0–0.5 (Stenqvist & Nilsson, 2012). Results showed that the total net electricity improvements were between 689 and 1015 GWh per year. In addition, heat and fuel savings of up to 950 GWh per year were made, which can be considered as an indirect impact of the programme (Stenqvist & Nilsson, 2012). In studies of the PFE programme, investment costs and payback time were the primary factors affecting electricity savings during the programme period (Lawrence et al., 2019a).

During the first two years of the PFE, the Swedish Energy Agency has arranged several conferences and seminars for the participating companies. Topics that have been discussed are for example best practice in the energy efficiency area, implementation of energy management systems, life cycle cost (LCC) methodology, etcetera. Most of the PFE companies have participated in these activities. This has strengthened the cooperation and created better understanding between industry and authorities. Informal and formal networks between companies have also been created due to the PFE, both regionally and industry-vice. Unlike "command and control" based regulations, the PFE has a more marked based approach. The participating companies perform their own energy audit (within certain general requirements) and are free to choose the measures that are most suitable for their unique type of production (again, within certain limits). This approach has been very appreciated by participating companies.

Swedish energy efficiency policy programmes

When the second programme period of PFE ended in 2014, parts of the initiative were replaced by other policy instruments, such as the law for energy audits introduced the same year, which remains in effect (The Swedish Government, 2014), and the Energy Ladder programme implemented between 2018 and 2020 (Swedish Energy Agency, 2021; Swedish Parliament, 2018). Research indicates that an energy management standard is crucial tool for promoting continuous improvements in energy efficiency and for realizing the full potential of energy savings (Schützenhofer, 2021). This has also been emphasized in the three most recent EU Energy Efficiency Directives (EC, 2012, 2018, 2023). According to the latest directive, companies with annual energy use exceeding 85 TJ are required to have an energy management system in place. Until recently, there have been no explicit Swedish policies that directly or financially incentivize companies to adopt energy management practices, implement energy management systems, or apply life cycle cost calculations—although such measures are indirectly encouraged through the legislation on energy audits. According to Thollander et al. (2020), this gives rise to an energy policy gap between the possible energy efficiency improvements that the different policy instruments can encourage, and the improvements incentivized by the currently available instruments.

Table 1 Earlier and ongoing policy programmes for energy efficiency in Sweden

Programme name	Type of programme	Ref.
Local authority energy and climate adviser, 1980-	Free advice provided to citizens mostly, but could also involve companies	Kjeang et al., 2017
EKO-Energi 1994–2001	Voluntary agreement	Helby, 2002
Swedish Environmental Code 1998-	Law enforcement, Best Available Technology, self-control of energy use	MCE, 2000
Project Highland, 2003–2008	Energy audits, regional	Thollander et al., 2007
The Electricity Certificate System, 2003–2021	Market Based Instrument, electricity certificates	SEA, 2025a
Sustainable municipalities 2004–2006	Energy audits, in selected municipalities	Thollander et al., 2007
Energy and carbon taxes, 2004-	Taxation	SG, 2004; STA, 2025
EU ETS, 2005-	Market Based Instrument, emission trading	EC, 2025a, b
PFE 2005–2014	Voluntary agreement	SEA, 2011; Paramonova et al., 2016
SEA-seminars 2006–2008	Breakfast seminars, information	SEA, 2007, 2008, 2009
SEAP 2010–2014	National energy audit Scheme	Paramonova et al., 2016; MCE, 2009
Law for energy audits (EKL), 2014-	Energy audits, large companies	MCE, 2014a, b; SEA, 2014
Energy manager network forum, 2014-	Energy controller network, large companies	Ivner et al., 2014
Environmental Support, 2014–2019	Investment subsidy, primarily small and medium-sized enterprises (SMEs)	SEPA, 2025
EENet, 2015–2020	National energy efficiency networks scheme, SMEs	EKS, 2025
SEAP 2015–2019	National energy audit scheme; only SMEs with energy use above 300 MWh/year	SEA, 2015, 2017
Energy coaches, 2017–2021	Energy coaching, level one audit, for company energy use below 300 MWh/year	SEA, 2021
Energy Ladder, 2018–2020	Investment subsidy, large companies	MI, 2018; SEA, 2025b

Sweden, recognized as a frontrunner in environmental and energy policy implementation (Safarzadeh et al., 2020), has introduced and operated several policy programmes aimed at enhancing energy efficiency in the industrial sector. Table 1 outlines both past and ongoing policy initiatives focused on industrial energy efficiency.

Energy efficiency policy programmes in a wider perspective

A comprehensive review of approximately 300 industrial energy policy programs within the IEA was conducted by Tanaka (2011), highlighting the diversity of approaches across countries. Among the most prominent energy efficiency policies for energy-intensive industries are energy audits and Long-Term Agreements (LTAs), also known as Voluntary Agreement Programs (VAPs), as emphasized in Bertoldi (2001). A global review of 23 VAPs across 18 countries underscored the importance of regulatory design elements in achieving higher participation rates (Price, 2005). Similarly, a European-focused review revealed that while the historical emphasis has been on the process industry, there is a growing trend toward including small and medium-sized enterprises (SMEs) (Rezessy & Bertoldi, 2011).

In a study of 23 VAPs, Price (2005) concluded that, generally, programmes with some type of financial incentive have a higher participation rate than those that are completely voluntary. In addition, this type of programme normally fulfils its goals to a greater extent. An evaluation of the VAP in Flanders, Belgium, which targeted medium-sized companies, found that economically stronger firms were more likely to implement energy-saving measures (Cornelis, 2012). These findings, along with those from Price (2005) and Rezessy and Bertoldi (2011), suggest that energy audits are often a central component of VAPs. In Sweden, a former VAP was evaluated by Lindén and Carlsson-Kanyama (2002), with Uggla and Avasoo (2001) reporting that the energy audit was the most appreciated element. A preliminary evaluation of another Swedish VAP for small and medium-sized companies was presented in Thollander and Dotzauer (2010).

The effectiveness of administrative policies has also been scrutinized. For instance, the Japanese Energy Conservation Law was found to be less effective for larger firms, a finding that mirrors the limited adoption of Sweden's Environmental Code (Kimura & Noda, 2010, 2014; Johansson et al., 2007). In contrast, energy efficiency networks—particularly learning energy efficiency networks—have emerged as a promising policy innovation. First implemented in Switzerland, these networks have demonstrated roughly double the impact of traditional energy audit programs (Koewener et al., 2011).

In China, energy policies targeting energy-intensive industries have been reviewed (Li et al., 2014), alongside the development of low-carbon policy instruments that call for stronger law enforcement to improve efficiency and reduce emissions (Wang & Chang, 2014). Japanese case studies of VAPs have shown these programs to be more effective than alternative policy options (Wakabayashi, 2013). However, evaluations of climate change policies in Taiwan's energy-intensive sectors revealed no absolute energy savings, suggesting a broader challenge for developing economies (Chou & Liou, 2012).

Further research has explored energy management in non-energy-intensive manufacturing in Bangladesh, identifying key barriers and drivers (Hasan et al., 2019). In Sweden, studies of the pulp and paper industry have highlighted the importance of employee involvement, process knowledge, and internal communication for successful energy management (Lawrence et al., 2019b). Italy's White Certificates policy has been shown to enhance productivity and profitability in the paper and glass industries, particularly when firms are socially, relationally, or technologically connected—though geographic proximity offered no additional benefit (Caragliu, 2021).

Recent contributions also include evidence from Austria, where the implementation of energy management systems improved energy efficiency by 165% compared to business-as-usual scenarios (Schützenhofer, 2021). In the UK, industrial organizations that adopted management-based best practices achieved significantly higher energy efficiency than average, underscoring the untapped potential of such practices in sustainability policy (Ali & Evans, 2025). Additional studies have identified persistent economic, organizational, and behavioural barriers to industrial decarbonization, emphasizing the need for targeted policy interventions and further research across the supply chain (Kim et al., 2024). Finally, research into the environmental impacts of the pulp and paper industry has pinpointed key emissions drivers, the benefits of low-carbon manufacturing, and major barriers to decarbonization (Furszyfer Del Rio et al., 2022).

Non-energy benefits in relation to policy programmes

Energy efficiency improvements can also lead to several other advantages which are known as, for instance, multiple benefits or NEBs (Worrell et al., 2003). Nehler et al. (2018), Price (2005) and Johansson and Thollander (2019) have studied NEBs in relation to policy programmes targeting energy efficiency. Nehler et al. (2018) identify ten key areas where NEBs can emerge from policy instruments: knowledge, organizational development, social aspects, environmental impact, economic performance, marketing, production processes, work environment, inspiration, and collaboration. Among these, the most frequently observed NEBs are intangible or "soft" values, such as enhanced knowledge and improved organizational structures. Nehler et al. (2018) propose that anticipated NEBs from future policy instruments should be systematically integrated into evaluations and energy audits.

Price (2005) highlights that VAPs can generate NEBs by positively influencing companies' attitudes and awareness regarding energy efficiency. This shift in mindset can lead to long-term, sustained improvements. Furthermore, voluntary agreements are noted to foster innovation, encourage collaboration among stakeholders, and support market development. Further, Nehler et al. (2018) found that it is difficult to relate one NEB to a specific policy programme and that policy administrators are more aware of the NEBs than the companies.

Johansson and Thollander (2019) studied NEBs that arose from energy audit programs and energy efficiency network programmes. Frequently mentioned NEBs were related to production, such as extended equipment lifespan and increased production reliability. While participants from the energy audit program primarily associated these NEBs with technical installations, those involved in energy efficiency networks also attributed them to energy management practices. They showed that the studied companies who were more mature, and which had taken part in an energy efficiency network programme, could identify a greater number of NEBs than those who have taken part in an energy audit policy programme only.

Method

The *ex-post* impact and process evaluation is inspired by previous evaluation of the first programme period done by Stenqvist and Nilsson (2012). Stenqvist and Nilsson (2012) do conduct a process evaluation from a bottom-up perspective; however, they give limited attention to the role of the policy operator, beyond acknowledging the importance of the contract—an aspect also highlighted earlier by Price (2005).

Two sources of data are used for the purpose. The first is data on energy efficiency measures and energy use reported to the Swedish Energy Agency by companies that participated in the PFE programme, normally reported by the company's energy or sustainability manager. The second is in-depth interviews (Brinkmann & Kvale, 2015) with respondents from 11 companies that participated in both programme periods of the PFE.

Data on energy efficiency measures

To calculate the energy savings achieved during the PFE, data collected from companies was used. Reported data were binding within the policy to be implemented. The data were thoroughly quality controlled by senior staff at the Swedish Energy Agency and a specialist. This dataset included all reported measures, along with information such as which company implemented them, the estimated energy savings, and the type of measure. The data was compiled by calculating both the total number of measures per company and the resulting energy savings, as well as the number and savings of each measure type. An average energy saving per measure was then calculated for each type to identify which measures were most effective. First, total savings over the five-year period were calculated, after which the free-rider factor (see Section "Swedish energy efficiency policy programmes" and Eq. 1) was subtracted to estimate the savings directly attributable to the program.

Net energy savings calculation

Net energy savings were calculated based on the reported data. Following the approach of Stenqvist and Nilsson (2012), the data were adjusted using a free-rider coefficient. However, unlike their method, the multiplier and double-counting coefficients were excluded from the calculation. The net savings were thus determined as follows:

$$Net\,impact = Gross\,impact * (1 - FC) \tag{1}$$

where *Net impact* is the energy efficiency improvement with 100% additionality that is estimated to be achieved because of the PFE programme, *FC* is the free-rider coefficient and *Gross impact* is the total energy efficiency improvements during the programme periods.

The free-rider coefficient was estimated by asking respondents how many of the energy efficiency measures they would have implemented even without participating in the PFE programme. The calculated average of these responses was used as an estimate of the free-rider effect. Like Stenqvist and Nilsson (2012), measures identified through an energy audit, or the energy management system, were assumed to be due to the PFE. Measures suggested from a supplier, or measures previously known, were assumed to have been carried out even without the PFE. It cannot be determined whether some measures are due to PFE or not. Hence, an interval for the free-rider effect was obtained.

In-depth interviews

The interviews were performed five years after the program's end with the purpose to acquire the respondents' experience of the PFE's processes, absorption of energy-related knowledge, as well as energy management practices. The interviews also sought to study possible NEBs, the respondents' opinions regarding the current energy efficiency policy instruments, and how the future policy mix for improving industrial energy efficiency should be designed. Additionally, the respondents were asked what motivates them to work with improved energy efficiency. The results from the interviews were used in the analysis of how future policies should be designed. The facilitator model or intermediary derived from energy service research was used as an analysing model in this study viewing the policy operator as facilitator (Bleyl et al., 2013; Nolden et al., 2016).

For the interviews, the companies were sorted according to the amount of energy savings they had made. A selection was then made of companies with varying amounts of saved energy and from different industrial sectors. This was done to ensure that different types of companies were interviewed, as different industrial sectors may have experienced the policy instrument differently. Out of 91, 11 chose to participate in the interviews. The interviewees worked as energy managers or had a similar role. In most cases, the interviews were done by telephone, as the companies were scattered all over Sweden, but one company wanted to answer the questions in writing. Table 2 shows how many companies there were from each sector.

The interview guide was based on the research questions, which were broken down into more direct questions. These shorter questions could together provide answers to the more complex research questions (Kvale & Brinkmann, 2014). Some questions were asked so that they provided yes and no answers. The answers to these questions can be included in statistical analyses. Other questions were formulated more openly.

The interview material was compiled in a running text after each interview. The text was then divided into different themes. These were: differences between the periods, future policies, current policies, greatest effect, knowledge, control and leadership. All text in the same theme was compiled in a separate document where key words and sentences (for example, tax relief, difficulty with the processes, and more stable electricity price) were marked to count how many companies said the same thing. The results from the interviews were then compared with the results from

Table 2 The affiliation of the interviewed companies

Industrial sector	Number of companies
Iron and steel industry	4
Chemical products	1
Food industry	2
Pulp and paper mills	3
Transport	1

the first period of PFE (Stenqvist & Nilsson, 2012), with the aim of identifying similarities and differences.

Scoring model for energy management work

To assess how companies' energy management practices were influenced by the PFE programme, a scoring model was applied. Respondents were asked to evaluate their respective companies using this model. The assessment included three dimensions: the degree to which energy management was integrated with other business areas, the maturity of the energy management system, and the intensity of the companies' energy management efforts (as shown in Column 1 of Table 3). The number of companies at each level (Column 2) was multiplied by the corresponding score for that level (Column 3). The total score for each category was then divided by the number of companies to calculate a mean value. This aggregated score was determined for three time points—before, during, and after participation in the PFE—to evaluate how the programme influenced energy management practices over time.

Table 3 Scoring model for assessing the companies' energy management work

Category	Level	Points
Integrated into the company	Yes	10
	To some extent	5
	No	0
Certified energy management system	Yes	10
	No	0
Intensity in energy management	High	10
	Middle	5
	Low	0

Results

Impact of the second programme period

There were 91 companies that participated in the second phase of the PFE. A total of 1205 measures were implemented across these companies resulting in a total energy saving of 1 315 854 MWh/year, with an average of 14 460 MWh per company and per year. As shown in Fig. 1, 86% of the companies carried out 20 measures or fewer during this period, and the highest number of measures implemented by a single company was 73.

Of the companies that took part in the first phase, 14 did not participate in the second. Some companies were also reported as separate entities in the first phase but were merged into a single company in the second reporting. Of the 14 companies that did not continue into the second phase, 57% had an energy saving of less than 375 GWh per year, which according to Stenqvist and Nilsson (2012) was the target for the PFE.

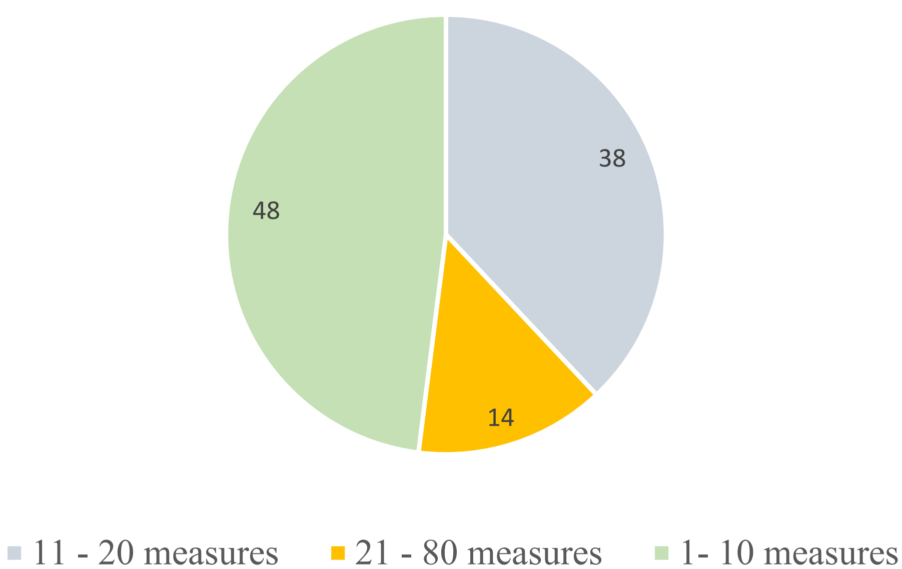

Fig. 1 Number of measures implemented by companies during the second program period, divided into three categories: 1–10 measures, 11–20 measures, and 21–80 measures

Nine of the 11 respondents stated that it was easier to find measures in the first period, when the low hanging fruits had not been picked. However, most respondents argued that they had established routines and working methods during the first period that allowed them to find and implement measures in the second period as well. This can be explained by a continued building of knowledge, routines and working methods, which means that they can reach measures beyond the low hanging fruits. In other words, companies that work on continuous improvement within energy management can continue to make major energy efficiency improvements, even though the measures become increasingly difficult to find. In fact, three respondents made greater savings in the second period, which they explained by the fact that the organization was more on track and now had well established routines in their work on energy efficiency improvements. One company emphasized that the routines established during the first period were one of the strengths of the programme and allowed for focus to be placed on energy efficiency. One company stressed that it could be more difficult to improve energy efficiency in the production processes, as these are often not so transparent in their procedures as support processes often are.

When companies were asked to estimate the share of measures that would likely have been implemented in their company even without the PFE, seven were able to give an estimate. The average was 37.5% and is within the interval reported by participants in the second period. Just over 1200 energy efficiency measures were implemented in the companies during the second programme phase. Figure 2 shows that 20% of the measures were proposed by a supplier or were already known before the programme and were thus not likely a direct result of PFE. Notably, fewer than 200 of the 1200 reported measures resulted directly from the energy management system—highlighting a common misconception that energy management and energy management systems are the same. Some measures were difficult to assess as to whether they were a result or not of PFE, such as new purchase or design routines. These measures represent 28% of the total number of measures, making the free-rider coefficient somewhere between 20 and 48%. This means that between 52 and 80% of the measures can be, or were likely, a result of the programme. This corresponds to 740 to 1140 GWh/year. A free-rider coefficient of 37.5% is similar to the coefficient estimated by Stenqvist and Nilsson (2012) for the first programme period of the PFE (40%).

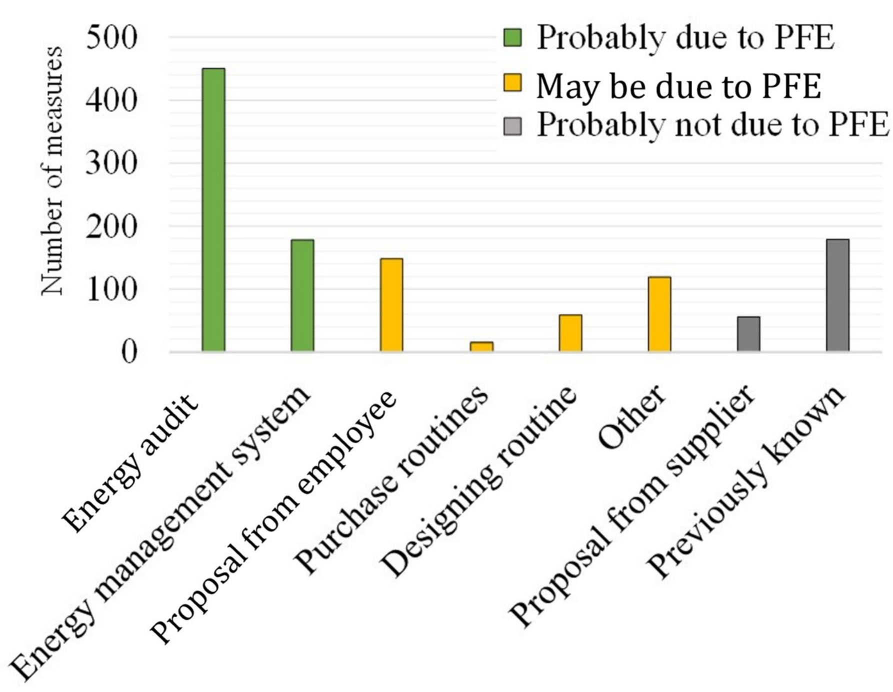

Fig. 2 Summary of ways that measures have been identified and their likely connection to the PFE program

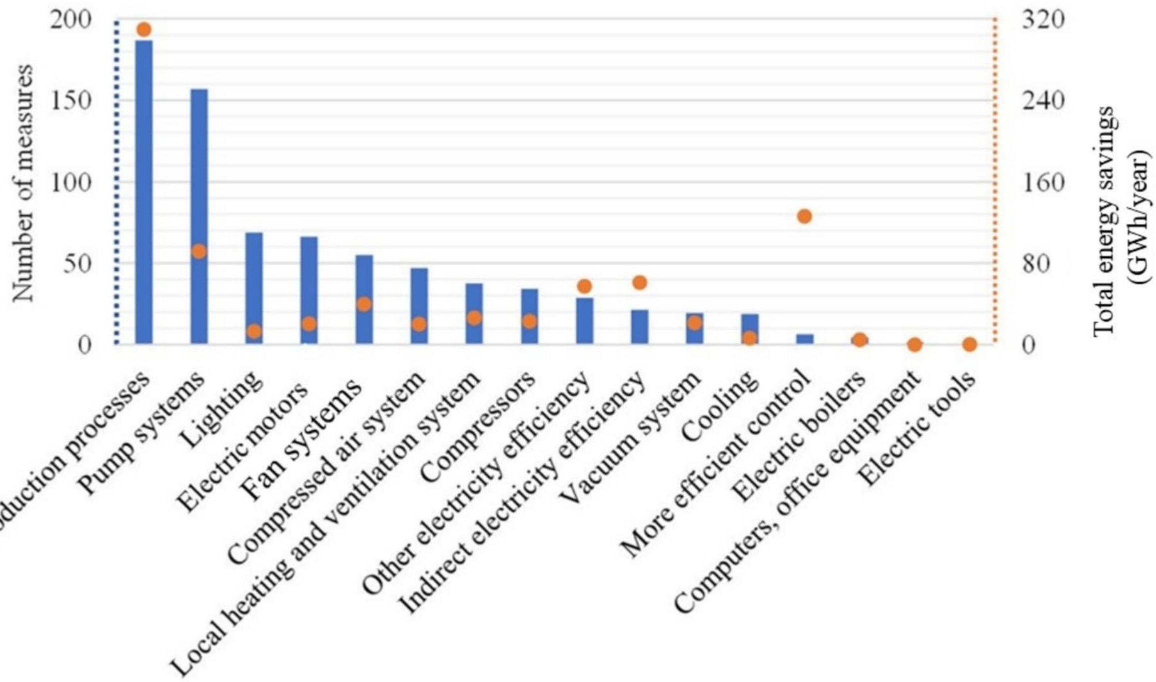

Fig. 3 Number of measures implemented during the second period, and corresponding total energy savings categorized by type of measure

The total energy efficiency improvement for all participating companies was 1482 and 1426 GWh/year respectively during the first and second period. With a free-rider coefficient of 37.5%, the net impact from the second period is 891 GWh/year.

In both the first and second programme periods, most of the measures were related to production processes and pumping systems, and measures for more efficient control constituted a major share of the energy savings in both periods. Figure 3 presents the categorization of energy efficiency measures, the number of measures implemented, and the total annual energy savings for each category, based on the taxonomy used by the Swedish Energy Agency for reporting purposes. Measures implemented in the production processes were the most common measures and resulted in the largest total energy savings. This is, in turn, interesting, as stand-alone energy audit programmes primarily result in measures from the support processes (Johansson, 2022), showing that, for industry, VAPs are crucial in targeting non-support process-related energy efficiency measures.

Figure 4 illustrates the average annual energy savings per measure. More efficient control provides greater savings per measure than the measures of technical character. However, very few measures were taken within that category, and it was primarily one that significantly raised the average. This makes it difficult to claim that the result is generally applicable, but it does indicate that more effective control has great potential to make a significant difference. Efficient management does not necessarily require investment cost, and such measures should therefore be attractive to the top management, unlike measures where processes with high investment costs need to be replaced, and the investment cost thus becomes high.

Measures that provide more efficient control and measures aimed at the production processes might be combined by working towards a more efficient control of the production processes. Combining large savings categories with categories that have high average savings per measure indicates where high impact measures can be found, i.e. a way to identify focus areas. Among the more commonly implemented measures, indirect electricity efficiency, electric boilers, and production process optimizations resulted in substantial savings per measure. In contrast, measures related

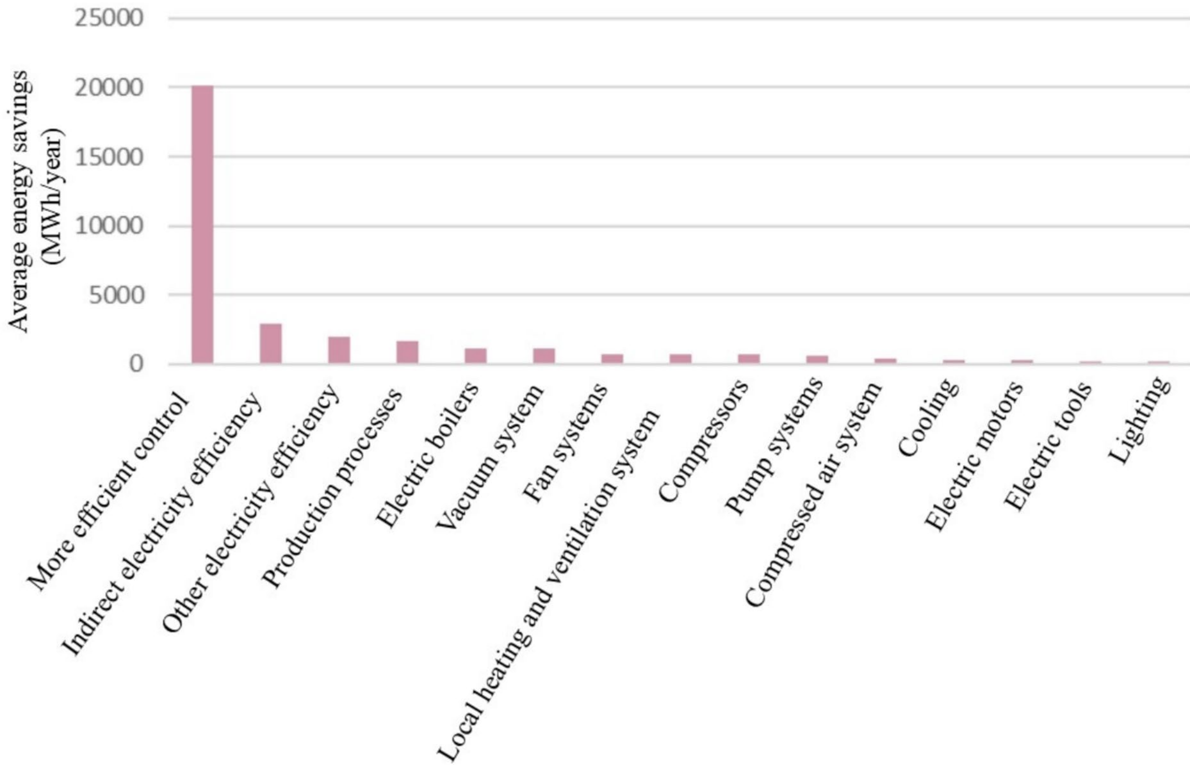

Fig. 4 Average energy savings during the second period, categorized by type of measure

to lighting, electric tools, electric motors, and cooling tended to yield smaller savings per measure.

Processes within PFE

The energy management system introduced as part of the programme facilitated integration of energy efficiency work in the companies, which largely remained after the programme was completed. However, the intensity of the work decreased slightly after the programme's completion by the end of 2014 – see the results from the scoring model (as explained in Table 2) in Fig. 5. This showed that the PFE was more of an initial driver for working more intensively with energy management, rather than solely a means for implementing an energy management system or conducting energy audits.

Of the 11 respondents, five stated that one of the most important contributions of the programme was that energy issues were raised with top management. A structured way of presenting energy efficiency measures combined with calculating payback time for the measures gave management a greater opportunity to make decisions. One of the respondents emphasized this as a major advantage of the programme, and in addition, a prerequisite for intensified energy management work. Four of the respondents stated that the programme gave a structure that allowed them to work efficiently with their in-house energy management programme. In addition, three respondents stressed that the programme made everyone in the company engaged in energy management work, compared to the former state in which only a few in the organization worked on energy efficiency-related issues. Therefore, everyone in the company was viewed as an asset in the energy management work.

The respondents were asked about the greatest benefits from the programme, and their answers could be divided into four different categories:

- energy saving which resulted in large financial savings (four respondents)
- energy issues gained greater interest among the operational management and were given higher priority, which had increased opportunities

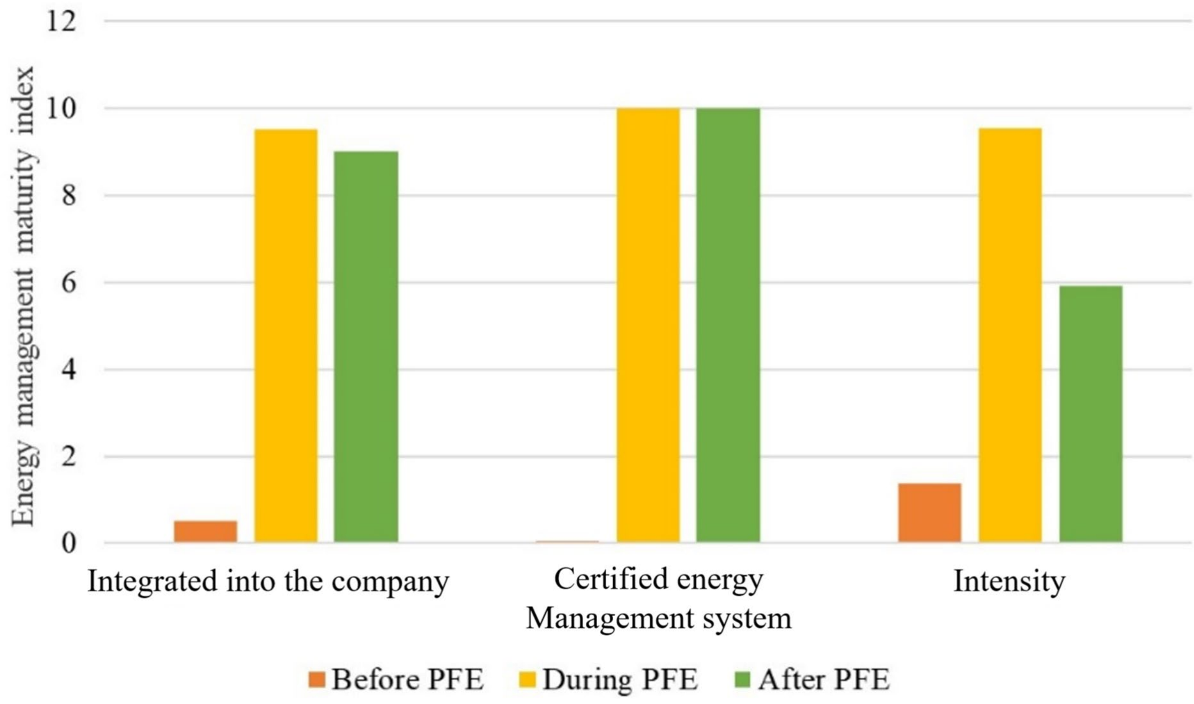

Fig. 5 The change in the companies' work on energy efficiency-related procedures before, during and after the PFE

for energy efficiency investment capital (three respondents)

- a standardized and structured way of working with energy management and new ways of thinking when it comes to energy (three respondents)
- knowledge about how much and in which processes energy is used (one respondent)

Non-energy benefits from PFE

Ten out of 11 respondents stated that the programme had generated several NEBs in addition to energy efficiency improvements. Results of the NEBs identified and experienced by the respondents are presented in Table 4. Most of the NEBs were related to knowledge and the organization. Enhanced knowledge about energy efficiency and production processes were the most common NEBs related to knowledge. Deepened knowledge about the production processes and more specific knowledge about their respective industries were stressed by the respondents as requirements for them to be able to continue making major energy efficiency improvements, in line with findings by Lawrence et al. (2019b). They also emphasized that such knowledge must exist internally at the company, since consultants do not have the specific contextual knowledge, which means that consultants generally tend to focus on common and general energy efficiency improvements, even though the greater energy efficiency potential may exist in the often more complex and context-dependent production processes. However, some of the respondents found it difficult to find competent staff who could work on this, and knowledge of processes therefore remains a knowledge gap for many companies. This is in line with the original findings by Solnørdal and Thyholdt (2019) that prior knowledge, for example in form of higher university degrees in the workforce and cooperation with universities and competitors, increase the companies´ possibilities to successfully work with energy efficiency. The finding in this paper is that not only does general Episteme knowledge play a key role, as Solnørdal and Thyholdt (2019) reported, but also the practical Techne knowledge acquired from experience and knowledge of a company's often unique and contextual processes. Four respondents found it possible to get the knowledge they needed, either via

Table 4 The NEBs observed by the respondents participating in the PFE

Category	Non-energy benefit (NEB)	Number of respondents
Knowledge	Increased knowledge about energy efficiency	9
	Increased knowledge of the company's production processes	6
	Spread of knowledge about energy management to other factories or production sites of the companies	4
	Considering energy efficiency in new constructions	1
	Development of new methods for finding energy efficiency measures	1
	Increased knowledge about NEBs	1
Organization	Structured working methods for energy management and measures	4
	Improved basis for the management's decisions on energy efficiency measures	1
	Energy management has been given a certain role in the business development	1
	Focus on energy efficiency from the management team	1
Authorities	Contacts with authorities had been simplified	5
	Easier to get permission from the Land and Environment Court	1
Social aspects	Increased responsibility and commitment among staff	2
Environment	Improved environmental performance at the company	1
Economy	Measures with < 3 years of payback time must be implemented even after the PFE	1
	Selects the most energy-efficient engines at purchase even after the PFE	1
Marketing	The value of showing that the company had worked on energy efficiency for a long time	1
Production	More efficient production processes	2
Work environment	Improved working environment due to the measures implemented	2
Management systems	Introduced an energy management system to other factories or production sites of the companies that did not participate in the PFE	1
	Introduced an energy management system in companies' factories or production sites in other countries	3

external sources or by using experts within the company. In addition, two respondents also emphasized that knowledge often exists if the company is willing to pay for it, but that it is often considered too expensive, and then a knowledge gap still exists in practice.

Structured working methods for energy management and measures were the most common NEBs regarding the organization. Another common NEB was simplified contact with authorities such as the Swedish Energy Agency, environment and health and other licensing authorities.

The programme has also affected the companies' factories and production sites in other parts of Sweden or other countries, either by spreading knowledge or by introducing energy management systems. Several of the respondents argued that the programme created a good example of how well an energy management system can function, which spread to parts of the companies that did not participate in the programme.

Current and future policy instruments

Several respondents indicated that current policy instruments— unlike the now-terminated PFE programme—lack the balanced combination of incentives and obligations that characterized the PFE programme. One respondent said the policy instruments also lack the systematic approach that the programme brought, and requirements on the companies. The respondent argued that current instruments have less focus on working on energy issues at an organizational level within companies. Figure 6 shows the share of respondents that were positive, neutral and negative towards the two instruments that were active in Sweden at the time of the interview: The Energy

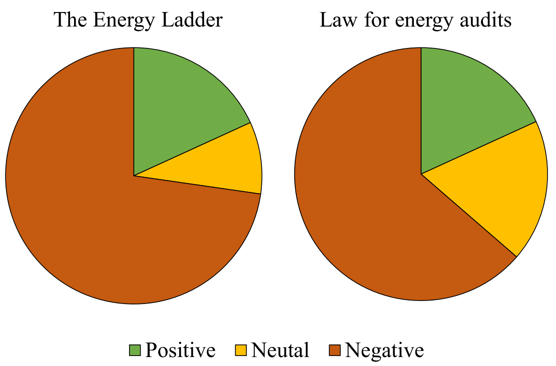

Fig. 6 The respondents' attitudes towards the Swedish policy instruments for industrial energy efficiency that followed PFE

Ladder and the law for energy audits. Some of the respondents were not responsible for energy issues when the PFE was operating. These interviewees were generally more positive about the policy instruments in place at the time, while those who handled energy-related issues during the PFE – for instance, they had roles such as energy managers – were generally more negative towards the subsequent policy instruments.

The respondents who were negative towards the law for energy audits argued that they do not get the same benefit as they received from the PFE. One respondent stated that the law for energy auditing is counterproductive, since they had already carried out energy audits, and thus have a clear view of their activities. Sweden has had various kinds of energy audit programmes in place since 1994. Five respondents argued that the law for energy audits does not have the same financial incentives as the PFE, which means that the motivation to implement the measures proposed in the energy audit report was lower, as formerly also emphasized by Price (2005). Another company emphasized the importance of requirements on implementing measures, as was the case for the programme under study. The respondents who expressed that they were positive towards the law for energy audits argued that it puts pressure on the companies to work on energy efficiency and constantly improve. One of the companies, however, emphasized that the law for energy audits involves a great deal of work and administration, which resulted in large costs related to hiring consultants. Notably, in line with the findings of Kimura and Noda (2014), this was also found to be an issue related to law-based policy instruments where companies lacking the internal capacity for energy management tend to rely on external consultants, leading to a low level of sustained energy efficiency work. A positive aspect mentioned by one respondent who was negative in general, was that the law on energy audits covers the company's entire energy use, while the PFE only focused on electricity use, which only accounts for two-thirds of that company's total energy use.

Most companies expressed a negative view of the policy in relation to the Energy Ladder, stating that it does not provide the same level of benefits as the previous PFE programme. One respondent emphasized a desire to make greater use of the Energy Ladder but admitted that they had not taken the time to complete the necessary applications to obtain support. Another company stated that it is difficult to see how the Energy Ladder policy benefits society, since it is not possible to know whether the companies would have implemented the measures even without the support, which in that case would make the policy deliver low additionality. This confirms the finding by Farla and Blok (1995) that investment subsidies face the risk of low additionality. Another respondent addressed that there were too few projects that fit into the available support and that it is therefore not a suitable policy instrument for them. However, one respondent argued that the Energy Ladder had made it possible for them to make significant energy efficiency improvement investments which would not have been possible without the support of the policy, since large investments were required. Another respondent was positive towards the Energy Ladder because the policy instrument put pressure on the companies to become more efficient.

Several respondents argued that neither of the policy instruments introduced following the PFE offer sufficient incentives to implement energy efficiency measures. Many of the respondents stressed that the motivation to participate in the PFE was to avoid the tax, even though the tax reductions ultimately accounted for a very small part of the total economic savings that were made during the programme period. For instance, a few respondents stressed that they would rather spend more on their electricity bill than paying tax to the government, and that this mindset is something that policy makers should consider. This also confirms Price's (2005) conclusion that VAPs are most effective when there are financial incentives linked to the instrument. Since tax exemption served as a financial incentive that, according to respondents, motivated companies to improve their energy efficiency, this mechanism should be carefully considered in the design of future policies. Currently, within the EU energy policy framework, the Energy Efficiency Directive hinders this approach by mandating legally binding energy management certification without offering corresponding financial incentives.

Several respondents noted that their companies' current motivation to pursue energy efficiency improvements—after the termination of the PFE—stems primarily from customer requirements (e.g., certifications), sustainability demands from owners and other stakeholders, and efforts to enhance competitiveness. Working with energy efficiency is, according to one respondent, a good selling point because the customers are interested in this. Another respondent points out that it looks particularly good that they have been certified (i.e. to the energy management standard) for a long time and not just jumped on a trend in recent years. Although companies are still motivated to work with energy efficiency, there are no longer the same legal requirements for implementing measures, which means that energy efficiency measures are often not prioritized, as other types of investments have a shorter payback time.

Most respondents stated that the PFE was a sound policy, and they were positive about seeing similar policy programmes in the future, with some form of economic incentive. One respondent highlighted the need for a clear deadline for when measures must be implemented, similar to the requirement in the VAP under study, which is justified by some form of economic incentive. It can be any type of tax or fee they stated, if it justifies the risk they must take. This is already the case under the Swedish Environmental Code, which legally requires the implementation of all energy efficiency measures that can be economically justified. However, as first observed by Johansson et al. (2007), the Code has been slow to gain traction within Swedish industry.

One problem that often recurred in the interviews was that the largest energy savings were generated by streamlining the production processes, but that it was difficult to change these processes without altering or disturbing the production. The Energy Ladder and the law for energy audit do not directly promote or support the development of deeper knowledge on how companies can improve energy efficiency in their production processes to the same extent as the PFE. These policies primarily focus on conducting energy audits and proposing energy efficiency measures, which are largely directed toward support processes and addressing the information gap—see, for example, Anderson and Newell (2004). Most of the energy efficiency work today was done by a consultant who did not possess the process knowledge that the companies view as important, and the knowledge the companies have received during the PFE disappears over time as staff change positions or retire. Herein lies a strategically important issue for any company and corporation to focus on building long-term competence within the company's energy team.

Several companies emphasized the importance of a long-term and stable policy instrument mix. Both society and the companies benefit from having long-term policy instruments in place that favour deployment of new technology and research to be conducted and is something that future policy instruments could consider.

In addition to the fact that parts of the PFE are missing in the current policy mix, the companies also identified aspects that were missing in the programme under study, which should be considered when introducing new policy instruments. One respondent emphasized that the PFE was limited by the fact that there was only a focus on electricity, when there are other energy sources that are used in the companies that have the potential to be streamlined.

Discussion

The results stem from the world's first industrial energy policy program that included certification of an energy management system. Participating companies had been working with the Swedish standard SS 62 750 for over a decade, as Sweden was the first country to implement a policy requiring a certified energy management system. This long-term engagement reflects a high level of energy management maturity, meaning that these companies had well-established routines, organizational structures, and strategic approaches to energy efficiency. Moreover, all measures with a payback period of less than three years were mandatory, further reinforcing a culture of continuous improvement.

In-depth interviews were done with 11 companies out of 91. Had we been able to analyse a larger number of companies, we could have captured a broader range of perspectives and experiences. However, given our focus on obtaining in-depth insights, 11 companies would provide a solid foundation for meaningful analysis and well-grounded conclusions. To support the credibility of our findings, we can also relate them with some reported studies in the literature, for example Wakabayashi (2013), Schützenhofer (2021), Stenqvist and Nilsson (2012) and Price (2005). Only those who held roles as energy managers were interviewed. Their views on PFE and other policy instruments may differ from those held by others within the company. The fact that energy managers were interviewed was not entirely a deliberate choice; rather, the companies that were asked to participate referred us to these individuals, as they possessed the most knowledge about PFE and the company's energy management work.

Conducting the evaluation five years after the program's end allowed for assessment of long-term effects but made it harder to find interviewees with full program experience. Some energy managers had only recently assumed their roles, limiting their ability to reflect on earlier phases. Ideally, an immediate post-program evaluation followed by a long-term follow-up would have captured both short- and long-term impacts. Still, some long-serving employees contributed valuable insights. Another limitation of the interviews was that only energy managers were interviewed. Future studies could benefit from interviewing a broader range of staff, including senior management, to compare perspectives across different roles.

Companies self-reported data on energy efficiency measures, which may have been interpreted inconsistently—especially regarding the type of measure. However, the data has been thoroughly quality controlled by both the Swedish Energy Agency with specialists subsequently by Blomqvist and Thollander (2015). Validation with earlier datasets (i.e. Stenqvist & Nilsson, 2012) helped validate the results. Net energy savings were estimated using a free-rider factor, assuming proportionality between the number, type, and impact of measures—an assumption that may not always hold. For example, if a company implemented both minor and major measures but claimed half would have occurred without the program, it's unclear which ones. However, given the large number of total measures, a roughly even distribution is a reasonable assumption. Estimating the free-rider factor was inherently uncertain, as companies struggled to predict what would have happened without the program. These are ultimately educated estimations, though energy professionals are likely the most qualified to make them.

The analysis in this study showed that most NEBs identified were linked to increased knowledge and organizational factors. Respondents highlighted that in-depth, industry-specific knowledge—particularly internal to the company—is essential for achieving significant energy efficiency improvements. This is in line with Lawrence et al. (2019b), who state that the main drivers for energy management in energy-intensive industries are primarily reduced energy costs, access to internal expertise with knowledge of the processes and daily operations, as well as VAPs with tax credits. Hence, how the companies embrace the need for knowledge, and in which areas more knowledge is required, are therefore important aspects. In this study, Aristotle's types of knowledge referred to as Episteme and Techne have been applied in the analysis of energy-intensive companies' views on their knowledge of energy efficiency improvements in relation to their manufacturing processes (Andrei et al., 2022).

The PFE was shown to be a policy instrument that has led to a vast improvement in energy efficiency, even when considering free-riders. In addition to improved energy efficiency among participating companies, the PFE also led to economic benefits for the companies, as well as a wide range of non-energy benefits (NEBs) that emerged in connection with the program. Today's current policy instruments in Sweden do not benefit society and companies in the same way. The law for energy auditing is seen as a cost that does not give many energy-intensive companies much in return. These findings may be generalizable well beyond the Swedish context, as Sweden has long been a front-runner in energy policy. Our paper suggests a critical role of a policy facilitator, engaging in the companies as has been the case in the PFE. Similar patterns could emerge in other countries in the coming years or decades—particularly in those that have not implemented structured energy policy programmes, such as energy audits, over the past thirty years. The Energy Ladder policy entails a public cost, as it is tax money that goes to financing the companies' investments. In other words, the policy instruments constitute a public cost for the government and private capital needed from the companies, compared to the PFE in which the companies benefited from the means of government and society benefited from a lower electricity use than would have been the case without any expenditure.

When developing new policy instruments, it remains critical to consider what type of knowledge the companies receive from the information generated by the policy instrument and ensure that it is the second level of knowledge that reaches the companies. This is a novel finding in this study, thanks to the process evaluation, i.e. moving beyond a policy impact evaluation. In addition, if a VAP like the PFE would be designed again in Sweden, it would be appropriate to also allow heat and other energy carriers to be part of the programme, to comprehensively ensure improved energy efficiency from a more holistic perspective.

Conclusions

This paper evaluated the second programme period of Sweden's largest policy programme for industry. Key previous research relevant to this study includes Price (2005) and Rezessy and Bertoldi's (2011) review of Voluntary Agreement Programs (VAPs), Wakabayashi's (2013) analysis of the Japanese VAP—the oldest in the world—Schützenhofer's (2021) comparison of companies with and without energy management systems, and the evaluation of the first phase of the PFE program by Stenqvist and Nilsson (2012). Something that is persistent in all parts of this evaluation is the importance of companies streamlining energy use in their production processes, and the knowledge required for this. This, together with Andrei's (2023) theory that radical changes are needed in the companies' production to change society, shows that the current energy efficiency policies (e.g. law for energy audits) are not enough, as they only serve the companies with general knowledge that does not embrace the full potential for improved energy efficiency (in particular for the production processes). Investing in new energy-efficient technologies, which is often proposed by consultants, can reduce the company's energy use. However, the largest source of potential to increase energy efficiency is found in changing routines and control, and by increasing knowledge on the whole process, primarily for energy-intensive companies, not just the technology. This is seen in Fig. 3 to yield high savings per measure and is also emphasized in Paramonova et al. (2021). It is not promoted through current energy policies to the same extent as the PFE was able to. The respondents stressed that process knowledge is required to make the changes as addressed by Andrei (2023). Process knowledge is achieved when the companies are working with energy efficiency integrated throughout the organization and allowing those who have good knowledge of the company's production to cooperate with those who have knowledge of energy efficiency. The programme under study made the companies work in a manner which gave them the chance to develop enhanced process knowledge, but as the work slowed down, the knowledge enhancement also slowed, even though the companies emphasized that more knowledge was needed. In other words, it can be stated that a knowledge gap indeed still exists. These findings back up the energy efficiency directive (2023) changing from mandatory energy audits to mandatory energy management system certification, as formerly also noted by Schützenhofer (2021).

What is not found in today's Swedish energy efficiency policy mix is primarily instruments that promote knowledge about energy linked to the company's production processes and requirements for implementing measures. The Energy Ladder policy could help companies financially to implement measures, but from the interviews it emerged that the means of control is used to a small extent, and many measures are not implemented when other investments are prioritized. Having a requirement to implement measures, like in the PFE, means that many more measures are being deployed, and the ability to meet them is a gap in today's policy mix. It is obviously not enough for companies to know what can be done if they have no incentive to implement the measures that they have found. The idea behind the law for energy auditing was that when the companies have information about what can be made more energy efficient, the energy efficiency gap will disappear, as the information will serve as a means for the companies to implement the measures. Unfortunately, the results of the interviews showed that this information was not enough. In addition, it can be assumed that if information had been sufficient, all possible measures would have been implemented in the PFE's first period, since they had then received information about this. However, the fact that equally large savings were reported during the second period indicates that there is more than an information gap that is needed to be removed or reduced. This also indicates that a third period of the PFE could have been beneficial. Notably, only about 15% of the reported measures in the VAP originated from the energy management system, raising questions about whether the current EU legislation—mandating energy management systems—is sufficient. A hypothesis derived from this study is that VAPs remain critical to promote and sustain industry decarbonisation, of which improved energy efficiency remains the first fuel. Our findings suggest that more structured approaches, such as VAPs that combine tax incentives with an active policy facilitator, may also be necessary to achieve broader and deeper energy efficiency outcomes.

A key finding of this study—originally highlighted by Johansson et al. (2022)—is that while energy audits are important, they are not sufficient to drive substantial improvements in energy efficiency within energy-intensive industries, where most energy use occurs in core production processes. In contrast, a Voluntary Agreement Programme (VAP), such as the one examined in this study, offers a more effective policy approach by facilitating improvements directly within these core processes. To address the current gaps in energy efficiency and energy management, policy measures are needed that encourage companies to optimize their production processes through more efficient control systems. This is most effectively achieved by combining financial incentives with the integration of energy management practices across the entire organization—ideally supported by an active policy facilitator. Future research should evaluate the effectiveness of today's energy efficiency policies to better understand their outcomes and the implications of replacing the VAP under study with the law for energy audits and the Energy Ladder.

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Data availability The authors do not have permission to share data.

Declarations

Declaration of generative AI and AI-assisted technologies During the preparation of this work the authors used ChatGPT and CoPilot to proofread parts of the text and facilitate a selection of the literature search. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Competing interest The authors declare no competing interests.

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