Re-viewing industrial energy-efficiency improvement using a widened system boundary

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Abstract

Improved energy efficiency in industry is important for reaching the targets within the EU strategy for increased sustainability. However, energy efficiency is not always prioritised within companies, and the improvement potential remains large. This paradox called an energy-efficiency gap is explained by energy-efficiency barriers. The low interest in energy efficiency is also explained by the fact that it is not within companies' core competences and not perceived as strategic. The public policies aiming at closing the gap have thus far been concentrated on the faster diffusion of energy-efficient technologies. This is not sufficient, and the gap can be extended by including energy management practices. To bridge the extended gap, there is a need to introduce an extended system perspective. The aim of this thesis is to investigate the industrial energy-efficiency potential and possibilities for reaching this potential using an extended system boundary.

In this thesis, the extended gap was quantified by means of classification of the energy data covering the most electricity-intensive Swedish industrial companies. The results show that technology-related measures represent 61% of energy savings, whereas management-related measures account for 38%. Energy efficiency due to management-related measures can be improved with lower costs. The energy-efficiency potentials for different levels of industrial motor systems were quantified, showing that the highest potential is found in the measures that include personal involvement and the optimisation of routines. This proves that the general approaches based on technological diffusion seem to not be sufficient to solve the energy paradox.

The evaluation of the Swedish energy audit programme for small and medium-sized enterprises (SMEs) proved that there is a lack of energy-related knowledge among SMEs. The implementation rate of measures proposed in the audits is only 54%, while there is also a need to reach the SMEs not covered by the programme. The international study of energy-efficiency potentials did not indicate energy management to be considered by SMEs at all.

To bridge the extended gap, the external experts' knowledge on how to work with energy efficiency has to stay within companies. For this, there is a need for methods based on long-term orientation as well as a systematic view of complicated processes. The methods should be universal and applied in a particular context. An example of such a method for large industries is presented in this thesis, whereas applying it to SMEs is problematic due to limited resources. Participating in networks for energy efficiency can be a way to initiate energy-efficiency work within SMEs on a continuous basis. Moreover, this thesis shows that there is a need for the development of a common taxonomy for energy data as well as the development of a central portal where energy data can be reported and stored. This would simplify the monitoring of energy end-use, the control of measures implementation and the comparison between processes, companies and sectors.

Sammanfattning

Förbättrad industriell energieffektivitet är viktig för att nå målen i EU:s strategi för ökad hållbarhet. Att energieffektivisera är inte prioriterat inom företagen och potentialen är därför stor. Denna paradox kallas för energieffektiviseringsgapet och förklaras av hinder för energieffektivisering. Det låga intresset för energifråga beror också på att den inte ligger inom företagens kärnkompetens och inte uppfattas som strategisk. De styrmedel som syftar till att överbrygga gapet har hittills handlat om snabbare spridning av energieffektiv teknik. Detta är inte tillräckligt och gapet kan utvidgas genom att inkludera energiledningsåtgärder. För att överbrygga det utvidgade gapet behövs ett utvidgat systemperspektiv. Syftet med denna avhandling är att undersöka den industriella energieffektiviseringspotentialen och möjligheter för att nå den genom att utvidga systemgränsen.

I denna avhandling kvantifierades det utvidgade gapet med hjälp av kategorisering av energidata som inkluderar de mest elintensiva svenska industriföretagen. Resultaten visar att teknikrelaterade åtgärder utgör 61% av energibesparingar medan energiledningsrelaterade åtgärder står för 38%. Dessutom kan energieffektivisering genom energiledningsrelaterade åtgärder förbättras med lägre kostnader. Energieffektiviseringspotentialer för olika nivåer av industriella elmotorsystem kvantifierades och det visar sig att den högsta potentialen ligger i de åtgärder som inkluderar personaldeltagandet och optimering av rutiner. Det bevisar att de vanliga metoder som baseras på tekniska lösningar inte till fullo kan lösa energiparadoxen.

Utvärderingen av det svenska energikartläggningsprogrammet för små och medelstora företag (SMF) som gjordes i denna avhandling visar en brist på kunskap inom energiområdet bland de företagen. Implementeringsgraden av åtgärder föreslagna i kartläggningar står för endast 54%, medan det också finns ett behov av att nå de SMF som inte omfattas av programmet. En internationell studie av energieffektiviseringspotentialen i SMF indikerade att energiledning inte prioriteras bland dessa överhuvudtaget.

För att överbrygga det utvidgade gapet måste externa kunskaper om hur man arbetar med energi stanna inom företagen. För detta behövs metoder som baseras på långsiktighet och systematisk syn på komplicerade industriella processer. Metoderna bör vara universella och tillämpas i en särskild kontext. Ett exempel på en sådan metod för stora företag presenteras i avhandlingen men att tillämpa den på SMF är problematiskt på grund av begränsade resurser. Deltagandet i nätverk för energieffektivisering kan vara ett sätt att initiera energiarbetet inom SMF på en kontinuerlig basis. Dessutom bevisar avhandlingen ett behov av skapandet av en gemensam taxonomi för energidata samt av en central portal där data kan rapporteras och lagras. Detta skulle förenkla övervakning av slutenergianvändning, kontroll av åtgärdsimplementering samt jämförelse mellan processer, företag och branscher.

List of papers

Paper I. Paramonova, S., Ivner, J., Thollander, P., 2014. “Outsourcing industrial energy management: industrial energy efficiency networks provided as an energy service”. *Outsourcing: Strategies, challenges and effects on organizations*, New York: Nova Science Publishers, Inc.: 71–98.

Paper II. Paramonova, S., Thollander, P., Ottosson, M., 2014. Quantifying the extended energy efficiency gap – evidence from Swedish electricity-intensive industries. *Renewable and Sustainable Energy Reviews* 51: 472–483.

Paper III. Thollander, P., Paramonova, S., Cornelis, E., Kimura, O., Trianni, A., Karlsson, M., Cagno, E., Morales, I., Jimenez, J.-P., 2014. International study on energy end-use data among industrial SMEs and energy end-use efficiency improvement opportunities. *Journal of Cleaner Production* 104: 282–296.

Paper IV. Paramonova, S., Thollander, P., 2016. Energy efficiency networks for SMEs: learning from the Swedish experience. *Renewable and Sustainable Energy Reviews* 65: 295–307.

Paper V. Paramonova, S., Thollander, P., 2016. Ex-post impact and process evaluation of the Swedish energy audit policy programme for small and medium-sized enterprises. *Journal of Cleaner Production* 135: 932–949.

Paper VI. Paramonova, S., Thollander, P., 2016. Technological change or process innovation – An empirical study of implemented energy efficiency measures from a Swedish industrial voluntary agreements program. *Energy Policy* (under review).

Paper VII. Svensson, A., Paramonova, S., 2016. The analytical model for identifying and addressing energy efficiency improvement opportunities in industrial production systems – model development and testing experiences from Sweden. *Journal of Cleaner Production* (in press).

Other publications

Backlund, S., Paramonova, S., Thollander, P., Rohdin, P., Karlsson, M., 2014. A regional method for increased resource-efficiency in industrial energy systems. In proceedings of ECEEE Industry Summer Study, Arnhem, 2nd–5th of June.

Paramonova, S., Backlund, S., Thollander, P., 2014. Swedish energy networks among industrial SMEs. In proceedings of ECEEE Industry Summer Study, Arnhem, 2nd–5th of June.

Thollander, P., Ivner, J., Paramonova, S., Svensson, A., Tuenter, G., Björkman, T., Moberg, J., 2014. Swedish energy manager networks for energy-intensive industry as a driver for improved energy efficiency. In proceedings of ECEEE Industry Summer Study, Arnhem, 2nd–5th of June.

Paramonova, S., Thollander, P., 2014. Energy efficiency potentials for different motor system levels – An empirical study of PFE implemented energy efficiency measures. Motor Summit 2014 Proceedings, Zurich, Switzerland, 14–15.

Blomqvist, E., Thollander, P., Keskisärkkä, R., Paramonova, S., 2014. Energy efficiency measures as linked open data. IOS Press. Semantic Web Journal, 1–5.

Carlén, A., Rosenqvist, M., Paramonova, S., Thollander, P., Municio, S., 2016. Energy efficiency networks for small and medium sized enterprises – boosting the energy efficiency potential by joining forces. In proceedings of ECEEE Industrial Efficiency, Berlin, 12th–14th of September.

Thesis outline

Chapter 1. Introduction

Chapter 2. Industrial energy efficiency and energy policies

Chapter 3. Extended energy-efficiency potential

Chapter 4. Industrial energy-efficiency networks

Chapter 5. Theoretical framework

Chapter 6. Method

Chapter 7. Results

Chapter 8. Discussion

Chapter 9. Conclusions

Chapter 10. Further work

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Abbreviations

BAT	Best available technologies
EEAP	Energy efficiency action plan
EEM	Energy efficiency measure
EEU	Energy end-use
EMDS	Electric motor driven system
ETS	The Emissions Trading System
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IEA	The International Energy Agency
IEEN	Industrial energy-efficiency networks
IPCC	The Intergovernmental Panel on Climate Change
LE	Large enterprises
LEEN	Learning energy-efficiency network
LTA	Long-term agreements
MOVE	Method for Optimisation of System Efficiency (Metod för Optimering av Verkningsgraden för Elmotorsystem, in Swedish)
NEB	Non-energy benefit
NPV	Net present value
PFE	The Programme for Improving Energy Efficiency in Energy Intensive Industries
SEA	The Swedish Energy Agency
SEAP	The Swedish Energy Audit Programme
SME	Small and medium-sized enterprise
VA	Voluntary agreement

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1 Introduction

This chapter provides a short introduction to this thesis followed by the aim and research questions. Further, the scope and delimitations are given. In the end, the paper overview and co-author statement are provided.

It is a known fact that unsustainable anthropogenic actions have already reached the point where these are causing various environmental problems (IPCC, 2014; Meadows et al., 1972; Steffen et al., 2004; Stern, 2007). In the middle of the 20th century, people started to realise that if proper actions were not taken, there could be irreversible damage to the planet, meaning that it could not be saved for the future generations in the unchanged state. This is when the sustainability issue was first brought up to the global agenda together with increased global warming, climate change and greenhouse gas (GHG) emissions (Bryson, 1968; Meadows et al., 1972; Sawyer, 1972). It is also recognised that there is a need to reach a trade-off between all sustainability dimensions – economic, social and environmental (Byggeth & Hochschorner, 2006). However, achieving global sustainability is challenged by a growing population and increasing use of material and energy. In the case of energy sector, reliance on fossil fuels and increased energy demands contribute to climate problems. The burning of fossil fuels causes the majority of GHG emissions. According to the latest Intergovernmental Panel on Climate Change (IPCC) report, fossil fuels together with industrial processes cause 78% of the global GHG emissions increase (IPCC, 2014).

A unilateral commitment of the European Union's member countries known as the 20-20-20 target was developed to transform the EU economy into one with reduced carbon emissions and improved energy efficiency. The target is to be fulfilled by 2020 and implies reaching a 20% GHG emissions reduction compared to the reference year 1990, a 20% share of renewable resources in national energy use and 20% improved energy efficiency (EC, 2015a). Between 2020 and 2030, the reinforcement of the target is proposed as a 40% GHG emissions reduction, a 27% share of renewable energy and 27% improved energy efficiency (EC, 2015b). The Energy Efficiency Directive (2012/27/EU) implemented in 2012 has been issued to comply with this target (EC, 2012). Another instrument is Directive 2009/125/EC, setting eco-design requirements for energy-related products (EU, 2009).

The industrial sector itself is responsible for 28% (38.6 PWh/year) of global energy end-use (EEU), which is 104.4 PWh/year. This results in 13 Gt of CO₂ emissions annually (IEA, 2015a; IPCC, 2014). In Sweden, the industrial sector accounts for 38% (146 TWh/year) of the Swedish EEU, where approximately 35% of the EEU is derived from renewables (CSB, 2016; SEA,

2015b). This is why industrial energy efficiency plays an important role in achieving the climate and energy targets. Apart from that, the security of the energy supply has become a hot issue, taking into account the strategic importance of energy resources. Improving industrial energy efficiency makes a great contribution to solving the problem (IPCC, 2014).

However, these justifications do not always sound convincing to industrial companies, as they seem to come from the perspective of global environmental problems. In reality, the maximisation of revenues is the priority task for companies, not the lofty matters. Investment costs are always estimated in relation to future profits (Gillingham et al., 2009). This is why energy-efficiency investments are considered if they result in energy cost savings or other non-energy related benefits (Fleiter et al., 2012a; Trianni et al., 2014). It has been shown that implementing energy-efficiency actions brings direct economic benefits in the form of cost reduction followed by increased competitiveness and higher productivity (Hirst & Brown, 1990; Hahn & Stavins, 1992; Worrell et al., 2003).

Why then are these actions not always prioritised, and why does the energy-efficiency improvement potential in industry remains large? This paradox has been broadly researched and is called an energy-efficiency gap (York et al., 1978; Stern & Aronson, 1984; Hirst & Brown, 1990; Jaffe & Stavins, 1994a; Sorrell et al., 2004; Rohdin & Thollander, 2006). This is explained by different energy-efficiency barriers (Jaffe & Stavins, 1994a; Sorrell et al., 2004; Thollander & Palm, 2012). At the same time, low interest in energy efficiency is explained by the fact that energy-efficiency investments lie outside industrial core competences: these save energy costs but do not create revenue streams (Thollander & Ottosson, 2010). This is why these are not perceived as strategic and remain neglected by top management (Cooremans, 2007). What is more, if energy costs do not represent a significant part of companies' expenses (low share in added value), there are not many incentives to reduce them (Thollander, 2008). While in energy-intensive companies the share of energy costs can reach 20%, in the non-energy intensive industry it is only 1–2% (Thollander, 2008).

It is argued that different public policies are required to overcome these hindrances (Brown, 2001). Historically, the policies have focused on development and the faster diffusion of energy-efficient technologies. However, recent research shows that this is not sufficient for achieving optimal levels of energy efficiency and that the energy-efficiency gap should be extended by including energy management practices (Backlund et al., 2012). Thus, there is a large untapped potential due to energy management practices which are not widespread in industry. To bridge the extended energy-efficiency gap, it is important to design energy-efficient public policies, understanding the magnitude of this extended energy-efficiency potential. The potential may vary depending on company size, and is higher for small and medium-sized enterprises (SMEs) than for large enterprises (LEs) due to historically lower attention to the energy issue in this sector (EC, 2007; Shipley, 2001).

The challenges mentioned above hinder the improvement of industrial energy efficiency and make public policies partly insufficient to achieve the stated targets (Thollander et al., 2012a,b; Wesselink et al., 2010). All the aforementioned issues call for viewing industrial energy-efficiency improvement from a broader angle by introducing an extended systems perspective.

1.1 Aim and research questions

The aim of this thesis is to investigate industrial energy-efficiency potential and possibilities for reaching this potential using an extended system boundary. For this, the following research questions have been formulated.

Research questions:

- 1) What is the energy-efficiency potential and extended energy-efficiency potential respectively in Swedish industry?
- 2) Are present efforts enough to reach the extended energy-efficiency potential?
- 3) What are efficient ways to incorporate energy-efficiency work in companies?
- 4) How should energy-efficiency policies be designed to promote the achievement of extended energy-efficiency potential?

To depict the focus areas of this thesis, the following research themes and subthemes have been allocated.

Research themes:

- Energy-efficiency potential
 - energy audits
- Extended energy-efficiency potential
- Internal work with energy efficiency (managerial implication):
 - a method for the incorporation of energy-efficiency work in SMEs (energy networks)
 - a method for the incorporation of energy-efficiency work in LEs
- External work with energy efficiency (policy implications)

The papers in relation to the research questions are presented in Table 1.

Table 1. The thesis's papers in relation to the research questions and research themes (with corresponding subthemes).

	Non-energy intensive SMEs	Energy intensive LEs
RQ1: Energy-efficiency potential - energy audits	Paper III, Paper V	Paper II, Paper VI
RQ2: Extended energy-efficiency potential		Paper II, Paper VI, Paper VII
RQ3: Internal work with energy efficiency (managerial implication) - energy networks for SMEs - a method for LEs	Paper I, Paper IV	Paper II, Paper VI, Paper VII
RQ4: External work with energy efficiency (policy implication)	Paper IV	Paper II, Paper VI

1.2 Scope and delimitations

The scope of this thesis entails the industrial sector – both SMEs and energy-intensive LEs – and their EEU. SMEs are defined by the European Commission as companies that have between 10 and 249 employees, a turnover in the range € 2–50 million/year and/or a balance-sheet of not more than € 43 million/year (EC, 2003). A company belongs to a category of energy-intensive companies if its energy costs in relation to added value exceeds 3% (Thollander & Palm, 2012). Mostly, the companies are studied in the Swedish context, but an international perspective is presented in one paper analysing three other countries. As stated in the title of the thesis, industrial energy-efficiency improvement is viewed through the use of an extended system boundary. This means that attention is paid to not only energy-efficient technologies but also to how these are managed by individuals in industrial systems. This implies considering interdependencies between technical, organisational and social aspects.

To quantify the discrepancy between the technological and extended energy-efficiency potential, the data from the most electricity-intensive industrial Swedish companies have been analysed. These data have also been used for the quantification of energy-efficiency potentials for different motor system levels. Similar quantification could not be done for industrial SMEs due to the fact that the data available for these come from the Swedish energy audit policy program. These can reflect the extended energy-efficiency potential for SMEs only limitedly, which is considered in the thesis.

The methods for the incorporation of energy-efficiency work via energy management are presented for both SMEs and energy-intensive LEs. Running *industrial energy-efficiency networks (IEENs)* is a method oriented towards SMEs via outsourcing energy management to an IEEN administration. A model for an IEEN is proposed in this thesis. A method for identifying and addressing energy efficiency improvement opportunities in energy-intensive LEs developed in the scope of this thesis represents a promising method oriented towards the second group of companies. This referred to as the *Method for Optimisation of System Efficiency (MOVE)* has been developed based on the theoretical and trial findings. IEENs, according to the model proposed in this thesis, have already been initiated at the national level. However, evaluation of their work was outside the thesis's scope.

1.3 Paper overview and co-author statement

An overview of the papers included in the thesis and the co-author statement is given below.

Paper I. Paramonova, S., Ivner, J., Thollander, P., 2014. "Outsourcing industrial energy management: industrial energy efficiency networks provided as an energy service". Outsourcing: strategies, challenges and effects on organizations, New York: Nova Science Publishers, Inc.: 71–98.

This paper is a chapter in the book "Outsourcing: Strategies, Challenges and Effects on Organisations". The thesis's author made a literature review in the fields of business network governance, corporate change and double-loop learning to enhance the understanding of how IEENs should be designed. The valuable guidance from Jenny Ivner and Patrik Thollander helped to identify the fields where the relevant literature could be found. Further on, a joint brainstorming activity resulted in the development of a general model of IEENs.

Paper II. Paramonova, S., Thollander, P., Ottosson, M., 2014. Quantifying the extended energy efficiency gap – evidence from Swedish electricity-intensive industries. *Renewable and Sustainable Energy Reviews* 51: 472–483.

In this paper, the magnitude of the extended energy-efficiency gap was quantified. For this, energy-efficiency measures proposed for the most electricity-intensive Swedish companies were classified by the author of this thesis from the point of view of whether these implied technological or behavioural change. The knowledge of Patrik Thollander and Mikael Ottosson contributed to enhancing the value of the discussion part as well as the paper as a whole.

Paper III. Thollander, P., Paramonova, S., Cornelis, E., Kimura, O., Trianni, A., Karlsson, M., Cagno, E., Morales, I., Jimenez, J.-P., 2014. International study on energy end-use data among industrial SMEs and energy end-use efficiency improvement opportunities. *Journal of Cleaner Production* 104: 282–296.

This paper is the result of a collaboration within one of the International Energy Agency's (IEA) annexes, the Industrial Energy-related Technologies and Systems (IETS) agreement, covering SMEs' energy efficiency. The data related to the Swedish context were gathered and analysed

by Patrik Thollander together with the thesis's author. The data from other countries were homogenised and visualised by the thesis's author, while the analysis and general conclusion is a result of the joint efforts of five countries' representatives that participated in the annex.

Paper IV. Paramonova, S., Thollander, P., 2016. Energy efficiency networks for SMEs: learning from the Swedish experience. *Renewable and Sustainable Energy Reviews* 65: 295–307.

The mapping of existing and finished IEENs for SMEs in Sweden was conducted by the thesis's author with the help of the students from Linköping University participating in the project. The analysis and evaluation were performed by the thesis's author. Patrik Thollander guided along the way and contributed with his valuable insights.

Paper V. Paramonova, S., Thollander, P., 2016. Ex-post impact and process evaluation of the Swedish energy audit policy programme for small and medium-sized enterprises. *Journal of Cleaner Production* 135: 932–949.

This paper is based on visits to the industrial companies that participated in the Swedish Energy Audit Programme. The visits were performed by Patrik Thollander, Jakob Rosenqvist, Magnus Karlsson and the author of the thesis. The data from the visits were combined together with the data from the programme's database (all the participating companies' approved reports) and analysed by the thesis's author. This laid the groundwork for the programme's evaluation. Patrik Thollander guided and contributed to the process with his advice.

Paper VI. Paramonova, S., Thollander, P., 2016. Technological change or process innovation – An empirical study of implemented energy efficiency measures from a Swedish industrial voluntary agreements program. *Energy Policy* (under review).

In this paper, the energy-efficiency potentials for different motor system levels were quantified by the author of this thesis together with Jakob Rosenqvist and Patrik Thollander. The results of the quantification formed a base for questioning the technology-oriented paradigm within the present energy-efficiency work. In accordance, the development of a new theoretical model describing this area was suggested. Patrik Thollander and his far-reaching ideas and profound knowledge and experience helped the thesis's author to shape the discussion section.

Paper VII. Svensson, A., Paramonova, S., 2016. The analytical model for identifying and addressing energy efficiency improvement opportunities in industrial production systems – model development and testing experiences from Sweden. *Journal of Cleaner Production* (in press).

The method that helps introduce and anchor the continuous energy efficiency work within energy-intensive manufacturing companies was developed within a collaboration project between Swerea Swecast, DynaMate Industrial Services and Linköping University and was trialled on four manufacturing companies representing the energy-intensive Swedish sector. The analysis and discussion of the results is a joint effort by Anders Svensson and the author of the thesis.

2 Industrial energy efficiency and energy policies

This chapter gives the background to this thesis. It starts with a presentation of Swedish industrial energy use. Further, a broadly accepted classification of energy-efficiency barriers and measures is given. The overview of public policies is provided together with its general criticism.

2.1 Industrial energy use

The global reliance on fossil energy (coal first and consequently on oil and gas) started with the Industrial Revolution and has been growing ever since. The share of hydro, nuclear and bio energy has grown significantly since the oil crisis of the 1970s (GEA, 2012). However, according to the global primary energy use data from 2014, oil remains the dominant energy source (33% of 140.2 PWh/year), while total energy from fossil fuels accounts for 87% (Figure 1). The global EEU is 104.4 PWh/year.

Figure 1. Global primary energy use¹ by energy source in 2014, PWh/year (BP, 2016).

¹ The global primary energy use is estimated from commercially traded fuels including renewables for electricity generation.

2. Industrial energy efficiency and energy policies

The industrial sector accounts for 28% (38.6 PWh/year) of the global EEU, which results in 13 Gt of CO₂ emissions (IEA, 2015a; IPCC, 2014). In Sweden, the industrial sector accounts for 38% of the total Swedish EEU, which is 146 TWh/year. There was a decreasing trend in Swedish industrial EEU in the 1970s. However, during the last 20 years the EEU has been quite stable at around 150 TWh/year, with a slight decline during the last four years. The production rate has increased during this time, however, and due to the undertaken energy-efficiency initiatives, the total specific EEU has been reduced. The trend of Swedish industrial EEU is shown in Figure 2.

Figure 2. Swedish industrial EEU trend (1970–2013) (SEA, 2015b).

Today, the major share of energy is derived from biofuels (Figure 3) which makes the Swedish industry quite unique in Europe. 36% of energy comes from electricity followed by coal (10%) and oil (7%).

Figure 3. Swedish industrial EEU by energy carrier in 2013, TWh/year (SEA, 2015b).

Approximately 84% of energy use belongs to LEs and 16% to SMEs (CSB, 2016). This sector has become increasingly important for the economy both in Europe and Sweden. Today this

sector provides 59% of the total value added and 66% of employment in Sweden. In Europe the corresponding numbers are 58% and 67% (EC, 2016). Sweden has quite favourable conditions for SMEs' development due to access to funding, competences development, innovation and internationalisation (EC, 2016).

Industrial companies can also be characterised by their energy intensity. In Sweden energy-intensive companies accounts for 85% of the total industrial energy use (SEA, 2015a). The group of energy-intensive companies includes such sectors as pulp and paper, sawmill, iron and steel, plastics and chemicals and mining and mineral manufacturing. Some parts of the food industry are also considered energy-intensive. The Swedish pulp and paper industry accounts for 52% of the total industrial energy use (mainly LEs). The energy-intensive sector consists mainly of LEs, except for the food sector. The energy-intensive sector is characterised by significant shares of exports and a need for continuous competitiveness development. Thus, the sector has worked actively on more efficient energy use in production processes, reduced coal and coke use in blast furnaces, and reduced use of other fossil fuel as well as increased use of biofuels. The majority of SMEs are non-energy intensive. However, even in this sector, energy-intensive companies can be found.

2.2 Energy-efficiency barriers

There is a general consensus about an unexploited potential for improved energy efficiency in all economic sectors (IPCC, 2014). For the industrial sector it is estimated to be 25% (Gutowski et al., 2013; IPCC, 2014; Saygin et al., 2011). Even though SMEs have lower energy use, the accumulative energy-saving potential for them is considerable and can be achieved at lower costs than for LEs. First, this is explained by historically less attention being paid to energy management in SMEs. Also, this is due to the majority of the improvements comprising "low-hanging fruit" and coming from support processes (EC, 2007; Shipley, 2001), and, therefore, there is no or low risk for production disruption. Furthermore, technologies and methods already developed for energy-intensive companies can be adjusted to fit SMEs as well. The potential for improved energy efficiency among SMEs is estimated to be 20% (Thollander et al., 2015) or even more (IEA, 2015b).

The gap between the potential for and the actual level of energy efficiency is called the energy-efficiency gap, which is a well-researched subject (York et al., 1978; Stern & Aronson, 1984; Hirst & Brown, 1990; Jaffe & Stavins, 1994a; Sorrell et al., 2004; Rohdin & Thollander, 2006). The energy-efficiency gap is explained as being caused by energy-efficiency barriers (Jaffe & Stavins, 1994a; Sorrell et al., 2004; Thollander & Palm, 2012), which are the factors that hinder investments into and the installation of energy-efficiency technology or reduce its diffusion on the market (Sorrell et al., 2004; Fleiter et al., 2011). Various public policies are used to reduce the energy-efficiency gap by tackling energy-efficiency barriers (Brown, 2001).

There are several ways to classify the barriers to energy efficiency (Cagno et al., 2013; Hirst & Brown, 1990; Jaffe & Stavins, 1994a; Sorrell et al., 2000; Sorrell et al., 2004; Thollander, 2008; Weber, 1997). In the orthodox economic approach to energy-efficiency barriers, they are

viewed as market barriers divided into two groups: market-failures and non-market failures. Market failures are those market barriers that contradict the criteria of a perfect market and perfect competition: perfect information about the market, an unlimited number of buyers and sellers, zero transaction costs, no externalities and homogenous products (Pihl, 2007). Examples of market failures are imperfect and asymmetric information. Non-market failures are those market barriers that do not violate the criteria of a perfect market and perfect competition: hidden costs, limited access to capital, risks and heterogeneity (Jaffe & Stavins, 1994a; Sorrell, 2004). Only barriers belonging to this category can justify the intervention of public policies (DeCanio, 1998). Thus, energy-efficiency barriers that do not belong to the market failures category cannot be solved through public policies. However, there can also be market failures that do not contribute to the energy-efficiency gap but that still can be tackled by public policies (pricing by average costs of energy, environmental externalities) (Jaffe & Stavins, 1994a).

Depending on how energy-efficiency barriers are viewed, the magnitude of the gap and thus of the energy-efficiency potential can vary (Figure 4). First, when eliminating market failures, the economist's potential for energy efficiency can be reached. The technologist's economic potential also includes the elimination of market barriers such as risks and uncertainties. The economist's potential is also lower due to the fact that it is usually estimated from aggregated data including more factors, while the technologist's potential is calculated bottom-up (Backlund, 2014). The hypothetical potential also accounts for "additional efficiency resulting from getting the energy price right".

Thus, two social optimums can be defined: the narrow corresponding to the elimination of barriers that pass a cost/benefit test and the true one accounting also for environmental externalities. In other words, the hypothetical potential for energy efficiency can be set quite high, but the implementation costs of public policies to achieve it may be found to have unacceptable costs.

Figure 4. Defining potentials of energy efficiency (revised from Jaffe & Stavins, 1994a).

Jaffe and Stavins (1994a) looked at energy-efficiency barriers based on rational decision-making, which does not account for organisational and behavioural aspects. The majority of energy-efficiency barriers are, however, not market failures and thus do not pass a cost/benefit test. However, according to Sorrell et al. (2011), depending on how we perceive them, public policies can still be justified (Figure 5). Transaction cost economics and behavioural economics do consider such aspects as the irrational decisions of individuals and biases. In these approaches, such non-market failures as hidden costs that are not accounted for by the orthodox economic perspectives can be tackled through organisational or public initiatives (information programmes) (Sorrell et al., 2011). This is also mentioned in the EU Energy Service Directive adopted in 2006, stating that all market barriers are to be eliminated by efficient public policy instruments (supposing that energy prices reflect all external costs). This is to be done by assuring energy market transparency and providing sufficient information about energy-efficiency possibilities as well as encouraging energy efficiency by means of market instruments (EC, 2006b).

Figure 5. Perspectives on barriers to energy efficiency (revised from Sorrell et al., 2011).

One more approach to energy-efficiency barriers was developed by Weber (1997), who divided them into four categories – market, behavioural, organisational (political and legal obstacles) and institutional – through answering three questions: “What is an obstacle?”, “To whom is it an obstacle?” and “Is it an obstacle to reaching what?”. Weber (1997) argues that any existing barrier can be assigned with institutional, economic, organisational and behavioural constituents.

The summary of the barriers to energy efficiency based on the classifications of Weber (1997) and Sorrell et al. (2000) and revised by Thollander (2008) is presented in Table 2.

Table 2. Barriers to energy efficiency (based on Weber, 1997 and Sorrell et al., 2000).

Category	Barrier	Description
Market failures	Imperfect information	Imperfect information hinders the implementation of energy-efficiency measures (EEMs).
	Adverse selection	If a buyer knows less about a technology than a seller, the choice is based on e.g. visual aspects.
	Principal–agent relationship	Due to lack of transparency in the seller’s action, a buyer may rely on the principles and overlook EEMs.
	Split incentives	When one department implements EEMs but another department profits from them
Non-market failures	Hidden costs	No visible costs related to e.g. collecting information
	Access to capital	Not enough access to capital

	Risk	Risk prevention
	Heterogeneity	Implementation of the same EEMs can differ on different sites.
Behavioural barriers	Form of information	Information should be easy to take in (simple, vivid, personal).
	Credibility and trust	Credibility and trust in a source of information
	Values	People with real ambitions that prioritise energy efficiency can spread ideas within the organisation.
	Inertia	Resistance to change
	Bounded rationality	Far from the optimal decisions made in constrained conditions
Organisational	Power	Position of people dealing with energy efficiency within the organisation
	Culture	Fostering a culture of environmental awareness

Another common categorisation of barriers is given by Sorrell et al. (2004) and Schleich (2009), dividing them into six main categories: imperfect information, hidden costs, access to capital, risk, split incentives and bounded rationality.

Cagno et al. (2013) suggest a broader taxonomy for energy efficiency barriers. It emphasises the division of barriers into internal and external as well as perceived and real barriers. The taxonomy pays attention to the effect of barriers on the decision-making process and different actors involved. The group of internal barriers includes economic, behavioural, organisational barriers, barriers related to competences and barriers related to awareness. The group of external barriers consists of market barriers, barriers related to government/politics, barriers related to technology/services suppliers, barriers related to designers and manufacturers, barriers related to energy suppliers and barriers related to capital suppliers. Cagno et al. (2013) argued that previous barrier taxonomies did not account for all necessary elements as well as neglected the overlap between various barriers. In this taxonomy, internal and external barriers are opposed to each other in order to identify the overlap. After that they are related to different stages of the decision-making process: Generation of interest, Research of inefficiencies and opportunities and Investment analysis and intervention implementation. Finally, the interactions between barriers are analysed. It was suggested to apply the taxonomy to different sectors, company sizes and technological options.

The empirical categorisation of energy efficiency barriers can sometimes be ambiguous and demand extensive questionnaires, interviews and numerous case studies. Examples of barrier studies include a study on barriers in Dutch industry (Velthuisen, 1993); barriers in the Swedish foundry industry (Rohdin et al., 2007); barriers in non-energy-intensive firms in Germany (Schleich & Gruber, 2008); barriers in the Swedish pulp and paper industry (Thollander & Ottosson, 2008); barriers in the Greek metals, machinery, food and drink, chemicals, paper and textile industries (Sardianou, 2008); barriers in Chinese SMEs (Shi et al., 2008); barriers in the Thai cement and textile industry (Hasanbeigi et al., 2010) and barriers in the brewing and

mechanical engineering sectors in Ireland, Germany and the UK (Masselink, 2007) overviewed in Sorrell et al. (2011).

Further, Fleiter et al. (2011) created a review of different bottom-up models of industrial energy demand (accounting, simulation or optimisation), focusing on their capability to incorporate energy-efficiency barriers. It was found that the barriers are included in the existing models in a very simplified way and often do not account for discount rates or technological diffusion rates.

To reduce energy-efficiency barriers in the industrial sector, it is important to design public policies based on the potential for energy efficiency, bearing in mind industrial companies' characteristics.

2.3 Energy-efficiency measures classification

Different energy efficiency measures have to be implemented to improve energy efficiency in the manufacturing industrial sector (IPCC, 2014). Even if EEMs are justified to be profitable, not all firms adopt them, because energy-related costs do not constitute a significant part in their calculations (Sorrell et al., 2004). Such parameters as energy prices, environmental externalities, hidden costs, non-energy benefits (NEBs) and risk assessments are neglected in calculations, while considering them can increase the profitability of EEMs (Backlund, 2014).

Fleiter et al. (2012a) as well as Trianni et al. (2014) argued that the analysis of EEMs' characteristics can help in understanding the process of adoption by industrial firms and thus improve the design of energy policies. Trianni et al. (2014) created a framework for EEMs' characterisation based on 17 attributes aggregated into six broader categories: economic (payback time, implementation costs), energy (resource stream, amount of saved energy), environmental (emission and waste reduction), production-related (productivity, operation and maintenance, working environment), implementation-related (saving strategy, activity type, ease of implementation, success/acceptance, corporate involvement, distance to core processes, check-up frequency) and interaction-related attributes (indirect effects). The framework was checked on EEMs in cross-cutting technologies such as electric motor systems and compressed air as well as heating, ventilation and air conditioning (HVAC). It was shown that some independent EEMs' characteristics appear simultaneously and that slightly less than a half of the analysed EEMs had indirect benefits from interaction with other systems. It is stated that the framework helps in understanding barriers and identifying the drivers of energy efficiency (Trianni et al., 2014).

Fleiter et al. (2012a) developed an EEMs classification scheme based on a review of EEMs' characteristics by choosing the 12 most important ones grouped into three areas: relative advantage (internal rate of return, payback period, initial expenditure, NEBs), technical context (distance to core processes, type of modification, scope of impact, lifetime) and information context (transaction costs, knowledge for planning and implementation, diffusion progress, sectoral applicability).

While Trianni et al. (2014) aimed to account for as many parameters as possible to weigh the profitability of EEMs, Flieter et al. (2012) attempted to understand why some EEMs diffuse more easily. Both schemes were recommended to decision-makers and policy-makers to increase their knowledge and support their decisions.

2.4 Public policies to overcome energy-efficiency barriers

The EU 2020 Energy Efficiency Action Plan (EEAP) was first presented in October 2006. According to it, the fulfilment of the 2020 target has to come from public policies (EC, 2006a). The European Energy Efficiency Directive from the 4th of December 2012 provides a common framework for the member states to pave the way for the mitigating actions.

Public policies can be divided into four categories: administrative, economic, informational and research-oriented (Table 3).

Table 3. The categories of public policies (SEA, 2011).

Public policy category	Example
Administrative	Regulations Limit values (emissions) Long-term (LTA) Voluntary agreements (VA) Environmental classification Fuels and energy efficiency requirements
Economic	Taxes Subsidies, grants Emissions trading system (ETS) Electricity certificate system (ECS) Sureties
Informational	Information provision Advisory services Training
Research-oriented	R&D Commercialisation Procurement Demonstration

Administrative policies include prohibitions or requirements from political and administrative organs and are obligatory. Economic policies affect industrial energy costs and in this way force companies to take actions. Informational policies aim at providing necessary information about energy efficiency and are intended to overcome information-related market barriers and failures. They also contribute to improving of public acceptance of other public policies. One example of informational policies is environmental labelling. Research-oriented policies work through building knowledge and a technical development base.

Swedish public policies for improved energy efficiency are presented in the Swedish national EEAP, which is updated every three years (EC, 2014). The administrative public policy instruments are presented in the Swedish Environmental Code and The Act on Energy Audits in Large Enterprises. Among economic instruments there are energy- and carbon taxes, the Electricity certificate system and the Emissions trading system (SEPA, 2011). The Programme for Improving Energy Efficiency in Energy Intensive Industries (PFE) is as both an informational and economic instrument due to the economic incentives that are provided to industrial companies in the form of energy tax exemption. The Swedish Energy Audit Programme (SEAP) provides financial support for performing energy audits in SMEs. Swedish informational policies include energy and climate advisory services. An overview of the Swedish public policies for improving energy efficiency is given below.

2.4.1. Administrative policies

2.4.1.1. *The Swedish Environmental Code*

The main objective of the Swedish Environmental Code is promoting sustainable development so that present and future generations can exist in good and healthy environmental conditions. This objective consists of five sub-objectives, where the energy aspect comes under the fifth sub-objective: “To promote reuse and recycle as well as other conservation/management of materials, raw materials, and energy”. The Environmental Code indicates the environmental rules necessary to achieve the objective. The rules are applied to the majority of activities that can affect human health or the environment (MB, 1998). According to Thollander et al. (2015) the Code has a unique place in the Swedish policy mix due to the fact that it combines a permitting role and a supervision role. The Swedish Energy Agency (SEA) takes the role of a supervision body to support coordination and cooperation on particular issues (SEA, 2012a).

The requirements to conserve raw materials and energy as well as to use renewable energy in the first place (if it is not unreasonable to comply with them) oblige industrial companies to have knowledge on how they use energy and how they can improve their energy efficiency. Furthermore, it is prescribed to implement necessary measures to prevent environmental damage and to use best available technologies (BAT). The BAT-requirement implies technologies technically and economically available in the field (SEA, 2012a).

The Swedish Environmental Code is oriented mostly towards energy-intensive industrial companies; however, in recent years it has been applied even to SMEs. It is quite problematic to estimate the effects of it in Sweden due to the fact that it has only been started being practised recently (Thollander et al., 2015).

2.4.1.2. *The Act on Energy Audits in Large Enterprises*

The act was accepted under Article 8 of the EED and implemented on the 1st of June 2014. According to the act, all LEs provide information about their activities covered by the act by the 5th of December and thereafter carry out an energy audit every four years. The SEA as a supervisory authority is responsible for fining companies for incompliance (EKL, 2014). The

requirements for company size are given by the European Commission as follows: at least 250 employees, turnover of more than € 50 million/year and/or a balance-sheet of more than € 43 million per year (EC, 2003). This act is also applied to companies belonging to bigger company groups. For example, if a company owns more than 25% of capital in another company, their employees and financial characteristics are added. Even the public sector (counties and municipalities) is affected by the act, while authorities and non-economic activities are excluded (SEA, 2016a).

2.4.2. Economic policies

2.4.2.1. Energy and CO₂ tax

Energy and carbon dioxide taxes are imposed when particular energy carriers are used in industrial companies. Energy tax is paid for industrial electricity use and most of the fuels and is calculated based on the energy content of fossil fuels. The tax was introduced on the 1st of July 2004 and is regulated by the Energy Taxation Directive. Today, the taxation of electricity used is equivalent to 0,5 öre/kWh (SEA, 2015b).

The CO₂ tax is paid for all fuels except for biofuels and peat and is calculated per emitted kilogram of CO₂ (SEA, 2015b). From the 1st of January 2015, manufacturing industries not covered by the EU Emissions trading system pay CO₂ tax at a rate of 60%, while industries covered by the EU ETS became exempted from it on the 1st of January 2011 (SEA, 2012b).

2.4.2.2. The electricity certificate system

The electricity certificate system was developed with the aim to benefit renewable electricity production by industrial companies. The companies producing renewable electricity on their sites receive one electricity certificate per each MWh produced (solar, wind, hydro power). The certificates can later be sold, thus covering the expenses for electricity production. Energy-intensive companies are exempted from buying electricity certificates required for the electricity used in their manufacturing activities (SEA, 2012b).

2.4.2.3. The EU Emissions Trading System

The EU ETS operated under the Emission Trading System Directive (2009/29/EC) coordinates the trading of GHG emission rights in industry. Since emitted CO₂ has a specific price for every ton, the system aims to develop low-carbon technologies. The EU ETS is based on “caps” or amounts of certain GHG allowed to emit by the industrial companies and combustion plants included in the system. If a company releases emissions in an amount exceeding the amount of allocated allowances, penalties can be applied. The task is to reduce GHG calculated by the CO₂ equivalent in a cost-effective way by selling/purchasing GHG allowances.

The EU ETS encompasses combustion plants that produce a thermal power of more than 20 MW, while in Sweden it also includes plants producing less than 20 MW if they are a part of district heating networks (SEA, 2012b). Between 2013 and 2020 (Phase III of the trading

period) the auctioning of certificates is being conducted to reward the most efficient plants by means of giving them free allocations and thus promoting international competition. The Swedish Environmental Protection Agency decides on the allocation of emission allowances and is responsible for following up on the industries' annual reporting.

2.4.2.4. *The Programme for Improving Energy Efficiency in Energy Intensive Industries*

The PFE is a policy measure for industrial EEU reduction in the form of a multi-year voluntary agreement. The PFE was launched in 2005, providing electricity-intensive companies an exemption from the energy tax (0.5 öre/kWh) given that they introduce energy management systems and implement EEMs. The requirements for the first two years of the programme were to perform an energy audit to detect EEMs as well as to introduce standardised energy management systems (according to Swedish standard SS 627750, European standard EN 16001 or international standard ISO 50001). After that a company has to implement the EEMs with a payback time of less than three years (SEA, 2014). By participating in the programme the companies also accept the requirement to introduce procedures for energy planning and purchasing energy-efficient equipment (SEA, 2006). The main goal was to improve energy efficiency in the amount equivalent to the electricity tax that would have been paid otherwise. During the whole programme period the companies should be working constantly with the EEMs' implementation, energy-efficient procurement and planning, which is to be presented in a final report stating the total reduction of electrical consumption (SEA, 2005). The continuous work with EEMs' implementation, energy-efficient procurement and planning under the PFE period was required to be reported to the SEA stating the total reduction of electrical consumption due to the PFE (SEA, 2005). The PFE was phased out the 31st of December 2014.

2.4.2.5. *The Swedish Energy Audit Program*

The Swedish Energy Audit Programme was organised by the SEA between 2010 and 2014 and was oriented at SMEs, offering them monetary support for accomplishing an energy audit (SEA, 2015c). LEs could apply for participation as well if they were able to prove the necessity of this monetary support for performing an energy audit. However, companies already participating in the PFE could not apply for participation in the SEAP. The support could be given to companies with an annual EEU higher than 0.5 GWh/year or minimum 100 livestock units in the case of farms.

The support given should cover half of the price for energy audits but a maximum of € 3,000. A given company could not apply for support more than one time, and companies with more than one facility could use the support at only one of the sites (SEA, 2015c). An energy audit has to contain an overview of the company's annual EEU specified in MWh per year and price for each energy carrier as well as energy efficiency measures proposed for different processes and process equipment (STEMFS, 2010). Those companies that received a subsidy had to present an energy plan where they listed the EEMs that they planned to implement within two years (SEA, 2015c). There were no requirements on who had to perform energy audits, and

companies could choose to do it themselves or use external energy consultants; however, the SEA recommended the latter.

2.4.3. Informational policies

Municipalities in Sweden provide energy and climate advisory services to give impartial, free-of-charge and technology-neutral advice. This service targets the general public, SMEs and organisations and associations. The main goal of the service is to spread the knowledge of energy efficiency, energy use and climate impact at local and regional levels. The SEA provides a review of the available services with the aim “to develop the organisation and increase socioeconomic efficiency” (SEA, 2012b).

2.5 General criticism of energy-efficiency oriented public policies

It is important to have in mind several well-known critiques addressed to public policies related to improved energy efficiency. One of them is a rebound effect or increased demand for energy when energy costs fall after implementing technological improvements. However, the dedicated studies found that the rebound effect is often rather moderate (less than 20% for the industrial sector) (Greening et al., 2000). Moreover, the rebound effect does not underscore the inefficiency of implemented actions but rather reflects some consumers’ response. Energy-efficiency measures as such still bring improvements as well as increase welfare. Thus, a solution can be to count on some rebound effect by default in preliminary assessments (SEA, 2005).

Another critical point is that technological progress is going to bring the new innovative technological options into the market even without market interventions (SEA, 2005). This is may sound relevant; however, according to Grübler (1998), technology exchange is a very slow process, and public interventions speed it up (Jaffe & Stavins, 1994a). Schulze et al. (2015) argue that significant technological improvements related to energy efficiency have been made in industry in the last 30 years thanks to policy instruments and tougher regulatory requirements. Other common critiques are whether public policies can be justified at acceptable social costs or whether it is possible to accurately estimate the outcomes of public policies.

All these concerns are valid and need to be taken into account when designing future public policies. For this, the evaluation of public policies is very important and requires a rigorous analysis to decrease the effect of the aforementioned critical aspects. The calculations should account for net present values (NPV), reasonable discount rates and energy prices. The market price of energy does not consider environmental externalities and social costs, because it can be problematic to define the ownership of natural resources, and environmental costs do not have to be paid for by individuals (Backlund, 2014). This thus has to be corrected by the state, which is not an easy task. Such aspects as the autonomous effect (due to increased energy prices and natural technological replacement) and structural effect (due to industrial development) are also often omitted in calculations. Such effects as the spill-over and free-rider effects need to

be considered as well to accurately estimate energy savings from public policies. Furthermore, NEBs have to be included in the calculations (examples are increased productivity, better working environment, and reduced pollutant emissions). All this requires a compromise to be found between a thorough analysis and the acceptable costs of it.

Apart from the aforementioned critiques, it is argued in recent research that the present policies are not enough and that their impact needs to be tripled to achieve the climate and energy targets (Thollander et al., 2012a; Thollander et al., 2013; Wesselink et al., 2010). At the same time, it is argued that the existing policies have been mainly concentrated on the promotion of the development and faster distribution of energy-efficient technology options in the market. However, this might not be sufficient for achieving optimal levels of energy efficiency and needs to be complimented by management measures (Backlund et al., 2012). Thus, there is a large untapped potential for improving industrial energy efficiency due to management practices. This will be further discussed in the following chapter.

3

Extended energy-efficiency potential

This chapter gives background to the concept of extended energy-efficiency potential which constitutes the take-off point for this thesis. This is followed by a description of the energy management concept.

The existing models for the classification of barriers to energy efficiency are made in favour of the technical aspect of energy-efficiency actions (Weber, 1997). As followed, public policies and supporting frameworks are shaped to increase the diffusion of energy-efficient technologies on the market, which is explicitly discernible in, for example, the EU's Energy Labelling Directive (EU, 2010) and Eco-Design Directive (EU, 2009). In the EU's Action Plan for Energy it is specified that encouraging the innovation, development and uptake of energy-efficient technologies is a means to achieve the potential for improved energy efficiency (EC, 2006a). For that it is necessary to set energy performance requirements for products and promote international collaboration in the area of tradable goods (EC, 2006a). It is stated that the awareness of energy efficiency can be raised by demonstrating successful technological examples and international collaboration in the field of energy-efficient technologies' trade and policy development (EC, 2006a). According to Backlund et al. (2012), such policies as VA, LTA, subventions and certifications for promoting energy service markets are enacted on the assumption that making energy-efficient technologies less expensive will eventually result in their increased demand in the market.

This vision has been built based on theories from innovation research and the model of technical diffusion in particular. According to this model, an innovation's distribution in the market follows an S-shaped curve. The distribution is slow at the beginning due to lack of knowledge about a technology and its profitability. It speeds up with time and slows down after market saturation. This gradual diffusion depends on such factors as the need to be first on the market, resistance to change, requirements on innovations' applicability etc. (Meade & Islam, 2006).

Jaffe and Stavins (1994b) argue that the slow diffusion of energy-efficiency technologies can be accelerated in a particular stage by providing governmental policies such as information campaigns and product labelling. However, as mentioned above, the potential for improved energy efficiency goes beyond the implementation of energy-efficient solutions (Backlund et al., 2012). The energy-efficient potential can be extended by adding management potential to technological potential (Figure 6).

Figure 6. Extended energy-efficiency potential (revised from Backlund et al., 2012).

However, the term energy management can be used differently. A systematic review on energy management has been performed by Schulze et al. (2016) and it was found that the scientific literature gives several definitions due to the fact that energy management can be oriented to different organisational focuses (strategic, operational or tactical):

- “Energy management is the proactive, organized and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives” (O’Callaghan & Probert, 1977).
- “Energy management is the judicious and effective use of energy to maximize profits and to enhance competitive positions through organisational measures and optimisation of energy efficiency in the process” (VDI, 2007).
- “Energy management is the strategy of meeting energy demand when and where it is needed. This can be achieved by optimizing energy using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems” (Abdelaziz et al., 2011).

What they all have in common is five key elements: strategy/planning, implementation/operation, controlling, organisation, and culture (Figure 7).

Figure 7. Main elements of energy management (revised from Schulze et al., 2016).

Schulze et al. (2016) suggest the following definition: “Energy management comprises the systematic activities, procedures and routines within an industrial company including the elements strategy/planning, implementation/operation, controlling, organization and culture

3. Extended energy efficiency potential

and involving both production and support processes, which aim to continuously reduce the company's energy consumption and its related energy costs”.

It has been shown that companies with well-established energy management have some factors in common, such as top management support, an energy-responsible person, a long-term energy strategy and, based on this, an energy plan with quantified goals as well as economical resources for sub-metering and the education of employees (Thollander & Palm, 2012).

It is important to distinguish between energy management work and an energy management system, which is an instrument for systematic energy management work. Likewise international standards ISO 50001 and EN 16001, it is based on the Plan-Do-Check-Act model (Figure 8). This implies a cyclic work that starts with planning, continues with implementing actions and following up and finishes with improvement (ISO, 2011). This model is used for other management systems such as environmental and quality (Thollander & Palm, 2015) due to its efficiency based on the fact that the improvement of earlier deficiencies is more effective than doing it right from the beginning (Bamford, 2005).

P – energy planning

D – implementation of energy-efficiency measures

C – control of the implemented measures

A – improvement actions

Figure 8. Energy management based on Plan-Do-Check-Act (revised from SEA, 2016b).

To sum up, an important part of the extended energy-efficiency gap is an energy management constituent alongside an energy technology constituent. In this context, energy management is regarded as continuous work on improving energy efficiency through auditing, maintenance, monitoring, reporting, analysing and training. It is worth noting that the key word in energy management work is *continuous* (Gordic et al., 2010) and that the aim is improving energy efficiency and decreasing energy costs. In this sense, the definition of energy management used in this thesis is very similar to that provided by Schulze et al. (2016).

4 Industrial energy-efficiency networks

In this chapter, the concept of industrial energy-efficiency networks is explained.

The network concept can be broadly interpreted. A network can be defined as a group of companies cooperating to achieve a particular goal and characterised by horizontal and flexible relationships and mutual engagement (Edgren & Skärvad, 2010). It should not be mixed with personal relations, association activities, business contacts and collaborations within agencies (Svensson et al., 2001). The reasons for networking can be costs reduction by sharing resources and information and via joint procurement and decreasing administrative and bureaucratic work as well as eliminating risks associated with unknown markets and uncertainties. In the mapping process, four types of networks were distinguished, as follows:

- 1) Cluster – companies located nearby (suppliers, service providers, industrial companies, associated institutions in a specific field) representing competitors but willing to cooperate (Porter, 2000).
- 2) Industrial district – a geographical and cultural area where employers and workers live and work (Lundberg, 2008). The companies are competitors but are willing to cooperate.
- 3) Strategic network – a deliberate and long-term network between companies oriented towards competitive advantage over companies outside the network (Jarillo, 1988). The companies are willing to cooperate and exchange information.
- 4) Regional strategic network – a strategic network supported by external actors and focused on companies in a specific geographical area (Lundberg, 2008). The companies are willing to cooperate and exchange information.

In the strategic types of networking, the companies themselves choose to participate in the networks, which often have an administration and consist of more than two companies.

An industrial energy-efficiency network is a group of companies coordinated by an external expert that meets continuously to exchange knowledge and experiences about their energy-efficiency work. The companies can expand their knowledge about different energy-related topics through consultancy with external specialists (energy efficiency in cross-cutting technologies, motor efficiency, etc.). The companies work together on achieving energy goals set on network and company levels. The IEEN performance is constantly monitored. These types of IEENs have started to gain attention among industry representatives, policy-makers, and energy agencies (IPCC, 2014; Koewener et al., 2014). Switzerland was the first to introduce the concept in 1987 under the support of the Swiss Energy Agency. Encouraged by their

4. Industrial energy efficiency networks

success, Germany established its first network in 2002. The German model is known as the Learning Energy-Efficiency Network (LEEN) and is presented in Figure 9.

Figure 9. The network concept (revised from LEEN, 2016).

A typical network starts with an acquisition phase, where the basic requirements are set and the companies are identified. During Phase 1, or the consulting phase, the initial energy saving potential is identified for each company with the help of an energy auditor. After that, Phase 2, or the network phase, starts, meaning regular network meetings where companies gather 3–4 times per year to share experiences, learn from each other, and work on the established goals. In this thesis, this concept is further developed into the IEEN model.

5

Theoretical framework

This chapter presents the main theoretical concepts that contributed to the understanding of industrial energy-efficiency improvement using an extended system boundary. Such concepts as a systems approach, absorptive capacity and situated actions are described here.

5.1. Systems complexity and alternative categorisation of energy-efficiency barriers

Since the logic behind public policies' design is to overcome existing barriers to energy efficiency, the way barriers are viewed (what is a barrier) will determine the way they are approached. At the same time, two other questions stated by Weber (1997) should be kept in mind: whom is this a barrier to, and what does it hinder? As mentioned, several studies have attempted to tackle the barriers by means of detailed categorisation as well as the EEMs which they hinder (Cagno et al., 2013; Fleiter et al., 2011; Fleiter et al., 2012a; Trianni et al., 2014). The reasons behind these categorisations were to find the difference between "perceived and real barriers", gathering the information required for choosing technologies and designing policies for their diffusion and a better understanding of EEMs' adoption. Most often it is taken for granted that EEMs are related to investments in technological improvements. Furthermore, there is often no proper explanation of what an EEM is and, as argued by Fleiter et al. (2012a), EEMs are taken as something homogenous.

However, the barriers to energy efficiency can be categorised alternatively. This can be done by connecting social and technical aspects and by considering the view that barriers are not only related to technological replacement but also to energy management practices. Thollander et al. (2010) first introduced a social context to a common technological context of energy efficiency barriers categorisation. This reasoning was based on system complexity, first described by Boulding (1956), who suggested a model representing 11 system complexity levels from a less complex (mechanical) to a more complex (social and transcendental) level.

The term "system" is used particularly broadly today in connection with the rapid development of information and computer systems. A system is "a set of components that work together for the overall objective of the whole" (Churchman, 1968). To understand the system and its relation with the environment and other systems, it may be necessary to place a map over it to show the connections (Ingelstam, 2012).

The three levels (starting from least complex) of Thollander et al.'s (2010) classification are as follows:

- The technical system: barriers related to technological options and the costs associated with them (Access to capital, Heterogeneity, Hidden costs, Risk)
- The technological regime: barriers connected to technologies but affected by human aspects (Imperfect information, Adverse selection, Split incentives, Form of information)
- The socio-technical regime: barriers less affected by technical aspects but more by human aspects (Credibility and trust, Principal-agent relationship, Values, Inertia, Bounded rationality, Culture, Power).

This is in line with Geels's (2004) model for socio-technical change. According to this model, any given novelty evolves in a niche (market or technological) that requires protection from mainstream competition, often in the form of small networks. The niches can be viewed in three levels (Thollander et al., 2010), as follows:

- Micro level – emergence of a technological novelty
- Meso level – inclusion of regimes: engineering practices, knowledge, problems embedded in institutional and market contexts (norms, infrastructures) – all the aspects providing the working conditions for the technology
- Macro level – including the socio-technical landscape (rules that guide design of the technology and market development) of different technological regimes (scientific, technological, financial) – a slow changing environment due to multiple connections and dependencies

The three levels of niches correspond to the three levels of the energy-efficiency barriers' classification. Similar to a radical novelty, EEMs have difficulties in breaking through the established socio-technical regimes and can only be helped if all three levels are considered. Thus, an involvement of users, engineers, policy-makers etc. is required for a novelty to be incorporated into the regime and make a socio-technical change.

In this way, Thollander et al.'s (2010) approach to the classification of energy-efficiency barriers is an attempt to expand system boundaries from a system component to an industry, the actors involved, their values, societal rules and regulations etc. By doing this, it can be possible to suggest other ways of approaching the energy-efficiency gap, which requires implementing a systems approach and lessons from systems studies.

5.2. Systems approach

Churchman (1968) argued that even if the technological means to solving everyday problems are available, the problems are not being solved. This statement is valid in relation to the energy-efficiency gap: there are technological means, but they are not always implemented. Churchman (1968) attributed this to the overlapping of problems and their solutions. There are many

parameters to consider when solving an issue, and there is a need for a theory or an approach that can consider them all (Thollander et al., 2010).

A systems approach starts from stating the question: “Where to start solving?” (Churchman, 1968). Firstly, this is important, because a systems approach is often misunderstood as listing all the systems’ constituents. This is not an efficient way, because this may lead to further division into sub-constituents. This may create many errors and mislead the problem solving toward a totally wrong direction. Thus, it is preferable to view the system right from the beginning from the point of view of its objectives. Secondly, it is necessary to recognise that “efficiency” is an ambiguous matter and that the efficient running of subsystems can lead to inefficiency of the entire system. Thus, it is the entire system’s performance that matters. Thirdly, it can help to solve a problem if the “is” is compared with the “ought” (Churchman, 1979). Understanding the theoretical background behind a systems approach can help to solve real technological problems.

It is common to build models to simplify the reality and explicate thinking. An “input-output model”, for example, is broadly used to illustrate the inflows in the form of resources (energy flows, for example) and outflows in the form of products and waste flows. This model is presented as a black box, where the processes inside this box are invisible. This approach is used when inputs and outputs have to be connected, but what is going on in between is unclear. However, it neglects the inner components (such as production lines), their management and conditions not under control (Churchman, 1968).

Using a systems approach helps to increase awareness of the problems that emerge when an input-output model is created. It also helps to avoid the sub-optimisation of the processes within the black box. Applying a systems approach is crucial in the case of industrial energy efficiency, because all manufacturing companies represent energy systems where production systems are intertwined with other sub-systems. In this sense, it becomes obvious that improving energy efficiency through only technological investments is not sufficient. This becomes even more valid due to the fact that energy-efficiency potential is often estimated under the assumption that a technological option is something stand-alone (EC, 2006a). A systems approach and thinking in system terms (system thinking) can also help to combine technical excellence (when engineering calculations are required), human values, and common sense (Churchman, 1968), because in the world of complicated interactions between humans and artefacts, the logic does not always seem sound.

5.3. System thinking and double-loop learning

Thinking in system terms has been addressed in areas of research such as organisational change. Senge (2004) defined five disciplines that can bring any organisation to a state where a change can occur: mental models of staff, personal mastery, group learning, shared visions and system thinking. Here, *system thinking* is a key element that binds other elements together. A change occurs within the organisation when it becomes a learning organisation (Senge, 2004). An alternative definition of this is the state of profound knowledge posed by Deming (1993). It is

argued that in the complex world of business, a company has to be more “learningful” to endure hard competition. Here, an important aspect in becoming a learning organisation is not to fixate on short-term events, because this bounds systematic view. Instead, it is vital to have a broader view: to “see circles instead of lines”. In other words, it is important to maintain within an organisation “a loop of iterative cause-effect responses” or “a double-loop learning”. Double-loop learning helps to correct the errors and select proper actions. This results in the adaptation of patterns of behaviour by means of finding structural explanations for the events (Argyris & Schön, 1974).

The abovementioned resonates with the feedback process used broadly within the informational systems field and automatic control engineering, where it is a basic aspect for the control and design of systems (Ingelstam, 2012). An understanding of these is required to be applied in the field of energy efficiency as well, where it is often hard to make changes due to energy-efficiency barriers, established frameworks and technological lock-ins.

5.4. Absorptive capacity

A system’s components are connected through informational exchange and communication, which is also found in informational systems and a process of constant feedback (Ingelstam, 2012). However, in the industrial context, if information is provided outside the organisation or outside familiar environments (if a change is produced externally), it may face negative reactions and resistance due to the fear of the unknown (Kanter, 1983). To approach this resistance, it is necessary to develop an ability to see value in the relevant outside information and apply it via the employees (Cohen & Levinthal, 1990). This ability is referred to as *absorptive capacity* and can be defined as a set of procedures within an organisation needed to acquire, understand, transform and apply external knowledge (Zahra & George, 2002). Hence, informational exchange and knowledge uptake or absorption undergo the following stages (Zahra & George, 2002):

- Acquisition – the ability of an organisation to identify and acquire external knowledge necessary for its operation. This ability is greater if the organisation holds expertise in different areas.
- Assimilation – the ability to analyse, understand and absorb external knowledge
- Transformation – the ability to develop and improve procedures for combining new knowledge with already existing knowledge within the organisation
- Exploitation – the ability to develop and expand existing skills or create new skills by means of using obtained knowledge and converting it so that it can be applied within the existing business activities

There are several aspects that can improve absorptive capacity. First, time and effort are required, because providing information on one occasion is not sufficient (Cohen & Levinthal, 1990). Secondly, a “master of change” (Kanter, 1983) is needed: one ultimately responsible individual who can coordinate work, organise participating actors and define goals and strategy as well as assure communication (Boddy & Buchanan, 1992). However, even if the knowledge

is absorbed by the participating actors, it is important to further disseminate and anchor the knowledge within the organisation (Cohen & Levinthal, 1990), because the staff can change, but the knowledge has to stay (Thollander & Palm, 2015). This is related to the third important aspect: the knowledge intake depends on prior knowledge and the specific context. This aspect is explicitly connected to the concept of situated actions.

5.5. Situated actions

The term *situated actions* comes from studies of science and technology (STS) (Suchman, 2006) and has implications in such fields of research as human culture and human-machine interactions. It can be defined as people acting in patterns depending on material and social circumstances. In other words, people use the course of circumstances to achieve intelligent actions instead of being rational (Suchman, 2006). Hence, the capacity to absorb knowledge and the rationale behind decision-making is governed by the particular circumstances of an event and the actors participating in it (Thollander & Palm, 2015).

Suchman (2006) argues that any given person has “an unfolding, shifting biography of culturally and materially specific experiences, relations, and possibilities inflected by each next encounter”. Thus, in the case of energy-efficiency work (concerning both the intake of knowledge about energy efficiency or decision-making processes), the employees’ choices are determined by individual beliefs and experiences shaped by their roles in organisations, organisational culture, existing policies, rules etc. Furthermore, it is the combination of participating actors (when they make a decision about energy-efficiency strategies) that plays a crucial role in outlining possible solutions, because mutual relations and group dynamics eventually create the outcome (Thollander & Palm, 2015). Situated actions thus formalise the knowledge, ideas and experiences of a group in a particular context (Thollander & Palm, 2015). Hence, the management models accepted within the company along with the accompanying standards and strategies are influential via the staff of the company. This is in line with Suchman (2006), who argues that a plan of actions is not always taken as an instruction. Thus, the implementation of strategies does not necessarily create change, and common behavioural patterns can still happen.

This is also connected to STS in the sense that people and artefacts (for example, in the form of technological options, management systems) should not be considered separately, because there are always interrelations between them. However, as was mentioned above, technologies are usually not approached in particular system contexts. Thus, introducing a human level to industrial energy systems gives them an “intelligent” dimension, making the boundary between technologies and humans less distinct. In this case, this interaction between humans and machines obtains a more dynamic character (Suchman, 2006), making the exploitation of machines more efficient.

6 Method

This chapter provides a general description of the thesis's research design. The methods used in the thesis are presented in relation to the thesis's papers, and an explanation is given regarding how they complement each other. The overall research journey is outlined, and each method is described.

6.1. Research design

Industrial energy use is a multidimensional area of intertwined production and other sub-systems. However, industrial energy-efficiency improvement is usually concentrated on individual technical systems and often omits the connections between separate systems and their components. Therefore, this thesis has aimed to contribute to the field of industrial energy-efficiency improvement from a broader perspective by means of extending system boundaries and including even an energy management component. Industrial energy efficiency has been looked upon not only using a pure technologist's approach but also by including "softer" aspects such as the interaction between individuals and technologies and their roles in the industrial energy systems. The combination of technically oriented research and social science with quantitative and qualitative research, so called "interdisciplinary research", is needed to cover different aspects of the *issue*: technological, economic, behavioural and organisational and their relationships.

Bryman (2012) highlights that research methods cannot be neutral and are connected to scientists' way of envisioning and examining reality. What is more, depending on the research rationale, methods can either be assembled on theoretical frameworks or specific social problems. Consequently, the research results will either be testing or building theories, which in this context is a description of observed common patterns. Whether the methods for data collection and analysis are shaped by existing theories or whether the results of data collection and analysis become a new theory determine, respectively, that a deductive or an inductive research approach was applied. Usually, both approaches are more "tendencies than fast decisions" (Bryman, 2012). This can be partly explained by the complexity of reality but also by our limited capacity to apprehend it (Law, 2004).

In this thesis, a combination of inductive and deductive approaches has been used. At the beginning, the general theoretical assumptions served as grounds for hypothesis formulation (inductive method). The grounding assumption was made that industrial energy-efficiency

potential lies beyond only technology-oriented EEMs. In this way, a postulation stemming from economic science was questioned: that improved energy efficiency can be achieved by faster diffusion of energy-efficient technologies in the market. This resulted in further assumptions. The first was that barriers to energy efficiency should be reconsidered, since they have been defined by viewing improved energy efficiency in the light of energy-efficiency investments only. The second is that present public policies are not sufficient and should be complemented. The ground assumption has been validated by the empirical context (deductive method). The results of the validation led to an increased understanding of how the existing theoretical models should be complemented as well as to the development of possible solutions (inductive method).

The complexity of the studied industrial energy systems and necessity to simplify some underlying principles and rules to test them against reality were considered along the way (Wallén, 1996). This helped in grasping their complexity to contribute to its understanding and find improvements areas. This issue is further connected with another important aspect to consider when conducting any given research – ensuring research quality. Research quality is determined by three prominent parameters: reliability, replication and validity. Good quality research should be based on reliable data; anyone should be able to replicate the study and obtain similar results, and the results of a particular study should reflect what is actually happening in the real world (Bryman, 2012). At the same time, Law (2004) argues that specific scientific results “only come along with inscription devices”. In other words, scientific results depend on the researcher’s abilities to interpret them as well as on his or her values and beliefs. The researcher’s transparency regarding the data collection and assumptions, as well as consistency in the reasoning, can assure the research quality. Another important aspect is the craft of the researcher to envision the research results to convince the reader in their soundness as well as to embrace the real circumstances so that they can be anchored in the scientific context.

6.2. The methods used

Various methods were used in this thesis, including interviews, questionnaires, case studies, mapping, energy data categorisation and analysis. The interviews in this thesis represent both qualitative and quantitative methods, because they resulted in quantified energy data as well as qualitative data in the form of the opinions of companies’ representatives and network coordinators. The questionnaires could not be used as a quantitative method due to the low response rate; however, they were used to study the experiences of the analysed networks’ participants. The case studies did not result in quantifiable data but rather in qualitative data from observations and workshops with the case studies’ participants. The network mapping process represents both quantitative and qualitative methods, since it resulted in a map of networks finished and ongoing as well as in data showing the networks’ characteristics. Finally, the energy data from the PFE and SEAP produced both quantitative results as well as qualitative results in the form of EEMs’ categorisations. The use of multiple methods creates the

foundation for triangulation, which is a practical means for the validation of the research results. The bottom line in triangulation is to approach a research subject from three various positions or to obtain research material from three various sources. Thus, research can be conducted by collecting different types of data, using different methods, and/or studying different groups of people (Larsson, 2005). In this thesis, the triangulation due to the use of various methods (Figure 10) also resulted in triangulation through various datasets, since the methods produced their own data sets.

Figure 10. The triangulation used in this thesis.

In Table 4, the methods used in this thesis are presented in relation to the respective papers and research questions. The policy implication aspect (Research Question 4) was not researched by any of the methods but was brought up in discussions, which is why this research question is not included in the table.

Table 4. The methods used in relation to the research questions and papers.

Paper	RQ1: Energy-efficiency potential	RQ2: Extended energy-efficiency potential	RQ3: Internal work with energy efficiency
Paper I			Literature review
Paper II	Quantitative and qualitative data analysis (PFE)	Quantitative and qualitative data analysis (PFE)	
Paper III	Quantitative data analysis (international)		
Paper IV			Mapping Interviews, questionnaires
Paper V	Interviews Quantitative data analysis (SEAP)	Interviews	
Paper VI	Quantitative and qualitative data analysis (PFE)	Quantitative and qualitative data analysis (PFE)	
Paper VII			Case studies

6.3. The research journey

As already mentioned, the research started from the hypothesis that industrial energy-efficiency potential lies beyond only technology-oriented EEMs. The focus was first on SMEs and a project on the evaluation of the SEAP was initiated. Later, an international study was conducted which was also based on the data from several energy audit programmes at the international level.

During that time, it was found that IEENs can be a method for improved energy efficiency via energy management practices in industrial companies and SMEs in particular (due to the possibility to outsource energy management work). A project aiming to study IEENs in Sweden and to make evaluation of these was initiated. Based on the preliminary results from the project as well as the literature review in the area related to IEENs and networks governing, the network model for SMEs was designed.

After that, the same hypothesis was applied to energy-intensive LEs – that the potential for energy efficiency is broader than merely investments in technological options. To verify the hypothesis, an attempt was made to quantify the extended energy-efficiency gap as well as energy-efficiency potential for different levels of electric motor systems comprising a significant part of industrial EEU. A method for how to explore this extended energy-efficiency potential in industrial systems as well as to improve them was further developed based on this hypothesis.

Since the methods within different research questions and areas are intertwined, it can be quite problematic to follow this historical flow in the methods' presentation. The historical flow looks like the following (Figure 11):

- 1) Company visits were performed, and the companies were interviewed regarding the question of their participation within the SEAP.
- 2) A study based on the data from several international energy audit programmes was performed followed by the categorisation and comparison of the obtained data.
- 3) The mapping of existing and completed energy efficiency networks in Sweden was performed.
- 4) In parallel with network mapping, the interviews with the networks' coordinators were conducted.
- 5) The network model for SMEs was developed based on the preliminary results from the interviews as well as the literature review.
- 6) The interviews with the coordinators were completed by questionnaires and interviews with the networks' participants on the topic of the advantages and disadvantages of participation in the mapped networks.

- 7) In parallel, the dataset from the PFE was used for estimating the extended energy-efficiency gap as well as energy-efficiency potential for different electric motor system levels in energy-intensive Les.
- 8) Case studies were performed to develop and trial a method for how to explore the extended energy-efficiency potential in industrial systems as well as to improve them.
- 9) The SEAP was evaluated based on the company visits as well as the dataset from the SEA. At the same time, the evaluation of Swedish energy-efficiency networks was conducted based on the interviews with the coordinators and the questionnaires and interviews with the participating companies.

Figure 11. The historical flow of the applied methods.

Throughout the process, the outcomes from the use of different methods completed each other and helped to create a general picture. However, for the sake of simplicity, the methods are presented in this chapter not in the same sequence in which they were used. First, the methods related to the investigation of energy-efficiency potential and the evaluation of SMEs are described. The energy efficiency network approach is presented together with network mapping followed by network evaluation. Second, the methods used for the analysis of LEs are presented, embracing the categorisation of the PFE data to quantify the extended energy-efficiency gap as well as energy-efficiency potential for different electric motor system levels. This is followed by a description of the case study method that was used for developing and

trialling the method for defining extended energy-efficiency potential in industrial systems and their consequent improvement in energy-intensive LEs.

6.4. The methods description

6.4.1. Mapping of energy-efficiency networks

The mapping process was used in Paper IV to discover the existing and finished IEENs in Sweden. It was performed via a snowball method, meaning finding a contact that can refer to another contact, similar to creating a snowball (Aktinson & Flint, 2001). First, the potential players for the coordination of energy networks were determined within the public sector (regional energy agencies, county boards), industrial and business organisations, or consulting firms that later suggested further contacts. The SEA's project database served to identify the majority of the networks. For each network project the following information was gathered:

- participating companies
- start and finish time
- meetings and their specifics
- participation fee
- availability of contracts
- reported energy end-use
- industrial sector
- funding methods
- goal and objectives
- underlying reasons for the network project
- activities performed
- monitoring and evaluation of results

The mapping resulted in 32 energy IEEN-similar projects in the form of a single energy network or several networks. The networks were defined as energy-intensive networks (four networks) and networks for SMEs (28 networks). The categorisation was based on the participating companies' EEU and size as well as the networks' financing methods. The energy-intensive networks consist of large enterprises with EEU greater than 0.5 TWh/year and financed by the Swedish Energy Agency to the tune of over SEK²2 million for network activities. The networks that do not fit these parameters represent the networks for SMEs. The energy-intensive networks were not considered in this thesis given our focus on SMEs, but they have been analysed in a related study (Ivner et al., 2014).

² 1 Euro is equivalent to 10 SEK.

6.4.2. Interviews and questionnaires

As mentioned, in this thesis, interviews were employed to query the companies participating within the SEAP, the Swedish IEENs' coordinators and participants. The questionnaires were sent out to the networks' participants. A general information about the interviews and questionnaires performed in the thesis is presented in Table 5.

Table 5. A general information about the performed interviews and questionnaires.

	Interviews	Questionnaires
The SEAP's evaluation	Interviews with 37 companies participated in the SEAP	-
The Swedish IEENs' evaluation	7 interviews with coordinators, 5 group-interviews with networks' participants	14 questionnaires obtained from networks' participants

Interviews and questionnaires are seen in many studies as the main methods for information gathering, while interviews, despite the defined focus, are more flexible compared to questionnaires (Yin, 2014). Interviews can be classified as qualitative or structured interviews (Yin, 2013). Qualitative interviews do not follow a strict pattern and consist of open questions relevant to the study that can be adapted to a particular context (Yin, 2013). Qualitative interviews allow for a communication exchange between an interviewer and a respondent as well as an understanding of a respondent's perception of a topic (Kvale & Brinkmann, 2009). They take a shape of a casual conversation but with a defined focus and offer the respondent the possibility to share personal views and beliefs from the open questions (Yin, 2014). On the other hand, structured interviews are based on a defined pattern consisting of a questionnaire (Yin, 2013). This thus can be used to obtain quantitative data within a certain range (Yin, 2014).

There is also a group of flexible interviews representing a mix between structured and qualitative interviews, which is called a semi-structured interview. This type of interview often consists of a list of questions; however, new questions can be added, and the existing questions can be altered to suit the particular context. An interview should be recorded to secure an accurate reproduction of the results (Yin, 2014). Recording can be eliminated if there is a limited time for transcribing the interviews or if it distracts the interviewer. Therefore, in accordance with good ethics, it is compulsory to ask if the respondent agrees to the interview being recorded.

6.4.2.1. Interviews in the Swedish Energy Audit Programme evaluation

For the SEAP evaluation study (Paper V), semi-structured interviews were used and consisted of a list of questions with the possibility to extend or alter them depending on the particular context. In total, 37 Swedish companies were visited to interview either an energy manager or

a top manager (depending on who was in charge of the work with the SEAP). The selection of the companies was based on the whole population of the SEAP participating companies with approved reports. These companies varied in sector, size, turn-over and annual EEU, and that is why special selection criteria were defined. First, they needed to have annual EEU higher than 1000 MWh/year and energy efficiency potential of around 20% of EEU. Secondly, the counties with the largest number of applications were considered; however, some counties were not visited due to the long distances and difficulties in organising the visits. Thirdly, the companies within the top 10 sectors that applied for the SEAP were considered. The majority of the companies are represented by “Real estate” (114 companies), “Crop and animal production” (93 companies) and “Manufacturing of fabricated metal products” (85 companies). The priority was given to the manufacturing industries due to the fact that they have higher energy intensity and were in the scope of the SEAP.

The aim of the interviews was to get an overview of how the SEAP functioned and what was accomplished through participation. The interview guide was divided into the following areas:

- information about the company
- energy efficiency measures
- quality of energy consultancy work
- free-rider and spill-over effects
- barriers to energy efficiency
- importance of energy issues etc.

There is always a risk that the answers of the interviewees are affected by their perception on what they think they are expected to say (Bryman, 2012), especially in an evaluation study like this where a governmental policy programme is being investigated. This risk cannot be eliminated but it was considered by instructing the interviewees that Linköping University is not an auditing organisation but rather an independent party and that the study was conducted not to judge their work and deliver the results to the SEA but to find out the actual outcomes of the SEAP to improve forthcoming programmes.

Every visited company’s energy audit report was briefly resumed regarding what advantages and disadvantages it had as well as being generally evaluated. It was recorded whether it had an energy balance, what processes are included in the audit, whether the energy consultant performed the necessary measurements to determine the energy-efficiency potential and whether it was possible to find additional EEMs after the visit. This was done with the intention to create a picture of the level of quality of energy audit reports submitted and thus the qualification of energy consultants. Quantitative data from the interviews served as a supplement to this.

6.4.2.2. *Interviews for the networks’ evaluation*

The interviews within the network project (Paper IV) aimed to study the existing and completed IEENs in Sweden. The interviews performed can be classified as qualitative and semi-

structured interviews as well. It was necessary to reach a trade-off between flexibility and importance to obtain answers to all important questions, since qualitative interviews tend to take a longer time to perform than structured interviews. Due to a quite large number of respondents and the long distances between respondents, the interviews with the networks' coordinators were conducted by telephone. In turn, the interviews with the networks' participants were performed in person due to the fact that only ongoing networks' participants were chosen for the interviews, which significantly decreased the number of respondents. When complementary information was required, the participants were additionally contacted via e-mail or telephone. Completed interviews were recorded and transcribed to assure the credibility of the information.

The study of the networks' coordinators' perspectives consists of seven interviews. At the time of the interviews, all respondents functioned as coordinators in IEENs. Five interviewees represented regional energy agencies and two other interviewees represented private energy service companies. The purpose of the interviews was twofold: to gather information about how the networks function and to obtain coordinators' subjective experiences and opinions about IEENs. The respondents had the freedom to develop arguments and add aspects that the study had not initially formulated, which allowed for new inputs, leading to new research questions for further studies.

To obtain network participants' perspectives, five visits to different networks were performed in total, during which the network participants were interviewed on particular topics. The areas in which the interviews' questions were built for both coordinators and participants are presented in Table 6.

Table 6. The interest areas of the interviews (coordinators and participants).

Network coordinators	Network participants
Initiation phase	Reasons to join a network
Organisation of networks	Positive experience
Activities and management	Negative experience
Goal	Possibility for further work
Follow up	Possibility for improvements

6.4.2.3. Questionnaires for the networks' evaluation

The questionnaire study aimed at quantifying the results of the work of Swedish IEENs by means of collecting data from the network participants. The participants were contacted by e-mail first to explain the aim of the questionnaire, which was followed by sending out the questionnaire forms. The questionnaires consisted of two parts. In the first part, the participants were asked to rank the driving forces behind participating in networks on a scale from 0 to 1.

The driving forces were categorised into four groups: internal drivers, external drivers, informational support and financial support. The following options were used:

- 0 – the driver is not important at all
- 0.25 – the driver is not important
- 0.5 – neutral
- 0.75 – the driver is important
- 1 – the driver is very important
- “Do not know” option

In the second part, the participants were asked to present the savings from EEMs in terms of MWh/year to quantify the participation in networks. The participants obtained a list of EEMs that were categorised according to the processes in which they were found. Moreover, the participants were asked to define whether particular energy savings were the result of networking or an energy audit performed prior to networking. The answers were obtained from 14 companies representing six networks. The first part of the questionnaire was answered by 12 participants, while the second part of the questionnaire was answered by only four participants, which was explained by their inability to define savings. Due to the low number of answers, the results of the questionnaires could not be used for quantitative estimation of savings potential due to networking. This can be explained by the fact that the majority of the companies could not put numbers on the amount of energy they have saved owing to participation in the networks. The reason is possibly that the evaluation was not a requirement in the network structure. Therefore, the questionnaires do not provide any generalisable results but instead give some insights into the participants’ experiences and attitudes.

6.4.3. Quantitative datasets

In this thesis, two different datasets were used: one for analysing SMEs and one for LEs. Both datasets are based on the reports submitted to the SEA during participation in the Swedish industrial energy programmes: The Swedish Energy Audit Programme is oriented towards SMEs, and the Programme for Improving Energy Efficiency in Energy Intensive Industries is oriented towards electricity-intensive LEs.

6.4.3.1. Data from the Swedish Energy Audit Programme

The overview of the SEAP is provided in Chapter 2 under the description of public policies. In total, the SEA received about 1,020 energy audit reports and approved 760 of them. To ensure the data quality, thorough control was performed by a research group from the Energy Systems division at Linköping University. In this thesis, 713 approved energy audit reports were analysed together with their corresponding energy plans, while the rest of the reports were not of appropriate quality. These reports served as the foundation for the database DEFRAM (Blomqvist & Thollander, 2015) used later in several projects within this thesis. The companies

have a total EEU of 5,370 GWh/year. Around 5,940 EEMs were suggested in the SEAP, which accounted for 560 GWh/year of saved energy and 11% of EEU.

The database included the following information:

- EEU of the companies divided into unit processes as well as energy carriers (when possible)
- EEMs divided into unit processes and subcategories within each process depending on where an EEM is found
- Investment costs for EEMs and pay-off time for EEMs that were not planned to be implemented within two years
- Statistics about EEU, energy savings, number of EEMs, EEMs' investment costs, energy savings per company, energy savings per EEM, the SEA's total costs and the SEAP's cost-effectiveness for different industrial sectors
- Statistics about EEU, energy savings, number of EEMs, EEMs' investment costs, energy savings per EEM and the SEAP's cost-effectiveness for different unit processes

The SEAP database was used in the evaluation of the SEAP (Paper V).

6.4.3.2. *Data from the Programme for Improving Energy Efficiency in Energy Intensive Industries*

The overview of the PFE is given in Chapter 2 under the description of public policies. In this thesis, the data corresponding to the PFE's first period were used. They were collected through the companies' interim reports submitted after the second year and through the final reports. In total, the PFE's database consists of 1,254 EEMs with corresponding electricity savings of 917 GWh/year reported for 91 electricity-intensive companies. There were additional electricity savings in the PFE of 533 GWh/year. These electricity savings resulted from more energy-efficient procedures, project planning activities and measures were separately categorised in the PFE for specific reasons and thus were not included in the thesis.

The PFE database includes the information about EEMs with their corresponding electricity savings in GWh/year, payoff time and the origin of the measures (how they were defined). The PFE database was used for the categorisation of EEMs to quantify the size of the extended energy-efficiency gap (Paper II) as well as to define energy-efficiency potential for different electric motor system levels (Paper VI).

The PFE and SEAP's data were also classified according to business sectors (the European categorisation NACE Rev.2³) (Eurostat, 2008). A general description of the sectors according to NACE Rev.2 is given in Table 7. The PFE data were presented by sectors B7–C32. The SEAP data included the sectors A1–S96.

³ NACE Rev. 2 – Statistical Classification of Economic Activities in the European Community within Reference and Management of Nomenclatures (RAMON).

Table 7. Description of NACE Rev.2 sectors (Eurostat, 2008).

Section	Division	Description
A	1–3	Agriculture, forestry and fishing
B	5–9	Mining, quarrying
C	10–33	Manufacturing
D	35	Electricity, gas, steam and air conditioning supply
E	36–39	Water supply, sewerage, waste management and remediation activities
F	41–43	Construction
G	45–47	Wholesale and retail trade, repair of motor vehicles and motorcycles
H	49–53	Accommodation and food service activities
I	55–56	Transportation and storage
J	58–63	Information and communication
K	64–66	Financial and insurance activities
L	68	Real estate activities
M	69–75	Professional, scientific and technical activities
N	77–82	Administrative and support service activities
O	83–84	Public administration and defence, compulsory social security
P	85	Education
Q	86–88	Human health and social work activities
R	90–93	Arts, entertainment and recreation
S	94–96	Other service activities
T	97–98	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	99	Activities of extraterritorial organisations and bodies

6.4.3.3. Data categorisation

Throughout the thesis, the taxonomy based on the unit processes concept was applied. The concept was developed at the Energy Systems division, Linköping University, and implies

dividing industrial EEU into particular processes depending on the process's aim (Söderström, 1996). There are two larger categories: production and support processes. Production processes are processes for making different products, and support processes serve to maintain production activities. This categorisation was further revised by Thollander et al. (2012b) and is presented in Figure 12 in its present form.

Figure 12. Taxonomy for EEU processes categorisation.

In Papers III and V, in the analysis of EEU processes based on the SEAP's energy audit reports, all production processes were presented as the single category "Production processes". This is due to the variety of activities in the SMEs sector. In Papers II and VI, production processes were also presented as one category. What distinguishes energy-intensive companies is that often pumping and steam systems can be counted within production processes. The EEU and energy savings were presented in MWh/year.

6.4.4. Evaluation

In this thesis, two papers (Paper IV and Paper V) deal with evaluation: the evaluation of existing and completed IEENs and of the SEAP. In both cases, process and impact evaluation were used.

In paper IV, the evaluation was performed by gathering information about existing and completed networks and examining their performance. For the networking process evaluation, the quantitative and qualitative analysis was conducted by means of network mapping and interviewing networks' coordinators and participants. The impact evaluation was performed by gathering quantitative data through questionnaires with networks' participants. Since it did not

produce quantifiable results for the estimation of savings potential due to networking, the networks' impacts were discussed instead based on the questionnaires' and interviews' results.

In paper V, the process evaluation was based on the companies' experience of participating in the programme, and the impact evaluation was based on analysing a quantitative dataset from the SEA on such aspects as the programme's cost efficiency, EEMs' implementation rate etc. In the evaluation of the SEAP, the insights from the programme theory were used, since it represents a public policy programme for SMEs. The programme theory as an evaluation method is used to explain why it is desirable to perform a public intervention and what the necessary resources are to achieve desirable effects that will arise from performing the activities. The other aspects to cover are the target audience of the intervention and the assumptions made as well as the external factors that may affect the result (ESV, 2012). The persistent problem in analysing the effects is determining whether it is the programme or something else causing the effect (Vedung, 2007). For this, it is important to consider what would have occurred without the intervention. This can be quite challenging, because the influence of public policy instruments is hard to "isolate" from the world around. In the case of the SEAP evaluation, this issue is addressed by distinguishing between gross impact evaluation and net impact evaluation.

Unlike gross impact calculations, net impact or net energy savings calculations take into account external factors (free-rider, spill-over and double counting effects) (Broc et al., 2009).

$$\text{Net energy savings} = \text{Gross energy savings} \times \text{double counting coefficient} + \text{spill-over effect} - \text{free-rider effect}$$

where:

- double counting coefficient (0÷1) considers mutual energy savings from different EEMs or public programmes;
- spill-over effect considers indirect energy savings from energy-efficiency measures or public programmes;
- free-rider effect considers energy savings by free-riders or those programme participants who would have undertaken energy-efficiency measures anyway.

In this study, free-rider and spill-over effects were addressed during the interviews with the SEAP participants. The double counting effect is not covered in the study which is explained further. Also, changes in electricity prices play an important role in the evaluation of energy-oriented public policies. This factor was not considered specifically in the interviews; however, it was brought up by the interviewees and thus was also partly covered.

6.4.5. Energy-efficiency measures extended categorisation

In this thesis, three papers deal with categorising EEMs using an extended system boundary. For this, the logic behind Boulding's (1956) system complexity levels was used.

6.4.5.1. Defining energy-efficiency potential for different motor system levels

In Paper VI, the EEMs implemented within the PFE were categorised based on Waide and Brunner's (2011) levels of an electric motor driven system (EMDS).

Level 1 (Electric motor): only the electric motor, with the boundary drawn at the electrical interconnection between the motor and the grid and at the mechanical interconnection between the motor and the piece of equipment it drives

Level 2 (Core motor system): the electric motor and the equipment between the grid and the motor to control speed or frequency as well as the mechanical equipment driven by it and the necessary interconnection (clutch, gearbox, transmission belts).

Level 3 (Total motor system): the electric motor, the core motor system and the system where the power is used (ventilation system, conveyor, stirring device)

In this study, an additional category, Level 4 (Extended motor system), was introduced. It includes EEMs related to the management and operative actions outside the total motor system that do not lead to technical changes but to changes in procedures or ways of operation. A boundary is drawn between a person and a motor system. The examples are measures that involve a person doing something ("use a new procedure for stop"), the modification of operational regime, demand-based adjustment, switching off equipment, control and optimisation measures. In this context, the expressions "higher" or "upper" system levels are used in relation to the levels that go beyond an electric motor, pointing out the higher system complexity of the levels (Figure 13).

Figure 13. Extended motor systems' categorisation (revised from Waide & Brunner, 2011).

For the categorisation of EEMs, only the quantified measures were selected. The categorisation was based on motor-related unit processes: Compressed air system, Hot tap water, Space cooling, Space heating, Production processes, Pumping, Steam system and Ventilation. All the measures were controlled in regard to whether or not they include a motor. The following assumptions have been made during categorisation:

- If several levels of motor systems were included in one EEM, it was ranked on the highest level; that is, if a measure “Replacement of a motor and installation of variable-frequency drive” includes motor replacement (Level 1) and the installation of a variable-frequency drive (Level 2), it was ranked Level 2. “Improving efficiency of compressed air system” is categorised as Level 4, because it can comprise all measures from purchasing a new compressor with variable speed (Level 2) to switching off routines for the existing compressor (Level 4).
- Such measure as “Heat recovery from compressor” were categorised as Level 2, since the compressor’s motor system and the measure belongs to Level 2 in this system. However, heat recovery as such can comprise a separate motor system with different levels.
- “Controlling” measures can be placed under different levels depending on whether they involve time- or demand-control. Time-control measures were ranked as Level 4, because they involve a change of procedures rather than a change in a motor system. Demand adjustment was ranked Level 2, because it involves change in the motor speed by means of a drive or a gear.

6.4.5.2. *Quantification of the extended energy-efficiency gap*

In Paper II, all the measures were divided into the following categories:

- Investment in new technology
- Adjustment of existing technology
- Control systems
- Behavioural changes

This was done to estimate the magnitude of the energy management gap in relation to the energy-technology gap. The main idea behind the categorisation was to separate EEMs that involve technological changes from behavioural ones. Control systems represents a transition category, which requires the involvement of staff.

These two categorisation systems (Paper II and Paper VI) are based on the same PFE data and may seem similar. However, these convey different messages and thus result in different implications. The quantification of the extended energy-efficiency gap shows how the technological measures are related to managerial ones. The categorisation of energy-efficiency potentials according to the electric motor system levels, in turn, displays on which complexity levels of the industrial systems the majority of EEMs can be found. The amount of EEMs and respective energy savings within the two types of categorisation are presented in Table 8.

Table 8. Two types of categorisation of energy-efficiency measures from the PFE database.

Measure category	Number of measures	Electricity savings (GWh/year)
Quantification of the extended energy-efficiency gap		
Investment in new technology	782	555
Adjustment of existing technology	30	22
Control systems	87	61
Behavioural changes	238	262
Other/undefined measures	117	17
Total	1254	917
Energy-efficiency potentials on different electric motor system levels		
Level 1. Electric motor	34	20
Level 2. Core motor system	424	232
Level 3. Total motor system	167	155
Level 4. Motor/human	217	220
Other/undefined measures	40	55
Total	882	682

Both categorisations have one assumption in common: if a measure implies several actions, for example, technological and behavioural changes in the first categorisation, and several motor system levels in the second, then the measure is assigned a broader level. In the first case it is assumed to be behavioural, and in the second it is assumed to be at a higher motor system level. This has an impact on the final result and has to be considered. Also, placing EEMs under the different categories can be criticised in general. However, the fact that the choice of the categories was made in consensus in an interdisciplinary group of people with significant knowledge in this field, both technical and managerial, the categorisations are justified to be reliable.

6.4.5.3. Motor system levels categorisation extended for industrial implementation

The categorisation used in Paper VI was further developed in Paper VII into the seven system level model (Table 9) to consider such aspects as adding values, production philosophy, automation rate and interaction between operators and motor systems.

Table 9. EMDS' extended categorisation.

System level	Category	Explanation
1	Electric motor	Type of motors
2	Core motor system	Use of variable speed drives, direct coupling or belt drives
3	Total motor system	Type of fans, pumps etc., heat exchange
4	System solutions	Overall system design: centralised or decentralised, continuous or batch flows, type of energy supply (boiler, district heating, hot water or steam)
5	Production philosophy	How resources are used to create customer value: supplied when required as much as required, supplied when a product is in a manufacturing step, supplied all the time
6	Automation	Control systems, data measurement and collection, ability to respond
7	Human factor	Behavioural patterns, “way of work”, instructions, common procedures

In Paper VII, the EEMs suggested in the case studies were defined within the abovementioned motor system levels with regards to the energy-efficiency rate of these measures: high, moderate and low efficiency.

6.4.6. Case studies and system analysis

The method for identifying possible energy savings in electric motor systems on the basis of theoretical research was suggested in Paper VII. In the paper it is referred to as the MOVE model. This was further validated in case studies through trialling, continuous improvement and the adaptation of knowledge from the fields. Such aspects were considered as developing technical solutions in real conditions and the role of management and leadership skills in improvement process. Moreover, the interdisciplinary theories mentioned in Chapter 5 were combined and considered.

Performing case studies was chosen as the method of development. This is due to the fact that using case studies can help to answer how-questions together with why-questions that have not been answered in earlier research (Yin, 2014). A well-thought-out structure of a case study can direct the study and help to keep a clear focus on the research questions. The necessary information about the studied object should be gathered before the case study by formulating

the research questions and defining ground assumptions (Yin, 2014). In this project, the case studies were performed in close cooperation with industries helping to transfer and test abstract ideas in reality. This is necessary to connect abstract and real outcomes (Yin, 2014).

The method was developed in four steps. First, the skeleton was sketched out based on the knowledge from such fields as systems research, value stream mapping, etc. It was trialled on a pilot study and modified after the gained experiences. Then it was trialled again in three case studies with consequent modifications based on the obtained results after each. Hence, the theoretical ground was verified and the knowledge from each step served for the model development. The final version of the method was the result of trialling, evaluation and verification at three companies with substantial use of electric motors representing the following sectors: foundry and engineering, truck manufacturing and iron and steel.

The case studies were performed in close cooperation with the companies' representatives. The companies' representatives were chosen so that they presented different expertise and skills to achieve a complete understanding of the studied objects. Throughout the project, constant cooperation among the working group members was maintained by a project management group. After each case study and model upgrade, workshops were held with the companies' representatives participating in the model trialling to disseminate knowledge and gain approval of the model revisions. The focus was not on obtaining the quantified results but to develop a well-functioning model by means of a trial-and-error approach and continuous improvement. User-friendliness and applicability in real conditions were emphasised.

Through the case studies, the theoretical grounds and reasoning were studied, namely how to find energy-efficient solutions on higher system levels (with an extended system boundary) employing external knowledge and leadership skills as well as internal expertise, how to make the knowledge remain within organisations and how to enroot systematic energy-efficiency work. The final workshop together with all the participants took place at the end of the project period, where the method was presented in its final form and discussed. The feedback from the participants collected throughout the case studies and workshops served in the qualitative evaluation of the method. The development of the method is shown on Figure 14.

Figure 14. The method development.

The generalisation of a case or, in other words, the extent to which the results of a case study can be applied to other similar circumstances is a broadly discussed topic. However, as long as one approaches the case study outcomes as a guide instead of an ultimate truth, case studies can serve as a good research method (Fejes & Thornberg, 2014). Another important issue to consider is that the researcher should be aware of the method weaknesses and have a critical thinking approach to the analysis of the study's outcomes.

7

Results

This chapter presents the main findings of this thesis's papers. It begins with a presentation of energy-efficiency potential and extended energy-efficiency potential. This is followed by a description of the methods for the incorporation of energy-efficiency work in SMEs and energy-intensive LEs. Last is a description of the data categorisation and homogeneity aspect.

7.1. Energy-efficiency potential in SMEs

7.1.1. Energy-efficiency potential in SMEs at the international level

Paper III presents and compares the available bottom-up energy data on EEU and EEMs for industrial SMEs in four countries: Belgium, Italy, Japan and Sweden (Table 10).

Table 10. Overview of the international data.

Country	Programme	Companies	Processes categorisation, EEU	Processes categorisation, EEMs	Saving potential
Belgium	VA scheme, Energy audit, 2005	>220 industrial MEs, 28–140 GWh/year	N/a	Core processes, Thermal oil, Hot tap water, Steam, Vacuum, Compressed air, Cooling, Lighting, Building, Power system, General Compressed air, Heating system, Cooling, Lighting	12% (Core processes, Steam, Cooling)
	First-line Energy audit, 2008–2013	520 companies, >28 GWh/year	Lighting, Compressed air, Cooling, Other		7% Electricity (Compressed air, Cooling, Lighting), 12% fuel (Heating)
Italy	Energy audit	255 industrial SMEs	Production processes, HVAC, Air compression, Lighting	Production processes, HVAC, Air compression, Lighting	18% (Production processes, HVAC)
Sweden	Energy audit	760 SMEs	Space heating, Hot tap water, Ventilation, Compressed air, Lighting, Space cooling, Administration, Other, Production processes	Space heating, Hot tap water, Ventilation, Compressed air, Lighting, Space cooling, Administration, Other, Production processes	17% (Space heating, Ventilation, Lighting)

All countries in the study have a large industrial sector. Here, Japan is excluded due to the fact that the data were available only for case studies or minor questionnaires based on a limited number of samples.

It was found that in Italy the EEU is much higher in production processes than in Sweden (there are no data available for Belgium). The major reason for this is that Sweden has a tradition of using electricity for many processes, while in other European countries other forms of energy are considered (Thollander et al., 2005). As EEU is studied, primary energy is not displayed, and this results in higher figures for companies who are using, for example, oil with major losses in the boiler, etc.

For industrial SMEs, the potential for improved energy efficiency in the production processes was found to be about 20% for both Italy and Sweden. For Belgium, the main potential in the voluntary agreement programme was found in the production processes, followed by the steam, cooling and power systems. The data regarding processes were not available for the first-line energy audit programme. For Italy, the largest figure apart from production process-related EEMs was found in the HVAC systems, followed by compressed air and lighting. For Sweden, the largest energy-efficiency potential was found in space heating followed by ventilation. Production process-related EEMs were only in third place. The high figure for Belgium is related to the fact that the dataset consists of medium-sized energy-intensive companies taking part in the VA, while the datasets for Sweden and Italy are related to a less homogeneous set of industrial SMEs. Despite the fact that about half or more of the EEU is found in the production processes, the major energy-efficiency potential is found among industrial SMEs in non-production-related processes for these three countries.

The way of categorising the data may also deviate from the respective country; for example, pumping may for some energy auditors and industrial companies be seen as part of the support processes, for some as part of the production processes and for others a distinction between support and production processes is not made. This may complicate comparisons between the datasets.

7.1.2. The Swedish Energy Audit Programme evaluation

The results in Paper III for Sweden are based on 71 industrial companies that participated in the SEAP. Paper V presents a more detailed analysis.

7.1.2.1. Energy end-use and energy savings

The total EEU of the companies participating in the analysis is 5,370 GWh/year ((around 4% of Swedish industrial EEU)). The most energy is used in sectors such as D35 (electricity, gas, steam and air conditioning supply), C24 (the manufacturing of basic metals), C16 (the manufacturing of wood and products of wood), C25 (the manufacturing of fabricated metal products) and C22 (the manufacturing of other non-metallic mineral products). The energy-saving potential for these sectors is 1%, 3%, 18%, 16% and 16%, respectively. The small potential for sectors D35 and C24 can be explained by the fact that EEMs were suggested for

7. Results

their support processes, whereas the majority of energy is used in production processes. Another explanation can be that some companies that applied for the monetary support are too energy-intensive for the SEAP and actually should have participated in the PFE instead.

The following results are derived from 37 company visits. The potential for improved energy efficiency in the visited companies is presented in Figure 15 by suggested and reported energy-efficiency potential and the outcome in form of implemented EEMs. The suggested measures are the measures proposed by energy consultants in the energy audit reports, and the reported measures are the measures that the companies stated would be implemented within two years. The outcome represents the measures that, as stated in the interviews, have already been implemented or will definitely be implemented in the future (referred to as “implemented” in the figures). The energy-efficiency potentials given in the energy audit reports are almost always higher than reported or implemented by the companies. Only in three cases did the companies report more measures than were found through the energy audits (Company 27, 24 and 18). The outcome was lower than reported in 10 cases; however, the total outcome for all the companies was higher than reported to the SEA in the energy plans. The suggested measures represent 17% energy-saving potential (35.5 GWh/year). The reported energy-saving measures account for 9% of EEU (19 GWh/year), and the outcome results in 13% potential, which is equivalent to 26.8 GWh. The outcome thus has a 22% higher implementation rate than reported (which was defined as participant spill-over effect).

Figure 15. Energy-efficiency potential of suggested, reported and implemented measures (37 visited companies).

The same situation as with energy-saving potential holds for the number of proposed EEMs. The average number of EEMs suggested per company was 13; however, the companies stated that eight would be implemented, while the number reported to the SEA was seven. The number of suggested EEMs by the energy auditors in the energy audit reports, those reported by the companies to the SEA and the implemented EEMs (according to the interviews with the companies' representatives) are shown in Figure 16.

Figure 16. Number of suggested, reported and implemented measures from the 37 visited companies.

As mentioned, the SEAP's evaluation was performed on 713 energy audit reports out of 760 reports approved by the SEA (a total of 1,020 companies participated in the SEAP). Thus, 25% of the cases did not proceed further (where 40% withdrew their participation application at their own request). According to the SEA's questionnaire, the reasons were lack of time and resources, the person responsible for the SEAP left the company, too much administrative work, other more important investments, economic difficulties and problems with energy auditors. The rest were not approved by the SEA, because the companies did not complete their progress reports, or their energy audit reports did not meet the SEA requirements, and the companies did not want to pay for the supplementary work.

The interviews with the companies showed, in turn, that the overall quality of the energy audits was satisfactory and that the companies were satisfied with their results. The energy audit

results served as an eye-opener and helped in seeing the whole picture of a company's energy performance. The results served as good decision support for energy-efficiency investments and prioritising them among other investments, even though the majority of the companies mentioned that the pay-off requirements for energy investments are not different from other investments related to production or maintenance. However, during to the company visits, it was possible to find further EEMs in the majority of cases.

7.1.2.2. *External factors and net energy savings*

Spill-over, free-rider and double-counting effects comprise external factors that may affect the evaluation of public policies. It was noticed that the majority of the visited companies implemented EEMs apart from the ones proposed by energy experts. Some EEMs that the companies had not reported as having been implemented were implemented anyway, resulting in a 22% higher implementation rate (participant spill-over effect). The free-rider effect was estimated to be quite low (15%). Only three companies stated that they would have performed an energy audit without monetary support from the SEA. This support was a good motivation to perform EEU analysis in the facilities, which would otherwise seem costly. Of the suggested EEMs, 58% were known, but there were no plans to implement them. The majority of the visited companies stated the importance of further energy audits. Double-counting or mutual energy savings caused by participation in other public programmes was hard to estimate, and the scientific literature provides no guidance in this regard on how to make adjustments, calling for future research to be conducted in this area. This might somehow be reflected in the larger stated implementation rate of EEMs than is actually the case when the aggregated results from the bottom-up reporting of energy-efficiency policies are presented. However, it is worth noting that there was no other national energy audit public programme. As for the Swedish Environmental Code, it has not been actively implemented among Swedish industrial companies due to the fact that this kind of policies act rather slow (Johansson et al., 2007). That is why the double-counting effect can be stated to be low.

In analysing the quantitative data from the approved reports, it was found that only 22% of energy savings belong to production processes, which does not show that the potential in this area is small but rather indicates that support processes were the focus for the energy auditors.

In total, the gross energy savings account for 589 GWh/year. Considering participant spill-over/free-rider effects, the total net energy savings are 630 GWh/year, which is 12% of the total EEU. The implementation rate of the EEMs is 53% (3,234 reported measures out of 5,941 suggested), which is about 4.5 measures per company. The EEMs reported as "to be implemented" result in energy savings equivalent to 315 GWh/year (6% of EEU). Considering participant spill-over/free-rider effects, the net energy savings from the reported measures increase to 340 GWh/year. Per company, the average energy savings are equivalent to 440 MWh/year. The ex-ante evaluation of the SEAP in 2010 predicted the programme's outcome to be 700–1,400 GWh/year of energy saved, or 780–1,560 MWh/year energy saved per company (Thollander & Dotzauer, 2010). The lower figure for the ex-post evaluation can be explained by the fact that Thollander and Dotzauer (2010) considered in their calculations

only manufacturing companies. The SEAP dataset includes 340 manufacturing companies while the rest is non-manufacturing.

The highest energy savings are found in ventilation (26%) and space heating (24%) followed by production processes (22%) and lighting (8%) (see Figure 17).

Figure 17. Energy-saving potential for different unit processes.⁴

7.1.2.3. Cost-effectiveness of the Swedish Energy Audit Programme

The results of the NPV calculations of the public and private cash flows, as well as the cash flows of the SEAP's energy savings, are presented in Table 11.

⁴ This figure is built on the data from 454 companies, because for the rest of the companies, there was no proper allocation of EEU among the unit processes. This was due to the fact that EEU was required to be reported in the spring 2012 so the first few hundred reported energy audits were not required to report this.

Table 11. The NPV of public and private costs and the SEAP's energy savings.

Net Present Value	Euro, thousand
NPV public per company (SEAP costs per company)	2.7
NPV private per company (audit costs + investment costs)	127
NPV public total (total SEAP costs)	2,025
NPV private total (audit costs + investment costs)	96,387
NPV of suggested measures	23,883
NPV of reported savings	12,747

On average, an individual company invested around € 520/MWh in EEMs. The SEA subsidised indirectly around € 700 per measure reported to the SEAP. Derived from the amount of energy saved, the SEAP's cost-effectiveness is €7/MWh or 140 kWh/€ saved energy per public cost.

7.1.2.4. Comparison with other energy audit programmes

A comparison of these results with other energy audit programmes is given in Table 12, including the United States Industrial Assessment Centers (US IACs) (Anderson & Newell, 2003; Muthulingam et al., 2009), the Australian Commonwealth Government's Enterprise Energy Audit Programme (EEAP Australia) (Harris et al., 2000), Project Highland (Thollander et al., 2007) and the German energy audit programme promoted by the KfW fund (the German promotional bank) (Fleiter et al., 2012b). Only actual savings are presented in the table, and only cost-effectiveness indicators related to the public expenses.

Table 12. Comparison of the international energy audit programmes.

Programme	Nº of companies	Nº of measures	Energy savings, GWh/year	Cost-effectiveness, €/MWh	Specific savings, kWh/€	MWh/measure	MWh/year per company	Payback, years
US IACs	14,800	55,500	18,833	n/a	n/a	303	1,278	1.1
EEAP Australia	1,200	5,640	4,167	n/a	n/a	736	3,469	1.3
Project Highland	139	142	76	7.5	86	535	547	n/a
KfW fund	9,292	14,500 (1.7/company)	1,055	1.8–4.1	240–555	70	120	6.1
SEAP (ex-post)	760	3,234 (4.5 company)	340	7	140	104	440	7.6

The oldest and largest American audit programme accounts for the greatest energy savings followed by the Australian programme. The comparison of cost-effectiveness is complicated by the fact that different approaches were used during the evaluations. The American programme was evaluated based on database records, while the Australian evaluation was conducted through phone interviews with 100 participating companies (Anderson & Newell, 2003; Harris et al., 2000). The German evaluation was based on online questionnaires and statistics from the KfW (Fleiter et al., 2012b), and the total energy savings in the German programme were estimated from the questionnaires (Fleiter et al., 2012b). Spill-over/free-rider effects were not considered in the first mentioned programmes, nor were the programmes' cost-effectiveness indicators calculated in these energy audit programmes. In the American programme, the implementation costs were estimated, while in the Australian programme, an average value of implementation was estimated. The free-rider effect was partly covered in the evaluation of Project Highland; however, no indicators were proposed. In addition, the cost-effectiveness calculations of Project Highland were not based on NPV calculations and, thus, did not account for the discount rates and lifetimes of measures. Correction factors as well as NPV calculations, were considered in the German programme. Thus, only the German energy audit evaluation programme and the present evaluation study seem to have indicators calculated in a similar manner. Comparing the German audit programme and the SEAP, the first appears to be more cost-effective in terms of kWh energy saved per public expenditures, whereas the number of EEMs and energy savings for an individual company is higher for the SEAP. The pay-off time for the German programme is also one year shorter and the public costs were much higher.

An important finding is that an energy audit is only the first step on the way to improved energy efficiency at SMEs. The interviewed companies stated the importance of energy management measures and measures requiring behavioural changes. However, energy management practices for SMEs are relatively undeveloped (Shipley, 2001; EC, 2007). In addition, since energy efficiency has not been prioritised among SMEs despite the existing potential and since the companies often do not know that they have this potential for improvement, there is an obvious need for energy-related support among SMEs.

7.2. Extended energy-efficiency potential

This section presents the results of papers II and VII, where the extended energy-efficiency gap and energy-efficiency potentials for different motor system levels were identified, respectively.

7.2.1. Quantification of extended energy-efficiency gap

In paper II, the EEMs from the PFE database were categorised (1,254 EEMs with total annual savings of 917 GWh). The EEMs are presented in Figure 18 according to the processes where the deployment of improved energy efficiency was achieved. Production processes showed the highest electricity efficiency followed by pumping, compressed air and ventilation systems.

Figure 18. Improved electrical efficiency from the Swedish PFE according to processes, GWh/year (the total savings are 917 GWh/year).

Tap hot water – 0 GWh/year;
Space cooling – 0.09 GWh/year;

Steam – 0.27 GWh/year;
Administration – 0.89 GWh/year

The categorisation results are presented in Table 13. Investments in new technology comprise 61% of all energy-efficiency measures followed by Behavioural changes (29%). Control systems and Adjustment measures obtain only 7% and 2%, respectively. The category of Undefined measures makes up 2%.

Table 13. The categorisation of the PFE’s energy-efficiency measures.

Measure category	Number of measures	Electricity savings, GWh/year	% of total savings
Investment in new technology	782	555	60.5
Adjustment of existing technology	30	22	2.4
Control systems	87	61	6.7
Behavioural changes	238	262	28.6
Other/undefined measures	117	17	1.9
Total	1254	917	

Figure 19 and Figure 20 show what kind of measures were proposed for the particular unit processes and the size of efficiency improvements they resulted in. Production processes are presented separately, because otherwise the numbers for some other processes become too

small to present on the same plot. As shown in Figure 19, the highest electricity savings for the category of “Investments in new technology” are found for pumping followed by ventilation and compressed air systems. High savings for the category “Behavioural changes” are found for compressed air and pumping as well as for energy supply. However, the number of energy-efficiency measures and the magnitude of electricity savings related to them is not always the same. The category “Investment in new technology” has the highest number of proposed measures in comparison with other categories for almost every particular process. However, the electricity savings and the number of measures are not in the same magnitude for these categories, making the specific electricity savings (the relation between the electricity savings and the number of measures) higher for the category “Behavioural changes” than for the

Figure 19. Electricity savings and number of measures for different unit processes (except production processes).

If only the measures proposed for the production processes are considered, the majority of improvements can be achieved by investment in new technologies, although electricity efficiency improvements due to behavioural changes show a rather large share as well (Figure 20). For the production processes, too, the relation between the electricity savings and the number of measures is higher for the category “Behavioural changes”.

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Figure 20. Electricity savings and number of measures for production processes.

As for a particular measure category, the specific electricity savings due to behavioural changes are higher for a single measure (Figure 21).

Figure 21. Specific electricity savings for different measure categories (MWh/measure).

The shares of the saving potentials for different categories of measures for various unit processes are shown in Figure 22 and Figure 23. The percent values above the bars represent the percent of saved electricity due the management-related measures. In Figure 22, the

management-related measures include adjustment, control and behavioural measures, while in Figure 23 the adjustment measures are not considered within management-related measures.

Figure 22. Energy-efficiency measure categorisation for various unit processes (management measures presented by Adjustment and Control systems measures and Behavioural changes), PFE database.

Figure 23. Energy-efficiency measure categorisation for various unit processes (management measures presented by Control systems measures and Behavioural changes), PFE database.

The origin of the EEMs is presented in Figure 24. The energy audit results in investments in new technology as well as adjustments to existing technology and control systems but shows considerably lower impact for behavioural measures. This is quite explainable, since an energy auditor is a technical expert providing guidance on improvements based on one or a few site visits. This finding shows the importance of energy management practices where behavioural measures are also dealt with.

Figure 24. The origin of the proposed measures according to their categories.

7.2.2. Quantification of energy-efficiency potential for different motor system levels

The PFE database was further used in Paper VI to categorise the motor-related EEMs by different motor system levels and to quantify the energy-efficiency potential for each level. In total, 842 measures were categorised as motor-related with corresponding energy savings of 628 GWh/year (Table 14).

Table 14. The categorisation of EEMs by motor system levels.

System level	Description	№ of measures	Energy savings, GWh/year	% of total savings	Variance, %
1	Electric motor	34	20	3	0–12
2	Core motor system	424	232	37	28–46
3	Total motor system	167	155	25	16–33
4	Extended motor system	217	220	35	26–44
	Total	842	628		
	Undefined	40	55	-	-

In total, the number of measures on Level 2 (Core motor system) is almost the sum of Level 3 (Total motor system) and Level 4 (Extended motor system). However, the energy savings for Level 4 only are close to those of Level 2. The results for particular unit processes vary. Figure 25 presents the energy savings for all motor system levels and all unit processes.

Only 12 EEMs were proposed for the category Space heating and cooling, which reduces the possibility of generalising from this category. For this category, the majority of EEMs belong to levels 2 and 3, while the energy savings are approximately the same for these levels. Level 1 has only one measure.

For the category Production processes, whose energy savings make up 56% of the total energy savings, the number of measures is approximately the same as that for levels 2, 3 and 4. At the same time the energy savings are higher for levels 3 and 4. Thus, on the higher system levels, greater energy savings are achieved with fewer EEMs. This underscores the importance of operational measures on the higher system levels for production processes.

For Pumping, the largest energy savings and the highest number of measures belong to Level 2. However, the energy savings for Level 2 are not of the same magnitude in relation to the number of measures for this level. The energy savings for levels 3 and 4 can be achieved with fewer measures (the number of measures and energy savings are proportional). The same holds for Ventilation: the magnitude for energy savings and number of measures is almost the same for Level 4, while for Level 2 the savings require the implementation of more measures. In other words, fewer measures on levels 3 and 4 results in higher electricity savings compared to Level 2.

Approximately the same energy savings can be achieved on levels 2 and 4 for Compressed air system, and the savings are of the same magnitude with the number of EEMs. For all processes, the EEMs on Level 1 result in insignificant energy savings.

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Figure 25. Number of EEMs and respective energy savings for different unit processes.

In total, the specific energy savings (MWh/measure) increase with higher system levels (Figure 26). For the measures on levels 3 and 4, energy savings per measure almost doubled.

Figure 26. Specific energy savings for different system levels.

7.3. Methods for incorporation of energy-efficiency work in companies

7.3.1. Energy networks as a method for incorporation of energy-efficiency work in SMEs

In this section, the mapping and results of the evaluation of the IEENs in Sweden first presented in Paper IV are shown. This is followed by a presentation of the model for IEENs' operationalisation, which was developed in Paper I.

7.3.1.1. Mapping of the Swedish energy-efficiency networks

The number of Swedish networks identified during the mapping are presented in Table 15 according to the networking types discussed above. The fifth category, "Alternative networks", combines the networks that do not fit in any of the types.

Table 15. Swedish energy-efficiency networks for SMEs.

Network type	Number of networks
Cluster with administration	1 network
Industrial district with administration	1 network
Regional strategic networks	15 networks
Strategic networks	5 networks
Alternative networks	6 networks

A map of the 28 defined networks is shown in Figure 27. Further information about the defined networks' characteristics is given in Paper IV.

Figure 27. A map of Swedish IEENs for SMEs.

7.3.1.2. Evaluation of the Swedish energy-efficiency networks

Energy-efficiency networks' administration

The identified IEENs differ greatly in character. Administration exists in all of them via a representative from a trade association, regional energy agency or energy service company. Various levels of ambition due to levels of knowledge and awareness are observed among both the participating companies and the administrative organisations. The administration plays a crucial role and determines the level of engagement. External and internal conditions and availability of resources are important for the success of networks, since they define the extent to which suggested measures are implemented.

Most networks for SMEs are funded by public organisations, including the SEA along with support from the county administrative boards. Other financial resources include regional councils, industrial associations and the companies themselves. Knowledge and experience exchange takes place via meetings. The strategic networks have always had a contract to ensure participation. Internal knowledge varied greatly depending on company size and the persons involved. External knowledge is delivered by consultants, who provide input to participants on particular topics. Energy audits were not a common practice. Energy audit practices are more common in the strategic networks, because this is often stated in their contracts. The companies that performed audits often received financial support from the SEAP.

Impact evaluation of the Swedish energy-efficiency networks

The driving forces to join networks were identified in a questionnaire study with the participating companies (Figure 28).

Figure 28. Driving forces in Swedish IEENs for SMEs.

The most important driving force was cost reduction resulting from lower energy use, ranked 0.9 on average. This factor was ranked as very important in 10 cases and as important in one case. This is followed by threat of rising energy prices (0.81), commitment from top management (0.71), energy advice from seminars (0.7), government-advised energy audit programmes (0.69), people with real ambitions (0.69), energy taxes (0.68) and long-term strategy (0.67). The factors that had the lowest ranking were European Emission Trading System (0.23) and pressure from the public sector and environmental organisations (0.25).

It was shown that such activities as meetings, courses and study visits took place but not regularly. Lectures and seminars were often given “as needed”. The short-term effects during networking defined in the interviews with the coordinators were participant education and information distribution (about the importance of energy audits in particular). However, the long-term quantified effects were not provided in the final reports due to the lack of evaluation activities, with some exceptions when the results were expressed in terms of energy savings. The final reports of the identified networks often lacked in-depth descriptions of the activities and final results. This could possibly be attributed to the fact that the projects were not focused on launching networks initially, although their activities resulted in that.

The results of the network participants' questionnaires for the quantitative estimation of savings potential resulting from networking cannot be used for impact evaluation, because the majority of the companies could not provide any numbers about the energy they have saved owing to the EEMs proposed during the networking. This could possibly be attributed to the fact that the evaluation procedure was not a necessary part of the network structure. Thus, the results of the questionnaires could not provide any generalisable quantitative results. In Paper IV, four specific examples can be found, but these accomplishments cannot be evaluated quantitatively to any extent.

Current status of energy-efficiency networks in Sweden

The concept of IEENs in Sweden has not been developed to the same extent as in Switzerland and Germany, explained by the lack of a national joint effort. The Swiss networks are part of a national policy, while the Swedish networks are local initiatives without tax exemption. The German networks, in turn, were founded by one German company. Many of the Swedish networks have been formed as projects without common framing, and they differ in form. The origin of the coordinating organisation does not affect any network's success, and there is no evidence that the regional energy agencies work in a more structured way than the energy service companies. There is however a need for a structural approach during networking, which was lacking in all networks.

Coordinators and participants agreed that a fee could be levied to ensure engagement and commitment to participate in meetings and implement EEMs. At this stage of energy network development in Sweden, it seems important that the government implement a national support scheme, because it can be difficult to make companies pay for a scheme that is not well known. When the networks mature, they can be financed by the participants. It is recommended that the participating companies sign an agreement committing to implement the proposed actions. One potential future direction for Swedish networks could be to offer a tax exemption, as is the case in Switzerland.

Engagement among participants was argued to be very important for success by both the coordinators and the participating companies. A network with common activities is by itself a platform for initiating engagement among companies. A correlation was found between the level of success of a network and the number of structured meetings conducted within it. The effectiveness of meetings depends on the number of participants, which should ideally be around 10 to ensure a healthy level of discussion. The presence of personnel from a management team can raise interest and increase the commitment to implement proposed EEMs.

Advantages of participating in IEENs

In general, the interest in creating IEENs from the companies' and municipalities' side was found to be strong. The municipalities perceive networking as a contribution to the EU climate strategy. The majority of the participants see networking as a way to reduce energy costs by means of learning and experience exchange. The companies' interest in the networks is

confirmed by their willingness to continue meeting after the end of the projects. The companies consider networks as a source of inspiration in their energy work. Many of the companies joined networks owing to the initiative of their respective top managements, and participation helped spread awareness further among the personnel.

Lack of time and of resources were considered decisive obstacles for SMEs to perform energy-efficiency actions on an everyday basis. By means of participating in an IEEN, the companies partly outsource energy management activities to the administration. In this way, energy-related work can be adapted to a specific company and external conditions (energy prices, taxes, economic conditions) and is thus sustained. Therefore, not only people with energy-saving ambitions determine the company's approach to dealing with energy but also energy saving in itself is considered a part of the decision-making process in companies. Mutual learning within an energy network contributes to learning within the participating companies. The administrative burden and risks are shared, while transaction costs are minimised.

Factors for energy-efficiency networks' improvement

Participation in an IEEN alone cannot guarantee improved energy efficiency. To bring about positive results, a network should be designed and managed properly. In relation to the more mature Swiss and German networks, the Swedish networks need to be developed in several respects. The success of a network depends on the network's governance. The coordinating organisation plays the role of the engine that drives work, organises meetings, invites external experts and creates engagement on the network level. Moreover, continuity plays a key role, because the network's work follows the definite cycle of mapping, planning, follow-up and new measures. Systematic work leads to changes in organisational behaviour and, when supported by administrative procedures, it can contribute to measurable results. In this way, SMEs can place the administrative burden on the coordinating organisation.

The administration is necessary for structuring the work by dividing it in stages and reporting the effects of the stages. Common procedures for network coordination are the most important parameters for effective networking together with the monitoring of networking activities and performance measurement. Hence, there is a need for network models that guide participants through the various phases of the networking process. However, networking can only be effective if the underlying administrative procedures are simplified and adapted to the users rather than following a strict pattern.

The other areas for improvement are proper goal-setting and establishing follow-up procedures. IEENs result in higher levels of EEMs implementation if their goals are defined clearly. There should be a common goal for the entire network as well as individual goals communicated internally and externally to the network. The goals should be specific (kWh/product, number of EEMs), measurable, and time-defined. The use of key performance indicators can help cope with differences in production. This would also facilitate the evaluation of network performance and define energy savings. The follow-up procedures should be determined at the network level. It is strongly recommended that future networks be clearer in reporting performance as well as in regard to what has worked and what has not worked well. Preferably, implemented activities

should be measured. Demonstrating the effects of participation can elicit greater commitment and more fruitful knowledge and experience exchange, because tangible results are easier to communicate among the participants.

Moreover, there is a need for better-qualified energy auditors and experts, which may be achieved by way of certification. The quality of energy consultants' work should be approved at the network level, and a list of good energy consultants should be available to the network members to secure a good level of the proposed EEMs.

7.3.1.3. A general model for a successful industrial energy-efficiency network

IEENs are a complex type of energy service that need structure to be successfully adopted. When properly managed, this can help reduce barriers to energy and contribute to improved energy efficiency. A general model on how an IEEN can be managed was developed and presented in Paper I. It was based on the theoretical research and findings from ongoing IEENs. The model is presented in Table 16 and consists of seven important elements, as follows:

- Network promotion and marketing
- Framework
- Strategy and goal formulation
- Administrative formalities
- Network operationalisation
- Quality control
- Network finalisation

The model is presented in a step-by-step operationalisation beginning with the pre-project phase followed by the initiation phase, energy action plan with investment estimation phase, implementation phase, monitoring and evaluation phase and finalisation and evaluation phase. On the most detailed level, the model consists of suggestions for tasks and deliverables for every step.

This should not be seen as the “one-and-only-model” but rather a theoretical model, a set of guidelines for the administrator. Thus, before the launching of a network, the administrator may need to revise the model to fit the region's culture and juridical conditions, the regarded companies which will form the network, the country's current policy mix and many other issues. A system should be simplified and adapted to the user. That is why it is very important that the administrative organisation has the necessary tools, knowledge and competencies to manage the network correctly.

The findings from the evaluation of the IEENs in Sweden as well as the suggested model have been applied for development of the Swedish National Energy-efficiency Network Programme.

Table 16. A general model for the management of an industrial energy-efficiency network.

Phases		Responsible	Pre-proj S0	Initiation S1	Energy set. pt. w. inv. est. S2	Energy set. pt. w. inv. est. S2	Implementation S3	Monitoring & evaluation S4	Finalisation S5	Finalisation S6	Evaluation S6
Network, strategy and goal formulation			Deliverable	Task	Deliverable	Task	Deliverable	Task	Deliverable	Task	Deliverable
Formulate strategy for the creation of innovative energy awareness culture in network organisations through continuous improvements		NC	D0.1	D1.1			D4.1				
Formulate strategy for the creation of innovative energy awareness culture in company		NC	D0.2	D1.2			D4.2				
Set impact in EUE (KWh) saved during the network & period		NC	D0.3	D1.3			D4.3				
Set impact in EUE (KWh) saved per company during the network period		NC	D0.4	D1.4			D4.4				
Promotion and marketing											
- Creation of information material		NC	D0.6	D1.5							
- Communication plan (where communication channels are set, e.g. form of marketing [radio, tv, telephone, email etc.])		NC		D1.5							
Framework											
- Who is participating (regional network, sector, size, company stakeholders (bank, ISCO), energy auditor, network, operator & administrative management consultant)		NC/NWC	D0.7	D1.7							
- Define network period		NC/NWC	D0.8	D1.8							
- Number of companies		NC/NWC	D0.9	D1.9							
- Financial support (external)		NC/NWC	D0.10	D1.10							
- Network fee (for participating companies)		NC	D0.11	D1.11							
- Letter of intent (contract signed from company to management)		NWC	D0.12	D1.12							
- Create a policy including joint vision formulation (e.g. including gender and ethical issues etc.)		NC/NWC	D1.13	D1.13							
Administrative model											
Management model (LIAN, PIKA, project management, etc.)		NC/NWC	D0.14	D1.14							
- Structure of network (set different phases with clear timelines, meeting frequency, locations, invited experts)		NC/NWC	D0.15	D1.15							
- Manage and build trust (the software, database, report templates etc.)		NC/NWC	D0.16	D1.16							
- Create a user manual		NC	D0.18	D1.17							
- Impact evaluation, network level		NC	D0.19	D1.19			D4.19				D6.19
- Process evaluation, company level		NC	D0.20	D1.20			D4.20				D6.20
- Process evaluation, customer level		NC/NWC	D0.21	D1.21			D4.21				D6.21
Network operationalisation		NC/NWC	D0.22	D1.22			D4.22				D6.22
- Site visits		NC/NWC		D1.23							
- Network meetings		NC/NWC		D1.24							
- Energy audit report		EA			D2.25						
- Energy action plan		NWC			D2.26						
- Reduction of energy efficiency potentials		NWC			D3.27						
- Monitoring & evaluation system		NC									
Quality control											
- energy auditor training and certification (e.g. use ISO 50001)		NC	D0.30	D1.31			D4.29				D6.29
- interim network report audit		NC	D0.31	D1.31			D4.31				
Network finalisation											
Final network report		NC/NWC									

NC = Network Coordinator

EA = Energy Auditor

S = Step

D = Deliverable

7.3.2. A method for the incorporation of energy-efficiency work at energy-intensive LEs

In this section, the model MOVE for identifying and addressing energy-efficiency improvement opportunities is presented as a method for incorporation of energy-efficiency work in LEs. The model was developed based on trialling in three industrial case studies, as follows:

- a foundry and engineering company (hydraulic system of a moulding line)
- a heavy truck manufacturing company (hot water system of a drive shaft painting)
- an iron and steel company (band washing process)

The case studies are presented in further detail in Paper VII.

7.3.2.1. Method description

Apart from the start-up phase, the model is shaped as a four-step chronological model. It aims to obtain facts and expand knowledge about EMDS in a chosen industrial process to elucidate the demands and requirements that determine EEU, to quantify the energy-efficiency potential of the system and to identify relevant EEMs. There are no criteria for choosing an industrial process other than that it should have some potential for improvement. A simple energy audit may be needed to define possible areas for improvement. However, this is not a requirement, and the model can serve as a starting point for initiating continuous work on different areas within a particular industrial activity. Figure 29 presents the process flow within the model.

Figure 29. The MOVE model's working process.

Start. First, a preparatory meeting between an external process leader and a process owner is held to give an overview of the model. The role of the external process leader is to coordinate the working team throughout the working process. The process owner is a person from the company that has formal responsibilities in the object (i.e. manufacturing process) being analysed.

Step 1. In step 1, the process owner assembles a working team and collects the necessary data about the chosen object. The working team should consist of at least four persons in addition to

the process leader who have knowledge and expertise regarding the process. This is followed by a feedback procedure involving the process owner and experts.

Step 2. The chosen object is mapped by means of gathering the required information from the working team. The process is similar to value stream mapping⁵ albeit combined with new approaches developed during the work on the model (Figure 30).

Figure 30. Step 2 – Process mapping design (external efficiency).

The scope is to visualise the process requirements that affect EEU, the product value flow and how it contributes to internal customer satisfaction. An example of such a requirement could be the purity of a product. An example of an internal customer could be a process step that is outside the system boundary or the product that is manufactured. The mapping activity entails the work concerning external efficiency. During the mapping, the most interesting process requirements are sorted out to form the overall criteria that must be fulfilled when EEMs are identified. This is followed by brainstorming to involve all participants and to capture EEMs outside the system boundary.

Step 3. In step 3, the data describing the technical components, current system routines and automation control level are collected. The data are then divided into seven motor system levels (numbers 1–7 are the system levels presented in Methods). The seven system levels were defined during the model development process to cover such aspects as system approach, automation, production approach and interaction between operators and EMDS (Table 9 in Methods).

⁵ Value stream mapping visualises flows of materials and information in an organisation from supplier to customer (LEAN, 2016).

The existing system is then described, and the data are evaluated according to three categories of energy efficiency: high, moderate and low. After that, improvement proposals are described and specified to a corresponding level of the system according to the appropriate efficiency category. Step 3 represents work with internal efficiency by choosing the best technology and ways of work to meet the requirements sorted out within external efficiency (Figure 31).

Figure 31. Step 3 – Identifying energy-efficiency measures (internal efficiency).

Step 4. The final step aims at combining the level-specific solutions from “1–7” into a list of EEMs. The measures are then described, analysed and placed into a priority matrix (Figure 32). EEMs from different levels are summarised to create new system solutions, meaning that improvements from multiple levels are merged into single system EEMs. The matrix considers two aspects: the effect of an EEM and its complexity. Finally, the measures are put to the vote, and the highest-rated measures are banked for future implementation.

Figure 32. Step 4 – Priority matrix.

After that, the process owner nominates an in-house candidate to be a future process leader in further implementation. This in-house person has a lot of knowledge about the company and its processes but less knowledge about how to work with energy efficiency. During the model's implementation, knowledge and expertise about how to work with energy efficiency are transfer from the external process leader to the internal responsible person. This helps to ensure that the knowledge remains within the organisation afterwards.

7.3.2.2. *The case studies' outcomes*

In the first case study, the expectations prior to the model's implementation were to find the improvement opportunities and to build knowledge based on the results. The outcome exceeded these expectations, because the knowledge obtained not only helped to understand the studied process but also showed that it was possible to change process conditions, making it more energy-efficient without losing quality. It was decided that the model would be applied for the optimisation of other processes. In the second case study, it was also found that the energy demands could be decreased as well as that a part of the process could actually be eliminated. The participants mentioned that the model was a good starting point for launching systematic energy work. It was noted that the model had the positive effect of causing participants with different skills to share their knowledge about the processes' subsystems. In the third case study, the results helped to demonstrate that the process's current method might not be needed to meet the quality requirements. Knowledge about that was lacking among the participants, but a new view on the process was created.

In total, 31 EEMs were suggested in the case studies. Only two of them were on the component level, while the rest related to higher system levels. This shows that the groups understood the purpose of the model. The visualisation practices exercised in the model helped to show the effect of system components on industrial processes, to show how they add value to internal customers and to put the customers' requirements into focus. This helps to create a link between energy demand and core industrial activities.

The EEMs were categorised by their complexity and effect on the processes in the priority matrix. Based on these two characteristics, they were given priority numbers. There was no tendency to prioritise only fast measures with low complexity, which is in contrast to single energy audits where most commonly the measures with a short pay-back time are chosen. The complexity of the measures did not seem to be the most crucial factor influencing prioritisation, either. The engagement of the staff in finding EEMs and their prioritisation gave them an opportunity to affect the decision-making process. The team members underwent a mutual learning process. This was exemplified by the fact that the analysed processes' operating parameters and even the process itself (in the third case study) were questioned in terms of optimality. During discussions, several myths and false perceptions about the processes were challenged and corrected.

7.4. Data categorisation, homogeneity and evaluation

Throughout the research, the aspect of data categorisation and homogeneity as well as reliability arose in several projects.

The analysis of the most relevant bottom-up energy data from different countries (Paper III) revealed a large number of various ways of categorising EEU and EEMs and did not allow for further comparison between countries, processes or sectors. Also, the scientific literature showed a number of different ways of categorising data in an attempt of detailed categorisation of EEMs (Fleiter et al., 2012a; Trianni et al., 2014). It was suggested to develop a common taxonomy for industrial SMEs with a division between “Production processes” and “Support processes”. The taxonomy should also include an array of processes under the category Support processes, such as Compressed air, Ventilation, Space heating etc. However, this has to be further explored before being decided upon.

The more non-energy intensive and the smaller the company, the easier it is to make a distinction between production processes and support processes. The category “Production processes” could be used without subcategories, because the production systems of industrial SMEs are greatly diversified. Sector-specific production processes can be structured under “Production processes”, enabling a general taxonomy not only for industrial SMEs but also for energy-intensive and large industrial companies.

For the sake of simplicity and follow-up reasons, it is recommended that the taxonomy for EEU is integrated with the already presented research related to EEMs, with at least an integration of type of sector and type of process (support and production processes etc.). The integration in regard to type of modification is more difficult to integrate with EEU data.

The need for a common structure for gathering bottom-up information about EEU as well as energy-efficiency potential is obvious. More homogenous information could lead to effective benchmarking activities that provide a basis for the promotion of the best actions at all policy-making levels – local, national or even international.

The datasets from the studied countries are the most highly representative data in the studied countries, and it is most likely that policy-makers do not have access to better data, either. This implies that stated energy-efficiency potentials, from, for example, governmental organisations presented for the industrial sector, are, at best, qualitative expert estimations and not based on real bottom-up data.

A homogeneous categorisation of the data was also stated to be relevant in Paper V and Paper IV in relation to the evaluation of energy-efficiency public policies (the SEAP) and the evaluation of IEENs in Sweden. It was found that more consistency in evaluation methods is needed if the evaluation results are to be comparable among programmes and countries as well as to obtain the quantification of energy savings in the case of networks. A common categorisation of energy-related data can be defined as early as at the energy audit stage. This would not only enable the comparison of the evaluation studies but would also increase the

quality of energy audits and gathered data. Assuring the proper recording and reporting of the outcomes of energy audit programmes and energy-efficiency networks is very important to perform a qualitative evaluation study. In turn, the evaluation studies should also be properly designed, performed, recorded, and reported to help policy-makers improve similar forthcoming programmes.

The SEAP and PFE reports underwent a thorough quality control and served as the foundation for the Swedish database DEFRAM (Blomqvist & Thollander, 2015) which is also the first database in Europe that integrates energy-efficiency data.

8

Discussion

This chapter provides a discussion about the major outcomes of this thesis. It starts with a presentation of the extended energy-efficiency potential followed by its ways of deployment. The implications of the thesis's findings on internal industrial energy-efficiency improvement together with implications on public policy development is further discussed.

8.1. Extended energy-efficiency potential

8.1.1. Economic approach in industrial energy-efficiency improvement

A systematic view is necessary to equally address economic, social and environmental sustainability dimensions. Industrial energy systems also embrace all three of them, and therefore energy-efficiency solutions have to be viewed from a system perspective. However, today, as has been shown in this thesis, the pure economic approach prevails. It is not questioned in a modern society to act from an economical point of view, because it is taken as something natural and definitely positive (Bonnedahl et al., 2007).

Defining energy-efficiency potentials accurately is crucial to coordinate the work in the right direction. Various assessment studies have outlined mitigation potentials for different industries and time horizons (IPCC, 2014); however, they focus only on initial investment costs and technological options. This is aggravated by the view that increased uptake of energy-efficiency technologies in the market would inevitably result in improved industrial energy efficiency.

Studies on energy-efficiency barriers that are widespread nowadays are also mainly built on mainstream economic assumptions and market principles. Moreover, in the barrier studies, the actual decision-making is investigated. Thus, energy-efficiency barriers entail barriers to making a decision on a particular technology investment (affirmative or not). Thus, these affirmative decisions are already taken as cost-effective measures. In this case, it is obvious that energy policies are going to be grounded on pure rational decision-making. This, in turn, affects organisational decision-making and investment priorities, creating a vicious cycle.

To better understand the barriers' nature, attempts in the latest research have been made to categorise them in more detail. However, the level of detail does not necessarily provide an answer to how to deal with them. What is important is to view the barriers in a particular context and to consider the cumulative effects of several barriers (Sorrell et al., 2011). All these aspects call for looking at energy-efficiency barriers differently, not merely viewing them as obstacles

to investments in particular technologies. This is why it is important to shift focus from solely technical aspects to a systematic view. For this, it can be necessary to view energy-efficiency barriers using different complexity levels. In other words, the attention should be paid not only to technical aspects but also technological regimes and socio-technical regimes.

8.1.2. Where the potential for improved energy efficiency can be found

One of the main findings of this thesis is that the energy management aspect comprises a significant part of the energy-efficiency gap. This extended energy-efficiency potential accounts for 35–38% in energy-intensive LEs (depending on how energy management is defined). It is worth noting though that this figure is underestimated due to the fact that the PFE database with the total electricity savings of 917 GWh/year does not include an additional 533 GWh/year reported independently for specific reasons.

Thus, technical assessments in the form of energy audits contribute to only part of the gap. Therefore, general economic approaches based on energy-efficient technology distribution models seem not to be enough to close the gap. Furthermore, the economists' and technologists' potentials are estimated higher than these are. This does not leave any room for extended energy-efficiency potential, which has to be revised as depicted in Figure 33 (compare with Figure 4).

Figure 33. Revising potentials to energy efficiency (revised from Jaffe & Stavins, 1994a).

The evaluation of the SEAP also showed that energy audits are only an initial step in energy work and that additional EEMs (to those suggested by energy auditors) could always be found. However, thus far it is common to consider the fact that expert information about the best technological solutions provided to industrial companies would inevitably result in improved energy efficiency. Another issue that arose in the SEAP evaluation study is that the implementation rate in the audit programme was only 54%. One of the major reasons for not implementing EEMs mentioned in the interviews was high payback times. However, the evaluation study of the U.S. IACs showed that even EEMs with low payback times may remain unimplemented. What is more, the SEAP evaluation showed that 10% of the programme's initial applications were withdrawn upon the applicants' request due to a lack of time and interest. This shows lower energy-efficiency awareness among these SMEs, while there are also companies that did not apply for the SEAP at all. This implies that energy-efficiency barriers for these inactive companies are not based solely on profitability and payback time criteria. These companies have to be reached to achieve improved energy efficiency in the whole SMEs industrial sector.

At the same time, it is important to see the difference between continuous energy-efficiency improvement work and the continuous replacement of technologies to BAT. For the former,

energy management-oriented measures and measures requiring behavioural changes are needed. However, the international study of energy-efficiency potentials did not indicate these kinds of EEMs in the analysed data, which also proves that these aspects are not considered at all.

This may seem strange, because industrial EEU is a complicated variety of different processes and cannot be seen as a sum of stand-alone appliances. As a complexity ladder illustrates (Figure 34), the diffusion of technology model may be valid in the ladder's lower parts. In the upper parts, represented by systems or multiple systems, it is not applicable due to challenges that arise when making changes there.

Figure 34. Complexity ladder of energy-efficiency measures (revised from Westling, 2000).

It was shown in this thesis that the majority of energy-efficiency potential is found at the higher levels along the complexity ladder. On the electric motor level, Level 1, the potential is only 4%, followed by the core motor system, Level 2, at 37%, the total motor system, Level 3, at 25% and the extended motor system, Level 4, at 35%. Technological diffusion (levels 1 and 2) comprises 28–49% of energy-efficiency savings. Thus, present energy-efficiency efforts in the form of short- to medium-term discrete activities that stop after the technical assessment belong to levels where not even half of the potential is reached. At the same time, equivalent energy savings at levels 3 and 4 are reached with fewer numbers of EEMs but demand a higher degree of communication and thus are more complex to achieve. The EEMs at the highest level are not represented as investments but rather as optimisation and behavioural change related EEMs. Thus, energy savings increase noticeably if companies have considered the entire system and people involvement. This requires managerial and organisational work which technical consultants performing energy audits in companies seldom can provide.

It is interesting to compare the findings for LEs to similar studies oriented at SMEs. A study of EEMs' categorisation in a manner similar to that in Paper VI was performed on the SEAP database. It showed that energy management potential in SMEs can vary between 3 and 23%, depending on whether control systems EEMs and adjustment EEMs are considered to be management related (Allert et al., 2016). However, the study is performed based on the results from stand-alone energy audits and cannot reflect the energy management work within the SMEs. This is due to the fact that an energy audit as such is only an initial part of energy management. Also, the EEMs proposed in the SEAP are the external expert measures and thus cannot be related to the internal energy-efficiency work. Moreover, considering the findings from the SEAP evaluation study it can be concluded that energy management work within SMEs is underdeveloped (though is considered important) and calls for further research. On the other hand, the participant spill-over of 22% found in the SEAP evaluation indicates that when the companies start to work with EEMs they find new ones.

8.1.3. Complementing existing economic approach

Extended energy-efficiency potential can be reached if the energy-efficiency work continues after a technical assessment by an external expert. Expert knowledge is required, but staff, management models, strategies, and common behavioural patterns within a particular company (all together situated actions) will eventually determine how the expert knowledge and recommendations are going to be used further.

Furthermore, as has been shown, technology replacement activities are not sufficient. EEMs beyond technological measures were found due to the fact that the companies started to work with energy management. This proves that energy management work brings about the ability to look at entire industrial systems instead of single components and promotes a long-term perspective. This is why the staff has to start carrying on energy management work (the optimisation of the performance of particular industrial processes and efficient operation in practice continuously). Outside knowledge covers mainly technological aspects and has to come along with training and energy management practices.

Thus, instead of project-based activities, energy work has to be introduced into the everyday agenda and incorporated into organisational strategies. To initiate this process, it is necessary to increase companies' capacities to absorb energy-related knowledge so that they can become learning organisations. This seems to be quite complicated if a common economic thinking and market models are applied alone; it does not create the conditions for relevant knowledge to stay within industrial companies. Also, in this case, too little attention is paid to the role of industrial personnel and their "integration" with industrial processes, which has been referred to in different parts of this thesis as acting on higher systems levels.

Therefore, the existing economically oriented and technology-focused approach of industrial energy-efficiency improvement has to be complemented by an understanding of how the organisational capacity to absorb energy-efficiency knowledge can be increased.

8.2. How to deploy extended energy-efficiency potential and incorporate energy-efficiency work in organisations

To deploy the extended energy-efficiency potential, it is important to know where to make improvements. However, a more detailed and complicated systematisation of energy-efficiency barriers and the aggregation of EEMs by different levels does not lead to a better understanding. Systematisation can become a never-ending process, causing further confusion (Churchman, 1968). This is why, when dealing with complicated systems, one has to start from identifying a particular context and continue with a system in mind. Further, an ongoing review of systems and components is required.

To incorporate energy-efficiency work within organisations, there is a need for new methods that develop absorptive capacity, the ability to work with energy management (with its continuous improvement and double-loop learning) and a systematic overview of complicated processes. These methods have to be applied to a particular context adding an outside perspective and expert knowledge.

8.2.1. A method to incorporate energy-efficiency work in LEs

A possible method for large companies is presented in the example of the MOVE model (Chapter 7 and Paper VII). It serves as an illustration on how continuous energy-efficiency work can be established in energy-intensive companies. It has been developed considering the aforementioned aspects of the involvement of external expertise, a systems approach, mutual learning and knowledge sharing. The method provides a natural platform for the exchange of experiences and reaching a consensus on how a studied process is operated and what measures can be appropriate at the moment or later.

In the method, management practices are introduced by an external expert, who later trains participants to think in system terms and apply information to a specific context. The participants should have a cross-functional background to make a complete picture of the studied process. The involvement of top management can help to overcome a split incentives barrier, since mutual work increases understanding and trust between decision-makers and operators. Visualisation practices are an important component of the method. They increase comprehension on how industrial systems are integrated and how energy flows add value to internal customers. Moreover, this helps to track and change the patterns in the staff's behaviour that contribute to inefficient EEU and deepens the understanding of processes, systems and potentials. Connecting EEU and internal customer requirements creates a link between energy demand and core industrial activities. In the long run, it can help to make energy efficiency an integral part of the corporate strategy.

The method resulted in finding EEMs at higher system levels. This can be explained by several method activities. Mapping processes by participants helped to determine the internal customer requirements and effects of these on EEU. The EEMs considering several system levels were

found due to the work with internal efficiency. Due to the voting and priority matrix, the measures most appropriate for the particular circumstances were selected. This also gave employees a sense of ownership. The external leadership skills helped to guide the working process along the way.

This proves that such kind of activities can help to shift the focus from discreet EEMs to continuous energy-efficiency work. It is important, though, that the company's energy responsible individual is the one who takes over the working procedures so that he or she can continue practising the method on other processes. In this way, the knowledge and obtained experience stay available within the company after the project ends. In the long run, it helps to change the organisational culture of a particular company.

It is worth noting, though, that this method has been developed and tested in Sweden, where the relationship within a particular company has a more vertical and flexible character, while in other countries it might have a more defined hierarchy, which can affect the outcome.

8.2.2. A method to incorporate energy-efficiency work in SMEs

Applying such approach as described above for SMEs can be problematic due to a lack of resources. Participating in an IEEN set up for SMEs, in turn, can help to overcome energy-efficiency barriers typical for SMEs. This is done by means of delegating energy management practices to network administration. The novelty of the method is thus centred around mutual learning and the consequent introduction of energy management practices under the coordination of the IEEN's administration.

By participating in an IEEN, SMEs can access resources they would not be able to access otherwise: knowledge and expertise in the energy field, information on available governmental support, help with bureaucratic procedures and inspiration from other companies etc. SMEs get help with making energy audits, setting energy goals and defining energy strategies and energy plans. Network participants who obtain information about available solutions from energy experts and their peers and through experience exchange eliminate many of the risks related to EEMs' implementation. Participating companies can achieve a higher level of self-confidence regarding trying new solutions due to the possibilities to consult and discuss with someone in the same field or experts. In this way, networking can increase the implementation rate of the EEMs proposed in audits. What is more, networks' representatives can transfer the knowledge and experience acquired to their respective companies.

For IEEN to be successful, good administration is crucial. An administrative role has to be taken by committed personal who are able to drive work within a network, organise meetings, create engagement and find experts within the field. IEEN administration has to create conditions for a good level of dialogue during meetings so that all participants can feel that they are contributing to the discussion and gain from it. Also, active enrolment in networking activities and commitment is required of the participants. Special attention should be given to the

involvement of top management, since its attitudes and actions are decisive for the whole strategy of the companies.

An IEEN is a complex type of energy service that requires continuous and structured work to be successfully adopted. Thus, a network should be properly designed and managed. A general theoretical model with phases, milestones and the necessary components, proposed in Paper I, can serve as a guideline on how an IEEN can be managed. Follow-up procedures comprise a necessary component of the model. This should be determined from the beginning on the network level to assure the evaluation of the network performance in terms of energy and money saved throughout networking and after it has finished.

By following these guidelines, an IEEN can become an area for double-loop learning and spreading knowledge about energy efficiency to every employee of a company. Therefore, networking by means of learning from one's own and others' experiences in IEEN can result in increased absorptive capacities within participating SMEs. Also, the entire energy-efficiency potential for networks not only involves technological measures (mostly proposed in energy audits) but also improvements related to training and operational measures. Participation in an IEEN can shift the attention from solely the techno-economic aspects of energy efficiency to the behavioural aspects as well. Thus, IEEN as such is a way of running energy management activities in a group of SMEs. In the long run, an IEEN can become a fostering organisation initiating changes in attitudes and behaviours among participants.

8.2.3. The homogeneity of energy data

Apart from the methods described above, the importance of the homogeneity of energy data and the proper way of handling it has to be mentioned and further discussed. It was relevant in the five papers that required a large amount of energy statistical data for analysis or the energy programmes' evaluation and analysis. Knowing where energy is used in industry and where the improvement potential can be found can further facilitate energy-efficiency work. However, different ways of data categorisation may complicate the process. Some efforts have been put forth by Fleiter et al. (2012a) and Trianni et al. (2014) to develop a detailed classification scheme for EEMs. However, it is not the level of detail that is important but rather the data homogeneity and a common taxonomy. This can enable an effective gathering of bottom-up information about EEU and EEMs and assure its quality from the very beginning.

As it was mentioned in Chapter 7, the data from the SEAP and the PFE resulted in a creation of the first in Europe energy-related database DEFRAM. In the future, the development of a central data portal where the collected energy data from LEs and SMEs can be reported and stored is suggested on a broader level, for example, on the level of the European Union. The importance of such a portal should not be underestimated, because it can raise the requirements on industrial companies regarding their energy-efficiency work (especially SMEs), the monitoring of their EEU and the control of EEMs implementation. Moreover, more homogenous data could lead to effective data comparisons on different levels (process, sector, international level) through the development of relevant key performance indicators. However,

this requires significant efforts to assure data quality control prior to storing it in the portal. During the work with the DEFRAM, the data quality control was undertaken by joint efforts of a research group from the Energy Systems division at Linköping University.

8.3. Implications for internal industrial energy-efficiency work

The methods presented are examples of how to integrate energy-efficiency work in the form of energy management within industrial companies. Industrial companies have different access to resources in the form of personnel, time and money, depending on their size. Therefore, the methods that can be used for increasing industrial absorptive capacity and incorporation of energy-efficiency work have to be shaped differently taking company sizes and access to resources into consideration.

The methods presented in this thesis are not provided as “solving-everything ultimate solutions”. It has been shown in this thesis that situated actions in the form of the particular industrial context, specific circumstances, employees’ backgrounds and interaction dynamics have a great effect on the outcome. However, both presented methods have several parameters in common. These parameters have to be taken into consideration when designing methods for successful energy-efficiency work:

- 1) Proper administration, the sound leadership and external skills are required from the very beginning to guide the work and serve as an initial source of skills and knowledge that should be translated to the companies’ employees.
- 2) The knowledge has to stay within organisations independent of personnel changes. This requires active staff involvement and initial top management support.
- 3) A continuous loop of learning, reflections and improvement is required, which are the intrinsic parts of energy management. As mentioned throughout the thesis, energy management work is the key to improved energy efficiency. However, this concept is often mixed with energy management systems, which is only a tool and does not necessarily lead to the establishment of successful continuous energy-efficiency work.
- 4) Maintaining a system perspective is crucial for finding the solutions beyond the component level. As shown in this thesis, these solutions bring the highest energy-efficiency savings.

The difference between the methods for LEs and SMEs is that energy management is accomplished either internally or externally, depending on the company’s available resources. In the first case, it means involving the staff, creating an energy management position (if there is no one) or even an energy team that would be able to work with industrial processes optimisation considering the energy aspect. In the second case, it means delegating energy management activities to IEEN administration. In the long run, with increased awareness of energy issues and the increased importance of the topic as well as improved competences, it may be possible to establish an energy management position even within SMEs or at least to assign its activities to a person dealing with quality and environmental issues.

Thus, both methods contribute to the initiation of continuous energy-efficiency work within the companies. Energy-efficiency improvement becomes activities related to the continuous optimisation of existing and new processes bearing energy efficiency in mind rather than discrete activities related to the replacement of technologies with more energy efficient ones. The role of staff should not be underestimated in this matter, because it is the operators who possess the actual knowledge about the industrial processes.

8.4. Implications for industrial energy-efficiency policies development

It is very important to ensure that scientific outcomes serve to policy-makers in reality rather than stay just scientific outcomes. Based on the findings of this thesis, some general recommendations can be given regarding the development of industrial energy-efficiency policies. The present EU energy policies rely a great deal on mainstream economic assumptions being the root cause of the energy policy gap. One example is the Eco-Design Directive that promotes the diffusion of energy-efficient equipment on the market or member countries' national energy-efficiency action plans. However, if public policies are designed based on a wrong assumption, this leads to unnecessary public expenditures. The oversupply of new technologies in the market might be less needed in coming years when every new generation of equipment becomes increasingly more reliable, especially considering the long retirement times of current technologies. Also, it does not solve the situation with the existing stock of equipment which has to be taken care of.

Thus, there is a need to overcome a policy lock-in on the view that the faster diffusion of energy-efficient technologies can help to overcome the energy-efficiency gap. This can be done by looking at industrial energy efficiency from an extended system perspective, which requires the development of complementary theoretical models. These models have not been developed in this thesis. However, the findings presented here lay the groundwork for that. It has been empirically shown that the technological aspect represents only a part of the energy-efficiency gap, and even this part is only limitedly approached by energy audits. In a new theoretical model, the technological focus on energy-efficiency work should be completed via requirements of the development of organisational learning skills for increased energy-related knowledge intake and the consequent establishment of energy management practices. Such new models can help to strengthen existing public energy and climate policies.

It is important for policy-makers to understand that a technical assessment of industrial facilities where the information comes from technology-oriented experts is only an initial step. This results in short- to medium-term discrete activities and cannot fully achieve reaching the energy-efficient potential. There is a need to ensure that the energy-efficiency work continues through the establishment of energy management practices within organisations. Thus, it seems essential to consider the application of energy management components in the design of industrial energy policies. The PFE dataset used in this paper for analysing the energy-efficiency potential in LEs is derived from the Swedish voluntary agreement policy PFE. This

shows that VAs in which energy audits are complemented with energy management activities are actually more reasonable policies for energy-intensive companies, since they can be a foundation for establishing continuous energy-efficiency work within the industrial companies. Energy audits within the PFE also resulted mainly in technology-oriented EEMs, meaning that the remaining EEMs that are more oriented at behavioural changes and the optimisation of processes were due to consequent energy management work.

As for SMEs, if these do not have enough resources and competences, energy management practices can be delegated to IEENs. Thus, this type of energy service in the form of a national governmental supporting scheme can be a sound approach. In later stages, when networks become more mature, they can be financed by participants. Another potential future for energy networks could be to offer a tax exemption as in Switzerland, which can be tested in other countries as well.

Support for the development of a central energy data portal for storing EEU and EEMs data from industrial companies can also be a sound solution. Such a portal can serve as a platform for presenting the national industrial EEU data and choosing the best EEMs at a national level. This can also contribute to easier and more thorough evaluations of public policies. Also, more trustworthy data assure higher transparency of the released public policies' outcomes. The latter seems to be quite problematic now due to the fact that evaluations are often based on economic estimations instead of real data and engineering calculations. In general, a central energy data portal could serve as a good means for the improvement of similar forthcoming policies.

9

Conclusions

This chapter wraps up the main findings of the thesis and presents the answers to the research questions.

In this thesis, the hypothesis that industrial energy-efficiency potential lies beyond only technology-oriented EEMs has been validated and extended energy-efficiency potential has been quantified. The theoretical insights within the fields of system research, organisational and innovation research, network governance and science and technology studies have been combined and served as a foundation for developing an understanding on how the extended energy-efficiency potential can be reached. The methods proposed in this thesis have been developed based on these theoretical insights. Furthermore, the deficiencies in the existing view of industrial energy-efficiency improvement have been revealed, calling for the development of new theoretical models that would be able to better describe this view. Thus far, attempts have not been made to complement the common technology-focused view on energy-efficiency improvement.

Building on this, the answers to the research questions stated at the beginning have been provided.

1) What is the energy-efficiency potential and extended energy-efficiency potential respectively in Swedish industry?

Extended energy-efficiency potential is the potential for energy-efficiency improvement considering energy management practices. Here, energy management entails continuous work on improving energy efficiency through auditing, maintenance, monitoring, reporting, analysing and training. It was quantified that energy management potential comprises 35–38% of the energy-efficiency gap in energy-intensive LEs. The technological potential thus accounts for the rest. A similar quantification for SMEs shows that energy management potential is 3% and 23% if control systems EEMs and adjustment EEMs are defined as management EEMs. However, the numbers for SMEs are not objective, since these come from energy audits and cannot reflect the energy management work within the SMEs. It is also hard to estimate the energy management potential within SMEs due to the fact that the energy management work there is underdeveloped. However, the company visits revealed a significant potential for further work.

The technology diffusion model is only valid in lower parts of the complex industrial energy systems, while the majority of energy-efficiency potential is found on the higher levels of these

systems. Technological diffusion comprises 28–49% of energy-efficiency savings which is likely underestimated as well. Moreover, the energy savings at higher levels can be achieved with fewer numbers of EEMs. EEMs at higher levels are not investments but rather optimisation and behavioural change related. These findings prove that technical assessments in the form of energy audits contribute to only part of the gap.

2) Are present efforts enough to reach the extended energy-efficiency potential?

The view that increased uptake of energy-efficiency technologies in the market would result in improved IEE prevails. Since the present potential assessments are based on the technological diffusion model, the focus is given to initial investment costs and technological improvement opportunities. The way energy-efficiency barriers are viewed is also based on the assumption that EEM represent investments in energy-efficiency options. Thus, the decision-making regarding these EEMs entails a simple process of deciding whether or not a particular technological option is cost-effective. This is based on an incomplete view and leaves behind the complexity of industrial energy systems, and public policies and supporting frameworks to overcome these barriers are designed accordingly (the EU's Energy Labelling Directive and Eco-Design Directive and the EU's Action Plan for Energy). Even such policies as VA and LTA, subventions and certifications for energy service markets' promotions are based on the assumption that making energy-efficient technologies less expensive will eventually result in improved energy efficiency.

Energy audits in the form of technical assessment are widespread, but these are only the initial step in energy work and are often bounded to the skills of an auditor. Moreover, energy audit programmes cannot reach the companies with lower awareness on energy efficiency, and the implementation rate of EEMs suggested in audits is often not higher than 50% in those companies who participated. Also, technical consultants performing audits cannot assure the establishment of consequent work on energy efficiency. Thus, energy-efficiency work is viewed as short- to medium-term discrete activities that stop after the technical assessment. This results in the fact that not even half of the potential is reached.

The international study of energy-efficiency potentials did not indicate energy management and behavioural change related EEMs, proving that these aspects were not paid much attention among industrial companies.

3) What are efficient ways to incorporate energy-efficiency work in SMEs and LEs?

To incorporate energy-efficiency work in industrial companies there is a need for new methods based on improving organisational capacity to absorb the energy-related knowledge coming from technical experts. These new methods have to include such aspects as management work with continuous improvement and a systematic view of industrial processes and apply them to particular organisational circumstances. The capacity to absorb energy-related knowledge and to work on energy efficiency continuously is different for SMEs and energy-intensive LEs due to different access to resources in the form of personnel, time and money. This is why these have to be approached differently depending on company size and access to resources.

In this thesis, it was exemplified how energy-efficiency work can be integrated within SMEs and energy-intensive LEs. Both methods are based on the idea that industrial companies have to step aside from project-based technology replacement activities and incorporate energy work into their everyday agendas and organisational strategies. The presented methods are not provided as ultimate solutions. However, they depict the main important parameters that have to be taken into consideration when developing alternative methods for successful energy-efficiency work (Figure 35). Firstly, proper administration and expert skills are required at the beginning. Secondly, there is a need to assure that skills and knowledge remain within companies independently of personnel changes. Thirdly, continuous improvement work is required in the form of energy management. Fourthly, maintaining a system view is required for finding the solutions beyond the technological level. The importance of energy data homogeneity can be considered here as well.

Figure 35. Important elements of methods for the incorporation of energy-efficiency work within companies.

Depending on the availability of resources, energy management practices can be accomplished internally or externally. In large companies, this involves the establishment of a team that would be able to find possible solutions for industrial energy systems' optimisation. In SMEs, energy management activities can be delegated to energy network administration. However, in the long run, an energy management position becomes a necessity. The staff's skills and knowledge of industrial processes should not be underestimated.

- 4) *How should be energy-efficiency policies designed to promote the achievement of extended energy-efficiency potential?*

The policy lock-in on the view that technological diffusion improves energy efficiency has to be overcome. This may require the development of complementary theoretical models based on the findings presented in this thesis. Such new models can help to strengthen existing public energy and climate policies. It is of utmost importance to consider the application of energy management components in the design of industrial energy policies. VAs in which energy audits are followed by energy management activities is an option for energy-intensive companies. In SMEs, energy management practices can be delegated to IEENs' administration. Networks represent a type of energy service that can be supported on a governmental level. A tax exemption for the companies participating in networks can also be a sound option.

When working on public energy-related policies, the importance should be given to viewing barriers to energy efficiency using a classification approach similar to the one introduced in Chapter 5. In other words, the system boundary of the present view on energy-efficiency barriers should be expanded to include entire industries, the involved actors and their values and societal rules and regulations.

The methods suggested in the thesis and their policy implications point to a way of achieving the hypothetical energy-efficiency potential by covering both the energy technology and management gap at the same time. This is an important remark because the extended energy-efficiency gap can only be bridged when synergies between those are considered. This should be taken into consideration when public policies are designed. This is depicted by Figure 36.

Figure 36. Reaching hypothetical energy-efficiency potential.

One final suggestion on public policies implication is to provide financial support for the development on a broader level of a central energy data portal. In this kind of portal, EEU and EEMs data from industrial companies can be stored in a way similar to the DEFRAM. This can serve as a platform for energy work at a national level and can also contribute to the evaluation of public policies as well as assuring public policies' greater transparency. The central energy data portal can also serve as a good means for the improvement of forthcoming policies.

10

Further work

In this chapter, the possibilities for further work are outlined.

The findings of this thesis revealed the need to complement the existing view of industrial energy efficiency with theoretical models that look at this not only through the mainstream economic theories but also include management aspects and the human factor. The insights into absorptive capacity found in innovation research, organisational change and learning can be a significant contribution to the theoretical development.

Also, the growing field of research in the area of barriers to improved energy efficiency – which is commonly based on the assumption that technological diffusion is the solution for energy-efficiency improvements and that EEMs are made in the form of investments – has to be reconsidered. Future research in this area has to reconsider how energy-efficiency barriers are viewed: “what is a barrier?”. It is thus suggested to complement existing studies with studies on barriers to energy management and related measures. This can be especially relevant to such particular barriers as hidden costs, as these costs might be higher for some types of energy management practices.

Moreover, the methods presented in this thesis should be further studied and evaluated. First, it is important to obtain quantitative data on the work of IEENs for SMEs. This can not only help to evaluate their performance but also provide the foundation for estimating the energy management potential for SMEs. The MOVE model as an example of a method for energy-efficiency work establishment in LEs has to be further applied on a larger scale. This also requires collecting quantitative data and the further evaluation and estimation of the energy savings the method results in. In relation to this a need for a common taxonomy can be mentioned here again.

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