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TOWARDS INCREASED ENERGY EFFICIENCY IN SWEDISH INDUSTRY
- BARRIERS, DRIVING FORCES & POLICIES

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This thesis is based on work conducted within the interdisciplinary graduate school Energy Systems. The national Energy Systems Programme aims at creating competence in solving complex energy problems by combining technical and social sciences. The research programme analyzes processes for the conversion, transmission and utilisation of energy, combined together in order to fulfil specific needs.

PROGRAM
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The research groups that participate in the Energy Systems Programme are the Department of Engineering Sciences at Uppsala University, the Division of Energy Systems at Linköping Institute of Technology, the Department of Technology and Social Change at Linköping University, the Division of Heat and Power Technology at Chalmers University of Technology in Göteborg as well as the Division of Energy Processes at the Royal Institute of Technology in Stockholm.

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Abstract

Industrial energy efficiency is one of the most important means of reducing the threat of increased global warming. A higher use of electricity than their European competitors, and increased energy costs due to increasing energy prices in Swedish industry have negative impacts on results and competitiveness. Of great importance are thus different means which promote energy efficiency such as industrial energy policy instruments. However, cost-effective energy efficiency measures are not always undertaken. In order to formulate and adopt accurate industrial energy end-use polices, it is thus of importance to identify the barriers which inhibit the implementation of cost-effective energy efficiency measures. It is also of importance to identify the factors which promote the implementation. The aim of this thesis is to analyze industrial energy systems and more specifically study factors that promote or inhibit energy end-use efficiency in Swedish industrial companies.

Results from this thesis show that the implementation of technical energy efficiency measures is a major means for energy-intensive as well as non-energy-intensive Swedish companies to overcome the threat of rising energy prices, for example for electricity. While energy efficiency measures in the non-energy-intensive industry are related mainly to support processes, measures in the studied energy-intensive Swedish foundry industry are related to both support and production processes.

In the various case studies of barriers and driving forces, the most significant barriers to energy efficiency - with large variations for some of the barriers among the studied cases - were found to be: *technical risk such as risk of production disruptions*; *lack of time or other priorities*; *lack of access to capital*; *cost of production disruption/hassle/inconvenience*; *other priorities for capital investments*; *technology regarded as inappropriate at the site*; *difficulty/ cost of obtaining information about the energy use of purchased equipment*; and *lack of budget funding*. The largest driving forces, apart from *cost reductions resulting from lowered energy use*, were found to be the existence of a *long-term energy strategy* and *people with real ambition*. These driving forces did not, unlike the results of barriers to energy efficiency, vary widely across the studied sectors.

Investment decision support such as optimization has shown to add more information for larger capital-intensive investments in energy-intensive industrial SMEs. The thesis also showed that energy audits are an effective means, in terms of public money spent per kWh saved, of providing the industry with information on potential energy efficiency measures.

Based on the results presented in this thesis, a policy approach towards non-energy-intensive companies and industrial SMEs should primarily include providing energy audits free of charge and involve the local authority energy consultants.

Sammanfattning

Industriell energieffektivisering är ett av de viktigaste sätten att reducera hotet om en global uppvärmning. En högre relativ elanvändning, i jämförelse med europeiska konkurrenter, tillsammans med stigande energikostnader beroende av stigande energipriser för den svenska industrin, riskerar leda till försämrad lönsamhet och försämrad konkurrenskraft. Det är således av stor vikt att främja energieffektivisering, exempelvis genom olika typer av styrmedel. Lönsamma energieffektiviseringsåtgärder genomförs emellertid inte alltid, till följd av olika hinder för energieffektivisering. För att kunna formulera precisa styrmedel är det därför av stor vikt att dessa hinder som förhindrar implementering av energieffektiviserande åtgärder, identifieras. Det är också av stor vikt att identifiera drivkrafterna. Syftet med denna avhandling är att analysera industriella energisystem och mera specifikt studera faktorer som främjar och förhindrar effektiv slutanvändning av energi i svensk industri.

Resultaten visar att hotet om stigande energikostnader, exempelvis beträffande elektricitet, både för icke energiintensiv och för energiintensiv svensk tillverkningsindustri, kan reduceras kraftigt om energieffektiv teknik implementeras. Medan åtgärder i icke energiintensiv industri främst är relaterade till stödprocesser så visar sig åtgärderna i den studerade svenska energiintensiva gjuteriindustrin vara relaterade till både stöd- och produktionsprocesser.

I fallstudierna beträffande hinder och drivkrafter visade sig de största hindren vara - med stora variationer mellan fallen - *tekniska risker såsom risk för produktionsstörningar och avbrott*; *brist på tid/andra prioriteringar*; *brist på kapital*; *kostnader för produktionsstörningar*; *icke energirelaterade investeringar prioriteras högre*; *tekniken passar ej för företaget*; *svårigheter/kostnader att erhålla korrekt information beträffande energianvändningen av den inköpta utrustningen*; och *brist på budgetmedel*. De största drivkrafterna var, utöver *kostnadsminskningar till följd av minskad energianvändning*, förekomsten av en *långsiktig energistrategi* och en *eldsjäl*. Drivkrafterna varierade inte, till skillnad mot hindren, så mycket mellan de olika undersökta fallen

Beslutsstöd såsom exempelvis optimering har visat sig kunna ge ökad information vid större mer kapitalintensiva investeringar i energiintensiva små- och medelstora företag. Vidare har energianalyser visat sig vara ett effektivt sätt, i termer av besparad kWh per statligt insatt krona, att ge industrin information beträffande möjliga energieffektiviserande åtgärder.

Resultat från avhandlingen indikerar att ett stöd gentemot icke energiintensiva och små och medelstora företag framförallt bör inkludera statligt finansierade energianalyser med den lokala energirådgivaren som en deltagande aktör.

And further, my son, be admonished by these. Of making many books there is no end, and much study is wearisome to the flesh. (Ecclesiastes 12:12)

List of appended papers

Paper I

Patrik Thollander, Magnus Karlsson, Mats Söderström, Dan Creutz
Reducing industrial energy costs through energy-efficiency measures in a liberalized European electricity market: case study of a Swedish iron foundry
Applied Energy, 81 (2): 115-126 Elsevier (2005)

Paper II

Patrik Thollander, Jenny Palm, Mats Söderström
Industrial energy auditing - a key to competitive energy-efficient Swedish SMEs
Invited publication in Energy Efficiency Research Advances, ed. David M. Bergmann, 213-238 Nova Publisher (2008)

Paper III

Patrik Rohdin, Patrik Thollander
Barriers to and driving forces for energy efficiency in the non-energy-intensive manufacturing industry in Sweden
Energy, 31 (12): 1836-1844 Elsevier (2006)

Paper IV

Patrik Rohdin, Patrik Thollander, Petter Solding
Barriers to and drivers for energy efficiency in the Swedish foundry industry
Energy Policy, 35 (1): 672-677 Elsevier (2007)

Paper V

Patrik Thollander, Patrik Rohdin, Maria Danestig
Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs
Energy Policy, 35 (11): 5774-5783 Elsevier (2007)

Paper VI

Patrik Thollander, Mikael Ottosson
An energy-efficient Swedish pulp and paper industry - exploring barriers to and driving forces for cost-effective energy efficiency investments
Energy Efficiency, 1 (1): 21-34 Springer (2008)

Paper VII

Patrik Thollander, Nawzad Mardan, Magnus Karlsson
Optimisation as investment decision support in a Swedish medium-sized iron foundry - a move beyond traditional energy auditing
Accepted for publication in Applied Energy, Elsevier (2008)

Acknowledgement

The very first week of my PhD studies at the division of energy systems and the interdisciplinary research programme, Energy Systems Program, my supervisor Mats Söderström suggested, based on my previous experience at the Energy Agency of South East Sweden working in particular with industrial SMEs, e.g. energy auditing, that a suitable research topic would be: *obstacles and driving forces for energy efficiency in industrial SMEs*, emphasizing both energy-intensive and non-energy-intensive industrial SMEs. In addition, the interaction with social science researchers within the interdisciplinary research programme, at the beginning of my PhD studies, opened up for a wider methodological and theoretical approach than what would have been the case without the programme. I owe great thanks to all parties involved in this transition, including my PhD student colleagues (within the research programme and the division of energy systems), senior researchers and my supervisors. I would especially like to express my great appreciation to my supervisor Mats Söderström who throughout the process has been a tremendous help and encouragement, especially when things did not turn out as planned. A few minutes in his office and motivation began to flood again. Thank you Mats! I would also like to express my gratitude to my co-supervisors Magnus Karlsson and Jenny Palm. Magnus, you have been a great encouragement, not least when conducting *MIND* studies and Jenny, sincere thanks for all the hours of commenting on my early drafts of various papers and the discussions about, among other things, social science research issues! I am also grateful to Dr Anna Wolf who provided useful comments on an early draft of this thesis. I would also like to thank all the co-authors of the appended papers, Patrik Rohdin, Mikael Ottosson, Petter Solding, Nawzad Mardan, Maria Danestig and Dan Creutz, not to mention all the people who were involved in commenting on and providing support on the appended papers. Thank you all! I would also like to express my appreciation of the great collaboration with Swerea SWECAST, previously the Swedish Foundry Association, throughout the years. I would also like to express my appreciation to Åke Eriksson and Marja Andersson and everyone else involved in the research related to the foundry industry. Furthermore, I would like to express my gratitude to all my colleagues at the division of energy systems under the leadership of Professor Bahram Moshfegh and all the staff involved in the industrial consortium of the Energy Systems Program under the leadership of Professor Thore Berntsson. Thank you! Also, thank you Sara for all the support throughout the years, for being such a precious jewel, a wonderful wife and my very best friend! Great thanks also to my lovely children David, Johannes, Hanna and Simon, my dear brothers Carl-Johan and Erik, my lovely mother, Ingrid, my dear grandmother Eva, her husband Karl-Axel, and my mother- and father-in-law, Ingrid and Åke! Finally, may I also express my great thanks to the Living God for the strength you give through faith in your Son’s finished work on the cross of Calvary. The joy of the Lord is my strength!

Thesis outline

The thesis consists of an introduction to, and a summary of, the seven appended research papers and the appended papers. The thesis is outlined as follows:

Chapter 1 gives an introduction to the conducted research. The subject of the study is introduced along with aim, research themes, scope and delimitations. Then a paper overview, co-author statement as well as a description of the research journey is presented.

Chapter 2 presents an overview of industrial energy efficiency, both from the industry's and the society' perspective along with some European and Swedish energy polices.

Chapter 3 includes an overview of the research in the field of barriers to energy efficiency.

Chapter 4 presents some important aspects related to industrial energy programmes and include a summary of actions taken in Sweden.

Chapter 5 addresses the methods used, and describes, in brief, how the methods have been applied.

Chapter 6 presents briefly the different cases studied.

Chapter 7 presents the results from the case studies.

Chapter 8 discusses and summarizes general conclusions along with a policy discussion related to the Swedish industry. The chapter also includes a presentation of the thesis major contributions along with suggested areas of interest for further research.

TABLE OF CONTENTS

Chapter 1

1 INTRODUCTION

In this chapter, the thesis' background is outlined together with the aim and research themes. The scope and definition of major terms is presented and an overview is given of the appended papers, as well as other publications not included in the thesis. Co-author statements as well as a brief overview of the research journey are also presented.

Increased global warming resulting from the use of fossil fuels is posing a major threat to the environment. Industrial energy efficiency is one of the most important means of reducing the threat of increased global warming (IPCC, 2007) as the industry accounts for about 78 percent of the world's annual coal consumption, 41 percent of the world's electricity use, 35 percent of the world's natural gas consumption, and nine percent of global oil consumption (IEA, 2007). Of great importance are thus different means which promote energy efficiency for the sector. In the European Union, growing concern for increased global warming has led to the implementation of a number of policy instruments such as the EU Emission Trading Scheme (ETS) and the European Energy End-Use Efficiency and Energy Services Directive (ESD) where each member state is obliged to formulate and design a National Energy Efficiency Action Plan (NEEAP). From the industry's perspective, the adoption of demand side policy instruments like the *ETS* will most likely result in higher European energy prices which on the one hand will motivate the industry to take actions toward increased energy efficiency but on the other hand may lead to competitive disadvantages compared to industries outside Europe (ECON, 2003). For the Swedish industry, energy prices have risen significantly in recent years. Between 2000 and 2006 electricity prices in Swedish industry almost doubled and oil prices rose by about 70 percent (Johansson et al., 2007, SEA, 2006a). The electricity price increases were partly due to the liberalization of the European electricity markets (EC, 2001) as the liberalisation has caused the domestic markets to converge and Sweden has for a long time enjoyed one of the lowest electricity prices in Europe (EEPO, 2003). While the oil price increases may not create competitive disadvantages solely for Swedish industry, the electricity price increases most likely will, as this is particularly related to the Swedish industries and the fact that the historically low electricity prices have resulted in a higher use of electricity than their European competitors in many Swedish industrial sectors.

Industrial enterprises are, however, affected differently by higher energy prices depending on the energy cost in relation to the added value[1]. Energy-intensive industries like foundries and pulp and paper mills are threatened to a much larger extent than non-energy-intensive industries like the engineering industry. While the non-energy-intensive engineering industry has energy costs in relation to the added value of only 1-2 percent, energy-intensive foundries are facing values of 5-15 percent (SFA, 2004) and energy-intensive process industries like pulp and paper mills are facing figures well beyond 20 percent (SEA, 2000).

Closely related to the energy intensity is the discrepancy between support and production processes. While support processes are categorized as processes which support production, production processes are related to the actual production. For the heavily capital-intensive paper industry, where, for instance, a paper machine may cost several hundred million EUR, a shift in the production process is not easily accomplished, nor are investments in new melting units within the foundry industry. On the other hand, the implementation of more energy-efficient support processes within non-energy-intensive industries may be easier to implement. This is in turn closely related to the discrepancy between operational and strategic actions and the investment's initial cost. While many of the energy efficiency actions related to the support processes such as ventilation, space heating and lighting have a lower initial cost compared with heavily capital-intensive production processes, the former type of measures may be taken on an operational level while many of the heavily capital-intensive production process related investments are more closely related to strategic activities.

Regardless of the magnitude of energy costs in relation to the added value, increased energy costs in an industry have negative impacts on results and competitiveness, which in turn may lead to lower production and in some cases even cause enterprises to consider moving abroad (ECON, 2003). On the other hand, such increasing energy costs will most likely increase the motivation to take energy efficiency actions. Increased energy efficiency positively affects a company's overall costs directly and also in many cases leads to greater productivity which in turn leads to higher profits (Worrell et al., 2003). However, while the motivation for taking energy efficiency action exists, and for the Swedish industries has even increased, research has shown that cost-effective[2] energy efficiency measures are not always undertaken, due to different barriers to energy efficiency such as *imperfect information*, *hidden costs*, *lack of access to capital*, *risk* and *heterogeneity*, to name only a few (Sorrell et al., 2000). Of special interest are barriers related to so-called *market failures* or *market imperfections*, e.g. *imperfect* and *asymmetric information*, as these may motivate public policy intervention. In order to formulate and adopt accurate industrial energy end-use polices, it is thus of importance to identify the barriers which inhibit the implementation of cost-effective energy efficiency measures as well as to identify the driving forces which promote the implementation.

While studies regarding energy efficiency, both at strategic and operational levels (mainly in production processes) has been frequent in the Swedish pulp and paper industry (Klugman, 2008, Wolf, 2007, Andersson et al. 2006, SEA, 2006b, Wising et al. 2005, Sandberg, 2003, Bengtsson et al., 2002), the energy-intensive Swedish foundry industry has not been paid as much attention, which emphasizes the need for studies at both operational and strategic level in this sector. Scientific studies of energy efficiency have also been conducted in the non-

[1] For a more thorough description of the definition of added value, see PWC (2007).
[2] A cost-effective energy efficiency measure is defined as an investment which lowers the use of energy, and which is considered cost-effective according to the company's investment criteria.

energy-intensive industries, mainly regarding the support processes identified through energy auditing (Trygg, 2006, Nord-Ågren, 2002, Dag, 2000), while studies beyond applied engineering approaches on, for example, both the degree of implementation after an energy audit, studies of the actual energy audit method itself and areas of improvement for the method, have not been given as much attention. Moreover, studies on barriers to and driving forces for energy efficiency in Swedish industry have until now been scarce and research focusing on non-energy-intensive companies and industrial small and medium-sized enterprises (SMEs) have been limited. Finally, the adoption of the *ESD*, which targets non-energy-intensive industries and SMEs in particular, emphasizes the importance of discussing plausible energy end-use policy options for these sectors, not least in relation to the *ETS* and its effect on energy efficiency[3].

1.1 Aim and research themes

The aim of this thesis is to analyze industrial energy systems and more specifically study factors that promote or inhibit energy end-use efficiency in Swedish industrial companies.

The aim is partitioned into four research themes. The first theme regards what type of energy efficiency measures that exists in the energy-intensive Swedish foundry industry and energy efficiency measures' impact on future energy cost. The second theme regards barriers to, and driving forces for energy efficiency. The third theme regards optimization as investment decision support. The fourth theme regards energy audits and energy audit programmes.

1.2 Scope and delimitations

This thesis deals with industrial energy end-use efficiency in Sweden, mainly from the industry's perspective but European and Swedish perspectives on the issue are also included. The thesis is focused on non-energy-intensive industrial companies and industrial SMEs. However, the energy-intensive process industry is also included as a part of the thesis comprising the largest Swedish energy using industrial sector, namely the pulp and paper industry. In studying energy end-use efficiency in industrial energy-using organizations, not only the part of the system dealing with technology and the potential for the implementation of efficiency measures but also the part dealing with individuals and industrial organizations who are the ones who are to implement the technology, are of importance. This emphasizes the use not only of applying engineering approaches but also social science research methods. Moreover, the complexity of industrial energy efficiency comprising individuals, organizations, technology etc., emphasizes the importance of not solely narrowing the research into studying one single factor, promoting or inhibiting energy efficiency, from one single perspective. Instead, a systems approach has been applied to study different energy efficiency technologies, barriers and driving forces, including production and support processes at both operational and strategic levels.

As stated previously, research has identified plausible technical energy efficiency measures for both Swedish non-energy-intensive companies, in particular related to the support processes, and technical energy efficiency measures for the energy-intensive industries, for

[3] According to the Swedish Climate Committee (2008), energy efficiency actions related to electricity and district heating will not necessarily result in lower CO_2 emissions within an *ETS* period, see chapter two for an overview of this discussion. For a more detailed discussion of this, see SCC (2008).

example the Swedish pulp and paper industry, mainly related to the production processes. However, neither technical energy efficiency measures in the energy-intensive Swedish foundry industry, nor the impact the implementation of energy efficiency measures will have on an industry's aggregated energy costs have been extensively studied, motivating the first research theme to be investigated: this part begins with identifying technical energy efficiency measures, related to both production and support processes, within the Swedish energy-intensive foundry industry, and the role of energy efficiency with future, higher electricity prices. This part comprised an energy-intensive Swedish iron foundry and a non-energy-intensive engineering industry which were thoroughly audited, as well as five other Swedish iron and steel foundries.

Technical energy efficiency measures exist in different industrial sectors, but cost-effective energy efficiency measures are not always undertaken due to the existence of different barriers to energy efficiency. The lack of Swedish barrier studies in different industrial sectors together with a need to identify barriers to energy efficiency in order to formulate and adopt accurate energy polices towards the industrial sectors, among other things, motivated the second research theme to be investigated: this part of the thesis includes four case studies of barriers to and driving forces for energy efficiency, related to cost-effective energy efficiency measures, i.e. measures which according to the company's own investment criteria are considered cost-effective. This part of the thesis was focused on operational measures and encompassed eight non-energy-intensive industrial companies in the city of Oskarshamn, 28 Swedish foundries which with a few exceptions consist of SMEs, 47 industrial SMEs in the Swedish Highland region, and 40 energy-intensive mainly large- and medium-sized pulp and paper mills. The last study was motivated mainly by the fact that it would strengthen the external validity. The barrier studies mainly include economic, organizational and behavioural barriers from a company perspective. Like Schleich and Gruber (2008), and unlike for example Almeida et al. (2003a-b) and Almeida (1998), the part of the thesis concerning barriers to and driving forces for energy efficiency investigates energy-efficient technologies in general and does not focus on one single technology.

While the use of investment decision support, such as optimization methods and in particular the *MIND*[4] method have been cited as useful investment decision support for strategic investment decisions in Swedish energy-intensive larger industries (Sandberg, 2004, Karlsson, 2002), the method applied on Swedish energy-intensive SMEs had not been examined motivating the third research theme to be investigated. This part investigates the usefulness of optimization as investment decision support for energy-intensive industrial SMEs through a case study of a Swedish medium-sized iron foundry comprising a potential investment in a new production process, namely a new melting unit, using *MIND*.

The use of energy audits and energy audit programmes has internationally been an important means of stressing energy efficiency and overcoming barriers to energy efficiency (Andersson and Newell, 2004, Harris et al., 2000) motivating the fourth research theme to be investigated. In Sweden, over the past fifteen years, the use of such a policy instruments has been very limited. A few minor programmes as well as the largest programme, in terms of participating

[4] The MIND method was originally developed at Linköping University for optimization of dynamic industrial energy systems and is based on Mixed Integer Linear Programming (MILP).

companies, namely *project Highland*[5], are exceptions. This part evaluates *project Highland* in terms of measures actually implemented, relates the programme to other Swedish programmes, and investigates how the energy audit method used in *project Highland* and other projects may be developed and improved. The exploration of how the industrial energy programme reduces the use of energy in Swedish SMEs comprised 47 industrial SMEs in the Swedish Highland region. The part comprising the energy audit method comprised 11 industrial SMEs in the Swedish Highland region, ten non-energy-intensive industrial companies in the city of Borås and eight non-energy-intensive industrial companies in the city of Oskarshamn as well as an energy-intensive medium-sized Swedish iron foundry and a non-energy-intensive Swedish engineering company. In addition, the Swedish *LTA*-programme *PFE* (Programme for improving energy efficiency in energy-intensive industries) was used in a comparison with *project Highland*.

The urgency to design and adopt energy end-use polices due to the *ESD* led to the inclusion of a policy discussion at the end of this thesis based partly on the case studies' results.

When approaching energy end-use efficiency using a widened systems approach, savings in for example electricity leads to even higher savings when the losses in the generation of electricity in power plants are taken into account (EC, 2006). In the case of Sweden, this is an intricate matter having half of the generation of electricity located in hydropower and half in nuclear power. Yet another such issue is that conversion to district heating enables more generation of electricity, where CHP is used, as the heat load increases. This in turn may lead to less generation of electricity in those plants with the highest cost (lowest efficiency). These intricate issues and others involving system boundaries and their definition have made restrictions necessary. The various case studies have been restricted to solely deal with energy end-use efficiency issues at the actual firms. The figure recommended by for example the European Commission (2006), stating that savings in electricity in fact yield a saving about 2.5 times higher due to reduced losses, was thus not included, nor was the fact that conversion to district heating leads to greater heat loads. A more general discussion is however held of CO_2 emissions related to industrial energy end-use efficiency measures and the *ETS*.

The thesis is based on seven papers. An overview of the results is presented, based on the different case studies, in the thesis while more thorough descriptions can be found in the relevant individual papers. As regards the method and theory related to the thesis, however, a more thorough description is in most cases presented in the thesis and not in the appended papers. Before continuing on the theme of energy efficiency and more precisely industrial energy end-use efficiency, a few central terms such as energy efficiency related terms, energy intensity and SMEs need to be clarified. As regards energy efficiency terms, this thesis has, in accordance with EC (2006), defined:

- Energy efficiency as: *A ratio between an output of performance, service, goods or energy, and an input of energy.*
- Energy efficiency improvements as: *An increase in energy end-use efficiency as a result of technological, behavioural and/or economic changes.*

[5] *Project Highland* is the most extensive action targeting the adoption of energy efficiency measures in Swedish industrial SMEs offering energy audits free of charge between the years 2004-2007, to companies located in six Swedish municipalities in the Swedish Highland region.

- Energy savings as: *an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of one or more energy efficiency improvement measures, whilst ensuring normalization for external conditions that affect energy consumption*.
- Energy efficiency (improvement) measures as: *all actions that normally lead to verifiable and measurable or estimable energy efficiency improvement.*
- Energy (efficiency improvement) programmes as: *activities that focus on groups of final customers and that normally lead to verifiable and measurable or estimable energy efficiency improvements*.
- Energy audits as: *a systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, of an industrial operation and/or installation or of a private or public service, identify and quantify cost-effective energy savings opportunities, and report the findings.*

As regards the definition of energy intensity and SMEs, this thesis has defined:

- An energy-intensive company as: *a company with energy costs in relation to the production value*[6] *of more than three percent.*
- SMEs as: *small companies with 10-49 employees and medium-sized companies with 50-249 employees.*
- *Large companies as: companies with more than 250 employees*[7].

1.3 Paper overview

The appended papers, presented below, are roughly organized in accordance with the stated research themes. The exception holds for Papers II and V, which do not solely involve studies of technical energy efficiency measures (Paper II) and barriers to energy efficiency (Paper V), but also evaluate energy audits and energy audit programmes, i.e. relate to the fourth research theme.

Paper I

Patrik Thollander, Magnus Karlsson, Mats Söderström, Dan Creutz

Reducing industrial energy costs through energy-efficiency measures in a liberalized European electricity market: case study of a Swedish iron foundry

Applied Energy, 81 (2): 115-126 Elsevier (2005)

The main purpose of the paper was to investigate the effect of higher electricity prices on the Swedish iron and steel foundry industry, quantify an energy efficiency potential for a medium-sized Swedish iron foundry resulting from a thorough industrial energy audit, and investigate what impact implemented energy efficiency measures would have on the foundry's energy cost.

[6] For a more thorough description of the definition of production value, see PWC (2007).

[7] One exception is that of paper V where the American definition was used (Shipley and Elliot, 2001).

Paper II

Patrik Thollander, Jenny Palm, Mats Söderström

Industrial energy auditing - a key to competitive energy-efficient Swedish SMEs

Invited publication in Energy Efficiency Research Advances, ed. David M. Bergmann, 213-238 Nova Publisher (2008)

The paper presents an energy audit method, evaluates the method used in different Swedish programmes and projects and comes up with improvement proposals for the method to be even more effective. The paper also presents an energy efficiency potential for a medium-sized Swedish engineering site and gives some minor suggestions for how a national industrial energy programme for Swedish industrial SMEs could be designed.

Paper III

Patrik Rohdin, Patrik Thollander

Barriers to and driving forces for energy efficiency in the non-energy-intensive manufacturing industry in Sweden

Energy, 31 (12): 1836-1844 Elsevier (2006)

This paper was the first in studying barriers to energy efficiency in Swedish industry and comprised Swedish non-energy-intensive industrial companies based on a case study of the eight largest industrial sites in the city of Oskarshamn, Sweden. In addition, the paper also presents some driving forces for energy efficiency. This paper also opened up for the possibility to use barrier models and the applied method in other Swedish industrial sectors.

Paper IV

Patrik Rohdin, Patrik Thollander, Petter Solding

Barriers to and drivers for energy efficiency in the Swedish foundry industry

Energy Policy, 35 (1): 672-677 Elsevier (2007)

Based on the findings from paper III, this paper investigates the existence of different barriers to and driving forces for the implementation of energy efficiency measures in Swedish foundries.

Paper V

Patrik Thollander, Patrik Rohdin, Maria Danestig

Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs

Energy Policy, 35 (11): 5774-5783 Elsevier (2007)

The most extensive action targeting the adoption of energy efficiency measures in industrial SMEs in Sweden over the past 15 years was *project Highland*. This paper presents an evaluation of the first part of this local industrial energy programme including which measures were implemented, what barriers were inhibiting the implementation of energy efficiency measures and the driving forces for the latter. Finally, the paper compared the programme with other Swedish programmes.

Paper VI

Patrik Thollander, Mikael Ottosson

An energy-efficient Swedish pulp and paper industry - exploring barriers to and driving forces for cost-effective energy efficiency investments

Energy Efficiency, 1 (1): 21-34 Springer (2008)

This paper investigates barriers to and driving forces for energy efficiency in Swedish pulp and paper mills.

Paper VII

Patrik Thollander, Nawzad Mardan, Magnus Karlsson

Optimisation as investment decision support in a Swedish medium-sized iron foundry - a move beyond traditional energy auditing

Accepted for publication in Applied Energy, 2008

This paper investigates whether investment decision support practices may be used successfully by Swedish energy-intensive industrial SMEs when complex production-related investment decisions are to be taken. The paper involves a Swedish medium-sized iron foundry.

1.4 Co-author statements

Paper I was written entirely by this thesis' author, except for chapter three where an initial first draft of the chapter was written by Dan Creutz. Mats Söderström and Magnus Karlsson contributed valuable insights on the paper.

Paper II was written entirely by this thesis' author with the exception of the section regarding effective energy auditing and the *Sustainable Municipalities*' case were Jenny Palm contributed with an early draft. The responsibility for the collection of data was, with the exception of the *Sustainable Municipalities*' case, the author's. Mats Söderström, provided valuable comments throughout the writing.

Papers III and IV were written entirely together with Patrik Rohdin. As a matter of principle, the author's names were listed in alphabetical order. In Paper III, the interviews were conducted together with Patrik Rohdin while the data collection procedure (the questionnaire) in Paper III was initiated and completed by this thesis' author. The results were in both the papers analyzed by both authors. All the work was supervised by Mats Söderström.

The research upon which Paper V is based was planned and supervised by the thesis' author. Even though the paper was based on an early draft by the author and the author was responsible for the paper, the final version of Paper V was completed in collaboration with Maria Danestig and Patrik Rohdin, especially the later parts of the paper. All the work was supervised by Mats Söderström.

Paper VI was written entirely together with Mikael Ottosson. The data collection procedure (the questionnaire) in the paper was initiated and completed by Mikael Ottosson while the results were analyzed by both authors. All the work was supervised by Mats Söderström.

In Paper VII, this thesis' author was responsible for the building of the model and the data collecting procedure. The paper was written entirely together with Nawzad Mardan who was responsible for the optimization of the cases. Magnus Karlsson contributed valuable insight throughout the process from building the model to the authoring of the final paper. All the work was supervised by Mats Söderström.

1.5 Other publications not included in the thesis

Apart from the appended papers outlined above, a selected sample of publications that were written during the PhD period and which directly or indirectly influenced the thesis work are presented below.

Thollander, P., 2008. Drivkrafter för energieffektivisering i svensk gjuteriindustri [Driving forces for energy efficiency in the Swedish foundry industry]. Swedish Foundry Association, Jönköping. Working paper, download at: http://www.energimyndigheten.se /Global/Filer %20-%20Forskning/Industri/Swecast/6-Drivkrafter%20f%C3%B6r%20energieffektivisering %20 i% 20svensk%20gjuteriindustri.pdf [In Swedish].

Thollander, P., Tyrberg, M., 2008. Drivkrafter för energieffektivisering i små- och medelstora industriföretag [Driving forces for energy efficiency in small- and medium-sized industrial enterprises]. Working paper, Energy Agency of South East Sweden, Växjö [In Swedish].

Thollander, P., 2006. Barriers to and driving forces for the implementation of manufacturing simulation in the Swedish foundry industry. Proceedings of the 2006 Winter Simulation Conference, Monterey.

Solding, P., Thollander, P., 2006. Increased energy efficiency in a Swedish iron foundry through use of discrete event simulation. Proceedings of the 2006 Winter Simulation Conference, Monterey.

Rohdin P., Thollander, P., 2006. Synen på energieffektivisering, produktionssimulering, energianalyser och styrmedel - en studie av nio svenska gjuterier [Perspective on energy efficiency, manufacturing simulation, energy audits and policies]. Swedish Foundry Association, Jönköping. Working paper, download at: http://www.energimyndigheten.se/Global/Filer %20-%20Forskning/Industri/Swecast/2-Synen%20p%C3%A5%20energieffektivisering,%20 produktionssimulering,%20energianalyser%20och%20styrmedel.pdf [In Swedish].

Persson, J., Rohdin P., Thollander, P., 2005. Hinder och drivkrafter för energieffektivisering i svensk industri - två fallstudier. [Barriers to and driving forces for energy efficiency in the Swedish industry - two case studies] Arbetsnotat 32, Energy Systems Program, IEI, Linköping Institute of Technology, Linköping [In Swedish].

Rohdin P., Thollander, P., 2005. Hinder och drivkrafter för energieffektivisering i svensk gjuteriindustri [Barriers to and driving forces for energy efficiency in the Swedish foundry industry]. Swedish Foundry Association, Jönköping. Working paper, download at: http:// www.energimyndigheten.se/Global/Filer%20-%20Forskning/Industri/Swecast/1-Hinder%20och %20drivkrafter%20f%C3%B6r%20energieffektivisering%20i%20svensk%20gjuteriindustri.pdf [In Swedish].

Thollander, P., 2005. Tryckluftssystemets uppgång och fall? En studie av svensk teknikutveckling [The rise and fall of compressed air systems? A study of technology change in Sweden]. Gyberg, P. Palm, J, Karlsson, M. (Editorial Board). Drivkrafter för förändring: - Essäer om energisystem i utveckling [Driving Forces for Change: - Essays on Energy Systems under Development], Arbetsnotat 27, Energy Systems Program, Linköping [In Swedish].

1.6 Research journey

For various reasons, including participation in a three year long research project led by the Swedish Foundry Association which was initiated about a year into my PhD studies, and an initial thorough energy audit (Paper I), a major part of the thesis covers energy end-use efficiency in the Swedish foundry industry, mainly consisting of small and medium-sized foundries. Apart from foundries, three studies explicitly cover non-energy-intensive and/or industrial SMEs. The initial study of barriers to and driving forces for energy efficiency among companies in Oskarshamn was a result of the last course in the Energy Systems Programs' PhD course package, and was the first (Paper III) in a number of studies regarding barriers to and driving forces for energy efficiency. In that study, the focus was on non-energy-intensive companies who had received energy audits free of charge. That study enabled the questionnaire to be developed, with some more barriers and driving forces for energy efficiency included, which was used to study the latter in Swedish foundries (Paper IV). In the two consecutive papers (Papers II and V), energy audits and their impacts were studied both quantitatively and qualitatively. In Paper V, an evaluation of a local Swedish energy programme directed at SMEs, the questionnaire also included barriers to and driving forces for energy efficiency. A questionnaire on barriers and the fact that the Swedish pulp and paper industry is the largest energy user in the Swedish industry - accounting for almost half of the industrial aggregated energy use - made a study of that sector quite appealing, even though it was not within the main scope of the thesis. As a direct outcome of the Energy Systems Program colleague Mikael Ottosson, who emphasized conducting research in the sector, a study of the sector was conducted as one of the last papers within my PhD studies (Paper VI). If it had not been for Mikael Ottosson, I do not think it would have occurred in this thesis as it was not wholly in line with the initial research topic. Now, however, the study's results provide not only interesting input from the sector but also a methodological development. Also, research regarding optimization as investment decision support for energy-intensive SMEs as a means to promote energy efficiency was conducted by studying a potential real case strategic investment in a new melting unit in a medium-sized Swedish iron foundry (Paper VII). As regards the latter, I was personally in two minds about the method applied on SMEs as I considered such industries to be somewhat too small for this type of method. In this, I was greatly influenced by my supervision of a Bachelor thesis which, applying the method on a non-energy-intensive engineering firm showed that the method was not that useful when studying only support processes. To my surprise, my doubts changed into a greater understanding and appreciation of the method when conducting the study in the energy-intensive medium-sized iron foundry, not least when I found that the results were considered useful for the foundry executives in its investment decision process.

Chapter 2

2 INDUSTRIAL ENERGY EFFICIENCY

This chapter begins with a presentation of energy and the Swedish industry, continues with an industrial perspective on energy efficiency, a presentation of the current main European and Swedish industrial energy polices that directly or indirectly affect the industrial sector, with particular emphasis on energy end-use policies, and ends with a European and Swedish perspective on energy efficiency.

The role of industrial energy efficiency from a company perspective is of importance as it leads to direct economic benefits, increased competitiveness (Hirst and Brown, 1990) and higher productivity (Worrell et al., 2003). Society's incentive to stress energy efficiency may, however, differ from the company's own perspective. While the company's incentives are closely related to business-related benefits such as reduced costs, i.e. not solely an incentive to reduce the use of energy but rather the cost of energy, society's incentive in turn is more related to socio-economic benefits such as reduced environmental impact, i.e. not solely related to reducing the cost of energy but rather the use of energy. While these two perspectives often coincide, i.e. reduced use of energy often leads to reduced energy costs - it is still of importance to make a distinction between the two. In the following section, energy efficiency is outlined both from the industry's perspective as well as that of Europe and Sweden.

2.1 Energy and the Swedish industry

The Swedish industry consists of about 59,000 companies using about 155 TWh annually where about 60 TWh is electricity, 54 TWh is biofuels, and 20 TWh is coal and coke. In addition, about 5 TWh district heating and about 4 TWh natural gas is used. An overview of the Swedish industrial energy use, split into sectors, is presented in figure 1.

One way of categorizing industrial companies is in terms of its energy intensity, another by number of employees. As regards the former, among the 59,000 Swedish industrial companies, 58,600 are considered non-energy-intensive. The remainder, i.e. about 600, are considered energy-intensive where the majority are located in industries related to pulp and paper, iron and steel, and mining and chemical industries and account for about 75 percent of the aggregated Swedish industrial energy use (SEA, 2004a). Figure 1 shows the use of energy in Swedish industries.

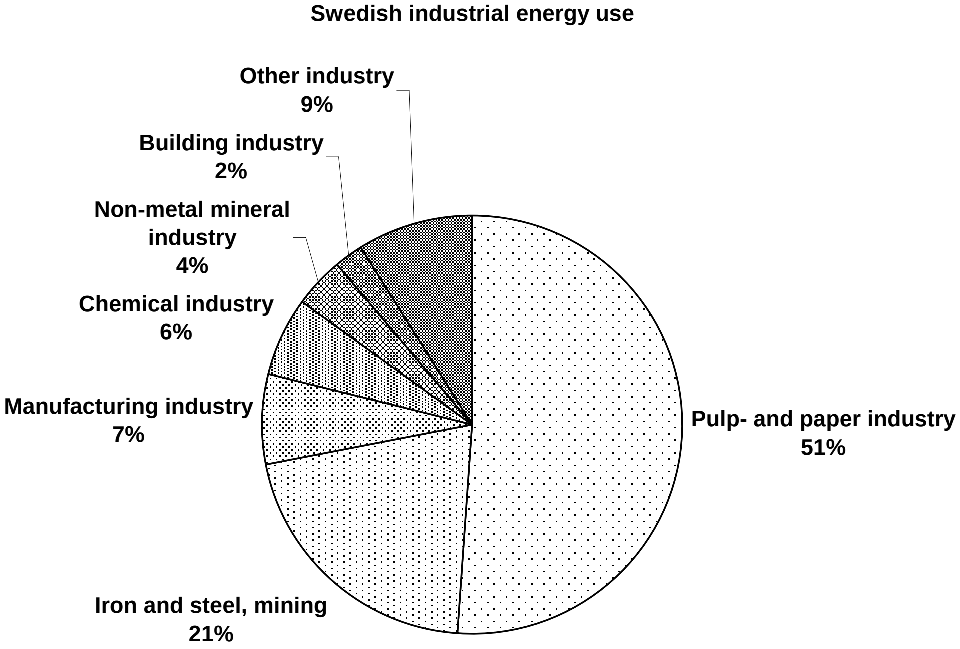

Figure 1. Industrial energy use distributed by industrial sector in Sweden (Based on Johansson et al., 2007).

As regards the other way to categorize industrial companies - in terms of number of employees - in Sweden, 98 percent of the companies, or more than 57,000 companies, are small and medium-sized (EEC, 2008).

2.2 Energy efficiency - an industrial perspective

The role of industrial energy efficiency from a company perspective is of importance as it leads to direct economic benefits, increased competitiveness (Hirst and Brown, 1990) and higher productivity (Worrell et al., 2003). One of the major threats to Swedish companies, in particular energy-intensive companies, is energy price increases.

2.2.1 Implications of increasing energy prices for Swedish industry

The aim of the liberalization of the gas and electricity markets in the EU is increased cost-effectiveness through market mechanisms causing the prices of gas and electricity to converge (EC, 2001). A somewhat homogenous, symmetric gas and electricity market will, as a consequence of the market liberalization, most likely cause prices in European countries to fall. However, studies of the effects of the liberalization in Sweden show that electricity prices most likely will not fall because Sweden already had very low electricity prices (Trygg, 2006, Trygg and Karlsson, 2005, Gebremedhin, 2003, ECON, 2003, Dag, 2000). In fact, a study of electricity prices in the EU conducted by the European Electricity Prices Observatory (EEPO) in 2002 showed that Sweden had the lowest industrial electricity prices in the EU (EEPO, 2003). The deregulation of the Swedish electricity market in 1996 caused prices to drop but since 2000, electricity prices have begun to rise again, see figure 2.

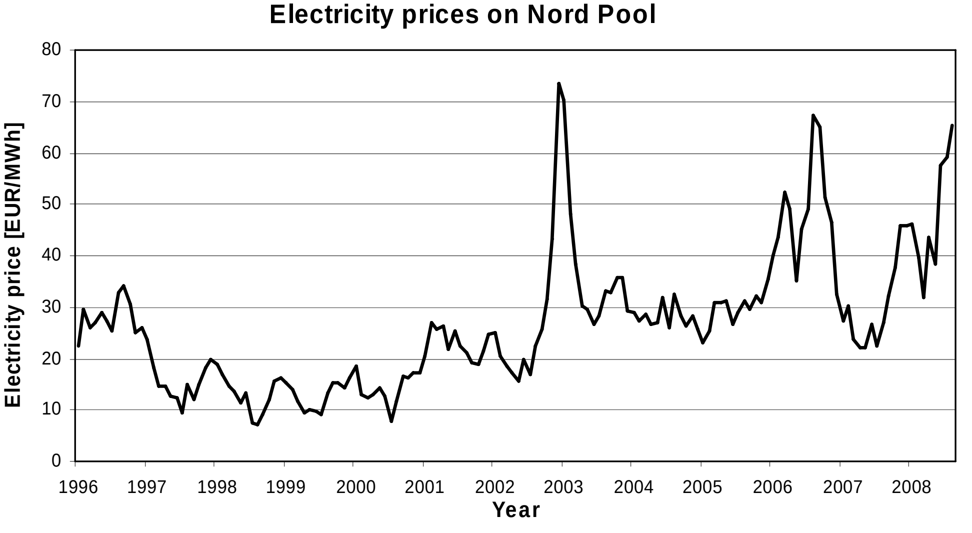

Figure 2. Average monthly electricity prices on NordPool for the period January 1996 to August 2008 (NordPool, 2008).

A study by Melkersson and Söderberg (2004) indicated that future electricity prices in Sweden can be expected to converge towards 80 €/MWh, Monday through Friday, from 6 am to 6 pm, and 44 €/MWh during the rest of the week. The average electricity price found from the EEPO (2003) study also corresponds well with the prices found in the above-mentioned study, taking the average price of a 24-hour weekday, except that prices in the EEPO (2003) study were slightly higher. Further electricity price increases are thus expected, not least larger price fluctuations over the day. While spot prices in other member states vary considerably over the day, this has historically not been the case in the Nordic marketplace. Furthermore, in comparison with European competitors, the historically low electricity prices in Swedish industry seem to have influenced domestic enterprises to use more electricity and favour the use of electricity over other energy carriers (Trygg, 2006, Nord-Ågren, 2002, Dag, 2000).

As regards electricity prices for Swedish industry, prices have almost doubled between 2000 and 2006 (Johansson et al., 2007, SEA, 2006a). As regards oil prices for the Swedish industry, prices have risen by about 70 percent over the same period (Johansson et al., 2007, SEA, 2006a). These price increases represent price increases of 33-38 €/MWh for electricity and 20 €/MWh for oil (Johansson et al., 2007).

Higher energy prices together with a higher use of electricity than other European countries may pose a threat to domestic industrial activity in Sweden. Higher energy costs have a negative impact on results and competitiveness, which in turn may affect production and perhaps even cause enterprises to consider moving to another country (ECON, 2003).

Industrial enterprises are affected differently by higher energy prices depending on the energy cost in relation to the added value and energy-intensive industries like foundries and pulp and paper mills are threatened to a much larger extent than non-energy-intensive industries like the engineering industry. While the non-energy-intensive engineering industry has energy costs in relation to the added value of only 1-2 percent, energy-intensive foundries are facing values of 5-15 percent (SFA, 2004) and energy-intensive process industries like pulp and paper mills are facing figures well beyond 20 percent (SEA, 2000). For the industry there are mainly two means of overcoming the threat of rising energy prices, namely energy management focusing on:

- Supply measures such as energy price management practices.
- Demand side measures such as energy management practices.

The latter, namely industrial energy management is outlined in the following section.

2.2.2 Industrial energy management

Research and experience in other European companies have shown that industrial companies who take a strategic approach by adopting energy management practices may save up to 40 percent of their total energy use (CADDET, 1995). Successful industrial energy management demands strategic thinking and also full support from top management. The strategic approaches vary but do have some elements in common such as (CADDET, 1995):

- An initial energy audit.
- Senior management support.
- The monitoring of energy use.
- Recognition that management is as important as technology.
- An ongoing and co-coordinated programme for energy saving projects.

The last should include:

- A long-term energy saving scenario.
- A factory-wide plan for the medium term.
- A detailed plan for the first year.
- Actions to improve energy management, including the establishment of an energy monitoring system.

A large part of the in-house energy management programme should involve the motivation and training of staff and a successful energy management approach includes both the managerial techniques described above and technical measures appropriate at the site in question (CADDET, 1995). As regards the energy-using equipment at an industry these may be split into two major categories (Trygg and Karlsson, 2005): support processes and production processes. While the former is related to processes supporting the production such as ventilation, space heating, pumping, compressed air, lighting and hot tap water, the latter is related to actual production units. The type of energy efficiency measures differ between industrial companies depending on, among other things, size, sector, and type of production, which in turn affects the relation between the degree of support and production processes. There is thus no ‘one-size fits all’ approach to energy management.

2.3 European industrial energy policies

2.3.1 The European emission trading scheme (ETS)

One European energy policy which has been adopted by the EU's member states is the *ETS*. The first *ETS* period within parts of the European economy[8] started on 1 January 2005 and was concluded at the end of 2007. The concept was then evaluated and a new period was launched for the years 2008-2012. With the *ETS*, the level of CO_2 emissions within the EU has been limited within parts of the economy (SEA, 2006c).

2.3.2 The European energy end-use efficiency and energy services directive (ESD)

The *ESD* came into force in 2006, and propose a reduction in energy use of nine percent in each member state, to be achieved by the ninth year of application of the directive (EC, 2006). The purpose of the *ESD* is to enhance cost-effective improvements of energy end-use efficiency in member states by: *(a) providing the necessary indicative targets as well as mechanisms, incentives and institutional, financial and legal frameworks to remove existing market barriers and imperfections (market failures) that impede the efficient end-use of energy and (b) creating the conditions for the development and promotion of a market for energy services and for the delivery of other energy efficiency improvement measures to final consumers (EC, 2006).* In other words, the *ESD* takes a leap further than traditional economic policies based on mainstream economic theory as the directive's aim is to reduce not only *market failure barriers* but also *market barriers*. For a distinction between these two categories, see chapter three.

The *ESD* addresses a number of activities and services, like the availability of energy audits for industrial SMEs. It also highlights the availability of energy efficiency funds to all market actors and promotes energy audits and financial incentives for the adoption of energy efficiency measures and energy services (EC, 2006). The *ESD* promote, among other things, the need to find possible energy end-use policy initiatives directed towards SMEs in a national context: *In order to enable final consumers to make better informed decisions as regards their individual energy consumption, they should be provided with a reasonable amount of information thereon and with other relevant information, such as information on available energy efficiency improvement measures* (EC, 2006). It should be noted that a great portion of the Swedish industrial energy use is not included within the *ESD*, such as large parts of the iron, steel and metal industry as well as the pulp and paper industry (EC, 2001).

2.4 Swedish industrial energy policies

Energy policies should, according to the Swedish Ministry of Enterprise, Energy and Communications (2001) be general and not targeted towards one single technology. Energy policy instruments may be categorized into *economic policy instruments* like taxes, duties, subsidies, financial incentives, etc., *administrative policy instruments* like rules and regulations, acts of parliament, etc., and *informative policy instruments* like information campaigns/programmes. Energy policies directed at industry, in turn, may take a number of

[8] The EU's emission trading scheme includes only a limited number of actors, chiefly energy supply and energy-intensive demand side companies. All member countries must participate. The type of utilities concerned during the period 2005-2007 include plants with an installed capacity above 20 MW, mineral oil refineries, coke plants, and companies producing and refining iron, steel, glass and glass fibre, cement, pulp, and paper.

different forms such as price-based and fiscal instruments, regulations and voluntary approaches like *LTAs* (Long-Term Agreements) and energy audit programmes. A combination of policy instruments is often more effective (Lindén and Carlsson-Kanyama, 2002). For a summary of current industrial energy policies in Sweden, see Johansson et al. (2007).

2.4.1 The electricity certificate system (ECS)

Even though the *ECS* (Electricity Certificate System) not affects the end-use to any large extent it thus affect industrial actors using CHP. The *ECS* is a Swedish market-based support system intended to increase cost-effective electricity production from renewable sources, supporting electricity produced from solar power, wind power, hydropower, CHP plants with biofuels, and peat combustion. The Swedish state gives the producers of renewable electricity a certificate for each MWh of renewable electricity that they produce, affecting all renewable electricity suppliers including the Swedish pulp and paper industry. The certificate can be sold, and therefore, provides additional revenue for the energy supplier in addition to that from the sale of electricity. Only Paper VI in this thesis regards the ECS,

2.4.2 Taxes

As regards Swedish economic policies related to the industry there is a *carbon tax* of approximately 21 €/ton which was launched in 1991 with regulations for different sectors (Johansson et al., 2007). Furthermore, in 2005 the Swedish industry was faced with an *electricity tax* of approximately 0.55 €/MWh.

2.4.3 The Environmental Code

The *Swedish Environmental Code* came into force in 1988 and addresses, among other activities, energy efficiency as a key aspect. One issue is for example that the best available technology (BAT) should be used, taking the additional cost in relation to the benefits into consideration. Energy efficiency requirements have recently gained increased attention when the environmental permits for companies are being processed. The authorities thus have the possibility to enhance energy efficiency measures and activities through the *environmental code* when issuing a permit as well as through the supervision procedure. It should be noted that even though legal grounds exist, this instrument is quite slow and has only recently begun to be practiced (Johansson et al., 2007).

2.4.4 The programme for improving energy efficiency in energy-intensive industries (PFE)

The *PFE* (programme for improving energy efficiency in energy-intensive industries) began in 2005 and is a type of *VA* (Voluntary Agreement) or *LTA* (Long-Term Agreement) between the Swedish authorities and the energy-intensive Swedish industry. In the programme, energy-intensive firms are offered a discount of 0.55 €/MWh on the newly introduced tax on electricity for Swedish industry if the company fulfils the requirements. Within the first two years, the companies within the *PFE* must undertake an energy audit with a systems approach, which should result in a number of energy efficiency measures that could be implemented over the remainder of the period (the last three years), and the implemented measures should result in savings at least equivalent to the tax discount. The programme also includes the mandatory implementation of an energy management system, the introduction of standardized routines for purchasing and planning energy-efficient technologies, energy systems, and plants. Of the approximately 1,200 firms that are eligible for participation, only 117 have joined the programme (Ottosson and Peterson, 2007). Of these, 103 were accepted in August 2008 (SEA, 2008).

2.5 Energy efficiency - A European and Swedish perspective

The European energy end-use efficiency and energy services directive (ESD) states that: *improved energy end-use efficiency will make it possible to exploit potential cost-effective energy savings in an economically efficient way. Energy efficiency improvement measures could realize these energy savings and thus help the Community reduce its dependence on energy imports*. Furthermore, the *ESD* is claimed to be consistent with the directives concerning common rules for internal electricity and gas markets: …*which provide for the possibility of using energy efficiency and demand-side management as alternatives to new supply and for environmental protection* (EC, 2006). Positive effects of increased industrial energy efficiency from a European and Swedish perspective thus includes increased security of supply, environmental benefits, as well as increased industrial competitiveness (Hirst and Brown, 1990). One ongoing debate on this system level is whether energy efficiency actually will create sustainability in the long-run or if the so called *rebound effect* and other mechanisms and factors inhibit energy efficiency.

2.5.1 The rebound effect

The so-called *rebound effect* is a commonly cited criticism of energy efficiency (Herring, 2006, Saunders, 2000, Khazzoom, 1980). Cost-effective energy efficiency measures are always positive as energy efficiency strengthens competitiveness through lower production costs and are also positive because energy efficiency will promote a more efficient and prosperous economy. However, it is argued to not always lead to reduced overall energy use (Herring, 2006). The *rebound effect* may be split into two major categories:

- The direct *rebound effect*: a price effect where a new technology might increase energy efficiency corresponding to a reduction in the price of energy services that leads to an increased demand for energy (Bentzen, 2004).
- The indirect *rebound effect*: which means that an energy efficiency activity lowers overall energy costs leading to more money left to spend on other goods and services.

The question of importance is not so much whether the *rebound effect* exists but rather how great the magnitude of such an effect is considered to be. The direct *rebound effect* for industrial process use was found to be less than 20 percent and the indirect *rebound effect* about half a percent in a study by Greening et al. (2000). In the study it was concluded that: *For the energy end-users for which studies are available, we conclude that the range of estimates for the size of the rebound effect is very low to moderate* (Greening et al., 2000). In a study by Bentzen (2004) studying the direct *rebound effect* in US manufacturing industry between 1949 and 1999 it was found that the size of the *rebound effect* was likely to be less than 24 percent for the sector.

2.5.2 Energy efficiency related to the ETS

One type of effect regarding energy efficiency and the *ETS* which is closely related to the *rebound effect* is that energy efficiency actions related to electricity and district heating, resulting from for example the implementation of industrial energy efficiency measures, will not necessarily result in lower CO_2 emissions within an *ETS* period.

Within each period of the *ETS*, the level of CO_2 emissions within the trading parts of the economy in EU has been fixed. This leads to stepwise efforts to reduce the emissions of CO_2 at the start of each period by lowering the emission levels, see figure 3.

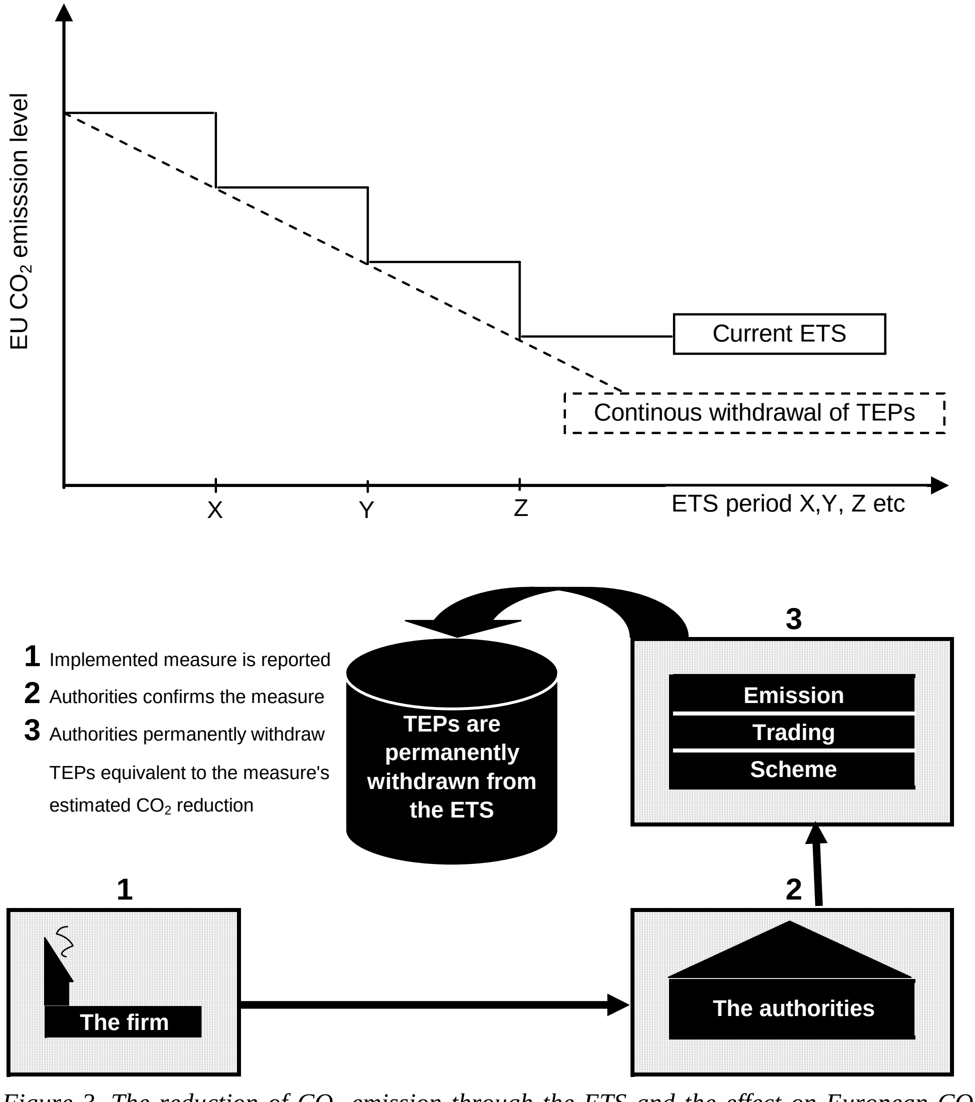

Figure 3. The reduction of CO_2 emission through the ETS and the effect on European CO_2 emission reductions if instant withdrawal of TEPs would be used. The figure is inspired by the Swedish Climate Committee's (2008) report.

Inevitable, *ETS* is an important means when it comes to lower the emissions of green house gases, e.g. CO_2 emissions. However, the *ETS* may slow down the possibility to reduce CO_2 emissions through energy efficiency activity. The Swedish Climate Committee (2008) has argued that a Swedish energy efficiency action within an *ETS* period not necessarily will reduce the CO_2 emissions: *Lowering the electricity demand in Sweden will give rise to reduced production in coal fired power plants and thus lowers the electricity production in other European countries. This reduction, however, takes place within the ETS. Electricity efficiency (as well as the use of district heating) has, therefore, in the short run - within an ETS period - no effect on the emissions within the ETS. However, prices within the ETS are under pressure and it will be possible to lower the emissions level at a lower cost, compared with if no energy efficiency actions had taken place. The prerequisites for lowering the maximum level and by doing so lowering the emissions from production plants on the continent, are therefore enhanced, Efficiency activities thus affect, in a long perspective, the possibilities to lower the emissions (my translation)* (SCC, 2008). For a more detailed discussion of this, see SCC (2008).

In order to achieve CO_2 emission reductions through Swedish energy efficiency activities even in the short run, the authorities may instead withdraw *TEPs* (Tradable Emission Permits) continuously from the *ETS*, see figure 3. This would lead to more efficient energy efficiency programmes, from a European and a Swedish point of view, using a CO_2 emission reduction perspective. This is due to the fact that energy efficiency actions leading to potential CO_2 reductions may be achieved instantaneously through the withdrawal of *TEPs* within an *ETS* period, equivalent to the implemented energy efficiency measure's CO_2 emission reduction.

2.5.3 Market forces and market failures

One criticism against for example industrial energy policies, is that technological advances and rising energy prices would cause energy efficiency measures to be implemented, even without governmental intervention (IEA, 2005). This argument is closely related to mainstream economic politics, see for example Sutherland (1996), relying heavily on the market and market restructuring for energy efficiency improvements to be carried out (Jaffe and Stavins, 1994). This theory is an elaboration of the 18th century economist Adam Smith, who stated that the actions of individuals acting in a decentralized market setting can lead to results that are collectively beneficial. Some of the underlying axioms or ideal conditions required to ensure efficient outcomes are:

- A complete set of markets with well defined property rights exist such that buyers and sellers can exchange assets freely.
- Consumers and producers behave competitively by maximising benefits and minimising costs.
- Market prices are known by all consumers and firms.
- Transaction costs are zero.

If any of these axioms fails to hold, a *market failure* or a market imperfection is manifested which may justify public policy intervention. There are four broad types of *market failures*:

- Incomplete markets.
- Imperfect competition.

- Imperfect information.
- Asymmetric information.

Of these four broad types of *market failures*, the two latter, *imperfect information* and *asymmetric information* are of special interest when studying industrial energy end-use efficiency (Sorrel et al., 2000). Sanstadt and Howarth (1994) wrote that: *It is not a deep insight to observe that, relative to the theoretical ideal, these market failures are common if not pervasive in the real world*. The two former *market failures* presented above, *incomplete markets* and *imperfect competition*, are less important when conducting empirical studies on barriers to energy efficiency, see for example (Sorrell et al., 2000), as they may not explain why cost-effective energy efficiency measures, already available on the current markets, are not implemented. However, *incomplete markets* and *imperfect competition* are not irrelevant for explaining the non-take-up of energy efficient technologies (Sorrell et al., 2000). As Sorrell et al. (2000) write: *Environmental externalities represent a form of incomplete markets, but do not explain the failure to adopt technologies at current prices. Similarly, monopoly energy suppliers may depart from marginal cost pricing but this again does not explain the gap*. In studies related to the energy supply market, Woo et al. (2003) concluded, based on studies of electricity market reforms in the UK, Norway, Alberta and California, that: *it is an unrealistic expectation that restructuring will achieve perfect competition in a properly functioning market. A more realistic expectation is workable competition in a reasonably well-functioning market environment. This would hopefully produce prices that are close to the marginal costs under least-cost dispatch* (Woo et al., 2003).

While low energy prices have shown to lead to a greater energy use the reverse procedure, i.e. increasing electricity prices lead to increased energy efficiency, may not be as easily accomplished in the short run. Bertoldi et al. (2005) write that; *price increases per se are an inadequate approach to inducing energy efficiency*. In summary, the adoption of cost-effective energy efficiency measures are not solely, according to Bertoldi et al. (2005), based on price mechanisms, such as energy price increases, even though they are of course of great importance.

Furthermore, the adoption of the *ESD* itself does indicate that markets mechanism solutions in the current energy service markets may not alone provide an answer to the adoption of energy-efficient technologies without any public interference.

In summary, the fact that energy price increases may not autonomously lead to increased industrial energy end-use efficiency, the existence of *market failures*, and environmental concern, among other things, may justify public industrial energy policy intervention. Furthermore, while the actual *rebound effect* for the industry based on the above cited studies may not be considered to be a main argument against industrial energy efficiency, the proposition that energy efficiency within an *ETS* period may not result in reduced CO_2 emissions should, from an environmental point of view, be of greater concern.

Chapter 3

3 BARRIERS TO ENERGY EFFICIENCY

This chapter presents theoretical perspectives on barriers to energy efficiency derived from different scientific disciplines and briefly describes each barrier and its mode of operation. In addition, some means of overcoming barriers to energy efficiency are presented.

There are numerous publications stating the existence of a 'gap' between potential cost-effective energy efficiency measures and measures actually implemented. This is referred to as the 'energy efficiency gap' or the 'energy paradox' (York et al., 1978, Blumstein et al., 1980, Stern and Aronsson, 1984, Hirst and Brown, 1990, Gruber and Brand, 1991, Stern, 1992, DeCanio, 1993, Jaffe and Stavins 1994, Sanstad and Howarth, 1994, Weber, 1997, Ostertag, 1999, Sorrell et al., 2000, Brown, 2001, de Groot et al., 2001, Schleich, 2004, Sorrell et al., 2004, Schleich and Gruber, 2008). This 'energy efficiency gap' or 'energy paradox' is in turn explained by a number of barriers to energy efficiency. A barrier may be defined as: *A postulated mechanism that inhibits investments in technologies that are both energy-efficient and economically efficient* (Sorrell et al., 2004). Barriers are explanatory variables derived from mainstream economics, organizational economics, organizational and behavioural theories. There are also structural barriers or institutional barriers to energy efficiency that do not affect the 'gap'. Barriers may be divided into three broad categories, namely *Economic*, O*rganizational* and *Behavioural categories* (Sorrell et al., 2000). Based on an extensive review of the existing literature on barriers to energy efficiency, Sorrell et al. (2000) compiled a barrier framework categorized into 15 different barriers, see Table 1. The barriers presented in table 1 are explained in more detail in the following sections of this chapter. It should be noted, however, that the classification of barriers is not unambiguous; one type of real-world phenomena may be explained by several of the presented theoretically derived barriers (Weber, 1997).

Jaffe and Stavins (1994) outline a number of different levels of 'energy efficiency potentials', or 'energy efficiency gaps', see figure 4. The figure shows that the actual level of potential savings are dependent on which view is applied - while the technologist's potential in a sense is real, the economist's potential is indeed real for that person or organization - the difference between the two levels being dependent on which theoretical perspective is being applied.

Table 1
Classification of barriers to energy efficiency (based on Sorrell et al., 2000).

Theoretical Barriers	Comment
Imperfect information (Howarth and Andersson, 1993)	Lack of information may lead to cost-effective energy efficiency measures opportunities being missed.
Adverse selection (Jaffe and Stavins, 1994)	If suppliers know more about the energy performance of goods than purchasers, the purchasers may select goods on the basis of visible aspects such as price.
Principal-agent relationships (Jaffe and Stavins, 1994)	Strict monitoring and control by the principal, since he or she cannot see what the agent is doing, may result in energy efficiency measures being ignored.
Split incentives (Jaffe and Stavins, 1994)	If a person or department cannot gain benefits from energy efficiency investment it is likely that implementation will be of less interest.
Hidden costs (Jaffe and Stavins, 1994)	Examples of hidden costs are overhead costs, cost of collecting and analyzing information, production disruptions, inconvenience etc..
Access to capital (Jaffe and Stavins, 1994)	Limited access to capital may prevent energy efficiency measures from being implemented.
Risk (Jaffe and Stavins, 1994)	Risk aversion may be the reason why energy efficiency measures are constrained by short pay-back criteria.
Heterogeneity (Jaffe and Stavins, 1994)	A technology or measure may be cost-effective in general, but not in all cases.
Form of information (Stern and Aronsson, 1984)	Research has shown that the form of information is critical. Information should be specific, vivid, simple, and personal to increase its chances of being accepted.
Credibility and trust (Stern and Aronsson, 1984)	The information source should be credible and trustworthy in order to successfully deliver information regarding energy efficiency measures. If these factors are lacking this will result in inefficient choices.
Values (Stern, 1992)	Efficiency improvements are most likely to be successful if there are individuals with real ambition, preferably represented by a key individual within top management.
Inertia (Stern and Aronsson, 1984)	Individuals who are opponents to change within an organization may result in overlooking energy efficiency measures that are cost-effective.
Bounded rationality (DeCanio, 1993)	Instead of being based on perfect information, decisions are made by rule of thumb.
Power (Sorrell et al., 2000)	Low status of energy management may lead to lower priority of energy issues within organizations.
Culture (Sorrell et al., 2000)	Organizations may encourage energy efficiency investments by developing a culture characterized by environmental values.

3.1 Economic barriers - market failures

One important categorization is which barriers may be seen as *market failures* violating the underlying axioms of mainstream economic theory. According to mainstream economic theory, a true *market failure* may justify public policy intervention. However, the mere existence of such may not justify such intervention according to mainstream economic theory, as *market failures* are pervasive (Sorrell et al., 2000). As Brown (2001) writes: *The existence of market failures and barriers that inhibit socially optimal levels of investment in energy* *efficiency is the primary reason for considering public policy interventions. In many instances, feasible, low cost policies can be implemented that either eliminate or compensate for market imperfections and barriers, enabling markets to operate more efficiently to the benefit of society. In other instances, policies may not be feasible; they may not fully eliminate the targeted barrier or imperfection; or they may do so at costs that exceed the benefits* (Brown, 2001). It is thus also important that the benefits arising from an intervention exceed the cost of implementation.

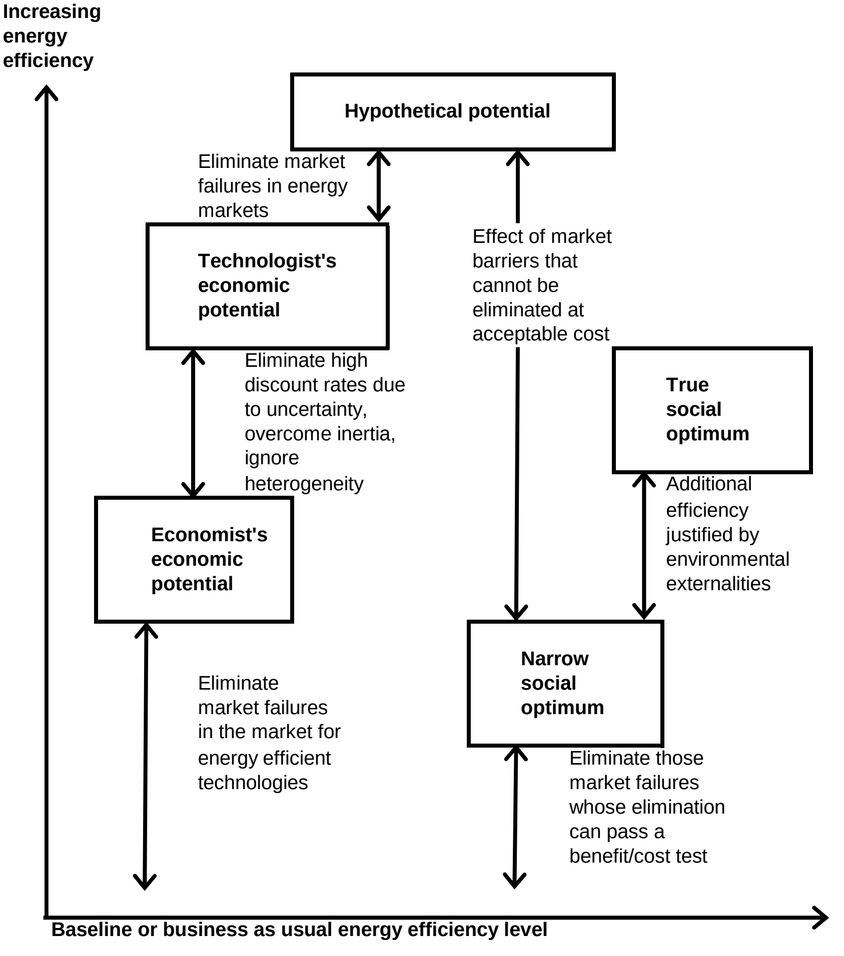

Figure 4. Different levels of energy efficiency potential (Jaffe and Stavins, 1994).

One much cited *market failure* barrier is, and which has been shown to be significant, *imperfect information* (Sorrell et al., 2000). Other *market failure barriers* include *asymmetric information,* a special form of *imperfect information* where *split incentives, adverse selection,* and *principal-agent relationships* may also be categorized (Sorrell et al., 2000). These *market failure barriers* are presented below.

3.1.1 Imperfect information

A large body of research has found that consumers are often poorly informed about market conditions, technology characteristics and their own energy use. Lack of adequate information about potential energy-efficient technologies inhibits investments (Sanstad and Howarth, 1994). *Lack of information* is one form of *imperfect information*, i.e. energy performance of energy-efficient technologies is not available to agents. Another form of *imperfect information* is *cost of information* which means that there are costs associated with searching and acquiring information about the energy performance of an energy-efficient technology. Yet another form of *imperfect information* is *accuracy of information* which means that the information provider may not always be transparent about the product provided. Problems with *imperfect information* are likely to be most serious when the product is purchased infrequently, performance characteristics are difficult to evaluate either before or soon after purchase and the rate of technology change is rapid relative to the purchase intervals (Sorrell et al., 2000), which is the case for many energy efficiency measures.

3.1.2 Adverse selection

Adverse selection means that producers of energy-efficient equipment will in general be much better informed about the characteristics and performance of equipment than prospective buyers, i.e. the information between the two parties engaged in the transaction is asymmetric. A central theme is that *asymmetric information* is extremely common in real world markets so inefficient outcomes may be the rule rather than the exception (Sanstad and Howarth, 1994).

3.1.3 Principal-agent relationship

Principal-agent relationship arises due to lack of trust between two parties at different levels within an organization. The owner of an industry, who may not be as well informed about the site-specific criteria for energy efficiency investments, may for example demand short pay-back rates/high hurdle rates on energy efficiency investments due to his or her distrust in the executive's ability to convey such investments leading to the neglect of cost-effective energy efficiency investments (DeCanio 1993, Jaffe and Stavins, 1994).

3.1.4 Split incentives

Split incentives may for example be explained by intermediaries who make choices for energy users but whose interests coincide with those of the organization that pay the bill (Stern and Aronson, 1984). If the potential adopter of an energy efficiency investment is not the party that pays the energy bill, then information about available cost-effective energy efficiency measures in the hands of the potential adopter may not be sufficient: adoption will only occur if the adopter can recover the investment from the party that enjoys the energy savings (Jaffe and Stavins, 1994). This is a deterrent to the use of energy-efficient technologies, in particular those which have higher initial costs but lower life-cycle costs than conventional technologies (Hirst and Brown, 1990).

3.2 Economic barriers - non-market failures

Apart from *market failures*, there are a number of barriers that explain the '*gap*' but can not be categorized as *market failures* but rather as *non-market failure barriers* or *market barriers*.

A *market barrier*, according to Jaffe and Stavins (1994), is defined as any factor that may account for the *'gap'* while Brown (2001) define *market barriers* as obstacles that are not based on *market failures* but which nonetheless contribute to the slow diffusion and adoption of energy-efficient measures. Barriers which may be categorized as *market barriers* are, for example *hidden costs, limited access to capital, risk* and *heterogeneity* (Sorrell et al., 2000). These barriers are presented below.

3.2.1 Hidden costs

Hidden costs are often used as an explanatory variable to the 'gap' by economists (DeCanio, 1998). The argument is that there are costs associated with information seeking, meeting with sellers, writing contracts etc., which are higher than the actual profit from an implementation and thus inhibit investment. Accordingly, cost-effective measures may not be cost-effective when such costs associated with the investment are included. In a study by Hein and Blok (1994), for example, it was found that the *hidden costs* in large energy-intensive industrial firms ranged from three to eight percent of the total investment costs. In smaller, non-energy-intensive firms, such costs are likely to be even higher.

3.2.2 Limited access to capital

Technologies which are energy-efficient are often more expensive to purchase than alternative technologies. Furthermore, obtaining additional capital in order to invest in the energy-efficient technology may be problematic. Apart from low liquidity, *limited access to capital* may also be due to problems of lending money (Hirst and Brown, 1990).

3.2.3 Risk

Risk is another explanation for the 'energy efficiency gap'. For example, even though managers know what the capital cost is for an energy efficiency investment, uncertainty about the long-term savings in operating costs means the investment is a *risk* (Hirst and Brown, 1990). Also, the industry and commercial entrepreneurs are unsure whether installing new equipment will disrupt operations and whether the new equipment will increase downtime or reduce productivity during operation. Such concerns have been found to be very important to decision-makers (Hirst and Brown, 1990).

Stern and Aronson (1984) also point out *risk* as a barrier to energy efficiency as accurate estimations of the net costs for the implementation of energy efficiency measures depend on future economic conditions in general, and in particular, on future energy prices and availability. Energy prices have fluctuated in the past, leading to perceptions of uncertainty about future prices. *How are consumers to make 'rational' choices about the purchase of new energy-using systems such as cars, heating equipment, new buildings, and motors when the basis for estimating long-term operating costs is so uncertain?...Uncertainty about fuel prices is a barrier to investment in both the manufacture and purchase of energy-efficient systems* (Hirst and Brown, 1990). Moreover, studies of SMEs have found that some may not even be able to reduce uncertainty to a calculated *risk* due to lack of time and money to make the mandatory estimations (Stern and Aronson, 1984).

3.2.4 Heterogeneity

Heterogeneity is associated with the fact that even if a given technology is cost-effective on average, it will most probably not be so for some individuals or firms. If the relevant population is heterogeneous with respect to the amount of energy it uses, e.g. even a technology that is energy-efficient for the average user will be unattractive for a portion of the population (Jaffe and Stavins, 1994). *Heterogeneity* holds in particular for production processes where firms are often specialized in one type of goods and where an energy efficiency measure is then difficult to implement in another firm. Even though very similar goods are produced, small differences in the products, such as different size and shape, inhibit the implementation of the measure in another firm (Jaffe and Stavins, 1994). *Heterogeneity* may be an explanatory variable for the 'gap' when constructing models of a population of firms but is less likely to hold if site-specific information regarding a cost-effective energy efficiency measure, resulting from, for example an energy audit, is presented. This is explained by the fact that a measure then is more likely to be implemented because the auditor considers it possible.

3.3 Behavioural barriers

Apart from economic theory explanations for the 'gap', outlined above, there are also a number of barriers derived from behavioural sciences that explain the 'gap', like *form of information*, *credibility and trust*, values, inertia, and *bounded rationality* (Sorrell et al., 2000). These barriers are presented below.

3.3.1 Form of information

One barrier to energy efficiency is that the *form of information* does not receive as much attention as people (often) are not active information seekers but rather selective in attending to and assimilating information. Research in the field points out some characteristics in the way information is assimilated. People are more likely to remember information if it is specific and presented in a vivid and personalized manner and comes from a person who is similar to the receiver (Stern and Aronson, 1984).

3.3.2 Credibility and trust

Another barrier is the receiver's perceived *credibility* of and *trust* in the information provider. As energy users cannot easily gain accurate information about the ultimate comparative cost of different energy options, they will rely on the most *credible* available information. An example from the household sector illustrates this. In a study, pamphlets describing how to save energy in home air-conditioning systems were sent out to 1,000 households in New York. Half the households retrieved information in a mailing from the local electricity utility and the other half received the pamphlet from the state regulatory agency for utilities. The following month, households that had received the pamphlet from the regulatory state agency used about eight percent less electricity than households that had received the same pamphlet from the local electricity utility company (Stern and Aronson, 1984). Effective spreading of information thus relies on a trustworthy information provider. As concerns the industry, intermediaries such as sector organizations or consultants may play an important role as these often tend to be regarded as trustworthy (Ramirez et al., 2005, Stern and Aronson, 1984).

3.3.3 Values

Values are another type of barrier to energy efficiency. *Values* such as helping others, concern for the environment and moral commitment to use energy more efficiently are influencing individuals and groups of individuals. However, studies of households indicate that norms only have strong impact on cost-free energy efficiency and energy conservation measures and show weaker correlation to low-cost measures (Stern and Aronson, 1984). With high uncertainty about energy prices and lack of trust in formal information sources, interpersonal influences like imitation of behaviour are likely to have greater impact on people’s behaviour as friends and colleagues implementing energy efficiency equipment or conservation behaviour acts as a vivid example and because information from close associates are outstanding (salient) (Stern and Aronson, 1984). This was exemplified in a study by Aronson and O’Leary (1983) on showering in a university building. In the study it was shown that the number of students taking short energy-saving showers increased from six percent - when a sign encouraging short showers was put up - to 19 percent when an intrusive sign was used - to 49 percent when the researchers used a student who set an example by always turning off the water and soaping up whenever someone came into the facility - to 67 percent when two students serving as examples were used (Aronsson and O’Leary, 1983). Consequently, lack of *values* related to energy efficiency may inhibit measures from being undertaken.

3.3.4 Inertia

Inertia means that individuals and organizations are, in part, creatures of habits and established routines and it may be difficult to create a change in such behaviours and habits. This is put forth as an explanatory variable to the ‘gap’. People work to reduce uncertainty and change in their environments, and they avoid or ignore problems (Stern and Aronson, 1984). Also, people who have recently made an important decision seek to justify that decision afterwards - convincing themselves and others that the decision was correct. This description of *inertia* may partly explain the failure of many energy users to take economically justifiable action to save energy and also that energy efficiency often begins with small commitments that later lead to greater ones (Stern and Aronson, 1984).

3.3.5 Bounded rationality

Another cited explanation for why cost-effective energy efficiency measures are not undertaken is *bounded rationality* (Simon, 1957). Most types of *market imperfections* have to do with problems in the economic environment that impede economic efficiency even when assuming fully rational agents, that is, utility maximizing consumers and profit maximizing firms. In the case of energy related decisions, this hypothesis formally requires individuals and firms to solve what may be extremely complex optimization problems in order to obtain the least cost provision of energy services (Sanstad and Howarth, 1994). Studies of organizational decision-making identify two major features of organizations that affect the fit of a simple rational view to their actions. Firstly, the organization is not a single actor but rather consists of many actors with different, sometimes conflicting, objectives. Interests of one employee or department may be in conflict with other departments’ or employees’ interests. For example, workers with innovative ideas for changes in technology often require the agreement, or even collaboration, of managers and others in order to implement the change. Secondly, organizations, according to Sanstad and Howarth (1994), just like individuals, to some extent do not act on the basis of complete information but rather make decisions by rule of thumb (Stern and Aronson, 1984).

3.4 Organizational barriers

Apart from economic and behavioural barriers there are also barriers, for example *power* and *culture* which are sprung from organizational theory (Sorrell et al., 2000). These barriers are presented below.

3.4.1 Power

Lack of *power* is put forth as an explanatory variable to the 'gap'. Energy management typically has low status within organizations leading to constraints when striving to implement energy efficiency measures (Sorrell et al., 2000).

3.4.2 Culture

Culture as a barrier to energy efficiency is closely connected to the values of the individuals forming the *culture*. An organization's *culture* may be seen as the sum of each individual's values where the executives' values or the values of other workers who have influence within the organization, may have greater impact on the organization's *culture* than 'lower status' workers (Sorrell et al., 2000).

3.5 Barriers not fully explaining the existence of the 'gap'

Apart from the above presented barriers to energy efficiency, there are also barriers which do not fully answer the non-take-up of cost-effective energy efficiency investments in a single industry but which nevertheless represent barriers to energy efficiency on a higher system level that affect the degree of energy efficiency in the industry. These barriers may be categorized as structural or institutional barriers according to Weber (1997). Some of these barriers will be presented in the following section.

3.5.1 Distortions in fuel prices

Distortions in fuel prices means that the prices that consumers pay for fuels do not fully reflect all the environmental and social costs associated with fuels' production, conversion, transportation and use. These so-called, externalities are difficult to estimate but fuel prices would rise significantly if they reflected the full social costs (Hirst and Brown, 1990). For industrial firms, higher energy prices would in turn lead to lower pay-back periods for energy efficiency investments and thus plausibly increase the chances of implementation.

3.5.2 Different perspectives on energy

The energy efficiency issue is only one among many in energy politics. Stern and Aronson (1984) present four different views of energy directly affecting energy politics. First, energy is often seen as a commodity, or more accurately, a collection of commodities. A second view of energy is as an ecological resource. A third major view of energy has also become increasingly important in the last years; energy as a social necessity. In this view, consumers have a right to receive energy. A fourth significant view of energy is as strategic material. In this view, the important properties of each energy source include its geographical location in the world, the political stability and orientation of the countries in which it is located, and if an energy source is located in an unstable area, the availability of domestic or other reliable substitutes (Stern and Aronson, 1984). As far as European energy politics are concerned there is also a fifth view. The EU started out as a coal and steel union and has been giving subsidies to the coal and steel industries amounting to about 160,000 million EUR (Hansson, 2005). The different views on energy thus make energy politics, and energy efficiency in particular, an intricate matter and a strong emphasis on one perspective, deviating from the energy efficiency issue, may lead to a lower priority on for example energy efficiency policies.

3.5.3 Government fiscal and regulatory policies

The Swedish government has provided greater support for the energy supply side than for the demand side of the energy system. Since the Swedish people voted for a future shut down of the Swedish nuclear power plants in 1980, subsidies for research and development of new environmentally sound electricity generation, like windmills and small-scale hydropower plants have been provided, while less funding has been put into the demand side stressing energy efficiency (Löfstedt, 1993). Increased energy prices would however be assumed to result in more attention being paid to energy efficiency issues but, as stated previously, this is not always the case. A variety of government policies, practices, and programmes thus implicitly affect decisions regarding the purchase and operation of energy-using equipment. The low support from the Swedish government on the demand side is not endemically connected to Swedish energy politics. The American authors Hirst and Brown (1990) write that: *Unfortunately, these government actions tend to favour increased energy use rather than greater energy efficiency* (Hirst and Brown, 1990). In conclusion, this means that lack of energy end-use policies may be an institutional barrier to the adoption of energy efficiency measures.

3.5.4 Supply infrastructure limitations

Another barrier concerns *supply infrastructure limitations* where the availability of new energy-efficient technologies may be limited to particular geographic regions of the country (Hirst and Brown, 1990). In regions where district heating for example is available it is often more energy-efficient to use district heating than for example heat-pumps (Gebremedhin, 2003) representing an illustrative example of where limitation in the energy supply infrastructure constitutes a barrier to energy efficiency.

3.5.5 Codes and standards

Codes and standards are usually viewed as instruments of change and not as barriers. In spite of that, the process of setting and revising *standards* and *codes* is often slow, cumbersome, and dominated by special interests. Because *codes* and *standards* take a long time to adopt and modify, they sometimes specify obsolete technologies, thereby inhibiting innovation (Hirst and Brown, 1990). One such Swedish example is the CE-standard.

3.5.6 Structure

It has been argued that organization schemes are an old fashioned way of visualizing organizations resulting in widely diverse organizational theories ranging from metaphors of organizations operating like the nervous system (Beer, 1981) to mathematical modelling of firms (Forester, 1965). An organization's *structure*, however, has an impact on energy efficiency (Cebon, 1992). Even though it is difficult to state *structure* as a barrier to energy efficiency it is clear that organizational *structure* will constrain the range of opportunities for improved efficiency (Sorrell et al., 2000). In a paper by Cebon (1992) on how organizational *structure* influenced energy efficiency at two universities it was found that the centralized university was successful in implementing a complex Building Energy Management System while the decentralized university was successful in installing simple technologies like compact fluorescent lighting involving the active participation of users (Cebon, 1992).

3.6 Means of overcoming barriers to energy efficiency

Various means exist to overcome barriers to energy efficiency in the industry, one of the most cited being *industrial energy programmes* (Andersson and Newell, 2004). In table 2, different means are outlined in relation to some of the above outlined barriers to energy efficiency.

Table 2
Means to address barriers to improved energy efficiency (Based on Hirst and Brown, 1990).

Barriers	**Possible policy solution**
Limited access to capital	Offer financial incentives for energy-efficient systems
	Provide tax credits for energy efficiency investments
Behavioural barriers	Conduct energy information programmes
	Provide visible leadership from top government and corporate officials
Risk	Conduct demonstration programmes
	Provide performance based contracting
Imperfect/asymmetric information	Conduct energy information programmes
	Conduct model energy audits of industrial plants
Split incentives	Conduct energy information programmes
	Offer financial incentive programmes

As seen in table 2, *energy information programmes* are one of the major means of overcoming a number of different barriers to energy efficiency.

Chapter 4

4 INDUSTRIAL ENERGY PROGRAMMES

The following section outlines some important aspects related to industrial energy programmes, mainly those towards non-energy-intensive companies and industrial SMEs. The chapter also includes a summary of actions taken in Sweden.

One of the most cited means of promoting industrial energy end-use efficiency and overcoming barriers to energy efficiency is to use *industrial energy programmes*. So far, no such programmes targeting the whole Swedish industry have taken place.

The European Climate Change Commission has concluded that the implementation of *energy audit programmes* and *LTAs* are two of the most important means of reducing CO_2 emission in industrial processes (Bertoldi, 2001). While *energy audit programmes* is a means, in particular for non-energy-intensive industrial companies and industrial SMEs, *LTA* programmes are more suitable for energy-intensive industries (Bertoldi, 2001). As this thesis is focused on non-energy-intensive industrial companies and industrial SMEs, the following section includes some important aspects of *industrial energy programmes* targeting non-energy-intensive industrial companies and industrial SMEs.

4.1 Industrial energy programmes for non-energy-intensive and SME industries

Government-funded *industrial energy programmes* have internationally been one of the most common means of increasing industrial energy efficiency and overcoming, among other barriers to energy efficiency, the *imperfect information* barrier (Hirst and Brown, 1990). *Information programmes* may also include educational workshops and training programmes for professionals, advertising, and product labelling (Anderson and Newell, 2004). Another type of programme is general information campaigns. While such general information campaigns result in increased awareness of the importance of energy efficiency, general information campaigns, however, seem to result in only a small increase in the adoption of energy efficiency measures according to Stern and Aronsson (1984).

Industrial energy programmes offering audits are one of the most useful policy instruments in order to overcome barriers to energy efficiency and provide the industry with adequate information about available energy efficiency measures and by doing so, enable the industry to take action towards increased energy efficiency (Schleich, 2004). So far, the non-energy-intensive and SME sectors have often received little attention when it comes to energy end-use policies (Ramirez et al., 2005), and Sweden is no exception. In fact, Swedish energy policy activities focusing on industrial energy end-use efficiency have, in relation to many other countries, been relatively few. In Denmark, for example, the energy-saving policy is well developed and quite strong compared with the policy in many other countries (Bach, 2001).

Energy efficiency programmes for non-energy-intensive companies and industrial SMEs can generally be divided into two areas: technology improvement opportunity identification (generally through energy audits or other technical assistance) and direct financing or other implementation facilitation of identified opportunities where successful programmes often bring these two elements together (Shipley and Elliot, 2001).

For energy-intensive companies including energy-intensive SMEs, *LTA* programmes may be a sound option. An *LTA* is a type of agreement between the authorities and the industry and have been outlined as a means with a large potential, in fact one of the most effective energy policy instruments towards the energy-intensive industry, to increase the implementation of economically viable energy efficiency measures within the EU (Bertoldi, 1999). Apart from promoting technical energy efficiency measures, *LTAs* also aims towards 'soft' issues like the implementation of energy management routines. One of the most important attributes of an *LTA* is that it is flexible (Bertoldi, 2001). There is currently work in progress regarding the design of *LTA* programmes for industrial SMEs, named *the EU LTA-uptake project*.

4.2 Important aspects regarding industrial energy programmes

As outlined in previous sections, industrial energy audits are one of the most widely used means of providing non-energy-intensive industries and industrial SMEs with information on ways to decrease energy costs and increase overall energy efficiency. Studies on the outcome of different audits have found that the outcome of an energy audit and the programme as a whole are dependent on a number of factors.

Stern and Aronsson (1984) emphasize that the type of information given is important for whether energy-efficient measures will be implemented or not. Information must be specific and vivid, i.e. individual energy audits are better than general advice regarding potential cost reductions such as information campaigns and seminars (Stern and Aronsson, 1984). The latter measures, however, should not be underestimated as they have been shown to increase awareness of the need for energy efficiency and energy conservation (Stern and Aronsson, 1984, SEA, 2006d). Research has found that companies with low competence (in energy efficiency issues) often show more interest in external information than companies with high competence and who have knowledge about how much and where energy is used within their site and also have the ability to carry through energy efficiency measures (Edén, 1991). Public-sponsored energy audits are thus valuable when offered to SMEs and non-energy-intensive industries (Schleich, 2004). Research on offering subsidies for SMEs, however, is not unambiguous. A study by Gruber and Brand (1991) found that a grant for energy audits in

German SMEs only showed limited success. Many SMEs were not aware of the grant and many were reluctant to use it as the outcome of future benefits was uncertain, i.e. the costs of the audit (with the grant) may exceed future potential energy savings at the firm (Gruber and Brand, 1991). Consequently, there is a need for sound marketing of such an energy audit subsidy in order for companies to accept the offer.

An understanding of the specific energy characteristics related to the individual company is also of importance. From this the auditor can propose measures related to the specific conditions and the specific company's problems and need of support (Edén 1991). Consequently, sector or trade organizations should be more effective assuming they have the relevant skills in carrying out energy audits as they are aware of the specific characteristics related to the industrial sector concerned. It should be noted that for non-energy-intensive industries, this might be less important as a large proportion of the energy-using processes are related to the support processes and not the production processes.

Earlier research on energy audits reveals the importance of creating continuity in ongoing networks (Russell, 2006). It requires frequent contacts and regular energy audits for companies in order to continuously invest in cost-effective energy efficiency measures also in the future. The companies sometimes forget the information given and invest after some time in inefficient measures. Earlier studies have shown that simple methods such as reminding the companies of simple routines or requiring consumption figures give good results also in the long term (Edén, 1991). The need for continuity in the communication process indicates that intermediaries, who are closely related to the particular firms, are again better off when it comes to supporting industry with energy efficiency information than governmental institutions. The chances for energy information to influence decision makers are also dependent on how trustworthy the presenter of the information is considered to be by the receiver. If the receiver lacks trust in the giver, there is a significant risk that the information will be ignored. Firms may also value information regarding potential energy efficiency measures differently.

Effective energy auditing also includes technically skilled auditors who have good knowledge about the energy-efficient technologies currently available in the marketplace as well as theoretical skills in performing valid calculations (Capeheart and Capeheart, 1995). Furthermore, even if companies have performed energy audits and have information regarding potential measures at their plant, extensive work is often needed in order for measures to be undertaken in the industry. Performing a number of energy audits in the same area has also been shown to be more effective than occasional audits, partly due to the fact that staff at the firm perceive energy efficiency matters as more concrete when nearby firms are also involved (Persson, 1990). Related to this are also findings that 'success stories', i.e. examples of successful energy efficiency investments, may have a large impact on other companies (TemaNord, 2003).

When the authorities are to cooperate with the region's SMEs, the contextual differences must also be taken into account, i.e. the structure of a programme which works in one country may not be as successful in another country depending on differences in culture, structure and previous contact with the authorities (von Malmborg, 2003). von Malmborg (2003) writes that for Swedish conditions, four different conditions have to be fulfilled if collaboration will take place and the project will turn out to be effective, namely organizational capability to participate, a bottom-up perspective with realistic objectives, project competence and mutual trust (von Malmborg, 2003).

4.3 Swedish industrial energy programmes

After the project *Uppdrag 2000*, a national demand-side management programme managed by Vattenfall[9], between 1986 and 1991, two Swedish energy efficiency programmes directed towards the energy-intensive industry are running or have been concluded. The two national programs which have been carried are *EKO-Energi* and the *PFE*, where the latter is still running. *EKO-Energi*, a *VA*, was carried out between the years 1994 and 2001 including 72 large energy-intensive industrial companies. A qualitative evaluation of *EKO-Energi* revealed that in particular the audits had given increased priority to energy efficiency and environmental issues (Uggla and Avasoo, 2001). Despite intense efforts, it was unfortunately not possible to evaluate the programme quantitatively (Lindén and Carlsson-Kanyama, 2002, Widerström, 2007). The other programme, *PFE*, an *LTA* approach, is presented in chapter two. Apart from these two programmes directed towards energy-intensive industries, a number of initiatives on various levels directed towards the industry have been taken in Sweden. The following section includes an overview of the current initiatives and the initiatives taken over the last 15 years in Sweden.

4.3.1 Project Highland

The most extensive action targeting the adoption of energy efficiency measures in the Swedish industry over the past 15 years was *project Highland*, funded partly by the EU's Programme Objective 2 South of Sweden. Energy use by industry in the Highland region is about 1.1 TWh annually and the programme covered about half of this industrial energy use.

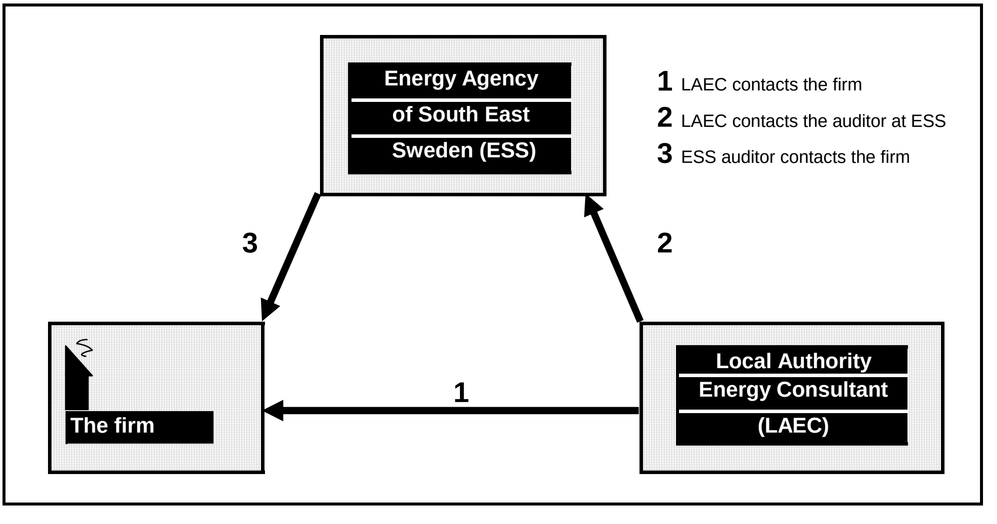

Figure 5. The beginning of an energy audit in project Highland.

[9] Vattenfall is Europe's fourth largest producer of electricity and the largest producer of heat and is owned by the Swedish state.

The local energy programme included 340 energy audits in six municipalities, of which 139 audits were directed towards the industry. A total of 359 industrial companies with three or more employees are located in this region (SCB, 2007). The structure of the beginning of an audit is presented in figure 5 and began when the local authority energy consultant in each municipality offered public-sponsored energy audits to the enterprises within the municipality.

The audits were carried out by *ESS* (Energy agency of South East Sweden), which, unlike the other Swedish regional energy agencies, works on a broad basis towards industrial actors, and is also by far the largest Swedish regional energy agency. The energy audits included individual energy audit reports where specific energy efficiency measures for each company were presented. However, due to the limited amount of time assigned to each audit, explained by the fact that the *SEA* (the Swedish Energy Agency) did not allow complete audits due to a risk of competitive disadvantages for firms not included in the programme, less than half of the recommended measures were quantified (ESS, 2007). *ESS* was the executive part and in some cases the local authority energy consultant supported *ESS* during field visits. The audits were restricted to two days: a one-day field visit and one day to compile the energy audit report. For some of the larger firms in the study, the audit time was extended.

4.3.2 Seminars, energy consultancy and other minor projects and campaigns

One action directed towards SMEs from *SEA* (the Swedish Energy Agency) in 2006 was a series of seminars given in 10 locations by six regional energy agencies (SEA, 2006d). An evaluation of the seminars, based on 40 telephone interviews with participants from industry, revealed that they viewed the seminars as valuable as they increased awareness of the energy efficiency issue, but that only a small number of the measures were implemented as a direct result of the seminars (SEA, 2006d). According to the participants, the motivation existed but the firms did not know how to become energy-efficient; nor did they have the knowledge, skill, or experience to work systematically with the issue. *SEA* also supports the local authority energy consultant in each municipality financially, and also, to some extent, the regional energy agencies by supporting specific projects. Other Swedish actions in the past include *Sparkraft*, which offered about 10 energy audits per municipality to different actors in south-eastern Sweden, carried out by three regional energy agencies between 2000 and 2003. The project was mainly aimed at the service sector, i.e. schools and other public buildings, but some industries were also covered (Sparkraft, 2007). Another project covered the nine largest industries within the municipality of Oskarshamn and was carried out between 2000 and 2001 by *ESS* and Linköping University (Trygg, 2006). Yet another project, named *ELOST*, involved energy audits and focused on reducing the use of electricity as an adjustment to an assumed electricity price increase, and many measures therefore include conversion from electricity to other energy carriers (Franzén, 2005). A project in southwest Sweden, named Energieffektiva Västra Götaland, concluded in May 2005, included nine energy audits for the industry (Environmental Health Collaboration, 2005). In another project funded by *SEA*, called *Sustainable Municipalities*, energy audits aimed at the commercial sector in each of the five participating municipalities were conducted by Linköping University between 2004 and 2006 (SEA, 2004c-d, SEA, 2005b, SEA, 2006e). The degree of adoption within these programmes has not yet been evaluated. Two regional energy agencies offered a total of 25 industrial energy audits in two regions in Sweden during 2007 where the results from the audits were later spread through seminars and a booklet. During the same time period, the

West Sweden Chamber of Commerce and Industry (WSCCI) offered advice to a total of 30 industrial companies that had energy costs over two million SEK (approximately 215,000 EUR), named Energy Focus (WSCCI, 2007), and *ESS* worked with a small number of industrial energy audits (three to four) in six municipalities in southeast Sweden (ESS, 2007).

Chapter 5

5 METHOD

This chapter begins by presenting the thesis' overall research design. The chapter continues with a presentation and motivation of the use of the different methods applied in the thesis such as systems analyzes, case study research, the MIND method, industrial energy auditing, evaluation of industrial energy programmes, and interviews and questionnaires. Each method presentation ends with a brief presentation of how the method is applied in the different case studies.

5.1 Research design

Based on the research themes presented in the introductory chapter, four research questions were formulated and examined. The four research questions are:

1. What types of energy efficiency measures exist within the Swedish foundry industry and what impact will the implementation of energy efficiency measures have on an industry's future energy costs?
2. What are the barriers that inhibit and the driving forces that promote the implementation of cost-effective energy efficiency measures in different Swedish industrial sectors?
3. How can the use of optimizing methods, such as *MIND*, provide energy-intensive industrial SMEs with additional information when strategic investments are to be made?
4. Which energy efficiency measures were implemented from the local energy programme, *project Highland,* how effective was *project Highland* in relation to the outcome of other Swedish energy programmes directed towards the industry, and how can the energy audit method used in the programme and other industrial sites be developed and improved?

In answering the first research question, the major means of collecting data was energy auditing and interviews. The second and fourth research questions were answered by means of interviews and questionnaires while the third research question was answered by means of the *MIND method*. The overall research design and the research methods used in the different studies is presented in figure 6 and basically involves two different paths: one comprising non-energy-intensive industries and one comprising energy-intensive industries, in particular the foundry industry. The choice of the latter was partly due to its energy intensity and its presumably strong incentive to improve energy efficiency.

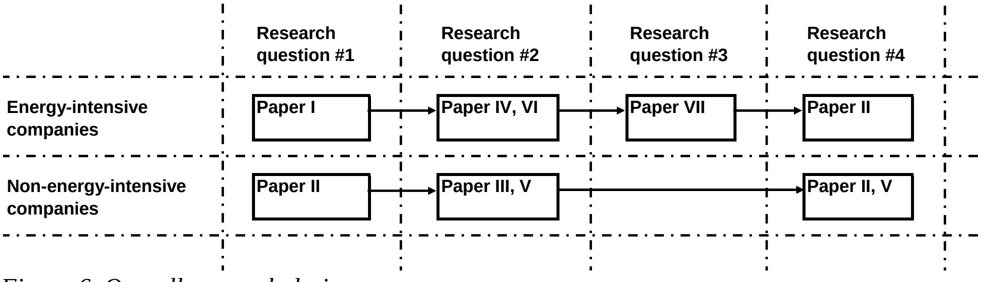

Figure 6. Overall research design.

The major emphasis in the thesis is on non-energy-intensive and industrial SMEs with the exception of Paper VI, where barriers to and driving forces for energy efficiency in the Swedish pulp and paper industry, which mainly consists of larger sites, are studied. It should be noted that *case study research* and *systems analyses* are not explicitly outlined as all the studies were conducted using *case study research* and *systems analyses* have been an approach throughout the whole thesis.

5.2 Systems analyses

The systems approach according to Churchman (1968) begins when first you see the world through the eyes of another, i.e., when a problem is illuminated from several perspectives. Churchman (1968) gives a number of examples of how a number of the problems in the world could basically be solved using modern technology but still remain unsolved, stressing the need for a systems approach to be applied. When conducting *systems analyses* it is of importance to state what is inside the system and what belongs to the environment. When conducting, for example, an energy audit, a technical approach is often applied to study the technical artefacts and their technical energy saving potential, i.e. the use of variable speed drivers for electric motors etc., leaving out issues such as managing the energy issue. In such an analysis, the company staff may be seen as outside the system boundary, i.e. as part of the environment, as the analysis does not consider that the staff’s effect on the technical artefacts could be controlled. Another perspective of viewing systems is to categorize systems depending on their different degrees of complexity. Boulding (1956) categorized systems, depending on their degree of complexity, into nine levels beginning with static mechanics at the very first level and the human itself and interaction between humans at the seventh and eight levels (Boulding also presents a ninth level which he calls the transcendental level, i.e. where questions asked could not in fact be answered). He argues that on the first levels of complexity it is somewhat possible to obtain a good picture of the system and the parameters affecting it. For example, if a force on an object changes in magnitude, the momentum increases around the centre of its momentum. However, as the complexity of the system increases, it becomes more and more difficult to study: *Beyond the fourth level it may be doubted whether we have as yet even the rudiments of theoretical systems. The intricate machinery of growth by which the genetic complex organizes the matter around it is almost a complete mystery. Up to now, only God can make the three* (Boulding, 1956). Boulding

(1956) thus states that when studying single individuals or a group of individuals it is very difficult to gain, from an objectivistic viewpoint, a general theory that includes all the parameters.

Systems analyses are a diverse field comprising numerous areas of research, one such being *OR* (Operational Research. *OR* may be seen as a type of systems analysis and in turn originates from military planning during World War II applying scientific methods in order to analyze military operations (Taha, 1976), the most prominent *OR* technique being linear programming, designed with linear objective and constraint functions. Other techniques include, for example, integer programming (in which the variables assume integer values), dynamic programming and nonlinear programming (Taha, 1976). In some cases there is a need to mix linear programming and integer programming, commonly referred to Mixed Integer Linear Programming (MILP) (Taha, 1976). In particular, MILP provides a methodology for determining optimal strategies in order to minimize the overall energy costs in for example industries (Taha, 1976, Nilsson, 1993, Arivalagan, 1995). A MILP problem can be described as (Dag, 2000).

$$\begin{aligned} \text{Min} \quad & Z = f(x, y) \\ \text{Subject to} \quad & g(x, y) = 0 \\ & h(x, y) \leq 0 \\ & x \geq 0,\ y \in \{0/1\} \end{aligned}$$

where $f(x, y)$ is the objective function, like system cost, $g(x, y) = 0$ are equations describing the performance of the energy system, like the relation between the mass flow through a process and the corresponding energy demand, $h(x, y) \leq 0$ are inequalities describing for example limits in capacity for the components in the system. The variable x is continuous and corresponds to such aspects as energy and material flows, while y is a discrete (binary) variable.

5.2.1 Systems analyses applications

The complexity of industrial energy efficiency comprising individuals, organizations, technology etc., emphasize the importance of not narrowing the research into studies of one single factor from one single perspective. Even though this thesis comprises only one study relating to *OR* (Paper VII), a systems approach was applied in more or less all the Papers studying an array of different energy efficiency technologies, both production and support processes at operational and strategic level as well as barriers to and driving forces for energy efficiency derived from various scientific disciplines.

5.3 Case study research

Case study research is particularly advantageous when ‘how’ or ‘why’ questions are asked about a contemporary set of events over which the investigator has little or no control (Yin, 2003). When conducting *case study research*, the researcher’s skills are of importance (Yin, 2003). Some basic skills include: asking good questions and interpreting the answers, being a good listener, being adaptive and flexible, having a good grasp of the studied issues and not being biased by preconceived notions, including theory-based notions.

In the design of a case study, besides the choice of studying single or multiple cases, one of the most important determinants in high quality *case study research* is the maximization of *construct validity*, *internal validity*, *external validity* and *reliability* (Yin, 2003). *Construct validity* means establishing correct operational measures for the concepts being studied. *Internal validity* (which only concerns explanatory or causal studies) means establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from false relationships. *External validity* means establishing the domain to which a study's findings can be generalized. *Reliability* means demonstrating that the operations of a study may be repeated, with the same results (Yin, 2003). Strategies for increasing the *construct validity* include, for example, using multiple sources of data and asking colleagues to comment on the findings that emerge (Merriam, 1998). Strategies for increasing *internal validity* include, for example, considering rival explanations for causal studies. *External validity* could be increased by, for example, choosing to conduct multiple case studies (Merriam, 1998). *Reliability* could be increased by the investigator being transparent of major assumptions made, the theory being used as well as the basis for selecting respondents (Merriam, 1998).

Yin (2003) means that the preparation for doing a case study includes for example the prior skills of the investigator, the training and preparation for the specific case study, the development of a case study protocol and the screening of candidate case studies. Merriam (1998) furthermore argues for the importance of reviewing relevant literature prior to conducting the study. Yin (2003) outlines six main sources of information, namely; *documentation*, *archival records*, *interviews (including questionnaires*), *direct observations*, *participant observations* and *physical artefacts*. Generally, receiving information from multiple sources means a higher quality outcome of a case study (Yin, 2003). The most important sources of information in case studies are *interviews* (Merriam, 1998). When analyzing the results from case studies, one pitfall is to incorporate ideas from statistics which view the results as general. Instead, case study researcher argues for 'analytic generalization ' which means that theories sprung from *case study research* may be of a general nature which may later be proved to hold or not hold in other cases. For example, it is not possible to generalize findings to the whole Swedish industry stating that the implementation of energy efficiency measures eliminates the threat of rising electricity prices based on one single energy audit. However, what is possible is to state a theoretical proposal that the implementation of energy efficiency measures eliminates, or greatly reduces, the threat of rising electricity prices. This theoretical proposal may then be tested in additional cases in order to strengthen or refute the proposal.

5.3.1 Case study applications

The research questions in this thesis made *case study research*, inspired by Yin (2003), suitable as how and why questions were asked, studying a contemporary set of events where there has been little or no control. In order to find the technical energy efficiency potential, the measures that can actually be implemented in a firm or group of firms as well as barriers to and driving forces for their implementation - one has to study the actual case/cases, see for example Trygg (2006) and Ostertag (1999). Ostertag (1999) writes: …*research on barriers to energy conservation…are strongly interdisciplinary, the predominant methodologies are borrowed from social sciences, e.g. case studies…* (Ostertag, 1999). The preparations for using *case study research* were made and included *pilot interviews, group discussions* reflecting interview schemes, and *questionnaires*, with the participation of the Energy Systems Program, an interdisciplinary research programme with researchers from both the engineering and the social sciences. The case studies concerning foundries were prepared in cooperation with representatives from *SFA* (the Swedish Foundry Association) and the foundry industry. Yin (2003) also argues for the positive aspects of quality control through colleagues listening to ideas and reading drafts of the case study report. This has been practised systematically throughout the research by numerous discussion boards, formal as well as informal, with colleagues within the division and the Energy Systems Program concerning research projects. In addition, results have been discussed with company representatives where this has been considered valuable as well as with representatives from SFA regarding the studies concerning the Swedish foundry industry.

The analysis in Paper I regarded technical energy efficiency measures in an iron foundry, using a single-case design. In Paper II, concerning energy audits, a multiple-case as well as a single-case design was used. In Papers III-VI, concerning the process of energy decision making in industrial firms, a multiple-case design was used. In the case of Paper VII, studying a potential investment in a new melting unit, a single-case design was used. The cases, single or multiple, were industrial companies in different industrial sectors. In this thesis, *case study research* inspired by Yin (2003) using *interviews*, *semi-structured* and *structured/ questionnaires* were used to study the higher region systems according to Boulding's (1956) categorization, i.e. human-technology interaction while *case study research* inspired by Yin (2003) and using the *MIND method* was used to study the lower levels of Boulding's (1956) system categorization, i.e. technology-technology interaction.

5.4 The MIND method

The *MIND method*, originally developed at Linköping University for optimization of dynamic industrial energy systems (Nilsson, 1993) is based on Mixed Integer Linear programming (MILP). *reMIND* constitutes a later development of the *MIND method* and uses a graphical interface. According to Nilsson (1993) there are five aspects that are of great importance when modelling an industrial energy system, also included in the *MIND method* (Sandberg, 2004):

- A simultaneous representation of the whole system in order to avoid sub optimization
- The representation of different flows such as energy and material
- The representation of nonlinear relationships
- A flexible time division in order to illustrate the dynamics of the modelled system
- The choice of different levels of accuracy in different parts of the system

MIND enables an entire industrial energy system to be modelled. The analysis basically includes four steps (Larsson et al., 2004). In the first step, the real system should be delimited. Processes must be identified and reasonable boundaries and simplifications introduced in order to describe the system mathematically. In the second step, the model is constructed from a set of equations based on the simplified, delimited problem identified in the initial step, and verification that the description of the problem is satisfactory (Larsson et al., 2004). In the third step, an appropriate optimization routine should be applied. *reMIND* normally uses CPLEX. In CPLEX a variety of different algorithms may be chosen (CPLEX, 1995). In *reMIND*, CPLEX normally uses simplex to solve the linear programming problems and branch and bound to solve the integer programming problems. In the last step, the model is validated and results are analyzed. This should include verifications of the solutions from the model. Furthermore, a continuous dialogue with representatives related to the modelled case (if such exists), primarily for discussion and verification of input data to and output data from the model, is important in order to create a reliable and credible model.

5.4.1 MIND method application

A screen dump of the graphical interface from *reMIND* originating from a model of a Swedish iron foundry is shown in figure 7.

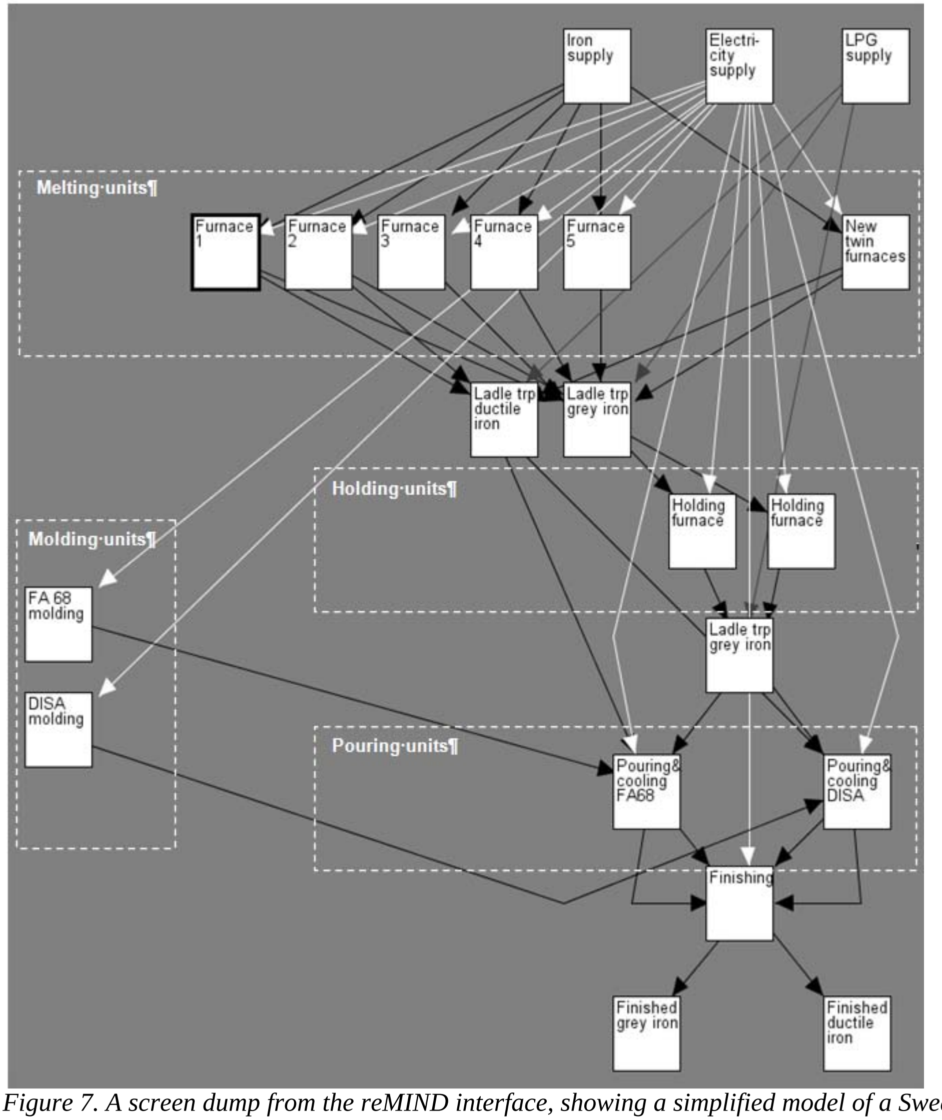

Figure 7. A screen dump from the reMIND interface, showing a simplified model of a Swedish iron foundry.

The use of *MIND* enables models to be constructed of a whole industrial energy system. *MIND* was used in Paper VII to analyze a potential investment in a new melting unit in a Swedish iron foundry. A model of the production system and its energy use was developed in *reMIND*. The different production processes were modelled and connected together by energy and material flows. The major material and energy flows within the system are shown in figure 7, where sand blasting and cleaning are named finishing. The production processes were split into several time periods determined with respect to the production unit activities. One production week was modelled, using 120 time steps, representing the current 120 production hours, based on hourly averages.

The objective function which was formulated to minimize the system cost included the energy flow variables that affect the system and its related costs. The costs for the different flows were based on current energy prices at the foundry as well as a case of future prices. The energy flows in the model were expressed in kWh/ton while the system cost was expressed in €/week.

During the process of building the model, the input data was continually verified by means of actual measurements from the plant and a continuous dialogue with company representatives. Finally, when an optimal outcome from the optimizations of the model had been obtained, the solution was verified through checking the different energy and material flows in relation to the actual flows at the foundry. It should be noted that during the whole process of constructing the model, a continuous dialogue with representatives from the company was carried on, primarily for discussion and verification of input data and optimization results.

5.5 Industrial energy auditing

One of the most efficient means of deriving energy efficiency measures in an industry, specifically when it comes to measures related to the support processes is the use of an energy audit. The energy auditing method used to derive energy efficiency measures in this thesis has been used in numerous industries over the last 20 years performed by the Division of Energy Systems, Linköping University (see for example Dag, 2000, Nord-Ågren, 2002, Trygg et al., 2005) and other Swedish actors including the local energy programmes *Sparkraft* (Sparkraft, 2007) and *project Highland*, both carried out by *ESS* (Energy agency of Southeast Sweden). The method uses a systems approach and has been used for one to two day audits up to audits taking several weeks to accomplish. The method is presented in detail in Paper II and is carried out in six steps:

1. First, a meeting is held with representatives of the industry in question and the conductors of the audit, either by phone or on-site and requirements and delimitations are formulated if needed.
2. Then, an on-site visit (walk-through) is made where quantitative data are collected through metering etc..
3. The collected data are then compiled into unit processes, which in turn are split into production processes and support processes like lighting, ventilation and compressed air. The data are then analyzed and confirmed.
4. Complementary calculations and, if needed, additional measurements are then made in order to compile a sound analysis of the present energy use.

5. In the fifth step, a meeting is held, by phone or on-site, with representatives of the industry concerned and the conductors of the audit about the proposed energy efficiency measures and the analysis of current energy use.
6. Finally, the energy audit is compiled into a two-part report that includes current energy use and proposed energy efficiency measures.

5.5.1 Industrial energy auditing applications

In the case studies where one of the main methods was to identify energy efficiency measures through the use of an energy audit (Papers I, II), the actual measurements which were carried out were electricity-related. As regards district heating and ventilation air flows, these were collected from already available data. In the case studies, the time to conduct the audits was considerably longer than the audits carried out in for example *project Highland*, which enabled longer metering periods and, naturally, more reliable data.

5.6 Industrial energy programme evaluation

An evaluation of an energy management programme consists of two phases: an information gathering phase and an analysis phase (Väisänen, 2003). For an energy audit programme, typical questions that may be of interest are for example (Väisänen, 2003):

- Programme interest in terms of applications received and the amount of audits undertaken.
- The impact of the programme in terms of energy actually saved and the quality of these units.
- The amount of public money spent per kWh saved.
- The environmental impacts.
- The target groups opinion of the programme.

The kind of data that should be collected is thus dependent on the issues that are chosen for consideration (Väisänen, 2003).

Evaluation of public policies and not least industrial energy audit programmes are an intricate matter involving a large number of plausible causalities (Vedung, 1998). Larsen and Jensen (1999) states that evaluation of energy audit programmes face a risk of being overly optimistic or, due to free-rider effects, even give a false-positive result as they are wrongly attributed to a given audit when in reality they would have been implemented anyway. In evaluating energy audit programmes in terms of energy actually saved, a questionnaire is a common means of collecting the figures (Väisänen, 2003).

5.6.1 Industrial energy programme evaluation application

A questionnaire and interviews were used in order to determine which energy efficiency measures were implemented from the conducted industrial energy audits within the evaluated energy programme, *Project Highland*, and receive the target group's opinion of the programme (audit). The questionnaire was sent out by mail in spring 2006 to firms that had participated in the energy programme before September 2005. The respondents were working in the companies that had participated in the local energy programme and the main criterion for selecting respondents was that they had been the contact person for the previously made energy audit at their company. The reason for excluding companies that had obtained audits after 1 September 2005 was that these companies were not considered to have had enough time to act on information given from the energy audit. A total of 64 respondents received the questionnaire and 47 replied. The questionnaire contained a list of the proposed energy efficiency measures and a number of barriers to and driving forces for energy efficiency that the respondents were asked to rank. In order to compare the results from the evaluated programme, two international energy audit programmes, the Australian *EEAP* (Harris et al., 2000) and the American *IAC* (Anderson and Newell, 2004), as well as a review of Swedish industrial energy efficiency actions were covered. Where possible, the figures of the costs for the Swedish programmes (*PFE*) were also presented. The aim was to include both the public costs, including the administrative cost for the Swedish programmes, and the firms' investment costs. Start-up costs were included in *project Highland* but not in *PFE* as the information from *PFE* were not publicly available at the time for the evaluation. Furthermore, a comparison between *project Highland* and *PFE* is not unambiguous as *PFE* deals with both strategic issues and energy audits, and *project Highland* included only energy audits. Another aspect of the comparison is that *PFE* focuses solely on electricity, while *project Highland* also focused on other energy carriers.

5.7 Interviews and questionnaires

There are three basic types of *interviews*: *unstructured*, *semi-structured* and *structured* (Kvale, 1996). The last may also be categorized as a *questionnaire* (Bryman, 2004). However, the *questionnaire* may be distinguished from the *interview* in that it does not imply actual contact with the respondent, face to face or orally by telephone, as is the case with *interviews* (Bryman, 2004). Therefore, the *questionnaire* as a scientific method is presented later in this chapter. An *unstructured interview* is where the respondent is intended to speak freely about a subject or a research topic. In a *structured interview*, on the other hand, the researcher asks the respondent questions based on a previously established array of question or interview scheme. The *semi-structured interview* is a mix of a *structured* and an *unstructured interview*.

The methodology of conducting an *interview* project may include several steps such as (Kvale, 1996):

- Thematizing - Interview studies should preferably be based on a specific theory or research topic.
- Designing - During the design of the study it is important to obtain a holistic overview of the whole project and among other things evaluate the number of interviews needed and if required increase the knowledge about the specific issue being covered.
- Interviewing - The interview part is perhaps the most crucial part of the project. Initially, the respondents should be informed about the background, aim, scope etc., of the project. In order to make the interview easier one may use an interview scheme including the issues to be covered and their consecutive order. In the ideal interview, the hypothesis or research question has been answered when the interview ends.
- Transcribing - Normally, an interview is transcribed, partly or fully. This enables the researcher to ex-post read through the transcribed interviews.

- Interpreting - As previously stated, the ideal interview is analyzed when the interview is finished. The transcription of the interviews may, however, lead to other, previously unforeseen, connections.
- Verifying - The verification process includes investigating the study's generality, reliability and validity.
- Reporting - The report should present a summary of how the study was carried out together with major conclusions and some final reflections. Furthermore, the report represents a basis for other researchers to evaluate the validity of the study.

Pilot *interviews* are important for trying out your questions. Multiple, leading, and yes-no questions should be avoided (Merriam, 1998). Furthermore, it is generally a good idea to ask for relatively neutral, descriptive information at the beginning of an interview (Merriam, 1998).

As previously stated a *questionnaire* differs from an *interview* in that it lacks actual contact, face to face or orally, by telephone, with the respondent (Bryman, 2004). This makes the design of the *questionnaire* particularly important. A *questionnaire* should therefore, in comparison with *interviews*, have fewer open questions in order for it to be easier to answer, have an easy to follow design to minimize the risk that the respondent will follow filter questions, and be shorter in order to reduce the risk of respondent fatigue (Bryman, 2004). Moreover, the design should limit the number of follow-up questions and also ask only one question at a time. Simple language with short questions, avoiding negations and emotionally charged words, is also preferred. A short letter should accompany the *questionnaire* presenting, for example, the study's name, its aim and scope, the name of the organization financing it, and the name of a person to contact (Trost, 2001). Advantages with the method include easy compiling and working with collected data as well as the possibility to cover a large number of respondents (Bryman, 2004).

A challenge when conducting research in the higher system levels involving people and social interactions is the *SDB* (Social Desirability Biases). *SDB* may arise out of *questionnaires* as well as *interviews* and has its roots in that respondents may like to appear different to what they are. *SDB* can appear by over-claiming, e.g. environmentally friendly behaviour or in the attitudes that someone expresses (Brace, 2004). The most common type of *SDB* is the need for approval. This needs to be avoided as far as possible when for example asking questions during an *interview* and could be done by initially making the respondent feel comfortable with the interviewer (Brace, 2004). However, in any study this type of bias will most likely occur in only a small and consistent set of questions. Another type of bias is the respondent trying to maintain their own esteem, convincing them that they think and behave in socially responsible ways (Brace, 2004). This type of behaviour may particularly affect questions regarding future predictions of likely behaviour (Brace, 2004). Yet another type of bias is instrumentation meaning that the respondent gives answers designed to bring about a socially desirable outcome, say a wish for a new energy policy to be put into action (Brace, 2004). The *SDB* could be lowered by guaranteeing the respondent confidentiality (Brace, 2004).

5.7.1 Interview and questionnaire applications

In Papers II, III and V *semi-structured interviews* were conducted. In Papers III and V *questionnaires* were also used in combination with *semi-structured interviews*. In Papers IV and VI, *questionnaires* were used. In addition to asking questions regarding barriers and driving forces, the *questionnaire* also included questions about the respondent's view of whether there exist cost-effective energy efficiency measures at their company which had not been undertaken. When the results were presented in the published Papers, as well as in this thesis, the questions were translated from Swedish to English.

Inspired by Yin (2003), the *questionnaires* were reviewed by staff at *SFA* (the Swedish Foundry Association), *SFI* (the Swedish Forest Industries) and *SEA* (the Swedish Energy Agency) as well as by senior colleagues before being sent out. The *questionnaires* were intended to be answered by energy managers or people in charge of energy issues. The reason for submitting the *questionnaire* to this category was that these people have knowledge both of the industrial process at the company - and therefore potential cost-effective energy efficiency investments - and of factors inhibiting and promoting their implementation. Furthermore, these people are often in charge of the companies' energy purchasing and contact with Swedish authorities. This implies that they are the ones who are most likely to be able to answer questions regarding market and public policy related issues accurately.

The design of the *questionnaires* was that the respondents were asked to rank different barriers to and driving forces for energy efficiency in the questionnaire as follows: one point if the respondent considered the factor to be often important, half a point for sometimes important and zero points for rarely important. One should be aware that in the analysis following from these quantifications of barriers and driving forces, simplifications are made as the quantified results contain several more perspectives of the issue than merely a single ranking score. Furthermore, it must also be kept in mind when drawing conclusions from these types of studies using *questionnaires* and *in-depth interviews* that the respondent's answers may include a degree of bias. Personal opinions, for example, may affect the respondent's answers to some questions. On the other hand, these people will most likely still act according to these opinions. Furthermore, in order to minimize such biases, the respondents have been given confidentiality in all the case studies where *interviews* and *questionnaires* were used.

In the initial study, 20 barriers were investigated. In the second study, four more barriers were added - *lack of sub-metering*; *lack of budget funding*; *slim organization*; and *long decision chains*. In the third study, three barriers were excluded by the people in charge of the evaluated industrial energy programme. It was therefore decided to exclude *cost of staff replacement, retirement, retraining*; *conflicts of interest within the company*; and *energy manager lacks influence* as these barriers had been shown to be of minor importance in the two previous studies. For the same reason, the driving forces *international competition* and *third party financing* were excluded while *EMS* and *environmental company profile* were integrated in one question. In the fourth study, the barriers investigated were the same as in the second study while the number of driving forces was expanded. In addition to the driving forces derived from the previous studies a number of driving forces based on a literature review were also included.

It should also be noted that the *interviews* and the *questionnaires* leading to classification of barriers to energy efficiency are not entirely accurate representations. As Weber (1997) states: it is empirically impossible to find the 'true' reason behind energy-conserving action which has not been taken (Weber, 1997). As all theoretical frameworks of complex real-world phenomena involving people and organizations, the theory should rather be seen as an analytical tool. This should be kept in mind when analyzing the empirical findings from the *interviews* and the *questionnaires* where many of the barriers expressed by the respondents fit into more than one theoretical barrier.

Chapter 6

6 ANALYZED CASES

In this chapter, the different cases are briefly described beginning with the Swedish foundry industry, continuing with the medium-sized iron foundry under study, Oskarshamn's eight largest industries, and the companies participating in Sustainable Municipalities. Finally, the industries in the evaluation of project Highland as well as a brief presentation of the Swedish pulp and paper industry are presented.

6.1 The Swedish foundry industry

The energy-intensive Swedish foundry industry (Paper I, II, IV and VII) employ about 7,500 people and have an aggregate domestic turnover of 1.3 billion EUR (SFA, 2005). The sector involves about 130 companies, mainly SMEs, that (SFA, 2008). The annual Swedish production is about 360,000 tons of castings - 74 percent iron, 20 percent non-ferrous and six percent steel - with a total annual energy use of about 1 TWh, mostly electricity (SFA, 2008). The foundry industry is a large user of energy, in both the production and the support processes, and in Sweden, in contrast to many other European countries, the foundries, with only one exception, use electricity for melting metal. The technical energy efficiency potential within the sector still remains to be explored: no recent figures are available as regards the technical energy efficiency potential for the Swedish foundry industry.

6.2 The iron foundry under study

The analyzed iron foundry (Papers I, II and VII) is located in the south-east of Sweden, produces bearing housings and castings mainly for the automotive industry and employs some 100 people. The foundry produces about 16,000 tons annually. The annual energy use is nearly 40 GWh, the majority represented by electricity. A minor part of the energy use at the foundry consists of LPG, which is used for preheating the ladles.

6.3 The engineering company under study

The analyzed engineering company (Paper II) is located in the south east of Sweden. Production consists of various metal cutting processes and the company employs some 400 people. The engineering firm produces about 11,000 tons annually. The annual energy use is almost 11 GWh, mostly electricity. A minor part of the energy use at the engineering company also consists of district heating.

6.4 Oskarshamn's eight largest industries

In the city of Oskarshamn, the largest non-energy-intensive industrial companies were studied (Paper II, III) consisting of five medium-sized and three large companies. The companies investigated had all participated in a project carried out about five years previously that offered public-sponsored energy audits. The companies studied produced for example trucks, batteries, candles and transformers. The companies aggregated annual electricity use is about 90 GWh and their total energy use about 175 GWh. The technical energy efficiency potential is 48 percent for electricity and 40 percent of the companies' aggregated annual energy use. The technical energy efficiency measures are mainly related to the support processes (Trygg, 2006).

6.5 The companies participating in Sustainable Municipalities

In the city of Borås, ten non-energy-intensive industries from different sectors were studied (Paper II) which were offered energy audits, free of charge, within the national project *Sustainable Municipalities* including, e.g. slaughterhouse, textile company, production of exterior and interior lighting. The companies consisted of five small, three medium-sized, and two large firms. The companies' aggregated energy use is about 70 GWh, of which about 40 GWh is electricity, about 22 GWh and 7 GWh is oil and LPG respectively and the rest is district heating. The technical energy efficiency potential is about 20 percent for electricity, 80 percent and 30 percent for LPG and oil respectively, while no figure is available for district heating (SEA, 2005b). The technical energy efficiency measures are mainly related to the support processes.

6.6 Industries within project Highland

A total of 359 industries with three or more employees are located in the Swedish Highland region consisting of six municipalities (SCB, 2007). The evaluated local energy programme, *project Highland* (Paper II, V) included 139 industries, of which 47 industries, were included in the evaluation. The number of employees at the evaluated companies ranged from just a few to about 450, the average being 72, and their total energy use is about 182 GWh, of which about 100 GWh is electricity and about 82 other energy carriers such as oil, LPG and district heating. The technical energy efficiency potential is about 21 percent for electricity and 23 percent for other energy carriers (ESS, 2006). The technical energy efficiency measures are mainly related to the support processes.

6.7 The Swedish pulp and paper industry

The studied energy-intensive Swedish pulp and paper industry (Paper VI) has an aggregated turnover of about nine billion EUR, and consists of nearly 60 mainly large- and medium-sized mills, which accounts for about 50 percent of the Swedish industrial end-use of energy. The sector uses about 50 TWh biomass, 22.5 TWh electricity and 7.3 TWh fossil fuels, and employs some 27,500 people (Swedish Forest Industry, 2005, SEA, 2007a). The potential for technical energy efficiency improvements vary from just a few percent (Ottosson and Petersson, 2007) and upwards (Nilsson et al., 1996). The lower figure is based on findings from the *PFE* evaluation, which identified an electricity efficiency potential of about three percent with a payback period of about three years (Ottosson and Petersson, 2007). A considerably higher figure was presented in a report by Nilsson et al. (1996), which stated a figure of about 30 percent technical electricity efficiency potential by replacing worn pumps, downsizing oversized equipment, installing variable-speed drives, etc. for pumps larger than 50 kW (Nilsson et al. 1996). In Swedish case studies of chemical mills, it was stated that it is not unlikely that this technical electricity efficiency potential may hold for the studied mills (Klugman, 2008). Other research indicates, at least technically, that potential exists for improvements also in other areas like for example heat integration (Wising et al. 2005, Bengtsson et al. 2001, Andersson et al. 2006, Holmberg and Gustavsson 2007, Möllersten et al. 2003, STFI, 2003).

Chapter 7

7 RESULTS FROM THE CASE STUDIES

In this chapter, the results found in the thesis are outlined in consecutive order according to the stated research questions, beginning with energy efficiency measures and their effect on industrial energy costs, followed by barriers to and driving forces for energy efficiency, optimization as investment decision support for industrial SMEs, and concluding with the implementation of measures, energy audits, and energy programmes.

7.1 Energy efficiency measures and their effect on industrial energy costs

The substantial technical energy efficiency potential identified among non-energy-intensive industrial companies (Trygg, 2006), in particular related to the support processes, and the lack of such studies among energy-intensive companies motivated the first research question to be examined. The study also included an analysis of the impact the implementation of such measures would have on the company's future energy costs, using electricity prices derived from Melkersson and Söderberg (2004) and local prices for LPG and district heating.

The results from the study are presented in table 3 and show that there exist a number of potential energy efficiency measures such as new melting furnaces, district heating supply and the elimination of compressed air leaks at the foundry.

When studying the impact these measures would have on the foundry's aggregated energy costs, it was found that the implementation of these measures would considerably reduce the threat of rising electricity prices, see figure 8.

Table 3
Energy efficiency measures for the foundry under study resulting from the industrial energy audit (Paper I).

Energy efficiency measures	**Electricity savings (MWh/year)**	**LPG savings (MWh/year)**	**District heating savings (MWh/year)**
New melting furnace	2,300	---	---
District heating supplied to municipality	---	---	2,200
Compressed-air leak elimination	1,100	---	---
New sand preparation	780	---	290
Different ladle heating	---	600	420
Lowering idling losses	1,140	---	---
Load management	---[10]	---	---
Other measures	920	---	1,770
Total figure	**6,240**	**600**	**4,680**
Total figure (%)	**23**	**51**	**70**

Table 3 show that the measures are spread among both the production and the support processes.

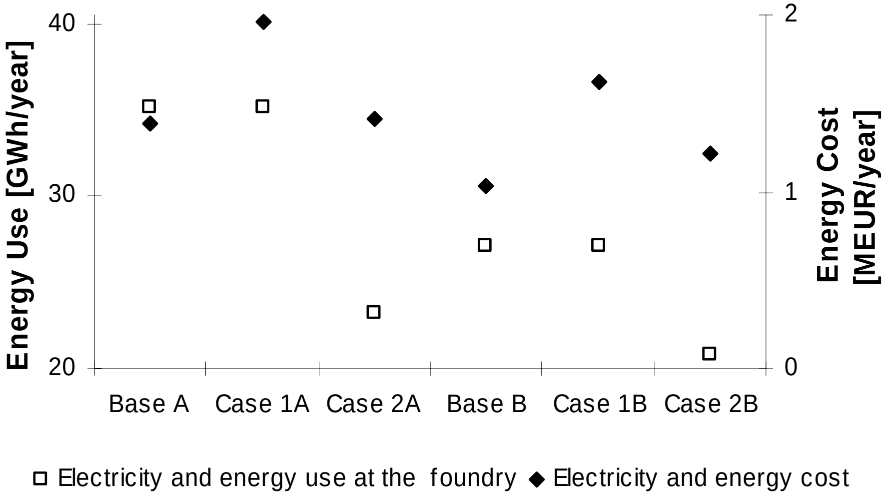

Figure 8. The foundry's electricity and energy costs and electricity and energy use for the 6 cases. Base A uses present electricity prices with no energy efficiency measures undertaken. Case 1A uses future electricity prices with no measures undertaken. Case 2A uses future electricity prices and undertaken measures. Base B uses present electricity prices and no measures undertaken, Case 1B uses future electricity prices and no measures undertaken, and Case 2B uses future electricity prices with measures undertaken (Paper I).

[10] Power reduction of 3 MW during peak-hours. The energy use is not affected by this measure, but the cost of power is reduced.

Table 4
Energy audit results from an engineering company (Paper II).

Energy efficiency measures	**Electricity savings (MWh/year)**	**District heating savings (MWh/year)**
New large-scale ventilation system	---	900
Investment in new lighting	330	---
Compressed-air leak elimination	700	---
New windows installations	---	410
VAV[11] in the shower rooms	40	120
Heat exchange from high temp. Oil separator flow	---	140
Heat exchanger on fan 815	---	120
Other measures	180	10
Total figure	**1,250**	**1,700**
Total figure (%)	**23**	**51**

In Paper II, a thorough energy audit carried out in a Swedish non-energy-intensive engineering company identified a large technical energy efficiency potential, presented in table 4, adding further strength to the findings from Trygg (2006). Table 4 shows that the measures are mostly related to the support processes. It should be noted that both the foundry and the engineering company are located in the same city and belong to the same company group. Notably, the energy efficiency potential was in fact slightly higher in the foundry case. What is also of importance to note is that the nature of the identified energy efficiency measures differs. While the measures in the non-energy-intensive case, the engineering company, mainly concern the support processes, the energy-intensive foundry case concerns measures related to both the production and the support process.

In conclusion, the implementation of technical energy efficiency measures is found to be a major means for energy-intensive as well as non-energy-intensive Swedish industrial companies to overcome the threat of rising energy prices, for example for electricity. However, the above findings do not consider the cost of the investments; the most substantial measures in the foundry case, for example, included a capital-intensive production process related investment (Paper I). An evaluation in Paper II of the energy audit conducted at the iron foundry showed that measures had been undertaken. However, the technical energy efficiency measures undertaken were mainly low-cost measures. The energy-intensive foundry industry, with a greater production process energy use compared to non-energy-intensive industries, may thus demand a different approach, apart from solely receiving information from an energy audit.

7.2 Barriers to and driving forces for energy efficiency

While previous research, including the two case studies in Paper I and Paper II, presented above, clearly indicates a substantial technical energy efficiency potential for Swedish industrial companies, figures regarding the cost-effectiveness of these measures were not

[11] Variable Air Volume.

included. Previous research has also shown that cost-effective energy efficiency measures are not always implemented, which is explained by the existence of various barriers to energy efficiency. Previous research on barriers to energy efficiency indicates that an enhanced understanding of barriers may be gained using ideas from not only mainstream economic theory but also, e.g. organizational economics (Sorrell et al., 2000). It was therefore important to incorporate ideas from different scientific disciplines when studying the complex factors inhibiting investments in energy-efficient technologies, i.e. using a more widened (systems) approach. In doing so, the issue was illuminated from several perspectives. In the part of the thesis concerning barriers, a well developed theoretical framework was used derived mainly from economic literature. But, as stated by Sorrell et al. (2000), it is rather useful to incorporate ideas from other areas as well. The barrier part of the questionnaire was originally developed and empirically tested by Sorrell et al. (2000) and was used in order to formulate questions included in a questionnaire. As regards the driving forces, there were initially, as far as the author is aware, no Swedish studies dealing explicitly with the issue. The driving forces initially studied were derived from the in-depth interviews (Paper III) and a workshop with representatives from the foundry industry (Paper IV). This resulted in a limited number of driving forces studied, and related mainly to matters within the firm such as *people with real ambition* and the existence of a *long-term energy strategy* (Paper III-V). In Paper VI, an attempt was therefore made to try to expand the driving forces investigated, incorporating the current Swedish energy policies affecting the case studied, potential public policies, and other external and internal driving forces derived from the scientific literature (de Groot et al., 2001, del Rio Gonzalez, 2005, Johansson et al., 2007 and Ottosson and Petersson, 2007) such as environmental pressure from non-governmental organizations (NGOs), i.e. not only empirically derived as was the case in the previous Swedish studies on the subject

The lack of studies of barriers and driving forces in different Swedish industrial sectors, among other things, motivated the second research question to be examined. While the part regarding barriers partly could rely on previous research and well developed theories, the part concerning driving forces had no such base to rely upon. The part concerning driving forces has therefore undergone continuous development during the different case studies.

Before one can examine barriers to energy efficiency one needs to determine whether any ‘energy efficiency gap’ exists in the studied cases. The introductory part of the questionnaires therefore included a question as to whether the respondents agreed (or disagreed) that cost-effective energy efficiency measures existed at their company[12]. With a few exceptions, the respondents agreed, confirming that an ‘energy efficiency gap’ exists in the studied industries, enabling the different barriers to energy efficiency to be investigated.

In the appended papers, Paper III-VI, there is a thorough presentation of the barriers to and driving forces for energy efficiency in the different cases investigated. The most important barriers and driving forces in the different studies are presented and discussed below.

[12] In Paper V, such a question was not included due to restrictions from the *project Highland* executive which insisted that the questionnaire should be as short as possible. However, the four firms which had not undertaken any of the proposed measures were phoned and asked why they had not adopted measures. The respondents reasons for non-adoption was not claimed to be lack of cost-effective measures. Instead, the respondents expressed great appreciation of the energy audit.

7.2.1 Barriers to energy efficiency

In table 5, the largest barriers to energy efficiency in the different studies are presented. For a more detailed presentation, the appended papers are recommended (Papers III-VI).

The case study results reveal that *technical risks such as the risk of production disruptions* is considered to be one of the largest barriers. It was only among the studied Highland SMEs that the barrier was shown to be of low importance.

Another of the largest barriers according to the conducted case studies was *lack of time or other priorities*. It was only among the foundries where this was found to be of minor importance. It should be noted that the qualitative part of the evaluation of the local energy programme presented in Paper V, found that the programme was considered to save a lot of time for the company staff, indicating energy audits as an important means in overcoming the barrier.

Among the studied foundries *lack of access to capital* was ranked first, among the studied Highland SMEs third, among the studied pulp and paper mills fifth and among the non-energy-intensive industrial companies in Oskarshamn ninth.

Cost of production disruption/hassle/inconvenience was considered to be a significant barrier in all sectors except for the studied foundries. While *technical risks such as risk of production disruptions* is closely related to this barrier, results from the studied foundries and the studied Highland SMEs showed large deviations regarding these two barriers. In the studied foundries, *technical risks such as risk of production disruptions* were ranked second, the *cost of production disruption/hassle/inconvenience* was ranked among the absolutely lowest ranked barriers. The opposite case was found among the studied Highland SMEs were *technical risks such as risk of production disruptions* were ranked eleventh and the *cost of production disruption/hassle/ inconvenience* fourth.

Other priorities for capital investment were also a highly ranked barrier in all studies except that comprising pulp and paper mills.

The fact that a *technology is not appropriate at a site* is a commonly known barrier to energy efficiency which, if not taken into account, may lead to overly optimistic estimations of the potential for energy efficiency measures. Among the studied firms, the barrier was shown to be of major importance only among the studied pulp and paper mills and of some importance among the studied non-energy-intensive Oskarshamn companies. In the two other cases, foundries and Highland SMEs, the barrier was shown to be of minor importance.

Difficulty/cost of obtaining information about the energy use of purchased equipment was considered to be the third largest barrier by the studied non-energy-intensive Oskarshamn companies, fourth by the foundries, eleventh by the Highland SMEs and of only minor importance by the studied pulp and paper mills.

Table 5
A summary of the largest barriers to energy efficiency identified in the different case studies.

	Oskarshamn companies	Swedish foundries	Swedish Highland SMEs	Swedish pulp and paper mills
1	Cost of production disruption/hassle/ inconvenience	Access to capital	Lack of time or other priorities	Technical risks such as risk of production disruptions
2	Lack of time or other priorities	Technical risks such as risk of production disruptions	Other priorities for capital investments.	Cost of production disruption/hassle/ inconvenience
3	Difficulty/Cost of obtaining information on the energy use of purchased equipment	Lack of budget funding	Access to capital	Technology is inappropriate at this site
4	Technical risks such as risk of production disruptions	Difficulty/Cost of obtaining information on the energy use of purchased equipment	Cost of production disruption/hassle/ inconvenience	Lack of time or other priorities
5	Other priorities for capital investments	Other priorities for capital investments	Lack of budget funding	Access to capital
6	Technology is inappropriate at this site	Possible poor performance of equipment	Lack of sub-metering	Slim organization
7	Lack of staff awareness	Lack of sub-metering	Difficulty/Cost of obtaining information on the energy use of purchased equipment	Possible poor performance of equipment
8	Lack of technical skills	Poor information quality regarding energy efficiency opportunities	Lack of technical skills	Lack of budget funding
9	Access to capital	Cost of identifying opportunities analyzing cost-effectiveness and tendering	Low priority given to energy management	Other priorities for capital investments
10	Poor information quality regarding energy efficiency opportunities	Low priority given to energy management	Lack of staff awareness	Lack of staff awareness
11	Possible poor performance of equipment	Lack of time or other priorities	Technical risks such as risk of production disruptions	Long decision chains
12	Cost of identifying opportunities analyzing cost-effectiveness and tendering	Technology is inappropriate at this site	Slim organization	Cost of identifying opportunities analyzing cost-effectiveness and tendering

Lack of budget funding was considered to be the third largest barrier among the studied foundries, fifth among the studied Highland SMEs, and eight among the studied pulp and paper mills. Interestingly, the interview part of the evaluation of the local energy programme presented in Paper V revealed that through the energy audits, the respondents considered it easier to obtain budget funding with a report to rely on, indicating that energy audits are of importance in overcoming this barrier.

7.2.2 Driving forces for energy efficiency

The first study (Paper III) identified a number of driving forces, even though this was initially not the main objective. The study showed that a *long-term energy strategy* was of importance as well as *people with real ambition* while for example the existence of an *EMS* (Environmental Management Systems), according to the respondents, had not influenced the implementation rate of energy efficiency measures at the studied sites.

In the second study (Paper IV), the questionnaire was expanded to include a part regarding driving forces, derived mainly from a workshop, but also partly from the first study (Paper III). The main driving forces were found to be similar to the first study, namely a *long-term energy strategy* and the existence of *people with real ambition* while the driving forces; *environmental company profile*, *EMS*, *international competition* and *third party financing* were ranked lower.

In the third study (Paper V), similar results were also found; a *long-term energy strategy* and the existence of *people with real ambition* were the most important driving forces while *environmental company profile and/or EMS* and *international competition* were lower ranked.

In the fourth study of driving forces (Paper VI), an effort was made to try to expand the driving forces investigated incorporating the current Swedish energy policies affecting the cases studied, potential public policies, as well as other external and internal driving forces derived from the scientific literature such as *environmental pressure from NGOs (non governmental organizations)*, i.e. not only empirically derived as was the case in the previous three case studies. The results revealed similar results to the three previous studies. Apart from *cost reductions resulting in lower energy use*, the existence of *people with real ambition* and a *long-term energy strategy* were ranked the highest. Interestingly, the *threat of rising energy prices*, also identified as a driving force in the first study (Paper III), was considered by the respondents to be the fourth most significant driving force. Notably, two policy measures were the consecutively ranked driving forces, namely the *ECS* (Electricity Certificate System) and the *PFE*. The two policies thus seem to be highly valued by the studied pulp and paper mills.

7.3 Optimization as investment decision support for industrial SMEs

While the use of optimization methods and in particular the *MIND method* has been stated to be a useful investment decision support for strategic investment decisions in energy-intensive larger industries (Sandberg, 2004, Karlsson, 2002), the method applied on energy-intensive industrial SMEs has not been examined, motivating the third research question. The research question was examined using the *MIND method*, applied at a Swedish medium-sized foundry to analyze a potential investment in a new melting unit.

Chapter 7

In order to investigate the usefulness of optimization as investment decision support, six different cases were devised, three which use current electricity prices and three which use future electricity prices. The different cases are described further in table 6.

Table 6
The six different cases analyzed.

Analyzed cases	Investment in new melting units	Use of the existing holding units	Electricity prices
BASE C		X	Current
BASE F		X	Future
CASE 1C	X	X	Current
CASE 1F	X	X	Future
CASE 2C	X		Current
CASE 2F	X		Future

An analysis was made for the new furnace cases using current electricity prices, i.e. CASE 1C and CASE 2C. Electricity prices from the Nordic electricity spot exchange from one week were also used to complement the analysis of the future electricity prices derived from Melkerson and Söderberg (2004). The average Nordic electricity spot prices during week 49 in 2007 were chosen as representative of the average prices during the 4th quarter of 2007, i.e. from 1 October to 31 December. In order to further enhance the analysis, prices from the German spot exchange for week 44 were also used, using the same evaluation criteria as for the Swedish spot prices. In order to enhance the analysis, the company's current power charges were also included in the analysis as these charges are not included in the spot prices.

Furthermore, an analysis of the possibility to lower the peak load was also conducted by setting constraints on the power load. The minimum load was then found by lowering the constraint in the model until an optimization of the model was unfeasible. Using the same reversed procedure, the weekly production was increased successively in order to identify the possible maximum weekly production for the different cases. The results from the optimization of the six different cases are shown in figure 9.

A comparison of BASE F and BASE C show that the energy cost would decrease, due to the fact that the optimal melting procedure mainly takes place at night when prices are low. A comparison of CASE 1C and CASE 1F, showed similar findings. When CASE 2C is compared with CASE 2F, it can be seen that the optimal production cost is still lowered with future electricity prices but not nearly as much. The difference is thus much lower than in the previously outlined comparisons as a lack of holding furnaces, with future prices, precludes storage of iron melted during low-cost hours. A comparison of the weekly energy use for the six cases investigated shows that energy use will decrease by about 20 percent with a new melting unit and an additional six percent if holding furnaces are not included in the model's production systems. The latter is due to the fact that the use of holding furnaces increases the aggregated energy use at the foundry. With fluctuating electricity prices, however, this does not necessarily lead to increased electricity costs as one may shift the use of the largest electricity consuming unit, namely the melting unit, to hours when electricity prices are lower.

The optimization results from the cases using Swedish and German spot prices are included in figure 9. The figure shows that when modelling the current system, approximately the same system costs were spotted for the case using future prices (BASE F) and the cases using Swedish (SWE) and German (GER) spot prices. For the cases with new melting furnaces and existing holding furnaces being retained, a comparative analysis shows similar findings for the CASE 1F and SWE 1 cases while the GER 1 case's system cost was slightly higher. For the cases with the new furnaces and no holding furnaces the system cost is lower for the SWE 2 case compared with the cases using current prices (CASE 2C) and future prices (CASE 2F) while the GER 2 case's system cost was slightly higher than CASE 2C and CASE 2F. This is explained by higher daily electricity prices resulting in higher system costs as the removal of the holding furnaces precludes storage of melted iron.

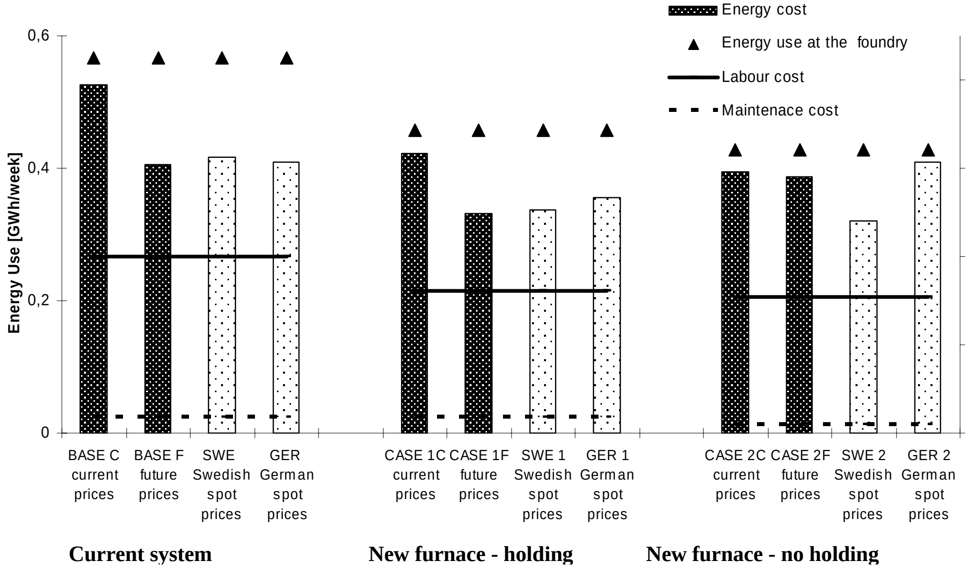

Figure 9. Optimization results for the six different cases including cases using Swedish and German spot prices from weeks 49 and 44 in 2007 respectively. Also, weekly labour and maintenance costs, inspired by Cooley (1996) are included in the figure.

An analysis of the electricity prices indicate that the system cost for CASE 1C is similar to the system cost for CASE 2C if the electricity price for the latter case rises with 5.4 €/MWh. If the electricity price remains on the same level daytime, Monday-Friday 6 am to 6 pm, but is reduced during the rest of the hours with 7.0 €/MWh, the system cost for CASE 1C turns out to be equal to CASE 2C's system cost. It should be noted that it is difficult to conduct such an analysis for the SWE and GER cases as these cases include hourly electricity price variations.
An analysis of the power demands showed that the cases representing the new melting unit with holding furnaces was able to decrease the power demand from 7.9 MW to 4.0 MW when setting constraints on the power load, while the new melting unit without holding furnaces was able to decrease the power demand from 7.9 MW to 5.5 MW when setting constraints. For the cases representing the current melting unit, the power demand could be lowered, when setting constraints on the power load, from 8.7 MW to 6.0 MW. The above difference between the two findings is explained by lower power demand for the new furnaces.

An analysis of the studied cases showed that the aggregated weekly production could be increased in all the studied cases by about 25 percent.

The conducted energy audit at the foundry presented in Paper I, and the evaluation of the audit presented in Paper II indicated that energy efficiency is of great importance in reducing the threat of increasing energy prices but that mainly low-cost measures related to the support processes were undertaken as a result of the audit. This supports the importance of studying other means such as investment decision support as energy audits alone may not provide the necessary means of promoting more costly strategic investments, i.e. energy audits in combination with investment decision support may be a means to further enhance the undertaking of measures, especially production-related measures, leading to reduced energy costs, greater competitiveness and higher productivity.

The initial investment plan for the studied foundry was to exclude holding furnaces since the overall operating energy costs in such a case are lowered, enabling a better investment figure to be presented for the corporate board. However, in the light of the findings from the optimization of the cases, one can conclude that, even though the energy use would be higher retaining these furnaces, it would not be so cost-effective to make the planned investment, even when taking the increased maintenance and labour costs for the holding furnaces into account, see figure 9. It would not have been possible to achieve this finding without the use of investment decision support such as *MIND*. One conclusion from this, stated in more general terms, is that Swedish foundries, from an energy cost point of view should try to retain their existing holding furnaces. From an energy use point of view, however, it is more efficient to remove holding furnaces as the energy use is then lowered. It should be noted that the optimal outcome is related to the foundry's specific abilities and commitment to planning production efficiently and therefore does not necessarily need to be the real outcome. It should also be noted that the foundry already uses shifts for the melting unit. For foundries with staff employed 24 hours a day, such as the investigated foundry, such a change in electricity prices would thus affect the energy related costs positively, assuming that production planning is carried out effectively. However, these results may not apply for all Swedish foundries as not all foundries operate round the clock.

Linking the above results to the research question, it is clear that the use of optimization as investment decision support is useful and provides company management with additional information for the type of investment studied. Using *MIND*, the energy-intensive medium-sized foundry's management team is able to obtain more basic data for decision-making and thus also additional information for the production-related investment being studied, in this case investment in a new melting unit. For energy-intensive industrial SMEs, the use of optimization as investment decision support when considering strategic investments - not least for the foundry industry with complex interactions between different production units - thus seems greatly needed. If not, the industry instead faces a risk of costly reinvestments if prices begin to fluctuate widely on a daily basis, which most likely will occur before long. Optimization as investment decision support may thus be one means of emphasizing energy efficiency for energy-intensive industrial SMEs beyond the level of traditional energy auditing when more costly, strategic, production-related investments are to be made.

7.4 The implementation of measures, energy audits, and energy programmes

Even though a few minor Swedish *industrial energy programmes* have been carried out over the past 15 years - the largest being the local energy programme, *project Highland* - evaluation of the implementation of energy efficiency measures has not been undertaken, even though efforts have been made, e.g. Lindén and Carlsson-Kanyama (2002). This led to the examination of the fourth research question which may be divided into three separate parts. The answer to the first part of the fourth research question - which energy efficiency measures were implemented from the local energy programme - is presented in figure 10.

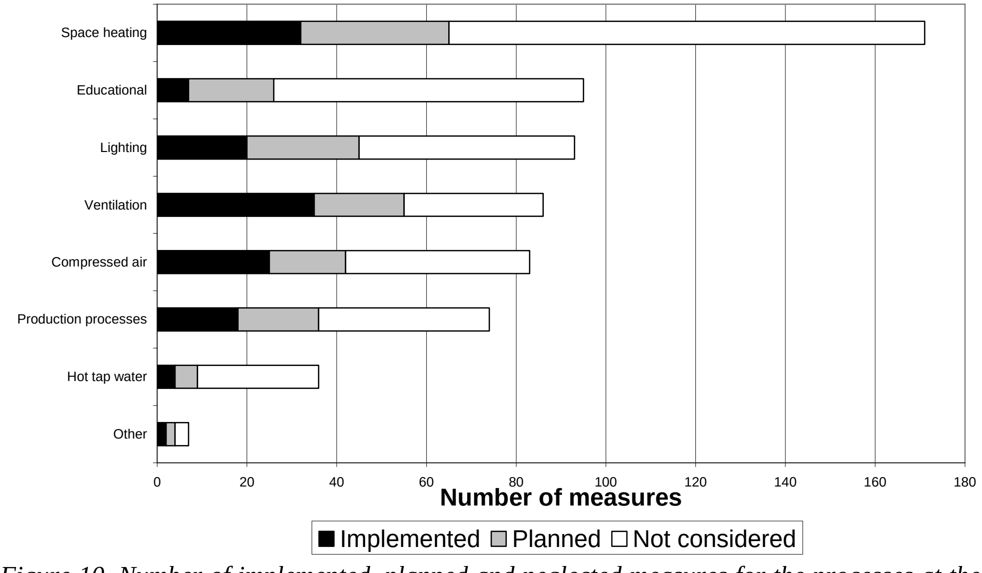

Figure 10. Number of implemented, planned and neglected measures for the processes at the 47 evaluated firms within project Highland.

In an attempt to answer the second part of the fourth research question - how effective was *project Highland* in relation to the outcome of other Swedish energy programmes towards the industry - a compilation of Swedish programmes over the past 15 years was made (presented in table I in Paper V). From the compilation however, it was found that lack of similar programmes made this part of the research question intricate to answer. The *PFE* was the only programme with available figures. The results from the comparison are presented in table 3 in Paper V. It should be noted that the large differences between the two programmes makes adequate comparisons complicated. The outcome indicates that the programmes, in terms of energy saved per private capital spent, show a slightly higher response for *project Highland* (7.5 kWh/€) than for *PFE* (5.8 kWh/€). In terms of saved energy per public capital spent in the programme, the first part of *project Highland* resulted in actual savings of about 86 kWh/€ or 47 kWh/€ for electricity alone. When the planned measures are included, the figure increases to 195 kWh/€ or 125 kWh/€ for electricity alone. The effectiveness in terms of saved electricity per public capital spent in the programme for *PFE* is approximately 11 kWh/€.

The comparison of the two programmes indicates that *project Highland* is much more effective in reducing the use of electricity. The comparison, however, is as mentioned not unambiguous as *PFE* deals with both strategic issues and energy audits, and *project Highland* included only energy audits. Furthermore, the outcome of *PFE* might also result in the reduction of non-information-related barriers and result in savings in other energy carriers, even though this is not presented in the figures. However, the comparison of the two programmes addresses the possibility to expand *PFE* by including other energy carriers in the programme, something that most likely would increase the effectiveness of *PFE*. Yet another factor worth noting is that the number of participating firms is larger within *project Highland* than in *PFE*. In *project Highland*, 139 of 359 the industrial firms in the region or roughly 40 percent accepted to receive energy audits, while *PFE* shows figures of about 10 percent (Ottosson and Peterson, 2007). The difference in energy intensity and type of production, among other factors, address the need to develop a portfolio of energy policies rather than solely using one approach if one wants to reach as many firms as possible. The evaluation of *project Highland* indicates that by using intermediaries like local authority energy consultants and regional energy agencies, the local energy programme model is an effective energy policy option in terms of public money spent in relation to energy saved for non-energy-intensive industrial companies and industrial SMEs.

The evaluation of *project Highland* involved a number of plausible causalities, the most important being the substantial increases in electricity prices in Sweden. In the evaluation, the causality of *project Highland* was therefore, inspired by Vedung (1998) and Larsen and Jensen (1999), examined by asking the six firms with the highest adoption rates and the five companies with the lowest adoption rates if they would have undertaken the measures regardless of the energy audit. Both these categories expressed great appreciation of the audits, and those firms with the highest adoption rates said that they would not have undertaken the measures without the information provided by the energy audits. Some of the local authority energy consultants involved in the project were also interviewed in order to increase the study's internal validity. None thought that the savings would have occurred without the energy audits. Even though there is a degree of uncertainty involved, the above finding strengthen the result's validity, i.e. that the presented outcome of *project Highland*, within a limited time period, actually refers to the input from the conducted energy audits within the evaluated energy programme. Another issue that needs to be commented on is why not all companies (64) answered the questionnaire (47 responses). It may be either because they have been less responsive for various reasons to adopting the proposed measures or because they were not satisfied with the energy audit. These are not uncommon problems when conducting *case study research* of this type; see for example Worrell et al. (2003).

The evaluation of the third and last part of the fourth research question - how can the energy audit method used in the programme and other industrial sites be developed and improved - in-depth interviews were carried out. As previous research has shown, when conducting energy audits it is important that the information given is specific, vivid and personal and that the company representatives have trust in the auditor. Intermediaries such as regional energy agencies sector organizations, i.e. non-governmental institutions, were found to be desired when it comes to carrying out energy audits for the industry as they, according to some company representatives, are considered more trustworthy, and furthermore, assuming they have the relevant skills to carry out energy audits, are aware of the specific characteristics related to the specific industrial sectors which they support. If so, the errors in the energy audit reports, which were identified during the in-depth interviews, could be avoided.

When it comes to providing energy audits, actors who are much aware of their energy use, showed less interest in external information. Consequently, public-sponsored energy audits should, in the first place, be offered to industrial SMEs and the non-energy-intensive industry where energy has been shown to be a less prioritized issue.

The interviews revealed that the Highland SMEs were more satisfied than the other two evaluated cases, Oskarshamn's eight largest industries and the companies participating in *Sustainable Municipalities*. Performing a number of energy audits in the same area has been shown to be more effective than occasional audits. The latter may be one plausible explanation for the higher degree of satisfaction among the respondents in the Highland region. Another explanatory variable is that the companies that had received energy audits in the Highland region were in general smaller than in Oskarshamn and Borås, i.e. have fewer resources to focus on energy efficiency and thus have a greater need to receive external information. Also, the aims of the Oskarshamn and Borås cases were related to factors other than solely serving the companies with relevant information and were also part of a research project. The sole aim of *project Highland*, on the contrary, was to increase the companies' productivity by increased energy efficiency, and by doing so increase the whole region's overall productivity. Yet another factor to keep in mind is the electricity price increases that have taken place in Sweden, see figure 2. With this in mind, the Highland companies were plausibly more interested in energy efficiency as payback periods have been shortened compared with the Oskarshamn audits made some years earlier. Also, organizational restructuring, budget funding or simply the fact that the business is running very well at the moment were shown to have an impact on the outcome of an energy audit. The timing when offering energy audits is thus of importance.

Several respondents mentioned that they would not have implemented the measures if they had not been visualized in the energy audit report. In general, the auditors' social and communicative skills were considered to be good and they were considered trustworthy, credible and good listeners. In some cases, however, this was not the case, where relatively inexperienced energy auditors performed the audits. The energy auditor's way of treating the company's representative during the on-site visit is thus a crucial part of the energy audit procedure. In two cases, the auditor did not pay enough attention to the company's representative and as a result the audit results were ignored. These two examples stress the fact that there is not only a need for experience and theoretical and linguistic abilities when performing and reporting an energy audit, but also a need for excellent social skills on the part of the conductor of the audit if the proposed energy measures are to be considered. The interviews also showed a need to validate the energy audit results and the proposed measures. This demands some type of database in order for a sound validation to be made, especially when it comes to more process-related measures.

Results from the interviews indicate that the respondents found the energy audit method helpful in providing information about energy efficiency solutions at their company. But the respondents also stated that there has been a lack of simplicity and vividness in the report as the resulting energy efficiency proposals in general lacked economic estimations and also that there was a clear lack of economic ranking between the proposed measures. In some cases, the measures were considered to have too long pay-off periods to be of any interest and in some cases the measures were considered to be too general. This criticism, from Borås and Oskarshamn, is however also dependent on the purpose of these audits which pointed out the need for structural system changes and where not solely aimed towards investments of the lower hanging fruits, i.e. measures which are easy to make and have short pay-back periods. These structural system changes have been proposed, keeping in mind the need to maintain Swedish industry's competitiveness also in the future, in light of the energy price increases. The company respondents' negative views might thus be related to the way of defining the energy efficiency potential as stated by Jaffe and Stavins (1994), i.e. the technologist's potential and the economist's potential do not coincide. These results indicate the need, when providing information of a more long-term strategic character, for it to be thoroughly explained by the energy auditor.

Furthermore, investment assessments were also required. In two larger international programmes, the Australian *EEAP* (Harris et al., 2000) and the American *IAC* (Anderson and Newell, 2004), fewer measures were proposed but included thorough investment assessments. These programmes showed greater implementation rates, in terms of number of measures implemented in relation to the total number of proposed measures, than *project Highland* (Thollander et al, 2007). In the in-depth evaluation, it was seen that minor investments with short pay-off periods were implemented, i.e. the lower hanging fruits were taken first. Regarding the more capital-intensive measures, more thorough investigations seem to be needed before actual implementation. Consequently, support with regard to these larger, more risky investments thus seems to be very much needed.

In the in-depth evaluation of an energy audit, measures related to energy-efficient behaviour, like more energy-efficient melting procedures and more efficient pre-heating of the ladles were found. Interestingly, these measures were found to account for nearly half of the aggregated savings, indicating that an energy audit may also work as a catalyst for behavioural changes at firms.

Chapter 8

8 CONCLUDING DISCUSSION

This chapter discusses the major conclusions from the thesis including a discussion of how energy end-use policies could be designed. The major contributions of the thesis are also outlined together with suggested areas for further research.

This thesis has extended the classical way of studying industrial energy end-use efficiency in the Swedish industry, not limiting the research by solely studying technical aspects and the technical energy efficiency potential. Through the use of social research methods, knowledge of industrial energy end-use efficiency has been extended. By doing so, the degree of system complexity has increased from the lower levels of Boulding's (1956) system categorization into the higher system levels, incorporating individuals and groups of individuals (organizations). This extended systems approach also has its limitations as studies of individuals and group of individuals may include larger uncertainties due to its increased system complexity. Inevitably, such a widened systems approach is argued to be needed if understanding of industrial energy end-use efficiency is to be enhanced. This widened systems approach enables, among other things, policy makers to formulate and adopt effective industrial energy end-use efficiency policies.

Results from the thesis have shown that there exists a number of technical energy efficiency measures related to both support and production processes, in the energy-intensive Swedish foundry industry, and that the implementation of technical energy efficiency measures will lead to significantly reduced energy cost which in turn will reduce the threat of rising electricity prices.

In the various case studies of barriers and driving forces, the most significant barriers to energy efficiency - with large variations for some of the barriers among the studied cases - were found to be: *technical risks such as risk of production disruptions*; *lack of time or other priorities*; *lack of access to capital*; *cost of production disruption/hassle/inconvenience*; *other priorities for capital investments*; *technology is inappropriate at the site*; *difficulty/cost of obtaining information about the energy use of purchased equipment*; and *lack of budget funding*. The results showed that some of the major barriers, e.g. *difficulty/cost of obtaining* *information about the energy use of purchased equipment* may be related to so-called *market failures* which in turn may justify public policy intervention. This raises the question of why public industrial energy end-use efficiency support historically has been so scarce?

The largest driving forces, apart from *cost reductions resulting from lowered energy use*, were found to be the existence of a *long-term energy strategy* and *people with real ambition*. These driving forces did not, unlike the results of barriers to energy efficiency, vary widely across the studied sectors. Thus, one main conclusion from this thesis is that while barriers to energy efficiency vary across sectors, driving forces do not. Studies of driving forces for energy efficiency in Swedish foundries and industrial SMEs confirms the results of the high ranking of *people with real ambition* as well as the existence of a *long-term energy strategy* (Thollander, 2008, Thollander and Tyrberg, 2008).

By studying both barriers to and driving forces for energy efficiency, unique results as regards barriers and driving forces have been obtained, as well as a methodological development incorporating a greater number of driving forces than in previous studies of driving forces for energy efficiency.

Energy efficiency measures might be of great importance in reducing the threat of increasing energy prices. However, mainly low-cost measures related to the support processes are undertaken as a consequence of energy audits, showing the importance of additional means such as investment decision support in combination with energy audits. Energy audits in combination with investment decision support may thus be a means to further enhance the undertaking of measures, especially production-related measures, leading to reduced energy costs, greater competitiveness and higher productivity. In the light of the findings from the case study on optimization, one can conclude that, even though the energy use would be higher retaining the holding furnaces, it would not be so cost-effective to not make use of these, even when taking the increased maintenance and labour costs for the holding furnaces into account. It would not have been possible to achieve this finding without the use of investment decision support such as *MIND*. One conclusion from this, stated in more general terms, is that Swedish foundries, from an energy cost point of view should try to retain their existing holding furnaces. From an energy use point of view, however, it is more efficient to remove holding furnaces as the energy use is then lowered. In conclusion, optimization as investment decision support is useful and provides company managements with additional information when planning investments on a strategic level.

The thesis showed that energy audits are an effective means, in terms of public money spent per kWh saved, of providing the industry with information on potential energy efficiency measures. In fact, the effectiveness of the evaluated local energy programme, *project Highland*, again raises the question of why Sweden has not provided the industry with such support, unlike the other Scandinavian countries, Denmark, Finland and Norway? The thesis has also pointed out a number of factors which are crucial for increased effectiveness of the energy audit method such as that the company representatives have trust in the auditor, and the timing of the audit in relation to both matters internal to the firms as well as external matters. The auditors' own experience, theoretical and linguistic abilities as well as excellent social skills have also been found to be of importance if measures are to be considered. Some kind of database was also found to be needed in order for a sound validation to be made, especially when it comes to more process-related measures when performing energy audits.

Yet another conclusion is that energy audits and energy management have proven to lead to not only technical energy savings but also to behavioural measures being undertaken, such as more efficient operation of melting furnaces. In Norway, similar results were found where the implementation of an energy management system led to increased energy efficiency through increased awareness reducing overall energy use by about five percent (only behavioural measures) (Väisenen et al., 2003).

The energy-intensive Swedish pulp and paper industry has great incentives to focus extensively on energy efficiency due to large shares of energy costs in relation to added value. For other business areas like industrial SMEs, with less energy-intensive production and thus less incentive to focus on the issue, it is left to a committed manager or *people with real ambition* if energy efficiency is to gain any major interest within the organization. In such organizations, energy audits and other external input should thus prove to be of greater interest than was seen in the energy-intensive pulp and paper industry. An energy audit is also often the starting point for further energy management activities. This supports the involvement of the authorities in offering energy audits to non-energy-intensive industries and industrial SMEs.

One major finding is that energy management not is receiving full support even in one of the most energy-intensive industries, the Swedish pulp and paper industry, in spite of substantial energy price increases. Promoting issues within the firm such as the adoption of a *long-term energy strategy* and an energy manager who is committed to his job and having full support from the company board would most likely lead to increased energy efficiency. This should be of great interest for policy makers and industrial managers, in designing polices and programmes, external as well as in-house, and indicate that *LTAs* may be of major interest for both parties.

One criticism towards parts of this thesis could be that it mainly investigates the barriers towards the economist's and the technologist's economic potential, i.e. what is economically viable with the technologies available on the market today. Research on new technologies and how these may lead to aggregated savings at a company or in a sector is of course also very much needed. However, even when only economically viable investments possible to undertake today are investigated, it is still of great importance to conduct such research as a reduction of these type of barriers leading to an overall increase in energy efficiency both have positive socio-economic as well as positive business-economic effects. Furthermore, identifying the barriers to energy efficiency, in particular the market-related ones, is a must in order for each member state (of the EU) to launch accurate policies. Another criticism towards parts of this thesis, in particular the part dealing with driving forces, is whether it is useful to investigate the respondents' opinions regarding different driving forces as such a study does not really investigate what net impact a policy or other types of driving forces actually have. To meet this criticism, it is argued that such studies indeed is very much needed, the net impact of a policy is still of great importance, but if one does not take into account the party who is affected by the policy, policies may have negative side effects. A study by ECON (2003) found for example that the *ETS* would lead to increased electricity prices creating a risk of Swedish energy-intensive companies moving abroad. From that point of view it is of utmost importance for the EU and its member states to design and adopt polices that both lead to net reductions in energy use and greenhouse gas emissions but do not lead to companies moving abroad. This thesis and other studies investigating the industry's opinion of different policies and driving forces are thus of utmost importance in a situation where the EU is aiming for increased sustainability.

8.1 Policy discussion

Substantial energy price increases in the past, growing environmental concern, and the *ESD*, among other factors, emphasize the need to adopt sound industrial energy end-use policies in Sweden. Some indicative policy formulations are possible, as an analytical generalization based on the results from this thesis' case studies, which may be of interest regarding the adoption of such policies in a national context.

In sectors *where technical risks such as the risk of production disruptions* and the *cost of production disruption/hassle/inconvenience* were considered to be barriers of major importance, there is a need for thorough studies regarding energy efficiency issues before measures can be justified. In the pulp and paper industry, one such means and one which has proven to be successful is heat integration, where thorough calculations of different heat flows are conducted, for example steam flows at pulp and paper mills. For this and other sectors another such means is to use optimization methods such as *MIND*, presented in Paper VII, or other types of investment decision support such as manufacturing simulation, e.g. Solding and Thollander (2006).

Another type of barrier is the *possible poor performance of purchased equipment.* This barrier is considered to be a barrier of somewhat importance in the energy-intensive foundry and pulp and paper industries (sixth and seven respectively) while it proved to be of less importance in the studies comprising the non-energy-intensive Oskarshamn companies and the industrial Highland SMEs (11th and 20th respectively). In sectors where this barrier is of importance, plausible policy measures could be practical research on different energy efficiency measures and examples of successfully implemented energy efficiency measures in different industries.

Lack of time or other priorities is considered to be a major barrier in all studies except for the foundry study. As regards the Highland SMEs and the non-energy-intensive Oskarshamn companies, this clearly indicates a need for simplicity when it comes to adopting energy end-use policies. While larger energy-intensive companies have resources to join for example an *LTA* programme such as the Swedish *PFE*, non-energy-intensive industrial companies and industrial SMEs in particular, appear to not have the time to invest in such activity; neither do they appear to have much time to apply for different investment funds.

One policy means which has been used for example in the Netherlands, and which is also proposed in the *ESD*, is investment funds. The fact that *lack of access to capital* was considered to be a barrier of major importance in all but one of the studies indicates that this might be a sound policy choice. However, the use of investment funds in the Dutch industry revealed that the free-rider effect using such a measure was at least 85 percent (Farla and Block, 1995). Among German SMEs, using a subsidy for energy audits did not prove to be successful. Swedish experience from the 1970s indicates similar results - only about 10 percent of the companies were covered using investment funds (Persson, 1990). Interestingly, results from this thesis seem to indicate why - energy is not prioritized among non-energy-intensive industrial companies and industrial SMEs. This means that even though investment funding is offered as a policy measure, it will most likely not be shown to be successful in companies where *lack of time or other priorities* constitutes a major barrier, i.e. in non-energy-intensive industries and industrial SMEs. On the contrary, such a measure would most likely be a success in, for example, the Swedish foundry industry, where *lack of time or other priorities* is not a highly ranked barrier. Such companies will most likely take the time to fill out forms and apply for such funds. Plausibly, this will also be the case for the energy-intensive pulp and paper industry. Addressing policy measures directed at the two latter sectors, an *LTA* might be a sound approach. Results from the studied pulp and paper mills regarding driving forces indicate that the current *LTA*, the Swedish *PFE*, is much appreciated. However, it is suggested that the programme includes other energy carriers as well.

As regards non-energy-intensive industrial companies and industrial SMEs, one plausible policy measure, and one which has been shown to be successful in both Sweden (Paper V) and internationally, e.g. Anderson and Newell (2004), is to offer energy audits free of charge. Interview results from Paper V indicate that such an approach is also useful for lowering barriers such as *lack of budget funding*, *other priorities for capital investments*, and *lack of time or other priorities* - barriers which have been shown to be of major importance in several of the studies regarding barriers to energy efficiency presented in this thesis. Moreover, energy audits target an array of technologies. Providing energy audits to all industrial sectors is thus in line with the Swedish authorities' statement that policies should not be targeted towards one single technology. The question then remains as to who is to carry out energy audits for non-energy-intensive industrial companies and industrial SMEs? Using actors who are considered trustworthy is of importance, which indicates that sector organizations, in cases where they are considered trustworthy, would be a passable road. However, results from this thesis indicate that the regional Swedish energy agencies also could be used. One important thing however, needs to be added regarding the issue - involving the local authority energy consultants may be of major importance as this signals an interest on the part of the authorities regarding energy end-use efficiency. Both in the *ESD* as well as in the reports written with regard to the Swedish *NEEAP*, on behalf of the directive, it has been stated to be of major importance that the authorities act as role models (Neij, 2007). In conclusion, this means that the policy model used in *project Highland* using both the local authority energy consultants and auditors from the regional energy agency may be a highly useful approach towards non-energy-intensive industrial companies and industrial SMEs in particular, not only from a public cost point of view, as was stated in Paper V, but also from the perspective of the results from this thesis regarding barriers to energy efficiency as well as the fact that such a model signals interest from the authorities regards the energy end-use efficiency issue. Moreover, using that model, the local authority energy consultants are able to gain more experience in the area and thus be able to provide these sectors with more thorough support. It should be noted that the conductor of the audit, assuming the auditor possess the relevant skills, does not necessarily have to be a public actor or a sector organization - using commercial energy consultants when conducting the actual audit would in the long run build up a greater commercial energy audit competence in Sweden.

It is left to the Swedish authorities to design the detailed *NEEAP* and later adopt the proposed policy measures. Based on the results presented in this thesis, a policy approach towards non-energy-intensive industrial companies and industrial SMEs should primarily include providing energy audits free of charge and involve the local authority energy consultants. After the provision of energy audits, *LTAs* and investment funds are additional means which may be used and perhaps later, when investment decision support, such as optimization, has been studied more thoroughly from a policy perspective, also include such support for strategic investments. Hopefully, the detailed Swedish *NEEAP* will involve the non-energy-intensive and industrial SME sectors on a broad basis and the design of the policy will thoroughly be grounded in results identified from research in the area, such as the results presented in this thesis.

As stated in chapter two in this thesis, the industries' and the authorities' perspective on energy efficiency may not always coincide. While the industries' incentives are more closely linked to business-related benefits such as reduced cost of energy, the society's incentives are more closely linked to socio-economic benefits such as reduced use of energy and thus reduced environmental impact. In order to combine the two perspectives and achieve instant CO_2 savings from industrial energy end-use efficiency activities, it is suggested that one may consider withdrawing *TEPs*, even within an *ETS* period, equivalent to the implemented energy efficiency measure's CO_2 emission reduction. Preferably, this should be adopted on a European level.

8.2 Contributions

One of the contributions resulting from this thesis is that the potential for energy efficiency, even in the energy-intensive foundry industry is shown to be large and that energy efficiency measures may significantly reduce the threat of rising energy prices. Moreover, another main contribution is the evaluation of energy audits showing, among other things, that low-cost energy audits are an important means of stressing industrial energy end-use efficiency for this sector. Furthermore, studies comprising barriers to and driving forces for energy efficiency has contributed to increased knowledge as well as methodological development, of these issues. Finally, the thesis has found that optimization as investment decision support may be useful even for energy-intensive industrial SMEs.

8.3 Further work

The reason for the non-activity on the part of the authorities regarding industrial energy end-use efficiency in Sweden would provide an interesting approach for an historical study. Also, studies of barriers to and driving forces for energy efficiency should be extended to include more cases involving other sectors (and regions) where also barriers and driving forces regarding one single technology as well as studies of factors outside of the industry, should be further studies. For example, more in-depth studies of ESCOs as a driving force for industrial energy efficiency in Sweden. Moreover, further research is suggested in the area of industrial energy end-use policies involving other sectors (and regions). For example, further work in order to improve the energy auditing procedure and studies of *LTAs* towards industrial SMEs is suggested as areas for future research. Also, enhanced studies of optimization as investment decision support is suggested, including both more cases of the method used in this thesis, as well as other methods. Also, further studies of the technical energy efficiency potential for different sectors, e.g. Swedish foundries would be of interest. Finally, it would be highly valuable if energy management in industrial organizations could be further studied.

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