Industrial energy efficiency improvement – the role of policy and evaluation

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Industrial energy efficiency improvement

The role of policy and evaluation

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Preface

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Lund, December 2013

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Abstract

At EU and to a varying degree at Member State (MS) level, industrial energy efficiency improvement (EEI) is considered an attractive means for reaching political objectives of different dimensions, not least environmental. For energy-intensive manufacturing industry in particular, EEI can lead to cost reductions, improved profitability and competitiveness. However, research and other analyses show that far from all privately profitable EEI actions are implemented, and for this reason a number of policies, programmes and instruments, have been launched to stimulate industrial EEI. For political objectives and measures to be credible, it is essential that the policy process is informed by close evaluations of progress, impact and other outcomes. Evaluation results can also contribute to the improvement of programmes in operation.

This thesis contributes with evaluations and assessments of existing programmes and instruments that, besides other objectives, targets industrial EEI and GHG emissions reduction in energy-intensive manufacturing industry in Sweden and partly elsewhere. The research combines a theory-based evaluation approach with impact evaluations and other forms of analysis to find out if and to what extent that desired results in terms of energy savings and GHG emissions reductions are achieved. Outcomes in terms of corporate responses to policies are also addressed in order to identify underlying factors for changes to occur. The results show that the Swedish programme for improving energy efficiency in energy-intensive industries (PFE) has resulted in large and cost-effective electricity savings. As a main programme instrument the implementation and certification of industrial Energy Management Systems (EnMS) has led to organizational changes among interviewed firms in the Swedish pulp and paper industry (PPI). Through its combination of instruments PFE has caused attention-raising effects and norm changes towards a higher priority for EEI. A top-down decomposition analysis of

energy trends in the Swedish PPI shows that especially electricity efficiency improvement has increased in the post-2000 period. This result corresponds well with bottom-up reported electricity savings in PFE and confirms the success of the programme.

Also CO_2 emissions have been reduced in Swedish PPI. An interview-based study on the influence of the EU emissions trading system (EU ETS) on corporate climate strategies shows that the economic value of CO_2 emissions is accounted for, but that the carbon price tag represents a minor factor among many that underpin industrial investment decisions. In the third period of EU ETS, the amount of free allocation to manufacturing industry is generally reduced compared to previous periods. However, the outcomes of the new allocation rules are dispersed in some industrial sub-sectors. For instance, the Swedish PPI will receive free allocation well above the actual emission level. To further stimulate industrial decarbonisation, the ongoing discussion on structural reforms of EU ETS is welcomed. To further stimulate industrial EEI the continuation of complementary industrial policies is recommended.

Populärvetenskaplig sammanfattning

Industrin i Sverige och i många andra länder står för en stor del av samhällets energianvändning och energi utgör en nödvändig insats i industrins processer och förädling av produkter. Industriell tillverkning sysselsätter dessutom många arbetstagare både direkt och indirekt i utbytet med övriga delar av samhället och ekonomin. Samtidigt medför energianvändning och relaterade aktiviteter – utvinning av bränslen, mark och resursanvändning, infrastruktur för distribution och omvandling, förbränning, hantering av avfall och restprodukter – flera negativa effekter på människors hälsa och livsmiljö, ekonomiska tillgångar och naturens ekosystem.

Energieffektivisering i industrin, det vill säga en minskad energianvändning per producerad enhet eller värdeskapande process, betraktas av många bedömare som en effektiv och kostnadsmässigt fördelaktig strategi för att hantera energianvändningens många baksidor. Samtidigt finns det starka ekonomiska drivkrafter för ökad energieffektivisering. Särskilt energiintensiva företag, för vilka energianvändning utgör en hög kostnadsandel, kan uppnå stora kostnadsbesparingar. Exempelvis genom investeringar i energieffektiv utrustning, ett förbättrat underhållsarbete, skärpta rutiner för driftsövervakning och optimering. Den politiska sfären har i ökad utsträckning uppmärksammat energieffektivisering som ett medel för att engagera industrin att bidra till samhälleliga målsättningar om ett förändrat energisystem. En politik som syftar till att förstärka industrins drivkrafter för energieffektivisering kan också sammanfalla med mål om att skapa goda förutsättningar för en konkurrensutsatt och exportorienterad industri.

I den här avhandlingen utvärderar och analyserar jag ett antal aktuella styrmedel som bland annat syftar till att stimulera ökad energieffektivisering och minskade koldioxidutsläpp i energiintensiv industri. Dessa är: det svenska programmet för energieffektivisering i energiintensiv industri (PFE), stimulans för införande och certifiering av energiledningssystem och EU:s system för handel med utsläppsrätter. I flera av mina studier har massa- och pappersindustrin, den i särklass största energianvändaren i svensk industri, fått spegla den energiintensiva industrins respons och anpassning till nämnda styrmedel.

Genom PFE som påbörjades 2005 erbjuds ett hundratal företag en nedsättning av EU:s minimiskatt för industriell elanvändning. I gengäld åtar de sig att kartlägga, identifiera, genomföra och rapportera kostnadseffektiva elbesparande åtgärder. Ett tydligt fokus i PFE är att främja energieffektivisering via organisatoriska förändringar såsom energiledningssystem samt rutiner för upphandling och projektering. Tidigare forskning har betonat vikten av informationshöjande insatser och företagsinterna normförändringar för att övervinna barriärer som hindrar att kostnadseffektiva energieffektiviseringsåtgärder genomförs. Mina resultat visar att PFE har åstadkommit detta. Under den första programperioden rapporterades kostnadseffektiva besparingsåtgärder motsvarande 1.5 TWh eller fem procent av deltagande företags årliga elanvändning. Enligt min utvärdering uppskattas 50–70 procent av dessa elbesparingar ha uppstått som en följd av PFE medan övriga åtgärder kan ha genomförts även utan programmet. Framgången med PFE motiverar utvidgade insatser för ökad energieffektivisering och en kontinuitet i samverkan mellan Energimyndigheten och tillverkningsindustrin. I en studie av långsiktiga trender med avseende på energianvändning och energieffektivisering i svensk massa- och pappersindustri visar jag att de senaste årens energieffektiviseringspolitik har bidragit till att skapa förändringar i önskvärd riktning.

Införande och certifiering av energiledningssystem är ett grundläggande krav i PFE. Genom intervjustudier i massa- och pappersindustrin utvärderades energiledning och de förändringar som detta har medfört med avseende på aspekter som roller och ansvarsfördelning, målformulering och uppföljning, kommunikation och utbildning. Dessutom studerade jag överväganden för en statlig stimulering av energiledningssystem i industrin, exempelvis rimlighet i krav och incitamentsstrukturer, betydelsen av en utvärderingsplan och extern revision samt förekomsten av målkonflikter. Resultaten visar att samtliga anläggningar har tillsatt en koordinator, med ansvar för att organisera regelbundna möten och skapa kontaktytor mellan avdelningar och personalkategorier. I regel har ungefär fem procent av personalstyrkan direkt involverats i energiledningsarbetet, särskilt processingenjörer och operatörer med stort inflytande över betydande energiaspekter. Övrig personal har i olika utsträckning informerats om målformuleringar, rutiner och ansvarfördelning. I samtliga fall har detta skett via interna kommunikationskanaler och i ett fåtal fall genom särskilda utbildningsinsatser. Rutiner för uppföljning av energianvändning i relation till uppsatta mål utgör ett viktigt verktyg som har förfinats genom energiledningsarbetet. I vissa fall finns en förbättringspotential med avseende på teknisk infrastruktur och intern kostnadsfördelning baserat på energimätning.

EU:s utsläppshandelsystem framställs ofta som det främsta medlet för att reducera den energiintensiva industrins koldioxidutsläpp. Det innebär, förenklat, att fri tilldelning av prissatta utsläppsrätter sätter ett tak för deltagande företags utsläpp. De företag som minskar sina utsläpp kan sälja sitt överskott av utsläppsrätter medan företag som ökar sina utsläpp över tilldelad nivå måste köpa motsvarade mängd utsläppsrätter. Genom en succesivt minskad tilldelningen ska de totala utsläppen reduceras på ett förutsägbart sätt och åtgärder ske där de anses vara kostnadseffektiva. I en intervjubaserad studie frågade vi oss hur utsläppshandeln har påverkat massa- och pappersindustrin, representerad av två företag med verksamhet globalt. Resultaten visar att företagen redan innan utsläpphandeln infördes hade etablerat mål och rutiner för att begränsa sina koldioxidutsläpp men att dessa strategier har skärpts över tiden. Utsläppshandels främsta inverkan har varit genom höjda elpriser, vilket har förstärkt intresset för energieffektivisering och intern elproduktion. Priset på koldioxidutsläpp utgör en av många faktorer som påverkar företagens investeringsbeslut, men det har hittills haft ett begränsat inflytande på genomförda utsläppsminskningar. Av flera skäl har utsläppshandelsystemet misslyckats med att begränsa tilldelningen till rimliga nivåer varpå utbudet på utsläppsrätter har överdrivits och priset tryckts ned. I flera omgångar har EU försökt att korrigera dessa tillkortakommanden. I en annan studie analyserade vi de förändrade reglerna för tilldelning inför utsläppshandelns tredje period. I den homogena cementindustrin ges en generell sänkning av tilldelningsnivåerna medan utfallet blir mycket olikartat i massa- och pappersindustrin. Utsläppshandeln som en del av EU:s klimatpolitik får även i framtiden svårt att leva upp till de förväntningar och tilltro som den tillskrivs. Det motiverar en fortsatt utveckling av kompletterande styrmedel som på olika sätt stimulerar industrins inneboende drivkrafter för energieffektivisering och minskade koldioxidutsläpp.

List of publications

The thesis is based on the following papers, which are referred to in the text by their Roman numerals. Reprints are published with permission from the respective publishers.

- Paper I: Stenqvist, C., Nilsson, L.J. (2012). Energy efficiency in energy-intensive industries – an evaluation of the Swedish voluntary agreement PFE. *Energy Efficiency*, 5 (2), 225–241.
- Paper II: Stenqvist, C. (2013). *Trends in energy performance of the Swedish pulp and paper industry: 1984–2011*. Submitted manuscript under review.
- Paper III: Stenqvist, C., Nilsson, L.J., Ericsson, K., Modig, G. (2011). *Energy management in Swedish pulp and paper industry – the daily grind that matters*. Paper presented at the 10th ECEEE summer study – Energy Efficiency First: The Foundation of a Low Carbon Society, France, 6–11 June 2011.
- Paper IV: Stenqvist, C. (2012). *Evaluating industrial energy management systems – considerations for an evaluation plan*. Paper presented at the International Energy Program Evaluation Conference (IEPEC), Rome, 12–14 June 2012.
- Paper V: Gulbrandsen, L.H., Stenqvist, C. (2013). The limited effect of EU emissions trading on corporate climate strategies: Comparison of a Swedish and a Norwegian pulp and paper company. *Energy Policy,* 56 (May), 516–525.
- Paper VI: Stenqvist, C., Åhman, M. (2013). *Difficulties of free allocation within EU ETS – a critical analysis of key sectors in the third trading period*. Manuscript.

The author's contribution to the papers:

I. Main author
II. Sole author
III. Main author
IV. Sole author
V. Co-author
VI. Main author

Other publications by the author not included in this thesis:

- Gulbrandsen, L., Stenqvist, C. (2013). Pulp and paper industry. In Skjærseth, J.B., Eikeland, P.O. (Eds.). *Corporate Responses to EU Emissions Trading: Resistance, Innovation or Responsibility?* (pp. 127–164). Farnham: Ashgate.
- Nilsson, L.J., Stenqvist, C. (2011). *Politik för energieffektivisering.* Report on behalf of the Nordic Council of Ministers, Working Group for Energy Efficiency. Lund: Lund University.
- Nilsson, L.J., Stenqvist, C., Takeuchi-Waldegren, L., Söderholm, P. (2011). *Counting beans or moving mountains – the predicament of energy efficiency policy.* Paper presented at the 10th ECEEE summer study – Energy Efficiency First: The Foundation of a Low Carbon Society, France, 6–11 June 2011.
- Stenqvist, C., Nilsson, L.J. (2009). *National Report on the Energy Efficiency Service Business in Sweden.* Report of the ChangeBest project. Lund: Lund University.
- Stenqvist, C., Nilsson, L.J. (2009) *Process and impact evaluation of PFE – a Swedish tax rebate program for industrial energy efficiency.* Paper presented at the 9th ECEEE summer study – Act! Innovate! Deliver! Reducing Energy Demand Sustainably, France, 1–6 June 2009.

- Stenqvist, C., Nilsson, L.J., Henriksson, E., Söderholm, P., Wårell, L. (2009). *Voluntary energy efficiency programs – an interim evaluation of PFE in Sweden*. Paper presented at the 10th European Conference Energy, Policies and Technologies for Sustainable Economies, Vienna, 7–10 September 2009.
- Nilsson, L.J., Stenqvist, C. Lopes, C. (2009). *EMEEES Bottom-up Case Application 20: Voluntary Agreements with Individual Companies – Engineering Method (Industry and Tertiary Sectors).* Report of the EMEEES project. Lund: Lund University and the Swedish Energy Agency.
- Stenqvist, C., Lindgren, K. (2009). *National Report from the Pilot Test of Case Application 9, Improvement of Lighting Systems (tertiary sector) and Case Application 17, Energy Performance Contracting*. Report of the EMEEES project. Lund: Lund University and the Swedish Energy Agency.

List of acronyms

CEI	Cement industry
EEI	Energy Efficiency Improvement
EEI action	Technical, organizational, or behavioural action implemented to improve energy efficiency
EnMS	Energy Management System
EU	European Union
EU ETS	EU Emissions Trading System
GHG	Greenhouse Gases
GWP	Global Warming Potential
MS	Member State (of EU)
LTA	Long-term Agreement
PFE	Programme for improving energy efficiency in energy-intensive industries
PPI	Pulp and paper industry
SEA	Swedish Energy Agency
TBE	Theory-based Evaluation
VA	Voluntary Agreement

Contents

1 Introduction

This thesis is about industrial energy efficiency in relation to public policies intended to facilitate such advancements. Policy analysis and especially policy evaluation provide a contextual framework. The appended research papers (Papers I–VI) are examples of independent academic evaluations and assessments of existing policy programmes and instruments which, besides other objectives, target industrial energy efficiency improvement in energy-intensive manufacturing industries. The research explores and applies different analytical tools and evaluation methodologies, to find out if and to what extent desired changes and policy impacts are achieved. Other outcomes in terms of corporate responses to policies are also addressed, as the thesis attempts to identify underlying and decisive factors for change to occur. This is an area where academic research so far has been scant and for several reasons this area calls for increased attention from authorities and researchers in Sweden and elsewhere. Firstly, the last decade has seen the strong emergence of an EU level goal-orientated energy and climate policy regime, with related requirements on monitoring and evaluation procedures. Secondly, considering the serious environmental and social challenges at stake, industrial energy efficiency and CO_2 emission reduction policies must prove to deliver results. Finally, complexity in the interactions of policies and market mechanisms in a multi-level governance setting raise challenges that require better understanding and a broad empirical knowledge base in order to be effectively addressed.

1.1 The role of industrial energy efficiency

Between 1970 and 2010 the Swedish economy grew almost four times faster than the country's primary energy supply. Over the last two decades in particular, this decoupling trend has strengthened, with the economy growing up to seven times faster than primary energy supply, which has increased by only 6% (SEA, 2012). This long-term development in Sweden follows the general trend of decreased energy use per unit of GDP experienced in many OECD countries. Behind this development lies foremost energy efficiency improvement (EEI), but also an impact from structural changes (Geller and Attali, 2005). Many factors taken together – technological improvements, energy prices and public policies such as building codes, energy efficiency standards and labelling, environmental regulations etc. – have driven this change forward. Experiences have built a strong case for EEI and growing political support, although contested on different grounds, for increased policy activity targeting industry as well as other sectors of the economy.

As this thesis will show, there are many merits with industrial EEI. Not least, energy efficiency is considered the most important and least costly policy strategy to reduce energy-related greenhouse gas (GHG) emissions in a trajectory consistent with the 2 °C target (IEA, 2013, 43). In 2012, the EU-15 collective achieved its Kyoto target with a safe margin (EC, 2013). In Sweden in particular, domestic GHG emissions had been reduced by 16% in 2011 compared with 1990 (Naturvårdsverket, 2013). However, despite the positive initial steps taken in some countries, global energy-related CO_2 emissions and other GHG emissions are increasing. Monthly observations of atmospheric CO_2 concentrations have now exceeded the symbolic threshold of 400 parts per million (ppm) compared with 280 ppm in the pre-industrial era (WMO, 2013). In its latest report, the Intergovernmental Panel on Climate Change (IPCC) concluded that the warming of the climate system is unequivocal. Many of the observed climate system changes since the 1950s are unprecedented over decades to millennia. Even if GHG emissions cease today, many aspects of climate change will persist for many centuries to come (IPCC, 2013). Tremendous negative impacts and social costs can be expected from global warming. To avoid the worst case scenarios, immediate actions have to be taken to transform energy systems and eventually reduce current global emission levels by about 50% by 2050 (Stern, 2007). For industrialized countries the debt burden is larger and the ambition has to be set at close to complete phase-out of GHG emissions by 2050. In its roadmap for a competitive low-carbon economy, the EU has set itself the long-term objective of reducing domestic GHG emissions by 80–95% in 2050 compared with 1990 (EC, 2011a).

This thesis examines the particular challenges, interactions and responses experienced in the energy-intensive manufacturing industry targeted by EEI and GHG emissions reduction policies. The manufacturing sector accounts for 25% of final energy use in the EU-27 and needs to contribute a proportionate share towards the achievement of climate mitigation, energy savings and renewable energy targets (EC, 2011a). However, current industrial energy prices do not reflect the full social cost of energy use and prices alone do not stimulate profitable EEI to the full extent possible. Therefore optimal levels of energy use – from private, societal or technological perspectives – are not attained, not even in the most energy-intensive industries with considerable energy cost shares. For industrial firms there are complementary driving forces, beyond energy cost reductions, that need to be invoked to overcome market failures and barriers to EEI (Thollander and Ottosson, 2008). An increasing number of industrial EEI and GHG emissions reduction policies have been launched in the EU and Sweden to address these challenges. Given the degree of complexity involved, systematic evaluation is key to verifying the results and desired changes of implemented policies, which often have multiple objectives. Results of evaluations are important as guidance for the formulation and improvement of the next generation of policy goals and incentives. For instance, the current target-orientated policy regime (e.g. EU 20/20/20) constantly requires new knowledge and capacity building to improve the effectiveness of policies and evaluation practices. Furthermore, within the EU, MS need to monitor, evaluate and report the results of policies.

The pulp and paper industry (PPI) is one energy-intensive sub-sector under the influence of EEI and GHG emissions reduction policies, which is analysed in this thesis. PPI alone accounts for 20% of final energy use and half of the manufacturing industry's final energy use in Sweden (SEA, 2012). It is also a large user of renewable energy sources, with over 90% of total fuel demand covered by biomass sources (Wiberg and Forslund, 2012). In return, PPI is a supplier of renewable electricity and heat to the surrounding society. Thus, the extent to which Sweden will achieve national targets and contribute to EU level targets on EEI, renewable energy supply and GHG emissions reductions is largely influenced by developments in PPI. At the same time, PPI is being challenged by weak markets in particular product segments, as well as increased competition from other regions of the world. This raises issues which are elaborated upon in this thesis about the role of structural changes and industrial EEI in the transformation of the energy system.

1.2 Aim and objectives

The overall aim of this thesis was to analyse the role of public policies that, alongside other objectives, target industrial energy efficiency improvement and CO_2 emissions reductions in the energy-intensive manufacturing industry in Sweden and partly elsewhere.

Policy analysis provides a contextual framework. The policy phase model – a simplified and practical construction of the seemingly logical chain of events in the public policy process – can be used to illustrate and narrow down the scope of the research. Figure 1 shows a phase model proposal which includes seven phases of the policy cycle.

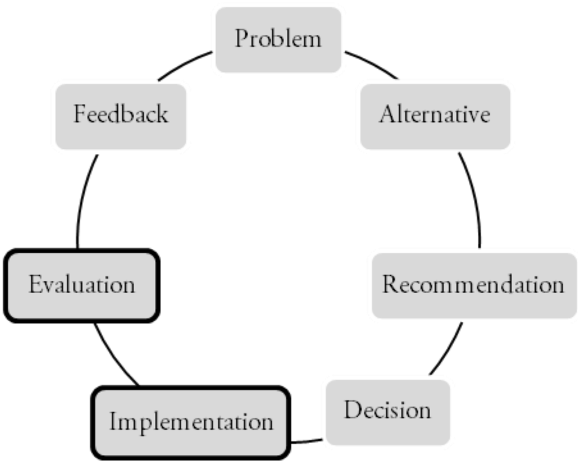

Figure 1. The policy process phase model. Source: Based on Premfors (1989)

The research focused primarily on the phases of policy implementation and policy evaluation. The main interest was in the actual subjects of implemented policies, i.e. specific programmes and instruments, and *ex post* evaluations and in some cases assessments were conducted to provide thorough estimates about the results of current industrial policy making. More specifically, the objectives of the thesis were:

- To evaluate and assess, by the use of different analytical tools and methods, the results of implemented industrial energy efficiency and climate mitigation policies in order to estimate to what extent that desired impacts are being achieved.
- To analyze broader policy outcomes and corporate responses in targeted sectors and firms of the energy-intensive manufacturing industry, in particular the pulp and paper industry but also in other industrial sectors.
- To analyze general trends in industrial development with regard to energy performance, CO_2-intensity and structural change, all with a bearing on policy interactions.
- To use the results of the evaluations to formulate recommendations to relevant stakeholders such as policy administrators, decision makers and programme participants, in order to facilitate improvements in policy formulation, implementation and evaluation practices.

The stated aim and objectives are important for at least three broad reasons:

Firstly, the energy-intensive manufacturing industry accounts for a large share of society's energy use and related CO_2 emissions. A transformation of the energy system inevitably involves actions by the energy-intensive industry. Energy efficiency improvement has been cited as the least-cost strategy for meeting ambitious climate mitigation targets (IEA, 2010a) and is often viewed positively as a cost-cutter in industry. For the latter reasons, it has been debated whether the energy-intensive industry should actually be incentivized by policy, or whether market forces alone can stimulate the desired change. By evaluating policy impacts and corporate responses, it is possible to form better informed policy decision for the future.

Secondly, an increasing number of industrial policies are being introduced in Sweden, the EU and elsewhere. Programmes and instruments are also becoming increasingly complex. They combine many incentives and obligations and involve technically complicated rules and exemptions (e.g.

allocation procedures in the third period of EU ETS). Thus, there is a need for systematic evaluations to grasp underlying policy theories and improve understanding about reported results.

Thirdly, the current target-orientated policy regime is strongly focused on monitoring, evaluation and reporting of results. This can be seen, not least, in the interface between the EU and its MS. However, with regard to industrial EEI, evaluation practices are to some extent underdeveloped compared with other areas of public policy making. The practical application of analytical tools and evaluation methods is an important step in the ongoing capacity building for improved evaluation practices.

1.3 Thesis structure and Papers I–VI

The thesis has the following structure. Section 2 contextualizes industrial EEI as a field for policy making. It starts off with some essential definitions. A discussion follows about the potential benefits and drawbacks of EEI from the perspectives of private decision-makers and society. Despite its many virtues, there are also controversies about the necessity and role of public policy to stimulate EEI. Some of the key disputed issues are elaborated upon here. The section ends with an overview of aggregated energy trends and policy developments with regard to Swedish industry. Section 3 presents the main programmes and instruments studied: (1) the Swedish programme for improving energy efficiency in energy-intensive industries (PFE); (2) industrial Energy Management Systems (EnMS) according to international standard; and (3) the EU emissions trading system (EU ETS). This is followed by a review of the evaluation methods that guided the research. Section 4 summarizes the results of Papers I–VI and Section 5 contains a concluding discussion.

Papers I–VI examine a number of issues related to the overall scope of the thesis:

- Paper I: A bottom-up impact and process evaluation was made of the Swedish voluntary agreement PFE, in order to review its effectiveness, cost-effectiveness and additional aspects of programme operation.

- Paper II: A top-down decomposition approach based on physical indicators was applied to analyse trends in the energy performance of the Swedish PPI. The development in a recent period (2000–2011) was compared with that in the preceding period (1984–2000) to explore responses by industry to increased energy efficiency policy activity.
- Paper III: An interview-based and dialogue-orientated evaluation of the implementation, organization, impact and other outcomes of the use of formal and certified EnMS in the Swedish PPI.
- Paper IV: This study explored and identified – through a dialogue-orientated approach that involved stakeholder consultations, literature studies and quantitative data assessments – considerations for EnMS evaluation to be addressed by energy authorities or contracted partners, and energy policy researchers evaluating the impacts and outcomes of industrial EnMS practices.
- Paper V: This interview-based study of corporate responses to EU ETS analyzed to what extent and how the EU ETS has influenced the climate strategies of two specific pulp and paper companies and the European PPI more generally.
- Paper VI: An assessment was made of the benchmark-based free allocation procedures of the third period of EU ETS (2013–2020), with the focus on the cement industry (CEI) and the PPI located in the UK, Sweden and France.

2 Industrial energy efficiency as a policy field

2.1 Definitions of energy efficiency and related concepts

Concepts such as energy use, EEI and energy savings may at first appear straightforward. However, as many energy analysts have pointed out, it can be difficult to provide clear definitions of these concepts. Any estimates about levels of improvements and savings involve many complications and underlying assumptions (Blok, 2006; Hardell and Fors, 2005; Phylipsen et al., 1998). In technical reports and academic contributions within different disciplines of energy system analysis (e.g. energy policy analysis, industrial ecology, energetics, energy economics etc.), concepts can be used with different meanings. Sometimes concepts are arbitrarily used and vaguely explained, which results in confusion. To clarify the terminology used in the thesis, this section starts off by framing some basic and essential concepts.

Energy consumption, final energy use or energy demand[1] can be defined differently depending on system boundaries and levels of aggregation. Final energy consumption in industry commonly denotes purchased energy by final

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[1] According to the first law of thermodynamics energy can neither be created nor destroyed in a process; it can only change from one form to another. Though the term energy consumption is incompatible with the laws of thermodynamics, from an economic perspective an input of energy has been consumed after being used as it possess no economic value. In energy statistics, terms like energy consumption and energy production are commonly applied. Thus, in the thesis energy consumption, energy use and energy demand are used interchangeably.

consumers (i.e. manufacturing firms) plus the amounts of on-site energy production used on-site, with correction for on-site energy conversions and transformation losses. It is possible to find many additional definitions (see e.g. Phylipsen et al., 1998, 5ff).

Primary energy consumption is often used on a level of energy system aggregation that goes beyond the manufacturing industry, as it includes the off-site losses due to conversion and transmission in the energy generation sector. It is commonly calculated on the basis of purchased amounts of final fuel, heat and electricity consumption, with the application of estimated conversion factors.

Energy efficiency is commonly understood, with regard to industrial activity, as the ratio between a physical output of activity or service and an input of energy, e.g. the production of one tonne of cement per GJ of energy input. The relevant type of energy input (i.e. the energy carrier) is preferably denoted e.g. tonne cement per $GJ_{\text{thermal energy}}$ or tonne cement per $kWh_{\text{electricity}}$.

Energy efficiency improvement (EEI) aims at obtaining an output of activity or service at a minimum level of energy input (Blok, 2006). EEI can be achieved by means of technological and behavioural changes introduced to the system in question.

Energy services is a designation for all types of societal activities that require some energy input to satisfy a human demand, e.g. heating or cooling, lighting, mechanical work in manufacturing processes.

Specific energy consumption (SEC) or specific energy use is the inverse of energy efficiency, i.e. the ratio between energy input and physical output. With regard to industrial activity, it is commonly expressed by energy efficiency indicators e.g. $GJ_{\text{thermal energy}}$ per tonne cement.

Energy-intensity is most commonly understood as the ratio of energy use per unit activity expressed in monetary terms (N.B. in some cases analysts refer to energy-intensity on a physical basis). Energy-intensive manufacturing firms are often defined through energy-intensity ratios such as energy use per unit of production value or energy use per unit of value added. In the latter case, value added is measured as the differential between revenues and the cost of the inputs of goods and services. Typical manufacturing sub-sectors classified as energy-intensive are: iron and steel, non-ferrous metals, basic chemicals, non-metallic minerals, pulp and paper. For these sub-sectors the cost for energy carriers in relation to value added can range between roughly 5% and 20% (Thollander and Ottosson, 2010).

Energy savings is the amount of saved or avoided energy use determined by means of measurement and estimation of energy use before and after implementation of one or several EEI actions. For better approximations, it is advisable to normalize external conditions that influence energy use (e.g. climate, production capacity etc.). The extent to which EEI results in actual energy savings is determined by the baseline used for comparison.

Energy performance is a broad concept which can relate to any of the three aspects energy efficiency, energy use and energy consumption. Guided by an EnMS an industrial firm can undertake a wide range of energy performance activities, e.g. reduce peak demand, utilize surplus or waste energy and improve the operations of its processes or equipment. Results in terms of improved energy performance can be measured against the organization's energy policy, objectives and targets (ISO, 2011).

In this thesis, industrial energy use and EEI are often presented at scales ranging from the specific energy consumption of particular production to that of industrial plants and industrial sub-sectors.

2.2 Energy efficiency improvement as a means to several ends

2.2.1 Private economic perspectives

Energy use is not an objective in itself, but rather a means to provide those energy services that are in demand, e.g. heating or cooling, mechanical work etc. It can also be discussed whether EEI is an objective in itself or a means to other ends. In a narrow sense, it is a means to provide energy services in demand with higher efficiency by minimizing the energy input, either from a primary energy or end-use perspective.

From the perspective of private decision-makers in firms, and especially energy-intensive manufacturing firms where energy costs account for a substantial share of production costs and value added, there is much evidence to show that EEI actions can reduce costs and increase profits and competitiveness (Reinaud et al., 2012). In addition to energy cost reductions, EEI actions can also generate various productivity benefits that go beyond the pure energy savings (Worrell et al., 2003; Pye and McKane, 2000). Whenever EEI actions require capital investments, the decision often involves a trade-off between a higher upfront costs and lower operating costs, as determined by the optimum/minimum point in the life cycle cost curve. For instance, the optimal heat exchanger area in a process industry is determined by investment costs, expected future energy cost savings and the discount rate for calculating the present value of those savings (Nilsson et al., 2011). With a lower discount rate the optimal area is larger, since future energy savings are valued higher. There is some evidence that the economic penalty for over-investment in energy efficiency is small, as the life cycle costs do not change much around the optimum with regard to different choices of energy efficient solutions (Steinmeyer, 1998). One policy implication is that a revenue-neutral tax on industrial energy use can be used to subsidize investments in energy-efficient solutions, and thereby enhance the willingness of firms to trade energy for capital (Ibid).

EEI can likewise benefit the collective of energy end-users by reducing the overall cost of energy services. See for example Fouquet and Pearson (2006) for an exposé of the price and use of lighting services in the UK over seven centuries. Lower energy prices can also follow when costly investments in new or refurbished energy supply infrastructure are avoided. One example is energy efficiency through load management, by which the reliability of energy services can be maintained without grid investments in capacity-constrained distribution networks.

2.2.2 Societal perspectives

When extending the scope from a private to a societal perspective, EEI or absolute energy savings can be seen as a means to several ends. For the EU, the three main pillars of EEI are: mitigation of climate change by reduction of energy-related GHG emissions; increasing energy security by reducing primary energy use and decreasing energy imports; and increasing competitiveness by diffusion of innovative technologies, economic growth and creation of high quality jobs (EC, 2012). The merits of EEI from a social perspective include:

- EEI mitigates climate change by the reduction of different energy system-related GHG emissions with large variation in global warming potential (GWP) e.g.:
    - carbon dioxide (CO_2) with GWP_{100}=1. EEI is considered the least-cost option to reduce CO_2 emissions from fossil fuel combustion (IEA, 2010a).
    - methane (CH_4) with GWP_{100}=25. EEI can prevent CH_4 emissions by avoidance of extraction and transmission of fossil fuels.
    - nitrous dioxide (N_2O) with GWP_{100}=298. EEI can prevent N_2O emissions in fuel combustion and flue gas denitrification processes.
- EEI can prevent all types of air pollutants related to fuel combustion and energy conversion, e.g. sulphur dioxide, nitrogen oxides, ground-level ozone, mercury, cadmium, particulate matters (PM) etc., that harm human and natural environments (e.g. via acidification) and deteriorate air quality, with serious damage to human health.[2]
- EEI can prevent land, habitat and biodiversity degradation associated with the construction of energy supply and distribution infrastructure, both from conventional and renewable sources.
- EEI can facilitate the transition to an energy system based partly on intermittent renewable energy supply.

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[2] Substances like PMs are carcinogenic, cause cardiovascular and respiratory diseases, and are responsible for millions of premature deaths globally. This occurs in China and other regions with booming economic development, but also in Europe despite that emissions are below limits set by EU air quality standards, which appear too lax to safeguard human welfare (Raaschou-Nielsen et al., 2013).

- EEI and especially absolute energy demand reductions can have positive effects on energy security (Jonsson and Johansson, 2013):[3]
  - by lessening the heavy reliance on imported energy, e.g. oil and natural gas, which can cause interruptions in energy supply and burden the national trade balance.
  - by mitigating technological, environment and health-related risk factors, e.g. ruptured gas pipelines or nuclear power accidents. To put it very simply, the more nuclear power plants, the higher the probability of an accident.
- EEI can facilitate new market development and job creation. Examples include building refurbishments and installation of energy-efficient equipment, which are more labour-intensive activities than energy supply-orientated activities (ACEEE, 2011).

Given this long list of potential benefits from EEI, the kWh saved can be viewed as being of the most benign form. Perceptions developed about the power of the "negawatt" (Lovins, 1990) are now being reflected at high political levels. The "negajoules" of avoided energy use through EEI have even been portrayed as Europe's biggest energy resource (EC, 2011b). The resource is as yet untapped, which is why the EU has set itself the target for 2020 of saving 20% of its primary energy consumption compared with a baseline projection (EC, 2012).

Downsides of energy efficiency improvement

Are there potential downsides of EEI? From an environmental and health perspective, it could be that the production, incorrect installation, use or disposal of energy-efficient materials and technologies can result in negative impacts. While many energy-efficient materials and technologies appear

[3] Most countries world-wide actually rate energy security as the principal driver of energy efficiency policy, though, in OECD countries climate change mitigation ranks higher (IEA, 2010b, 34).

harmless,[4] there are other examples that contain hazardous substances. One example is the risk of mercury leakage from relatively energy-efficient fluorescent lamps.[5] Another example is the risk of losses of ozone-depleting substances (e.g. HCFCs) or highly potent GHGs (HFCs) used in energy-efficient heat pumps and cooling machines. Energy-efficient equipment may also require higher raw material inputs in the production phase, which motivates a life cycle analysis (LCA) approach for evaluating their overall environmental performance. One example is electric motors, a universal technology which accounts for as much 70% of the electricity use in the manufacturing industry (IEA, 2011a, 11). Highly energy-efficient electric motors require more copper in the rotor and stator parts. Thus, the higher level of embodied energy will offset some of the energy savings achieved by the end-user. At some point in the life cycle perspective there will be a breakpoint, however, after which the energy-efficient alternative will outperform the obsolete equipment.

To prevent the examples mentioned above from seriously discrediting energy-efficient technologies, it is important to have careful policies and regulations that prevent and phase-out harmful substances and to have sound waste management, including striving for closed-loop recycling. It seems as though the main arguments against EEI are not about its direct merits, but rather concern the fact that public intervention for stimulation of EEI may create distortions in the market, out-rival other investments, or lead to socioeconomic losses.

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[4] For instance, glass wool insulation is produced mainly from recycled glass and a lesser share of abundantly available minerals. It can be produced with an input of renewable energy, but natural gas is often used for glass melting. Once properly installed in a building or in industrial equipment it provides thermal resistance and reduces energy demand over its lifetime without deterioration. It appear harmless to human health with no documented serious health effects (Eurima, 2012).

[5] However, through reduced electricity demand fluorescent lamps can reduce emissions from fossil fuel combustion in stationary installations like coal condensing power plants, which is the primary source accounting for almost half of global anthropogenic mercury emissions in 2005 (Pacyna et al., 2010).

2.3 Predicaments of energy efficiency policy

Representatives from different academic disciplines have opposing views about the relevance of energy efficiency improvement as a societal objective, the need for public policies to stimulate energy efficiency improvement and the preferred choices of programmes and instruments. The protracted controversy between "energy technologists" (or engineers) and "economists" has been analyzed by Jaffe and Stavins (1994), Sutherland (1994), Metcalf (2006) and others. In a Swedish context, such disagreements have been treated by e.g. Söderholm and Hammar (2005), Söderholm et al. (2010). It also came to fore in the work with the Swedish Energy Efficiency Inquiry, as representatives from different backgrounds found the collaboration to be more strenuous than expected (SOU 2008:110, 66).[6]

2.3.1 Why energy efficiency policy?

One disputed issue concerns the basic question: Why do societies need energy efficiency policies in the first place?

From an engineering perspective, EEI is seen as an effective means for overall energy resource efficiency, as well as mitigation of negative environmental impacts. In addition, EEI investments and actions resulting in reduced energy costs can make capital available for other more constructive needs. Scenario studies have identified EEI as the largest potential contributor, accounting for 49% of the much needed abatement of GHG emissions up to 2020 (IEA, 2013). To harness this potential, policies are deemed necessary to address a number of obstacles that can hinder the uptake of energy-efficient technologies and behaviours (Wesselink et al., 2010; Brown, 2001). In Sweden, the Energy

[6] The inquiry developed and proposed a Swedish strategy for energy efficiency including the first National Energy Efficiency Action Plan (NEEAP) under the EU Energy Service Directive (ESD) (SOU 2008:110, 59ff).

Efficiency Inquiry identified a substantial energy efficiency gap across all sectors of the economy (SOU 2008:110:78), which is supported by a large number of theoretical and empirical studies (Thollander and Palm, 2013, 35). The fact that far from all privately profitable EEI actions are being implemented confirms the need for energy efficiency policies to safeguard private and public interests (see section 2.2).

On the other hand, based on socioeconomic considerations, many economists view the input and use of energy as one production factor among many others in their division of primary- (i.e. land, labour, capital) and secondary-order factors of production. Improved efficiency of energy use is not seen as more or less important than other factors in production, for instance increasing the productivity of labour in order to improve overall economic efficiency at the output side of the production function (Söderholm et al., 2010). On the basis of hypothetical perfect market conditions, it is argued that market prices alone should be allowed to signal and guide private decision-makers to the most rational (i.e. profitable) decisions when choosing between alternative investments to increase utility. Policy intervention is warranted only if the market is influenced by one or several market failures that hinder optimal welfare, and if the socioeconomic benefits exceed the cost of the intervention.

2.3.2 Market failures and barriers

As indicated, different disciplines have diverging perspectives about market failures as opposed to barriers to energy efficiency and how these should be overcome to improve overall economic efficiency or energy efficiency in particular. According to Jaffe and Stavins (1994), differing views about the nature of such obstacles have led to fundamentally different views about the size of the so-called energy efficiency gap between actual and optimal levels of energy use.

Engineers have paid attention to, identified and categorized a number of barriers described as “mechanisms that inhibit a decision or behaviour that appear to be both energy efficient and economically efficient” (Sorrell et al., 2004, 27). According to Sorrell et al. (2004), common barriers include:

- Risk: The short payback periods often required for EEI investments could reflect an aversion to the technical or financial risks involved with EEI actions.

- Imperfect information: Owing to lack of information about cost-effective EEI options, such opportunities can be foregone.
- Hidden costs: EEI potentials can be overestimated if overhead costs for e.g. production disruptions, staff training and compiling information are overlooked.
- Access to capital: If internal funds are insufficient and loan uptake or other financing solutions are unattainable, EEI investments can be hindered. Investment appraisals and budgeting procedures can also hinder otherwise profitable EEI investments.
- Split incentives: An EEI action is not likely to be implemented if an actor cannot reap the benefits of the investment, e.g. if a sub-division is not accountable for its energy use.
- Bounded rationality: Even when information is available, actors may not behave as rationally as mainstream economic theory might expect. Due to constraints in time, attention and ability to comprehend information, EEI actions are sometimes neglected.

There are various ways, derived from different disciplines, to classify barriers and divide them into groups, such as economic, behavioural and organizational barriers. For a review of terminology and empirical research, see for example Thollander and Palm (2013).

From the perspective of economists, only two of the above-listed barriers, namely imperfect information and split incentives, cause situations which can be defined as market failures according to economic theory. For the other barriers, a common perspective among economists is that these reflect legitimate characteristics of markets such as transaction costs and high demands for return on investments, which in themselves do not motivate policy interventions (Söderholm et al., 2010). A longer list of market failures include: externalities, public goods, common pool resources, ill-defined property rights, non-competitive markets and imperfect information (Sterner and Coria, 2012, 2). In contrast to the theoretical ideal of the perfect market, many market failures are common in the real world (Sterner and Coria, 2012, 22). In particular, imperfect information and the existence of externalities (i.e. unpriced costs) characterize today's market situation. In relation to industrial energy use, an example of the former market failure could be a private firm which fails to make optimal investment decisions if inadequate information leads to poor estimates about the energy life cycle cost of a new piece of process equipment. An example of the latter market failure is the inability of the largest emitting industrial sectors to internalize the real cost of their energy-related CO_2 emissions.

In relation to industrial energy use, the two market failures exemplified above imply that more energy, including fossil energy, is used per level of industrial activity than can be justified had there been a rational allocation of resources. While the existence of market failures could warrant a government policy intervention, economists also require that the benefits from an intervention exceed the costs as quantified in a cost-benefit analysis. On the basis of the Kaldor-Hicks criterion a beneficiary could then compensate a losing party. However, whether such redistributive actions actually take place tends to be overlooked.

2.3.3 Policy solutions in theory and practice

There are also disagreements when it comes to selection of public policy interventions to correct for market failures and/or barriers.

Engineers, as mentioned, identify a large set of barriers that hinder EEI and on this basis advocate a range of policies to reduce the energy efficiency gap and bring energy use down to theoretically achievable limits (Jaffe and Stavins, 1994). For instance, some key energy efficiency policies suggested for the manufacturing industry are to ensure wide-spread adoption and compliance with minimum energy performance standards for electric motors, and to impose obligations on the use of industrial EnMS to facilitate continuous operation and maintenance for motor systems optimization (IEA, 2013, 53ff). Others have identified: (1) Energy audit programmes for non-energy-intensive small and medium-sized enterprises (SMEs) and (2) Voluntary Agreements (VA) containing a mix of incentives and obligations for energy-intensive firms, as two of the most important means of reaching EEI and CO_2 emissions reductions in the manufacturing industry (see Thollander and Palm, 2013, 25).

Economists, on the other hand, are more restrictive when it comes to expressing particular social goals and legitimate policy interventions. After having identified the external costs incurred by CO_2 emissions as the main market failure related to industrial energy use, they prefer to advocate policies that directly address this particular issue. According to economic theory, the "first best" policy option to correct for the market failure of external environmental costs (e.g. CO_2 emissions) is to enforce a tax (Fisher, 1981). An enhanced price signal alone should motivate market actors to reduce emissions without dictating the specific means for abatement. Other policies, e.g. that invoke energy-efficient behaviour, are often regarded as an unnecessary and costly interference (Broberg et al., 2010). However, given the political-economic dimensions typical for the export-orientated manufacturing industry (i.e. being vulnerable to international competition), the tax instrument is difficult to enforce when competitors in other countries do not face the same marginal cost increase. In addition, it is difficult to determine the correct marginal cost that arises from an externality (e.g. the damage cost incurred by emitting an extra unit of CO_2). Thus, energy-intensive industries are often largely or completely exempted from CO_2 tax, which contravenes the polluters pay principle held high by environmental economics. As an alternative to general and cross-sectoral carbon taxation, the EU has launched the EU ETS to engage the largest emitting sectors (e.g. power generators, the manufacturing industry, heat installations and lately also aviation) in a cap-and-trade system to promote CO_2 reductions in a "cost-effective and economically efficient manner" (EC, 2009a; Paper V; Paper VI).

2.3.4 Behavioural responses to energy efficiency policy

Another divergence is the different ways of accounting for behavioural responses by investors and adopters of EEI actions. This can be illustrated by the different shapes and positions of energy efficiency cost curves, which can be applied to estimate the economic potential of EEI actions (see e.g. Beer, 1998, 24). Engineering studies tend to focus on the direct costs of the equipment and its operation (Brown et al., 2001). However, they do not incorporate the broader impacts of market-wide behavioural responses to policies (Metcalf, 2006). Figure 2 shows a conceptual example of an engineering cost curve and an economist cost curve. The horizontal axis represents the potential for accumulated industrial energy savings from a number of EEI actions and the vertical axis represents the specific cost for their implementation. At an assumed average energy price of 6 Eurocents/kWh and a one year straight payback requirement, EEI actions can result in 12 GWh of annual energy savings based on the engineering curve. With the same assumptions only 6 GWh of annual energy savings can be achieved according to the economist curve. Notably, in the engineering curve up to 4 GWh can be saved at a negative cost through EEI actions that require no investment, e.g. change of operation.

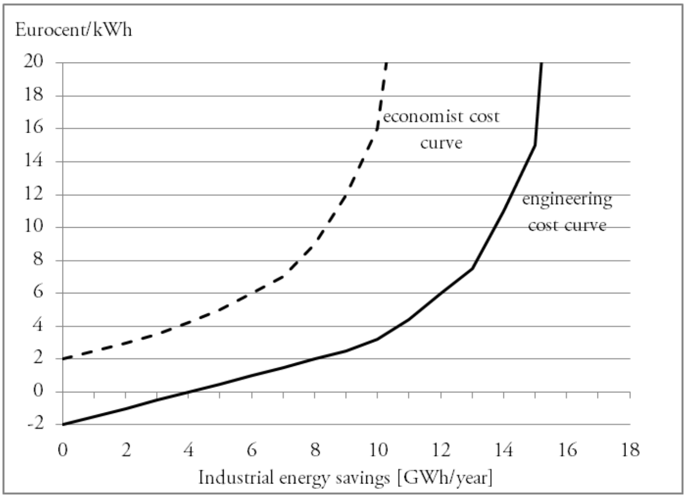

Figure 2. Conceptual cost curves of industrial EEI actions from an engineering and economist perspective.

The difference between the curves can be explained by the adjustments for various costs that economists tend to consider and incorporate in their model approaches. With regard to industrial firms, such concerns could include e.g.:

- Heterogeneity of firms: The average cost estimate of a certain EEI action may not represent the actual cost faced by individual firms within a larger distribution. For instance, one firm may operate the process equipment less than the average firm and so the cost per unit of energy saved will be higher than average.

- Rebound effects: When an EEI action generates energy cost savings, a firm may use the particular equipment more intensively due to its lower operating cost (direct rebound) or otherwise invest the cost savings in other energy services (indirect rebound). Either way, the behavioural response may offset some of the initial energy savings from an EEI action. Rebound effects are likely to vary between different technologies and sectors. Available studies of direct rebound effects in manufacturing industries estimate values that range between 0 and 25% (Bentzen, 2004; Greening et al., 2000).
- Market interactions: Upon high uptake of EEI actions by industry, a substantially lower energy demand could force energy generators to reduce energy market prices. This would then reduce the main driving force for EEI and make investment less profitable.

2.4 Evolution of industrial energy efficiency policies in Sweden

2.4.1 State-governed energy system expansion

Access to energy services is a prerequisite for business, employment and social well-being. Apart from its interconnected technological components (e.g. power stations, distribution grids, switchgears, heat exchangers etc.), the energy system is comprised of organizations and institutional components (e.g. firms, financial markets, authorities, interventions etc.). Changes to and interactions between socially constructed system components, physical or non-physical, contribute to shape the evolution of the energy system (Hughes, 1989).

State powers have often played important roles in large-scale technical projects and system developments over time. For instance, Sweden has a history dating back to the 17th century of state regulation to secure a reliable and inexpensive energy supply to emerging energy-intensive industry (Kaijser, 1994, 157). In the electrification process from the early 20th century onwards, the government granted the state-owned utility Vattenfall the right to cooperate closely with the private engineering firm ASEA in a "techno-nationalistic" manner to build up hydropower stations and transmission grids (Fridlund, 1999). In this way, state powers and private actors have been governed to safeguard mutual interests of developing the infrastructure to harness domestic energy sources and at the same time stimulate industrial competence. The Swedish development model resulted in an abundant power supply and the comparative advantage of low electricity prices for the industrial sector. The relationship between Vattenfall and ASEA, later ABB, was extended over the Swedish nuclear investment programme (1954–1985), initially governed by the semi-state owned company Atomenergi on the basis of a political objective of national independence in energy supply, but also to enable production of nuclear arms (Kaijser, 1994, 174). Similar examples of state interest and involvement in the early years of nuclear energy are found in other countries (MacKenzie and Wajcman, 1999, 14). The political ambitions were later dashed by the industry's preference for light water reactors, which also became the dominant nuclear power technology from the 1970s forward. By that time in Sweden, the power sector through state involvement had become a core around which other development blocks could form and many spin-off manufacturing firms were able to expand internationally (Enflo et al., 2008). The joint effort of developing the power supply is often portrayed as successful and it is one of several features of the Swedish 'Strong Society' model, in which government is seen as a legitimate vehicle for technical and economic development, social change and achievement of related welfare goals (Pierre and Peters, 2000, 2). Today, the state-owned company Vattenfall has become one of Europe's largest utilities and the ABB group is known as a global provider of power and automation technology. A similar development can be observed in the area of telecommunications.

2.4.2 The birth and development of industrial energy efficiency policy

It was first in 1960–1970, with growing evidence and awareness about the negative impacts of energy-related resource use and emissions, that the downsides of energy supply and use started to be recognized in public debate in Sweden and elsewhere in Western society (Meadows, 1972: Palmstierna, 1972). The oil crisis and price increase in 1973–74 was a triggering factor for many oil-dependent economies. Between 1950 and 1970 the Swedish energy supply had increased by 4–5% annually, largely driven by oil imports. By 1970, almost 80% of the national energy supply was from imported oil. From being absent from the Swedish policy arena, energy supply and use became a high priority issue for political debate and policy making (Moberg, 1988). The government energy bill of 1975 marked the real change and the dawn of a political energy planning philosophy:

> "It is now clear that energy must be used with restraint. Those days are gone when increased energy use could be regarded as obvious" (Prop. 1975:30, 8, my translation).

A long-term government objective was formulated to limit the annual increase in Swedish energy supply to 2% by 1985 and to keep total energy supply at a constant level beyond 1990 (Prop. 1975:30). Thus, from being the promoter and general provider of large-scale energy supply projects, the Swedish government started to launch energy policies for reasons of energy conservation and fuel-shifts. Combined with political objectives, energy balances on national and sector level were commonly applied in policy planning to define the level and composition of energy use and to construct scenarios and estimates about the future energy system (Moberg, 1988). A similar change in energy policy priorities could be seen in many other countries with large dependence on foreign oil. For instance, the Netherlands introduced EEI as an element of national energy policy in 1974 (Farla, 2000).

Table 1 provides an overview of the main energy efficiency policies targeting the Swedish manufacturing industry from 1970 until the present day. The underlying motives for policy making have changed over time. Initially, the main objective for the Swedish government was to reduce the dependence on imported oil. In 1975–1986, large funds supported industrial energy savings actions and oil substitution through investment subsidies and generous loan terms (NUTEK, 1993). The share of oil and petroleum products in national energy supply did decrease, from almost 80% in 1970 to 35% in 1985 and in line with political objectives (SEA, 2009). Later on, the oil price dropped and the planned phase-out of nuclear power became a motive to focus on electricity end-use efficiency, as exemplified by the Demand Side Management (DSM) planning of Vattenfall. Growing opposition to nuclear power in the 1970s and the accident at Three Mile Island in 1979 had spurred a referendum in 1980 about the future of Swedish nuclear power. As a result, the nuclear investment programme was restricted to half of the initially planned number of reactors. It was decided that the twelve reactors that were either in operation or under construction would be phased out by 2010, of which two reactors already in the 1990s. However, this decision was later repealed.[7]

Earlier implementations of energy and electricity taxes for fiscal motives have been revised at several occasions over the period, often resulting in larger exemptions for industry (DFE, 1980). CO_2 emissions and related climate change became a political issue in the 1980s and a general carbon tax was enforced in 1991. Successively, there has been a general shift from energy taxation towards increased carbon taxation, although industrial sector exemptions have been generous. Since the EU ETS was introduced in 2005 carbon taxation has been further removed and from 2011 forwards energy-intensive manufacturing industries of the trading sector are completely exempted from carbon tax. However, for industries outside the trading sector of EU ETS the carbon tax is set to increase (RIR, 2012). With exceptions for some metallurgical processes, from 2011 forwards, an energy tax according to minimum level of the EU Energy Taxation Directive (ETD) applies to all types of fossil fuel use in industry while biofuels are generally exempted (RIR, 2012). With regard to electricity tax, the manufacturing industry has been completely exempted during the 1990s and until 2004, when the ETD enforced the minimum electricity tax of 0.5 Euro/MWh. However, energy-intensive firms that participate in PFE are exempted until 2014 (Paper I).

[7] A 1997 energy policy decision allowed for ten reactors to operate longer than envisioned by the 1980 phase-out decision. To date two out of twelve commercial reactors have been shut down while power uprates have been and are about to be carried out in existing reactors. In 2010, a parliament decision repealed the phase-out decision and enabled permit applications for replacement of existing reactors.

Swedish policy implementation has responded to EU level policy recommendations from 2001, which identified energy audit schemes for non-energy-intensive SMEs and VAs (or LTAs) for energy-intensive firms as two of the most important means for EEI and CO_2 emissions reduction in industry (Thollander and Palm, 2013, 25). Early pilot or local scale initiatives (i.e. EKO-Energi and Projekt Högland) have been expanded to full scale programmes (i.e. PFE and the energy audit scheme).

As a general trend over the period, there has been a shift away from energy related taxes and direct investment support structures towards more attention-raising policies such as VAs and energy audits. So called market-based and technology-neutral policy making is preferred, through which firms themselves are expected to identify the most prioritised, effective and cost-effective solutions for EEI and/or GHG emissions reduction. With regard to the latter, EU ETS is considered to be the main climate mitigation policy for the energy-intensive manufacturing industry. Some of its proponents argue for less interaction from other energy related targets and policies, which they claim could hamper the carbon price signal and increase the cost for reaching climate mitigation targets (Broberg et al., 2010, 15f).

With regard to targets formulations, Sweden currently has two national targets that directly relate to EEI:

- An indicative target of 9% final energy savings by 2016 implemented under the EU Energy Service Directive (ESD) (EC, 2006).
- An economy-wide target to reduce primary energy use in relation to GDP by 20% between 2008 and 2020 (RIR, 2012).

The latter has been proposed as a national target under the EU Energy Efficiency Directive (EED), though it is less ambitious than the EU-level target of 20% primary energy savings by 2020 compared to baseline projections (Wesselink et al., 2010). There are no sector specific targets for the manufacturing industry.

Table 1. Overview of energy efficiency policies targeting the Swedish manufacturing industry 1970–2013.*

Policy,	Policy type	Main instruments and industry target	Ref. publ.
Electricity tax, 1951–	Tax on elec. use, sector differentiated	Enhanced electricity price signal. Revised tax rates over time, with large exemptions for industry. Minimum tax level of EU ETD since 2004, with expection for firms in PFE until 2014.	DFE (1980), SFS (1994:1776)
Energy tax, 1957–	Tax on fuel use, sector differentiated	Enhanced price signal on different fuel use with large exemptions for industrial sector. Minimum tax level of EU ETD since 2011.	DFE (1980), RIR (2012)
Energy savings fund, 1975–1979	Investment subsidy	Investement support for energy savings actions in industrial processes, buildings and demonstration plants.	NUTEK (1993)
Oil substitution fund, 1981–1986	Investement subsidy	Investement support for industrial oil use reduction and fuel substitution actions.	NUTEK (1993)
Carbon tax, 1991–	Tax on fossil fuel use, sector differentiated	Enhanced price signal on fossil fuel use. Large exemptions for industrial sector. The manufacturing industry in EU ETS is completely exempted since 2011.	RIR (2012)
Vattenfall Uppdrag 2000, 1986–1991	State-owned utility DSM programme	Technical-economic assessments of electricity saving potentials in less electricity-intensive manufacturing industry (and other sectors).	Eklund (1991)
Environmental Code, 1999–	Environmental legislation	Environmental regulation with general rules of consideration, e.g. about energy conservation. All entities are obliged by the rules.	Ds (2000:61)
EKO-Energi, 1994– 2001	VA, energy audit	Subsidised energy audits and cert. of environmental management systems focused on EEI. Target group of ~50 firms in manufacturing and service sector.	Helby (2002)
Projekt Högland, 2003–2008	Energy audit, local	Subsidised energy audits. Target group of ~300 SMEs in manufacturing and service sector.	Thollander et al. (2007)
EU ETS, 2005–	EU emissions trading	Cap-and-trade system. Divided into trading periods with intermediate revisions. Includes EU's energy-intensive firms and power and heat producers.	Paper V, Paper VI
PFE, 2005–2014	VA, EnMS, energy audit etc.	VA that combines many obligations with an electricity tax exemption of 0.5 Euro per MWh. Target group of some 100 energy-intensive firms.	Paper I, Paper III, Paper IV
Energy audit scheme, 2010–2014	Energy audit, national	Subsidised energy audits for firms with energy use >0.5 GWh/year. Other obligations on energy planning and reporting of implemented actions.	Thollander and Dotzauer (2010)

* The list is not exhaustive as it excludes, e.g. local and smaller-scale energy audit schemes (Thollander, 2007). Other energy policies such as the renewable electricity certificate system (since 2003) support industrial electricity generation, which could lead to primary energy savings. There have also been investment supports to utilise industrial waste heat for district heating.

2.4.3 Development of industrial energy use

In Sweden, the industrial sector accounts for almost 40% of the final energy use, which is a relatively large share given that the average for EU-27 is 24% (Lapillonne et al., 2012). Figure 3 shows industrial final energy use, including fuel and electricity use, as distributed among a number of sub-sectors in 2010 compared with 1970.[8] The pulp and paper industry (PPI) largely dominates the industrial sector energy use and accounted for more than half in 2010. The iron and steel industry is the second largest sector, followed by the chemicals industry and the engineering industry. Other sub-sectors cover a large number of industrial activities, e.g. mining, cement and lime, sawmills, food processing etc. (SEA, 2012). The total levels of industrial energy use are similar between the two years, but this disguises variations of about +/-10% observed in the complete time series (see Figure 4).

With regard to sub-sector composition, the most obvious changes over the 40-year period studied are the increased energy use by PPI and the decreased energy use by the iron and steel industry. The total production volumes of PPI have grown steadily, by about 70% since the 1970s (Wiberg and Forslund, 2012), but PPI is currently being challenged by diminishing demand in certain production segments, e.g. newsprint. In contrast to projections made by the Swedish Energy Agency, this can bring about substantial electricity demand reductions in the near term (Paper II). The iron and steel industry suffered from the structural crisis in the 1970s, which reduced pig iron and crude steel capacity by 30–40% (Isacson, 1987). Since then, production volumes have recovered to around pre-crisis levels, while specific and absolute energy use has been reduced.

[8] The industrial sector includes manufacturing industry as well as mining and quarrying as defined by NACE codes C10–33 and B5–9 respectively.

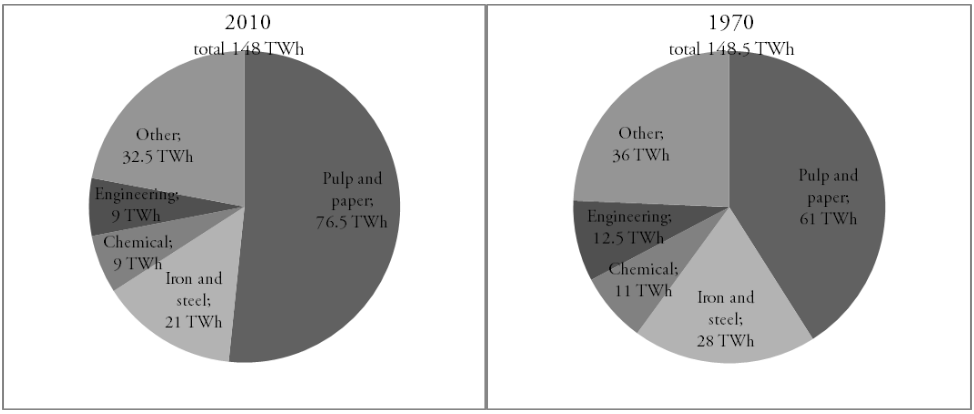

Figure 3. Total and sub-sector final energy use, i.e. fuel and electricity use, of Swedish industry 1970 and 2010. Data source: SEA (2012); Isacson et al. (1987)

Figure 4 shows the industrial final energy use and composition of energy carriers over the whole period from 1970 to 2010. Total level has ranged between 128 and 165 TWh, while the production output, expressed here as the production index (i.e. an economic indicator), has tripled over the same period. The economic downturn after 2008 had a clear negative impact on both production output and industrial energy use, but industry partly recovered in 2010.

The composition of energy carriers has undergone substantial changes. Most notably, the use of oil products has declined by 80%. Oil has been replaced by an increased use of biofuels, foremost spent liquors and bark in the PPI.[9] Industrial electricity use has also increased substantially, in parallel with the nuclear power expansion over the first half of the period. Coal and coke use has remained at a rather steady level. The iron ore reduction process is the main user of coke, while hard coal is used foremost for high temperature processes in the cement and lime industry and the iron and steel industry.

[9] The biofuel category may also include small shares of fuels of partly fossil origin (e.g. peat and waste fuels).

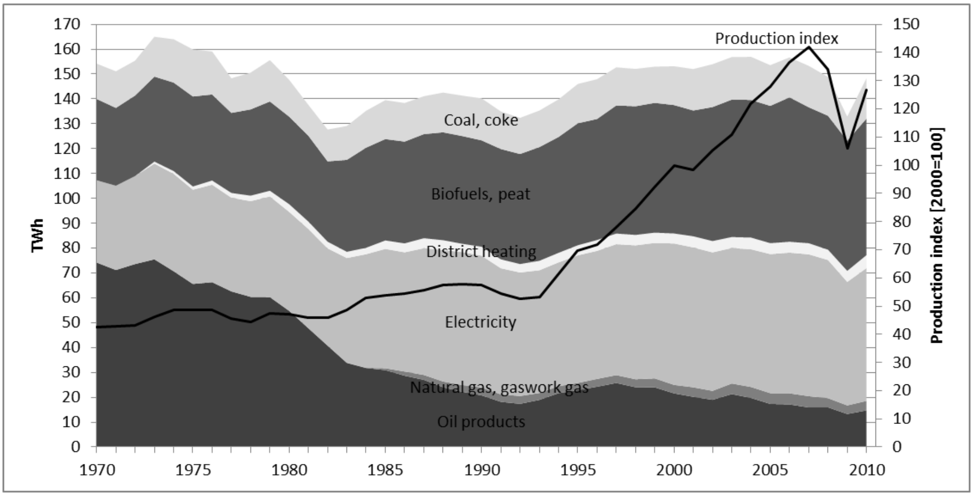

Figure 4. Changes in final energy use, composition of energy carriers and production output in Swedish industry, 1970–2010. Data source: SEA (2012)

As Figure 5 shows, the 80% absolute reduction in industrial oil use combined with a tripling in production output caused substantial declines in industrial oil intensities between 1970 and 2010. For the entire manufacturing industry, the oil use per unit industrial value added has decreased by almost 95% since 1970. As an illustrative example, the energy-intensive sub-sectors iron and steel and PPI have gone from using the equivalent of roughly a "coffee cup" of oil for every SEK of value added in 1970 to one or two tablespoons of oil for every SEK of value added in 2010.[10] Oil use reductions were most drastic between the second half of the 1970s and the early 1980s, a period which involved large fuel shifts in response to increasing oil prices (see Paper II for an analysis of fuel use in PPI).

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[10] As of September 30 2013, the following exchange rates applied to one Swedish krona (SEK): 1 EUR = 8.6757 SEK; 1 USD = 6.4297 SEK (Riksbanken, 2013).

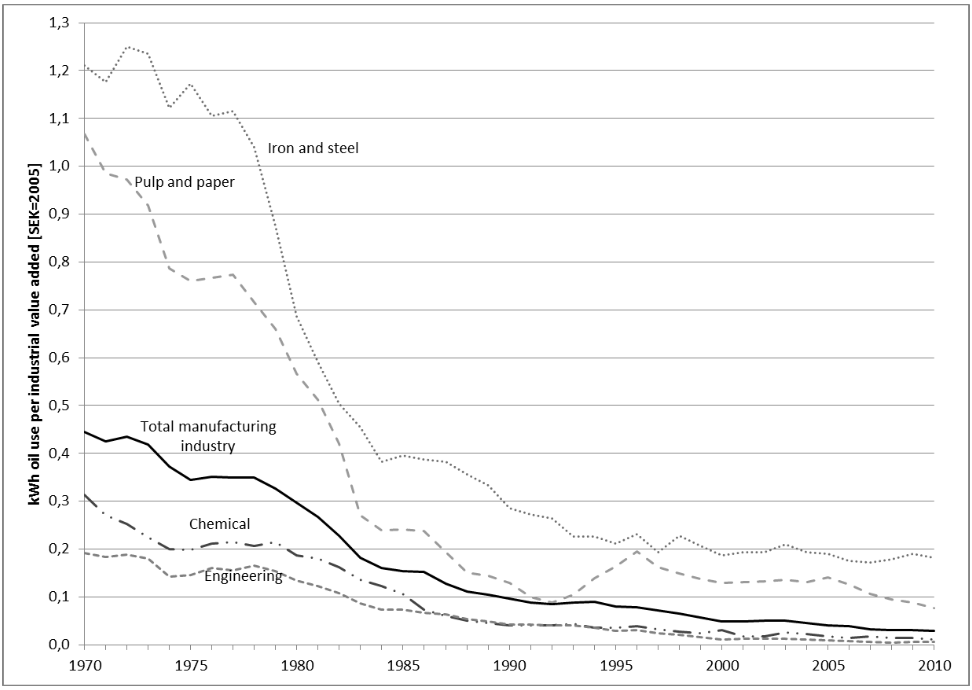

Figure 5. Changes in oil use intensity in the Swedish manufacturing industry and some main sub-sectors, 1970–2010. Data source: SEA (2012)

Figure 6 shows the change in industrial electricity intensity, expressed as electricity use per industrial value added, for the period 1970–2010. For the entire manufacturing industry, it started to decrease in the early 1990s and in 2010 it was reduced to half that in 1970. Unlike the other sub-sectors, the electricity intensity of PPI has been more or less unchanged. This is partly due to structural changes that involve increased electricity use on an aggregated level and partly due to weak development in terms of industrial value added (Paper II).

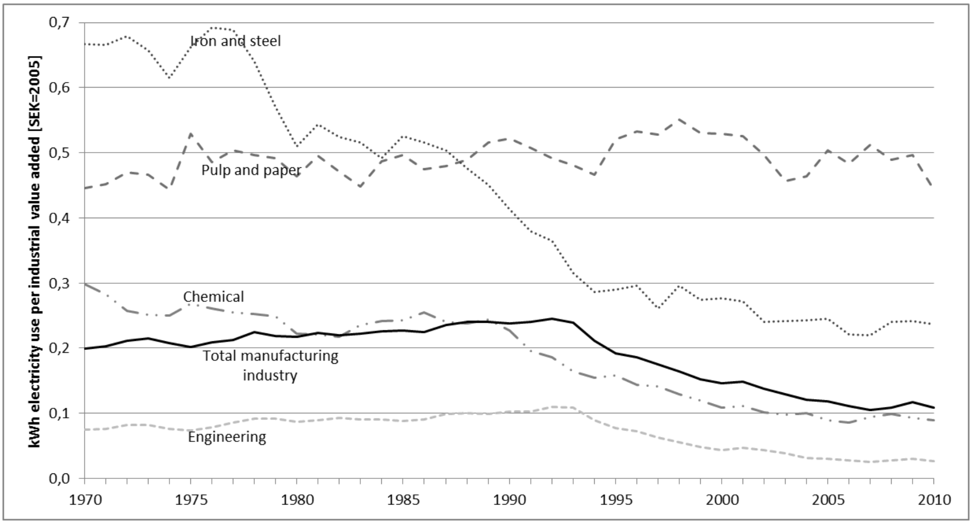

Figure 6. Changes in electricity use intensity in the Swedish manufacturing industry and some main sub-sectors, 1970–2010. Data source: SEA (2012)

The observed long-term trends in industrial energy use and energy intensities are a function of a combination of factors, including production volumes, structural changes, EEI and fuel shifts. Using disaggregated data on industrial sub-sector level, it is possible to disentangle the effects of such factors on overall industrial development. In this way it is possible to estimate, for instance, the contribution of EEI and structural changes to energy use or energy intensity developments. Paper II provides an example. On the basis of a disaggregated set of physical production and energy data, Paper II presents a decomposition analysis on the entire Swedish PPI, thus covering half of industrial final energy use. Other studies that provide energy analysts with detailed descriptions of Swedish industrial energy trends are available (e.g. Blomberg et al., 2012; Lindmark et al., 2011; Löfgren and Muller, 2010).

3 Policy implementation and evaluation

3.1 Policy implementation

As discussed in previous sections, there are many motives for governments to stimulate energy efficiency. The targets and objectives set at EU and Member State (MS) level bring obligations for action and improvement. Obviously, the industrial energy efficiency policy field overlaps with related fields of policy making, not least energy supply and climate mitigation. Such interactions can be a source of conflicts about the most effective ways for public steering against set targets. For instance, the view of EU ETS as the flagship policy to target energy-intensive firms is contested. MS have so far experienced many industrial EEI policies and there are further aspirations to complement the carbon pricing mechanism with more direct impetus for industrial EEI (MURE II, 2013). This section presents the programmes and instruments that have been evaluated and analysed in this thesis.

3.1.1 Programme for improving energy efficiency in energy-intensive industries (PFE)

The Swedish PFE was introduced in 2005 as a voluntary agreement (VA) for industrial EEI administrated by the Swedish Energy Agency (SEA). See Box 1 below for a general description of the VA framework. About 100 energy-intensive firms, covering some 250 industrial sites, participated in PFE in the first five-year period. The pulp and paper industry dominates PFE and other sub-sectors include mining, iron and steel, non-metal minerals and chemical industry. In some cases food processing, sawmills and engineering industries have qualified as participants (Paper I).

As a motivation and compensation for fulfilment of the PFE obligations, participating firms were offered an exemption from the EU-wide minimum tax on industrial electricity use at 0.5 EUR per MWh. The option to exempt energy-intensive firms from electricity tax was granted legal state aid, with support from the community guidelines on state aid for environmental protection (EC, 2001) and the EU ETD (EC, 2003, Art 17(2)):

> "…Member States may apply a level of taxation down to zero to energy products and electricity as defined in Article 2, when used by energy-intensive businesses…"

The outline of PFE, its timeframe and mix of instruments and obligations is specified by legislation (SFS 2004:1196). The five-year programme period is divided so that during their first two years, firms must:

- Conduct an energy audit and analysis at their production site(s) to identify energy saving potentials in a short- and long-term perspective.
- Identify profitable electricity saving actions to be implemented and reported.
- Implement and certify a standardized EnMS via a third party certification company (Paper III and Paper IV).[11]
- Implement procedures for energy-efficient project planning and procurement. The procedures require life cycle cost accounting to form the basis for investment decisions and procurement of high-consumption electrical equipment.

After the first two years, firms have to report their intermediate results to the SEA. A list of identified and planned electricity saving actions must be submitted and those with payback periods of less than three years must be implemented. In the remaining three years, the firms must:

[11] Initially the EnMS followed the national standard developed by the Swedish Standards Institute. As international standards were developed the EnMS had to conform to EN 16001 and ISO 50001.

- Implement the planned and reported electricity saving actions.
- Continuously improve energy performance under the EnMS.
- Continuously apply the procedures for energy-efficient project planning and procurement.

After the fifth year, in a final report to the SEA, firms have to prove by documentation their fulfilment of obligations and overall programme compliance. While the electricity savings actions are mandatory to implement and report due to the electricity tax exemption, heat and fuel savings are implemented and reported on a voluntary basis.

There is no explicit target or quantified level of electricity savings or EEI to be achieved by the firms. However, the condition that granted PFE the status of legal state aid is formulated by the ETD as (EC, 2003, Art 17(4)):

> "…agreements, tradable permit schemes or equivalent arrangements must lead to the achievement of environmental objectives or increased energy efficiency, broadly equivalent to what would have been achieved if the standard Community minimum rates had been observed."

Thus, each firm must achieve an electricity efficiency improvement equivalent to the improvement that would have been achieved had the minimum electricity tax been imposed instead of PFE (SFS 2004:1196). Programme goals and targets need to be properly understood in order to assess overall programme effectiveness, i.e. goal and target achievement. Thus, Paper I includes an analysis of the goal and target level and provides a practical interpretation of this contra-factual condition.

In 2009, following the success of the first PFE period, a second programme period started. As this second programme period is still ongoing, *ex post* evaluation is not possible. However, an *ex ante* assessment of deemed electricity savings have been communicated and indicates continued good programme results (SEA, 2013; Paper II; Paper IV). Nevertheless, PFE will be terminated by 2014 when all firms in the second programme period have submitted their final report. Following the revisions of the community guidelines on state aid for environmental protection the exemption from the EU minimum tax level is no longer applicable (EC, 2008).

Box 1. Voluntary Agreements for industrial EEI and GHG emissions reductions

The Swedish PFE belongs to a category of policy programmes known as Voluntary Agreements (VA), or sometimes Long-term Agreements (LTA). This policy concept has evolved and spread over the last two decades to stimulate industrial sector EEI and GHG emissions reductions, while supporting firms' competitiveness. Some early examples of VAs were initiated in the 1990s in the Netherlands, Denmark, France, Germany and Sweden (Krarup and Ramsohl, 1999). Pioneering VAs have in some cases been modified and extended in scope, and other countries have also launched programmes (Rezessy and Bertoldi, 2011; Tanaka, 2011; Price, 2005).

The basic idea is that a public sector agency and industry (i.e. individual firms or associations) negotiate and agree on an approach to industrial energy efficiency that may cover instruments and obligations such as: formulation of energy savings or GHG emissions reduction targets, energy audits and energy management, implementation of concrete EEI actions, monitoring and reporting practices etc. VAs may have different characteristics but features they share are the self-selection mechanism for firm participation and the use of informative instruments to bring about attention-raising effects and norm changes towards a higher priority for EEI, which may involve both management and technical staff. To safeguard competitiveness, economic incentives – tax rebates, free or subsidized energy audits, investment support – are often used as motivation and compensation for the administration costs imposed by the VA. Once signatories join a VA, they are usually bound by its obligations over a programme period of 5–10 years or until a second period is launched. Withdrawal of participation or repayment of any tax rebates are sometimes applied in cases of non-compliance (Price, 2005).

The experiences with regard to VA results and programme effectiveness are mixed. In a recent survey, a large majority of national experts found VAs to be "partly or very effective" in Sweden, the Netherlands and Denmark, while half of national experts in Austria and Spain found VAs to be "not effective at all" (Egger, 2012, 89). However, evaluations are sometimes inadequate and issues concerning additionality, i.e. net program impact, tend to be neglected by administration agencies. Thus, perceptions about programme success or failure are sometimes not well-founded. Due to vested interests of government and industry, it is advisable to critically review several sources and their underlying evaluation methodology to better grasp the results of any specific VA. Reviews and international comparisons of VAs for industrial EEI, though valuable as overviews, may miss important details and include errors about national programmes.

3.1.2 Industrial energy management systems

PFE directly stimulates the implementation and certification of industrial EnMS. Similar to other standardized management systems (e.g. for environment, quality and safety) an EnMS is based on the Plan–Do–Check–Act approach, which intends to facilitate continuous improvement in energy performance by incorporating energy management into the regular procedures of the organization (ISO, 2011). Paper III evaluates how EnMS was structured and put into practice in the Swedish pulp and paper industry.

The adoption of EnMS as a means for industrial EEI is supported by previous research. Surveys of barriers and driving forces in Swedish energy-intensive industry have found that after energy cost reductions, the most important drivers for EEI are the existence of "people with real ambitions" and a "long-term energy strategy" (Thollander and Ottosson, 2008; Rohdin et al., 2007). These two aspects are important elements of an EnMS. Staff at various levels in the organization should be appointed roles and responsibilities and be given the necessary resources and recognition to achieve targets and objectives of the EnMS. On the basis of the firm's energy policy and the regular review of its activities, the firm should also conduct energy planning to continually improve its energy performance (ISO, 2011).

EnMS can be regarded as a comprehensive tool for establishing EEI as a strategic issue. According to Cooremans (2012), the categorization of investments will strongly influence the firm's selection of investments. When an investment is of a strategic character and perceived to be important for the core business of the firm, it will be easier to raise investment capital. For this reason, it is essential that EEI becomes a strategic issue in organizations (Ibid). Via well-coordinated EnMS activities, both top management and process engineers are expected to embrace EEI. Organizational changes like the establishment of cross-functional EnMS teams and improved forms for communication can address and potentially overcome many of the barriers to energy efficiency (see section 2.3.2; Paper III). Profitable energy efficiency investments can thereby be realized and improve the competitiveness of the firm.

Stimulation and EnMS uptake

The stimulation of industrial EnMS via PFE in Sweden conforms to a larger trend of government support for EnMS observed over the last decade (Paper IV; Reinaud et al., 2012; Kahlenborn et al., 2010). As national and subsequently international EnMS standards (e.g. EN 16001 and ISO 50001) have been developed, many national VAs and similar industrial energy efficiency programmes have started to centre on EnMS as a core requirement. As one out of 25 energy efficiency policy recommendations, the IEA also advises national governments to require energy-intensive industries, and stimulate other industrial energy end-users, to implement EnMS according to ISO 50001 or equivalent standard (IEA, 2011b). As shown in Figure 7, there can be many ways to integrate EnMS into a policy framework to facilitate uptake and create linkages to other instruments for industrial EEI or CO_2 emissions reductions.

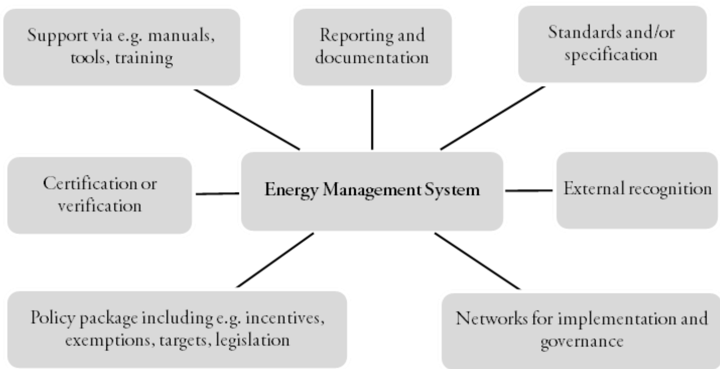

Figure 7. A programme approach centred on EnMS with linkages to other instruments for stimulation of industrial EEI and CO_2 emissions reductions. Source: Based on Reinaud et al. (2012)

Since the ISO 50001 standard was published in June 2011, it has been implemented by an increasing number of firms. It is estimated that the world-wide number of certified sites was: 900 in October 2012, 2600 in April 2013, and 4000 in October 2013 (Peglau, 2013). These numbers include all types of businesses, but there is a large representation of manufacturing firms.

The records also show that the EU has taken the lead, with more than 80% of the world-wide number of certified sites. Figure 8 shows the uptake in those five EU countries that currently have more than 100 certified sites. Germany is in undisputed lead with 2200 certified sites, followed by a group of countries including the UK, Sweden, Spain and Italy. By different means all these countries have stimulated EnMS implementation. The German success can be explained by the strong incentives provided for certification; from 2013 forwards large manufacturing firms are granted substantial energy tax exemptions, which are conditional on having certified EnMS in place (Küchler and Ruhbaum, 2012).

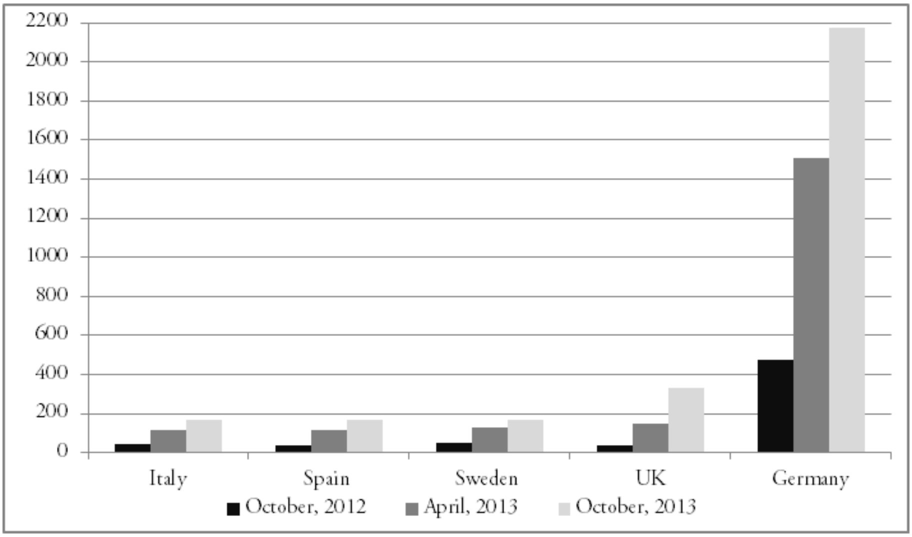

Figure 8. Number of ISO 50001 certifications in five EU MS with more than 100 certified sites. Data source: Peglau (2013)

Although it seems rational for the manufacturing industry to implement formal EnMS without any form of external influence, it appears to have little interest in doing so. This is evidenced by the rather low uptake in countries where there is no, or only weak, government stimulation. For instance in the USA, despite the existence of a national EnMS standard since the year 2000, it has been estimated that less than 5% of industrial energy use is covered by standardized energy management practices (McKane et al., 2009). In 2011, the pilot programme Superior Energy Performance was launched to promote ISO 50001. Records show that there are currently 45 sites certified with ISO 50001 in the USA (Peglau, 2013). Another example is the Netherlands. Since the early 1990s, the Dutch manufacturing industry has been engaged in a series of LTAs for EEI, which encourage energy management practices without specific requirements on certification. Records show that there are currently 24 sites certified with ISO 50001 in the Netherlands (Peglau, 2013).

The reluctance of firms to spontaneously certify a standardized EnMS may have several explanations. First and foremost, full-scale implementation and certification is associated with administrative costs, which firms are unwilling to accept without some compensation. It could also be the case that firms are fully content with their non-certified and non-formalized energy management practices. However, for government agencies the stimulation of EnMS can be an incentive to overcome firm-government information asymmetries and better align private and public interests with regard to energy performance. Third party certification of a firm's EnMS provides a stamp of approval. Linked with other instruments, government agencies can support industrial competitiveness and impose additional requirements on firms (Figure 7). For instance, firms can be required to report their actions to allow agencies to better monitor and evaluate the effects of policies. Issues on stimulation and evaluation of industrial EnMS are further discussed in Paper IV.

3.1.3 EU emissions trading system

The EU emissions trading system (EU ETS) has been presented as Europe's flagship policy to tackle climate change (Hedegaard, 2011). It should contribute to the achievement of EU's GHG emissions reduction targets in short- and long-term: the Kyoto target for EU-15, the 20% reduction target by 2020, and the 80–95% reduction objective by 2050 (EC, 2010; EC, 2011a). Since the introduction in 2005, the system has expanded to cover almost half of the annual GHG emissions in EU-28, Norway, Iceland and Lichtenstein. Participation is mandatory for high-emitting sectors such as power and heat producers, energy-intensive manufacturing industries and more recently also commercial airlines.

The EU ETS policy theory is constituted by the market-based cap-and-trade principle. Without delving on this principle, a cap of allocated emission allowances should set a limit for the total amount of GHG emissions that can be emitted by installations covered by the system (i.e. the trading sector).

Under the cap, installations can buy and sell allowances as required to make sure they have enough allowances to cover their emissions by the end of each year. The intention is that the cap should create a scarcity of allowances in the market, put some installations in short positions and force them to engage in either trading or mitigation, thereby generating cost-effective GHG emissions reductions (e.g. by means of EEI actions, fuel shifts or long-term innovative low-carbon solutions). To allow for policy revisions, EU ETS has been set up in separate trading periods: the first 'trial period' (2005–2007), the second 'Kyoto commitment period' (2008–2012) and the ongoing third period (2013–2020). By 2020, due to an annually decreasing cap, the emissions from fixed installations is intended to be 21% lower than in 2005 (EC, 2009a).

Due to the political ambitions linked with the EU ETS and its many complexities, it has been subject to a large number of studies, scrutiny and criticism. Some have called the implementation a remarkable achievement given its scope, timing and novelty (Ellerman et al., 2007). Literature covering the first period has estimated that EU ETS led to annual emissions reductions equal to 2–5% of the capped emission (Ellerman and Buchner, 2008; Anderson and Di Maria, 2011). In the second period, the economic recession has made it difficult to quantify eventual abatement and only few such attempts have been made (see Laing et al., 2013). The criticism has increased over the first and second period due to unresolved issues related to the grandfathering of allowances including the generous levels of free allocations to domestic manufacturing industry and the negative redistributive effects between power producers and consumers of electricity (Cló, 2010). In brief, the EU ETS has managed to impose a cap but due to several reasons the price of emission allowances has been volatile and far below the expected levels (i.e. currently below 5 Euro). Thus, the system has not managed to establish a long-term stabile and stringent price signal, which is deemed necessary to stimulate investments in innovative low-carbon technologies in the trading sector.

There have not been many studies on how EU ETS influences firms on the ground in terms of their interests, beliefs, norms, strategies, long-term innovation plans and deployment of low-carbon solutions (Skjaerseth and Eikeland, 2013). In this thesis, Paper V complements previous evaluations and analyses of EU ETS by focusing on corporate responses in the European pulp a paper industry. In particular, our study examined to what extent and how the EU ETS has influenced the corporate climate strategies of the two pulp and paper companies SCA and Norske Skog. According to our view, a corporate climate strategy is composed by: the recognition of the climate change problem; the acceptance and manifestation of responsibility for mitigation, through target-setting and related monitoring practices; and the implementation of technical and organizational actions for target achievement. Interviews with management representatives were conducted to understand the features of the companies' climate strategies and the influence of EU ETS was analysed from different perspectives (see Paper V).

Following the revised ETS directive a number of changes were introduced for the third period of EU ETS (EC, 2009a). Of particular relevance for the manufacturing industry, the rules for free allocation of emission allowances were changed from a decentralized approach based on past emissions that often created domestic over-allocations in previous periods. In the third period, the free allocation is based on past production volumes and EU harmonized performance benchmarks with the general aim to allocate less allowances than needed and put most firms in a short position. Few studies have been published about this revision of allocation rules, but one example is Lecourt et al. (2013). In Paper VI the focus was on analysing expected outcomes of the new allocation rules as applied to key sectors of the energy-intensive manufacturing industry. In particular, the study covered an assessment and comparison of outcomes in the cement industry (CEI) and the pulp and paper industry (PPI) located in the UK, Sweden and France.

3.2 Policy evaluation

Evaluation researchers have portrayed evaluation as a "megatrend" that sweeps over practically all fields of public sector administration. The boost in evaluation activity observed over the last two decades has been given several explanations (Vedung, 2010). Firstly, there is an underlying belief that the public sector can and should become more rational and evidence-based in its administration and execution of policy. Secondly, public sector bodies need to demonstrate effectiveness in goal fulfilment in order to legitimize their function and receive continued funding (Ibid). Finally, in a European perspective, the EU has taken a lead role as legislator, promoter and funder of policies. This requires EU MS to monitor and demonstrate compliance in the pursuit of establishing a harmonized market with EU-wide objectives. This applies not least to the area of climate and energy policy (EC, 2010). This section includes: an introduction to evaluation research, some observations of the characteristics of the evaluation trend in the area of energy efficiency policy and descriptions of evaluation methods applied in this thesis.

3.2.1 Evaluation as a theoretical framework

According to Vedung and Dahlberg (2013), evaluation can be defined as:

> "A careful ex-post examination and judgment of public interventions with regard to aspects such as results, end performances, administration, content and organization, which are considered to be important in a review" (Vedung and Dahlberg, 2013, 69, my translation)

The term *ex post* should be understood as retrospective evaluation when implemented public interventions are either ongoing or terminated. Thus, assessments that are made in advance, *ex ante*, of a proposed or adopted public intervention do not qualify as evaluation according to this definition. Public interventions can include all kinds of measures, programmes, policies, reforms etc. with the purpose of influencing social change in the public sector itself or in other sectors on the request of a public sector body. In this thesis, public policy programmes and instruments that target private firms were the focus of the evaluation. Thus, a suitable designation is the term "programme evaluation", which has been described as:

> "the use of social research methods to systematically investigate the effectiveness of social intervention programs in ways that are adapted to their political and organizational environments and are designed to inform social action in ways that improve social conditions." (Rossi et al., 2004, 29)

The systematic investigation here refers to the procedure of assessing a policy programme by separating its components, carefully examining these, interpreting them and communicating the results of the programme in relation to relevant benchmarks (e.g. programme targets, programme theory, autonomous trends, similar programmes or contra-factual scenarios). Programme evaluations can be funded and executed for many reasons, but two key functions are the summative and the formative (Weiss, 1998, 31ff). The summative evaluation, also referred to as an impact evaluation, serves to document and measure the impacts achieved in order to gain knowledge of the programme results and inform decisions on whether to continue, modify or terminate the programme. The purpose of the formative evaluation, also referred to as a process evaluation, is to understand why an impact occurred, or not, and to identify possibilities to improve the programme operation and effectiveness (Ibid).

Process and impact evaluations are preferably combined in a comprehensive evaluation study (Rossi et al., 2004, 58). One such approach is Theory-Based Evaluation (TBE) (Weiss, 1997), which guided the evaluations of PFE and its main instruments in this thesis (Paper I, Paper III, Paper IV). A similar process-orientated method is Intervention Theory Evaluation (Vedung and Dahlberg, 2013). Another designation, based on similar principles, is the programme theory approach to evaluation (Rossi et al., 2004, 139ff). The common thread is the meaning of "theory", which can be seen as the basis for how programme activities are expected to bring about desired changes. According to Weiss, programme theory should be understood as *"the set of beliefs and assumptions that undergird program activities"* (Weiss, 1997, 503). The challenge for the evaluator is that the programme theory is seldom explicit. Thus the evaluator has to reveal an implicit programme theory, or as Weiss chooses to put it: *"the evaluator has to discover the reality of the program rather than its illusion"* (Weiss, 1998, 49).

Today's evaluation practices have emerged from half a century of developments with linkages to contemporary ideologies and governance ideals. Vedung (2010) uses the metaphor of waves to explain how four waves have rolled in and deposited layers of sediment that have shaped the thinking and practices of evaluation:

- The *scientific wave* entered the stage in the 1950s. With rational scientific methods, such as randomized control group experimentation, academic researchers were to define the policies needed to reach the goals set by government decision makers. On this basis public agencies were to implement in full scale the most effective policies. Less emphasis was put on post-implementation processes.

- The *dialogue-orientated wave* prevailed in the 1970s as faith in scientific rational evaluation was battered. It was argued that evaluation should be participatory by involving concerns of relevant stakeholders such as target groups, operators, managers etc.
- The *neo-liberal wave* in the 1980s brought about a market orientation for evaluation, as ideas of New Public Management pushed for public sector reformation and privatisations. Evaluation became focused on customers, rather than stakeholders, as the users of public-private services. Accountability assessments became means for evaluating effectiveness and cost efficiency of delivered results.
- The *evidence-based wave* from around 1995 forward can be interpreted as a revival of the scientific rational ideals. Its proponents argue that a meta-analysis can be conducted to review and give weight to evidences from separate evaluation studies. Underlying studies are ranked according to their ability to provide high quality evidence, with a preference for experimental studies.

Thus, in the evolution of evaluation practices there have been shifts between scientific and more pragmatic evaluation postures. Rossi et al. (2004, 23f) summarize the divergent views represented by Campbell (1969) and Cronbach (1982). The former argues that policy decisions should be developed from persistent social experimentation that tests ways to improve social conditions, and that methodologies of social science make it feasible to extend the experimental model to evaluation research to create an experimenting society. Campbell clearly "surfs the scientific wave" described by Vedung (2010). Cronbach agrees that scientific studies and evaluation may use some of the same research procedures. However, he argues that there is an important difference in terms of purpose. While scientific studies strive to meet up with highest research standards, evaluation should be dedicated to providing the most useful information that the political circumstances, the programme constraints and available resources allow.

The focus on programme theory in TBE and similar approaches is important in this regard. By carefully outlining how a programme is intended to work, the programme theory also provides a benchmark for judging whether a programme has achieved its objectives. A number of analytical tools that are found fit for purpose, not necessarily randomized control group experimenting, can be used to evaluate how the intended effects were achieved and to attribute such changes to the programme.

3.2.2 Evaluation of energy efficiency policy in EU

The megatrend of evaluation is discernible also in the policy field of EEI. Over the last decade, the EU has advanced its position and launched several pieces of legislation that require increased activity by MS in terms of target setting, policy implementations, monitoring, verification, evaluation and reporting of energy efficiency policy measures. This can be observed for example in the Energy Service Directive (ESD) (EC, 2006), the climate and energy package of the Europe 2020 strategy (EC, 2010), and more recently the Energy Efficiency Directive (EED) (EC, 2012). In both the previous ESD and the present EED frameworks, the importance assigned to monitoring and evaluation at EU level trickles down and become MS issues via National Energy Efficiency Action Plans (NEEAPs). In their NEEAPs, MS have to report all significant EEI policies as well as expected and achieved energy savings (EC, 2012, Art 24).

However, although energy efficiency is often stated as a high priority, there remains a large gap between the rhetoric, including set targets, and the practice in terms of policy implementation and evaluation against set targets. In its assessment of the first round of NEEAPs under the ESD, the European Commission (EC) concluded that the quality was disappointing, leaving large potential untapped (EC, 2009b). Another assessment shows that the subject of monitoring and evaluation is largely overlooked, as many NEEAPs lack adequate information about the planned evaluation process for implemented or proposed EEI polices (Schüle et al., 2009, 36). With regard to EU's non-binding target of 20% primary energy savings by 2020, another assessment shows that the policy impact needs to be tripled to meet the target (Wesselink et al., 2010, 43). In the interface between the EU and its MS, there are several issues related to EEI policy evaluation that can be elaborated further.

Assessments rather than evaluations

The current situation on EU and MS level is foremost characterized by assessments and pledges about deemed future energy savings against set policy targets. Although there are large variations between MS in levels of ambition for energy efficiency policy (Egger, 2012, 6), less effort is generally put into *ex post* evaluation of programme results and broader outcomes. In this regard, the energy efficiency policy field appears to lag behind the trend identified in other policy areas, which involves a shift in interest from *ex ante* analysis to more *ex post* evaluations (Vedung, 2010). One explanation can be found in the ever-changing EU energy efficiency policy frameworks. Implemented directives are sometimes replaced ahead of plan (e.g. ESD and CHP). New directives with revised targets, measures and timelines for implementation are in some cases introduced only after prolonged negotiations, which tend to water down original proposals (e.g. EED). Eventually, when directives are implemented by MS, the target year is only a few years ahead, which leaves a tight schedule for programme operation, monitoring and evaluation. By this time, decision makers tend to have shifted the focus from existing policy activities to more forward-looking proposals, new policy frameworks and target years (e.g. 2030 or 2050). Obviously, the situation as described does not provide proper incentives for agencies on MS level to systematically evaluate EEI policies.

Accumulation of evaluation methodologies but limited uptake

In the last decade or so, there have been numerous efforts to develop and disseminate harmonized calculation and evaluation methods in the EU. Some examples of projects, partly funded by the EC through the Intelligent Energy Europe programme, include:

- The SAVE project phases I and II (1997–2001) provided a European guidebook for *ex post* evaluation of demand-side management and energy efficiency service programmes. The general guidelines were also tested for a number of programmes (SRCI, 2001).
- The Active Implementation of the proposed Directive on Energy Efficiency (AID-EE) project (2005–2007) aimed to contribute to further development and harmonization of *ex post* policy evaluation

methods and create comparable evaluation outcomes on the basis of a theory-based evaluation approach (Khan et al., 2007).

- The EMEEES project (2006–2009) had the specific objective to assist the EC in developing harmonized methods to evaluate the measures implemented to achieve the 9% energy savings target set out in the ESD (Thomas, 2009).
- The ODYSSEE and MURE projects comprise two databases with sector-level data on energy consumption drivers, energy efficiency and CO_2 emission indicators, as well as policy measures across EU MS (ODYSSEE, 2013; MURE II, 2013).

Other initiatives and efforts to develop international standard practices for Measurement and Verification (M&V) of energy efficiency projects include:

- The Efficiency Valuation Organization (EVO), an organization with support from a number of stakeholders internationally. Via the International Performance Measurement and Verification Protocol (IPMVP) and training sessions, EVO provides guidance on practices in M&V and reporting of savings from EEI actions (EVO, 2012).
- In 2012, the European Committee for Standardization published a standard for energy efficiency and savings calculations, based on top-down and bottom-up methods, to provide a general approach for such calculations applicable to industrial processes, buildings, appliances etc.

Given these examples of efforts to advance M&V practices and EEI policy evaluation, the available knowledge and number of guidelines has certainly accumulated. The obstacle to EEI policy evaluation so far appears to be limited uptake. MS and concerned agencies may lack clear mandates or otherwise have limited capacity to absorb and practically apply available methodologies and practices. For instance, it has been reported that public agencies lack staff in the energy efficiency field, which impacts on national implementation of EU directives and especially the monitoring of compliance (Egger, 2012, 8).

Policies guided by multiple but vague objectives

Another issue has to do with policy design and formulation. Energy efficiency policies often lack quantitative targets and clear timeframes, while they often have multiple but vaguely expressed objectives (Harmelink et al., 2008). For instance, industrial energy efficiency policies can have implicit objectives to boost the economy, protect domestic industry and increase industrial competitiveness. This could imply a low priority for careful monitoring and evaluation of programme results in terms of actual energy savings, which could prove to be disappointing. If so, industrial energy efficiency polices are not exposed to the same political pressure to deliver results that applies to social programmes in other policy areas. An option would be to express all related objectives in a policy evaluation plan including targets on EEI as well as other intended outcomes (e.g. increased competitiveness). Evaluators could then proceed to identify potential performance indicators and evaluate policies accordingly.

With regard to the energy-intensive manufacturing industry, there appears to be low interest for *ex post* evaluation of EEI policies. The EU ETS is promoted as the flagship policy and interactions from alternative policies is often discouraged based on worries that it may undermine the carbon price signal. Complementary EEI policies are nevertheless implemented in the energy-intensive industry (MURE II, 2013). Thus, evaluation has importance due to possible interaction with EU ETS and also the often high energy cost shares in these industrial sub-sectors, which by itself could motivate EEI. The EU state aid rules and possible exemptions that can enable MS to grant legal state aid on certain conditions add another dimension that could require MS to improve evaluation practices.

3.2.3 Bottom-up impact evaluation

Industrial EEI can occur on many levels, e.g. equipment level (e.g. a motor), process level (e.g. pumping), industrial plant level (e.g. a pulp mill) or across an industrial sub-sector (e.g. the pulp and paper industry). Industrial EEI can also arise in the interaction between production processes (e.g. pumping and heat exchange) (Hardell and Fors, 2005). Thus, when it comes to evaluating industrial EEI policies, various actors (e.g. equipment suppliers, site-level process engineers, energy managers, public agencies, researchers, consultants etc.) may be involved in different steps of monitoring and evaluation of programme impact (i.e. the quantified energy savings). A challenge in monitoring and evaluation is that energy savings cannot be directly measured. What can be measured is the energy use over specified periods of time. Energy savings, i.e. the avoided energy use, have to be estimated by the use of baselines. For instance, energy savings can be estimated as the difference between the baseline energy use before and the actual energy use after the implementation of an EEI action. The baseline energy use for comparison should preferably be adjusted to account for changing conditions (e.g. increased production output) (EVO, 2012, 7).

In a bottom-up impact evaluation of industrial energy efficiency programmes, the data acquisition starts at the micro-level of specific EEI actions implemented by firms targeted by a programme. The energy savings are thereafter aggregated across all EEI actions in order to estimate the total savings (i.e. gross energy savings). If deemed necessary, gross-to-net corrections are made to account for other factors that could influence the actual level of energy savings from the programme (i.e. net energy savings). The EMEEES project developed a general bottom-up methodology and a number of case-specific methods with the intention of guiding agencies in their evaluation of policies and measures to achieve the ESD target (Vreuls et al., 2009). However, the methodology has a general applicability and in this thesis it provided guidance for the impact evaluation of PFE (Paper I; Nilsson and Stenqvist, 2009). Box 2 explains the four basic steps involved with an explanatory example of a rebate programme for industrial motor replacement (see also Almeida et al., 2009).

Box 2. General bottom-up impact method for EEI policy evaluation

EEI policy case example: A rebate programme to stimulate industrial electricity end-users to install Super Premium Efficiency motors in the event of motor replacement.

Step 1: Unitary gross annual energy savings

Unitary gross annual energy savings = Annual energy savings due to one motor replacement

Example: How much electricity is saved annually by the replacement of one electric motor, e.g. going from a Standard Efficiency to Super Premium Efficiency motor class?

Data requirements: The firm determines unitary gross annual electricity savings on the basis of engineering estimates or case-specific metering under normalized conditions. Input data may involve: energy efficiency ratings and mechanical power of motors, operation hours and load factors.

Step 2: Gross annual energy savings

Gross annual energy savings = ∑ Unitary gross annual energy savings

Example: Summing up the electricity savings from all individual motor replacements made by all firms targeted by the rebate programme.

Data requirements: The rebate programme's administration agency provides a template for firms to report their unitary gross annual energy savings and then aggregates the results.

Step 3: Estimate gross-to-net correction factors to calculate net annual energy savings

Net annual energy savings = Gross annual energy savings x (1 - Free-rider coefficient + Multiplier coefficient) x Double-counting factor

Example: Free-rider coefficient: The share of the targeted firm's electricity savings due to motor replacements that would have occurred even without the rebate programme [0, 1]. Multiplier coefficient: The indirect "spill-over" electricity savings due to motor replacements made by non-targeted firms [≥0]. Double-counting factor: Treats the potential overlap from other policies targeting the same firms and EEI action [0, 1].

Data requirements: The administration agency estimates the size of correction factors that influence actual energy savings of the rebate programme and calculates the net annual energy savings. Surveys of firms, analysis of motor sales data, cross-checking with other EEI policies etc. can form the basis for such estimates.

Step 4: Determine energy savings lifetime to calculate period-wise net energy savings

Period-wise net energy savings = Total net annual energy savings x years of relevant period

Example: If the rebate programme's electricity savings are to be counted over a certain programme period, or towards an energy saving target, the lifetime, retention and performance degradation of electricity savings should be monitored and determined.

Data requirements: The administration agency decides the period or lifetime to calculate the energy savings. Case-specific operation tests, surveys of firms, laboratory tests by motor suppliers or default values can form the basis for decision.

3.2.4 Top-down evaluation

A top-down approach to evaluate industrial EEI is performed with statistical records, aggregated at some level of economic activity. Records can be in the form of energy efficiency indicators that express specific energy consumption (SEC) on a physical basis (e.g. GJ per unit of production) or in the form of energy intensity values that express energy use on a monetary basis (e.g. GJ per industrial value added). Examples of the latter is given by the oil and electricity use intensity trends in sub-sectors of the Swedish manufacturing industry 1970–2010 (see Figure 5 and 6 in section 2.4.3). The former can be exemplified by the ODYSSEE project, which gathers top-down physical indicators for benchmarking of energy efficiency levels and trends in the EU and for industrial sub-sectors such as cement, steel and paper industry (Lapillonne et al., 2012). In both these cases, analysis is performed on the basis of aggregated data; illustrated in Figure 9 by the upper half in the pyramid of energy efficiency indicators or energy intensity values. Although useful for demonstrating larger-scale industrial energy consumption and intensity trends an analysis based on aggregated data will disguise changes that occur within sub-sectors (i.e. at industrial plant, process- or product-level), and thus provide a coarse approximation of the actual industrial EEI.

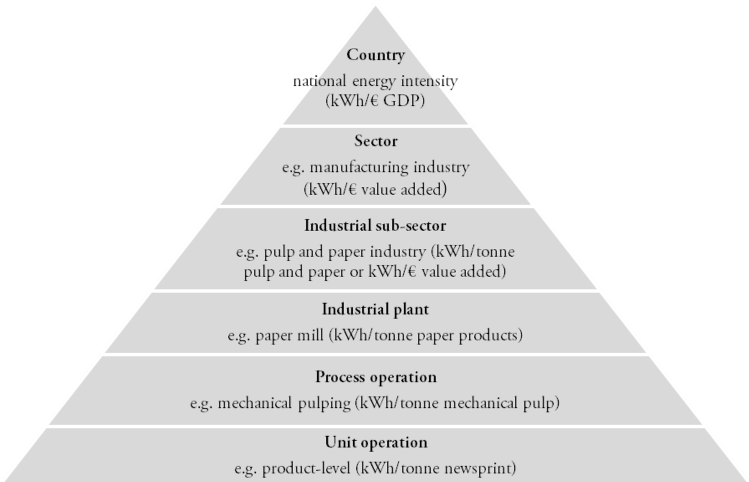

Figure 9. Pyramid of energy efficiency indicator and energy intensity values, with examples from pulp and paper industry. Source: Adapted from Phylipsen et al. (1998)

However, in an analysis based on disaggregated physical product-level data, as illustrated in the base of the pyramid, the changing energy use at sub-sector level can be explained by changes in any of the three factors (Phylipsen et al., 1998):

- Activity: the level and change in the aggregated production volume.
- Structure: the level and change in the composition of produced goods, i.e. the product mix.
- Intensity: the level and change in the specific energy consumption (SEC) of production, i.e. a close approximation of the actual EEI.

In Paper II, a top-down decomposition approach was used to disentangle the influence from these three factors on the aggregated energy trends of the Swedish PPI in 1984–2011. On the basis of a disaggregated data set, covering 27 pulp and paper product categories it was possible to estimate how production volumes, structural changes and EEI – with regard to electricity use, fuel use and primary energy use – have contributed to the changing energy use of the Swedish PPI.

In addition, plant level data on physical production, final energy use, electricity use and CO_2 emissions were compiled in an attempt to monitor the energy performance of firms with certified EnMS (Paper III and Paper IV).

3.2.5 A theory-based evaluation approach for PFE

According to basic categorizations, policy instruments are divided into e.g. informative instruments, economic instruments and regulations. However, as exemplified by PFE and other VAs (see Box 1) some EEI programmes do not fit into this simplified policy instrument archetype. Instead, programmes such as PFE should be regarded as policy packages including a larger set of instruments (e.g. legal requirements, tax rebate, EnMS, energy audits, procedures, supporting tools, networks etc.), which can be expected to interact at a higher level of complexity and potentially enhance or negatively counteract each other's function. The package of instruments makes evaluation challenging, as it is difficult to isolate the main drivers for change and to determine what this change consists of. This raises the question, for instance, of whether change should be judged as energy savings from tangible EEI actions, or as the value of organizational measures that could facilitate EEI in the long run. Similarly, it is difficult to identify programme components that fail to generate change, due to these being unnecessary or deceptive. In order to evaluate a programme package, a systematic approach such as the TBE is deemed useful.

As discussed in section 3.2.1, the TBE approach has advantages over a pure impact evaluation in that it can show not only how much change has occurred, but also if sequences in the programme implementation process appear as expected. If posited cause-effect relations for desired results break down along the way, the evaluation can tell at what point that breakdown occurred. In the AID-EE project, guidelines were developed to support evaluation of EEI polices based on these principles. The guidelines suggest that evaluators follow a six-step pathway (Khan et al., 2007):

- Make an initial characterization of the programme
- Draw up a programme theory
- Translate the programme theory to concrete indicators and identify success and failure factors
- Draw up a flow-chart of the programme theory
- Collect information to verify and adjust the programme theory
- Collect additional information and analyse all aspects of the programme theory (including target achievement, net impact and cost effectiveness).

These guidelines along with literature on evaluation research supported our evaluations of PFE and the EnMS as one of its main instruments (Paper I, Paper III, Paper IV). For example, the emphasis on the underlying programme theory contributed to a deeper understanding of the programme and its instruments. As a result, it was not deemed necessary, or feasible, to conduct a complete evaluation, covering all instruments of PFE. As Weiss (1972) has stated, an all-purpose evaluation is a myth. In addition, some monitoring and evaluation studies of certain programme aspects had already been conducted on behalf of the SEA and these provided usable knowledge (e.g. Hardell and

Fors, 2009; Franck and Nyström, 2008; Hörnsten and Selberg, 2007; Sjögren et al., 2007). Box 3 illustrates the applicability of the TBE and the AID-EE guidelines and presents a flow-chart of the PFE programme theory including:

- Cause and effect relations: the main components (causes) of the programme implementation phase from which to expect certain effects (impacts and outcomes). The flow-chart also depicts steps in the policy phase model in order to show the background that led to PFE.
- Indicators: quantitative or qualitative measures to estimate to what extent the intended effects have occurred.
- Success and failure factors: plausible and subsequently empirically tested factors that explain the success or failure of the policy implementation process.
- Interactions with other instruments: complementing policies and market mechanisms that influence the same target group of industrial sub-sectors and firms. Such interactions can enhance or counteract certain steps in the implementation process.

Box 3. PFE programme theory

Interactions with other instruments	Cause and effect relations	Indicators	Success and failure factors
Policy problem	EU ETD: enforce minimum tax of € 0.5/MWh		
Policy alternative	Ds 2003:51: proposal and decision support for PFE		
Policy recommendation	Prop. 2003/04:170: government bill for PFE		
Policy decision	SFS 2004:1196: legislation introduces PFE		
Potential policies EU ETS Environmental Code Renewable. elec. cert. EU Ecodesign **Potential mechanisms** Electricity prices Business cycles	Swedish Energy Agency is appointed administration agency		
Policy implementation	1. Information campaign	Awareness of PFE among eligible firms	Relevance of information and outreach activity
	2. Participant firm admission	No. of participating firms; TWh of electricity use in firms	Size of economic incentive; estimated administration cost for compliance
	3. Energy audit and energy analysis	Conducted audits; size and profitability of identified saving potentials	Awareness of energy aspects; audit quality; payback requirement; priorities
	4. Introduction and certification of EnMS	No. of certified firms; staff involvement; energy policy	Allocation of resources; previous experience of management systems
	5. Adoption of procedures for energy-efficient procurement and planning	Existence and widespread use of procedures	Pay-back requirement; life cycle cost optimization versus other priorities
Policy assessment and feedback	6. Intermediate second year report	Reported deemed savings (in TWh and %) from all EEI actions	Goal achievement; withholding of relevant information
	7. Implementation of all types of EEI actions	Reporting and supervision	Available time, financial and human resources
Policy evaluation and feedback	8. Final fifth year report	Reported achieved savings (in TWh and %) from all EEI actions	Goal achievement; withholding of relevant information

3.2.6 Interviews and dialogue-orientated evaluation

While bottom-up and top-down evaluation methods are foremost concerned with policy impacts, in terms of quantified EEI or energy savings, TBE widens the scope to consider also broader outcomes of the policy process with the programme theory as a benchmark for comparison. As illustrated in Box 3, the programme components may involve different types of responses within a target group of participating firms, e.g. organizational changes, staff involvement, learning processes etc. To identify such policy outcomes qualitative methods and participatory forms of evaluation were considered useful. Thus, an interview-based and dialogue-orientated approach have been used to gather the perspectives of different firms and other stakeholders, foremost in the studies concerning EnMS (Paper III, Paper IV) and the study on corporate responses to EU ETS (Paper V).

For these studies in particular, it was found important to involve the industrial firms, as the receivers of the programmes and instruments, in a dialogue to evaluate the success or failure of implementation. For instance, some programme components and obligations are stimulated with the main purpose that they should become valuable and usable as tools for the firms. Firms' perceptions about value and usability are clearly matters for subjective interpretation. As a guiding principle, an EnMS should be tailored to fit the purpose, situation and specific requirements of the individual firm. For instance, the energy policy including its targets and objectives is decided internally to regard the most important energy aspects that are under the control of the firm (ISO, 2011).

In the case of EU ETS, one of its main purposes is that the carbon price signal should stimulate firms to search for innovative and long-term low-carbon solutions. This raises several questions. Firstly, how do firms perceive the carbon price tag? Secondly, is it integrated in their investment appraisals? Thirdly, what kind of low-carbon technologies and solutions are considered innovative from the perspective of firms in certain industrial sub-sectors? Finally, what are the time perspectives and planning horizons of energy-intensive firms, in terms of short- and long-term targets and abatement? Such considerations were captured in the analysis of corporate climate strategies in the PPI (Paper V).

Qualitative and semi-structured research interviews were conducted to understand the perspectives of firms and other programme stakeholders and to unfold the meaning of their experiences with the programmes (Kvale and Brinkmann, 2009). The interviews with representatives of the pulp and paper mills have been conducted during site visits including factory walkthroughs, which has contributed with additional insight through the dialogues that arose with different categories of staff (Paper III and Paper IV). Table 2 provides an overview of conducted interviews.

Table 2. Overview of qualitative research interviews.

Paper	**Informants**	**Interview situation**	**No. of interviews**
Paper III	EnMS coordinators, process engineers and staff in Swedish pulp and paper mills (8)	face-to-face interviews and site visits/factory walkthroughs. Duration: 1–3 h per occasion	8
Paper IV	EnMS coordinators, process engineers and staff in Swedish pulp and paper mills (8); certification company (1); PFE programme manager (1)	face-to-face interviews and site visits/factory walkthroughs. Duration: 1–3 h per occassion	10
Paper V	managers of corporate sustainability, energy and environemental affairs in two large pulp and paper companies (6); industry association (1); EU ETS policy experts (2)	face-to-face interviews, telephone interviews and communication via e-mail. Duration: 1 h per occassion	9

4 Results

4.1 Results and highlights of individual papers

4.1.1 Paper I

The process and bottom-up impact evaluation of the Swedish programme for improving energy efficiency in energy-intensive industries (PFE) showed that:

- Officially there is no quantified impact target. To evaluate programme effectiveness, we had to formulate a target level based on a hypothetical contra-factual situation.
- Large electricity savings have been reported. Estimates of gross annual impact (1450 GWh) and net annual impact (689–1015 GWh) clearly exceed the estimated annual impact of a minimum tax, which is 375 GWh according to our definition of the programme target.
- In addition to electricity savings PFE has had a multiplier effect of heat and fuel savings estimated at 950 GWh per year.
- Reported electricity savings have been cost-effective. Firms' average payback period is 1.5 years. The societal cost has been estimated to be 9.3–13.6 Euro per MWh of net electricity savings, which is substantially lower than the estimated cost for electricity production from new generation capacity.
- The small tax incentive matters. Almost 100% of eligible firms with electricity use exceeding 100 GWh per year joined PFE. Only 3% of eligible firms with electricity use below 100 GWh per year joined PFE.
- The most energy-intensive firms provide the bulk of total savings. However, they are less responsive to PFE in terms of their reported

percentage savings. For instance, average reported electricity savings are 3% in the pulp and paper industry compared with 5–7% in the food processing and the wood manufacturing industry.

- Less energy-intensive companies and SMEs can also gain from the attention-raising activities that are typical for PFE, such as energy audits, EnMS and energy efficient procedures.
- PFE has been an impetus for organizational changes that can have long-lasting effects in terms of industrial EEI.
- Reporting and documentation procedures, as well as a number of evaluation studies, have been important to legitimize PFE. However, PFE could be improved with an evaluation plan based on the programme theory, which defines a set of indicators for monitoring and evaluation. Such a plan should be developed already in the policy planning and formulation phase to ensure that relevant data are gathered over the programme period.

4.1.2 Paper II

This top-down decomposition study of trends in energy performance of the Swedish pulp and paper industry (PPI) showed that:

- Between 1984 and 2011, EEI led to the avoidance of: 26 PJ of final fuel use, 1.4 TWh of electricity use and 50 PJ of primary energy use (compared with an activity-based reference scenario).
- Structural changes had lesser impact on the PPI's energy use but the analysis demonstrated that production has become orientated towards more electricity-intensive and less fuel-intensive segments.
- Electricity EEI was negligible in the first half of the period but the analysis demonstrated electricity savings of almost 600 GWh in 2000–2007 and 2007–2011. It corresponds to 3% of annual average savings in relation to base-year electricity use in the respective periods.
- Final fuel use EEI was achieved in all periods but foremost in 2000–2007, which covered 11 PJ and almost half of all savings from final

fuel use EEI.

- Large fuel shift measures and absolute CO_2 emissions reductions occurred in the earlier period 1973–1984. Although the specific CO_2 emissions of the Swedish PPI decreased 1984–2000, absolute CO_2 emissions reductions were resumed only after 2003.
- The previous bottom-up evaluation results of the PFE impact (Paper I) and reported electricity savings of the PPI corresponded very well with the top-down results of electricity EEI. It provides evidence of the accuracy in firms' self-reported savings and the success of PFE.
- The results clearly demonstrated that the case for industrial EEI as well as CO_2 emissions reduction has been strengthened since 2000.

4.1.2 Paper III

This interview-based evaluation study of EnMS implementation in the Swedish pulp and paper industry (PPI) showed that:

- There is no standard way of implementation. The EnMS is tailored to fit the firm's cost structure, physical infrastructure, customer demands, previous experiences and perceptions about the future.
- All mills have an EnMS coordinator who is responsible (part-time) for communicating and coordinating the activities and chairing meetings with division-level staff.
- Between 2 and 5.5% of the entire staff at the mills are directly involved in the EnMS activities. Groups of mixed composition, including staff from different divisions and with particular expertise, meet regularly and form the core of activities.
- Advanced sub-metering is advantageous for monitoring and verification of EEI actions, not least for controlling certain energy aspects defined by the EnMS. For most mills such practices have improved since EnMS were introduced. A few mills lacked satisfactory infrastructure for sub-metering and internal cost allocation.

- In general, the training of staff has not been highly prioritized, which should be an area for improvement.
- The basic analysis of total and specific electricity consumption (SEC) against base-year provided little explanatory value in relation to reported electricity savings. Coherence was discerned in a few cases and otherwise not. Reduced activity in 2008–2009 has probably decreased capacity utilisation and influenced SECs upwards in some cases.

4.1.2 Paper IV

This other interview-based study of evaluation considerations for industrial EnMS showed that:

- If governments stimulate EnMS implementation by firms, the public goals should be defined, communicated and achieved. Hence, evaluation is needed.
- Potential indicators of improved energy performance should be defined by the firms and the administration agency and then monitored to ensure continuous improvement towards mutual objectives.
- Firms' objectives and targets include e.g.: reduced specific energy use, increased internal electricity production, reduced fossil fuel use and increased biofuel use. In some cases targets can be conflicting and some kind of prioritization is deemed useful to avoid sub-optimal outcomes.
- The basic analysis of potential energy performance indicators showed that specific total final energy use increased for a majority of mills, while specific final electricity use decreased for a majority of the mills. Specific CO_2 emissions were reduced substantially for all but on mill. Phase-out of fossil fuels, increased use of biofuels and increased electricity generation could probably explain these trends.
- Among EnMS activities the following were found to be the most important: energy audits and analysis, clear roles and responsibilities by the formation of EnMS teams, dissemination across the

organization and life cycle cost procedures.

- If economic incentives are provided for EnMS implementation, certification could be required in return. Competent external auditors that conduct yearly site visits to review EnMS compliance could fill a role in the administration agency's evaluation plan.
- Evaluators should consider how best to monitor and evaluate firms' organizational actions and changes. The documented activity of EnMS teams could reveal useful indicators for monitoring progress and real ambitions for improved energy performance.

4.1.5 Paper V

The evaluation study of EU ETS with regard to corporate responses and climate strategies in the pulp and paper industry showed that:

- Both companies studied, SCA and Norske Skog, accept the challenge of human-induced climate change and their participation in EU ETS. However, they are critical about specific issues (e.g. the influence on electricity prices and risk of carbon leakage).
- Company-wide CO_2 emissions objectives existed prior to EU ETS, as did systems for site-specific monitoring of emissions. More recently, both companies have strengthened their objectives and formulated quantified CO_2 emissions targets.
- The economic value of CO_2 emissions is recognized and accounted for, but the carbon price tag represents a minor factor among many that underpin industrial investment decisions.
- Increasing electricity prices is perceived to be the strongest influence of EU ETS. Due to its influence on electricity prices, EU ETS has reinforced commitments to improve energy efficiency. It has also led to strategic decisions about searching for alternatives to the electricity spot market.
- SCA is more active, than Norske Skog, in investing and implementing CO_2-lean actions. However, EU ETS has so far had a limited effect on

long-term and innovative low-carbon solutions in both companies.

4.1.6 Paper VI

The assessment of EU ETS and its third period benchmark-based allocation rules – applied to the cement industry (CEI) and the pulp and paper industry (PPI) in UK, Sweden and France – showed that:

- At aggregated EU level the new allocation rules have managed to reduce the allocation to the analysed sectors, by 15–17% in 2013, compared with the average allocation in the second period. However, both sectors will probably be in long positions in the third period.

For the CEI in the three countries the analysis showed that:

- With an exception for UK CEI, there is no evidence of abatement in previous periods. CO_2 emissions reductions by CEI in the UK and France are primarily related to production declines since 2008, while Swedish CEI appears unaffected by the recession.
- In all three countries the allocation to CEI is reduced, by 18–25% in 2013, compared with the allocation in 2012. Thus, the new allocation rules have coherent and expected outcomes in the homogeneous CEI.
- The emissions-to-cap ratio is expected to create a short position for Swedish CEI, but for CEI in the UK and France it depends on the rate of recovery from current downturn. However, stricter allocation will be offset by transferrable emission allowances from the second period.

For the PPI in the three countries the analysis showed that:

- The PPI has reduced CO_2 emissions since the start of EU ETS. In Sweden and France, emissions reductions have been 40–50% since 2005 with substantial contributions from abatement. However, abatement cannot be directly attributed to EU ETS due to generous emission-to-cap-ratios and generally low carbon prices.
- The outcomes of the new allocation rules are highly dispersed for the heterogeneous PPI. The EU-wide benchmarks have not provided a stringent representation of the PPI's (fossil) CO_2 emissions. Thus, long

positions are expected, especially in Sweden and France.

- Allocation to Swedish PPI is conspicuously high, being five times above the emission level. Conditions for low-carbon production – such as access to raw material, renewable energy and production in large integrated mills – are generously rewarded in the third period.
- The reference fuel for the EU-wide benchmarks is natural gas, while Swedish PPI has a fuel mix of 90% biofuels. Heat and fuel benchmarks further complicate the outcome of allocation. Biogenic CO_2 emissions have become entitled free allocation in the third period.

5 Concluding discussion

5.1 EU ETS and complementary policies

According to the theoretical underpinnings of the EU ETS, complementary policies targeting energy-intensive industries in the trading sector cannot reduce the EU's total CO_2 emissions. If one firm reduces direct or indirect CO_2 emissions, excess emission allowances will be traded within the system and become used for emitting activities by other firms, leading to a zero-sum game under the predetermined cap. In theory and based on a short-term perspective it is not disputed. However, for several reasons it should not be taken as an argument against complementary policies targeting, for instance, industrial EEI.

EU ETS has so far been burdened by over-allocations to manufacturing industries. Due to generous free allocation based on optimistic growth numbers and the unforeseeable impact of the economic downturn, the system has not enforced a stringent cap or a stable and high enough carbon price deemed necessary to induce innovative low-carbon investments in industry. This intended mechanism of EU ETS has failed to come about, which is exemplified by industry representatives that perceive the carbon price tag to be a minor incentive among the many factors that underpin investment decisions. On the other hand, with regard to CO_2 emissions in Swedish pulp and paper industry (PPI), the experience shows that a mix of policies since 2000 (i.e. targeting both EEI and renewable energy supply) and the PPI's exploitation of natural endowments has contributed to reduce emissions by half and moved the PPI closer to a complete decarbonisation.

The free allocation is generally reduced in the third period. However, the outcomes of the new allocation rules will be largely dispersed in some industrial sub-sectors. Not least the PPI, which clearly demonstrates the difficulties involved with setting strict EU-common benchmark values for a heterogeneous industry. In 2013, the Swedish PPI receives free allocation at an amount five times larger its current emission level. One would have to go back to the early 1980s in order to find emission levels that correspond to the allocation levels determined for the third period. Several of the product benchmarks developed for the European PPI do not represent the average performance of the 10% most GHG efficient installations in 2007–2008. In essence, since natural gas has been the reference fuel for setting the benchmark values the PPI has become entitled free allocation for its biogenic CO_2 emissions. Thus, emission-to-cap ratios are expected to cause long positions for PPI in those MS where biofuels account for a larger share of the fuel-mix (e.g. Sweden, Finland and France). In addition, transferable emission allowances from the second period will further enhance the surplus. Given that stringency in terms of allocation – combined with high and stable prices – could be important for inducing innovative low-carbon investments, large over-supplies may be problematic. Thus, complementary policies could be needed to further stimulate EEI and decarbonisation.

The EU ETS in itself does not reduce GHG emissions. It is the politically set cap that determines future emissions levels, while the actual abatement must be carried out by polluting firms. The slope of EU's target to reduce GHG emissions by 20% in 2020, compared with 1990, is not steep enough to meet long-term ambitions of 80–95% reductions by 2050. The ongoing debate on options for a structural reform of EU ETS revolves around increasing the target to 30% reductions by 2020, with consequential adjustments to the cap. However, a revised target would need to be set at 40% GHG emissions reductions by 2020 in order to bring EU on a trajectory consistent with its long-terms climate ambitions. Though it would be a tougher challenge for some industrial sub-sectors, the PPI (e.g. in Sweden and France) has demonstrated that 40–50% absolute reductions of direct CO_2 emissions have been possible within the short period 2005–2012. Thus, as some sub-sectors and firms have decreased emissions at a lower cost than expected, there could be political opportunities to raise the target and tighten the cap for the future.

There are many merits with EEI, which should be regarded a means to several ends. Industrial EEI programmes and instruments are justified by their role in overcoming barriers to energy efficiency and closing the energy efficiency gap, but also to provide other non-energy benefits. As of today, fossil fuels, nuclear- and large hydro-power account for 90% of the world's total primary energy supply. EEI is considered the most important and least cost strategy to reduce energy-related GHG emissions in a trajectory consistent with the 2 °C target. Also in countries where decisions have been taken to phase-out nuclear power, comprehensive policy strategies for EEI are increasingly motivated to facilitate the introduction of renewable power sources.

5.2 Systematic evaluation to improve the policy process

Evaluation based on programme theory has been found applicable and beneficial in the area of industrial EEI policy, in particular when programmes involve a larger set of incentives and obligations (i.e. PFE). By drawing up the programme theory the evaluator becomes familiar with the programme, its components, its goals and intended results. A misguided evaluation, which will serve no good, can thereby be avoided. In a dialogue, both the evaluator and the administration agency can become better informed about implicit assumptions on programme operation, make programme theory explicit and identify the need for relevant monitoring activities. To extend the scope of evaluation beyond the quantified impact of energy savings is also found important. When an evaluation considers the programme process and is able to identify particular programme components that did not meet with expectations, it provides valuable input to the administration agency. It allows for a programme to be modified and improved in a succeeding programme period, and can prevent that failures are replicated to other programmes.

A lack of relevant monitoring data is probably a universal problem in evaluation. To avoid costly and time consuming monitoring in retrospect, such activities should be planned in advance. The best option is probably to develop an evaluation plan in the programme formulation phase. On the basis of the programme theory and explicit targets and objectives, an evaluation plan should define the indicators of successful programme operation and the related need of monitoring data. Administration agencies could also be forward looking enough to identify the stakeholders on EU and national level that will be particularly interested in the programme results, including issues such as programme additionality (i.e. net impact) and cost-effectiveness of achieved energy savings. It needs to be decided if programme impact is best evaluated bottom-up or top-down, or perhaps both to cross-check results. Either way, it is required that the documentation and reporting procedures are accepted by the programme participants to ensure that necessary monitoring data is compiled.

A final remark can be made about the evaluator's role in discovering the reality or the true nature of a programme. Though it is worth striving for, it will be difficult to fully attain. Large programmes will often require that delimitations based on subjective judgments are made, as evaluations should aim at contributing with relevance and usefulness given the policy issue at stake.

5.3 State-governed energy efficiency improvement

Different perceptions about the relevance of objectives and policies for EEI are coming to the fore in the clashes between academic disciplines. These controversies are related to the fundamentally different views about the role of government in control of the energy system development. Is the role of government to provide legal frameworks for energy markets and possibly to correct for market failures when justified by socioeconomic considerations, but beyond that interfere as little as possible? Or is the role of government to point out a direction with visions and objectives and through a social contract mobilize industrial firms and citizens to create legitimacy for policies and measures that transform the energy systems? The different approaches are political-ideological divergent.

Neoclassical economics rest on a theoretical construction about the perfect market economy in which there is no need for public interventions to stimulate EEI actions, since it assumes that all cost-effective actions are continuously implemented. However, there is little evidence for the existence of a perfect market economy. The Swedish energy system has been characterized by a strong government involvement, historically via state ownership of natural resources and enterprises involved in the construction of energy supply infrastructure. Beyond that government has influenced the energy markets via e.g. investment subsidies, loan guarantees, diversified energy and emissions taxation, environmental regulations etc.

Eckhoff (1983) belongs to those emphasizing the role of government to steer society through policy interventions in order to safeguard natural resources for present and future generation and effectively reduce environmental impacts. However, such policy interventions (e.g. EEI policies) are likely to be met with opposition, as ideological factors contribute to build inertia in society. Since principles such as free trade, private markets and competition are highly valued by many, interventions will be opposed by larger forces than pure self-interests. This is discouraging for any government that wants to impose policies, since it could face the risk of not being re-elected. As a way forward, the opportunity for policy intervention lies in identifying areas where the desired change is mutually shared by the policy target group and the public. Indeed, expected costs and benefits need to be analysed in advance of policy implementation, but in general there are many benefits to industrial EEI in export-orientated and energy-intensive countries like Sweden. Through its combination of instruments PFE has caused attention-raising effects and norm changes towards a higher priority for industrial EEI. It has resulted in large and cost-effective electricity savings from EEI actions that were not implemented before the programme.

After ten successful years PFE will be terminated by 2014, due to revisions of EU state aid regulations that no longer accept energy tax exemptions below the EU minimum tax levels. This brings policy makers back to the policy problem step in the policy phase model, the problem being: how to stimulate industrial EEI in the future and in particular, how to couple incentives with obligations. Here is not the place to develop programme alternatives, but only to state that inspiration can be found among many industrial EEI programmes that have been launched in other MS and elsewhere. A good starting point for a new programme design would be the already proven approach with EnMS as a core requirement. Linkages to other obligations and incentives can then be added and adapted to the national circumstances.

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Paper I

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Energy efficiency in energy-intensive industries—an evaluation of the Swedish voluntary agreement PFE

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Abstract In this paper, we evaluate the Swedish Programme for improving energy efficiency in energy-intensive industries (PFE). Since 2005, some 100 energy-intensive companies have entered this 5-year voluntary agreement (VA) and been exempted from the EU minimum tax on electricity. In return, each company is required to: conduct an energy audit and analysis; identify and invest in profitable electricity saving measures; implement and certify an energy management system; introduce routines for energy efficient procurement and project planning. For most participants the first programme period was completed in 2009 and available data enables this PFE ex-post evaluation. An impact evaluation compiles and analyse data that the companies have reported to the administrating agency, the Swedish Energy Agency (SEA). This assessment of quantifiable results is complemented by a process-oriented approach that combines studies of policy documents, previous evaluations and personal communication with administrators as well as companies. The bottom-up calculation method distinguishes between gross and net impact. While the SEA estimates a gross impact of 1,450 GW h/year, the net impact consists of an interval between 689 and 1,015 GW h of net annual electricity savings. PFE has effectively and, to a low cost, exceeded the estimated impact of a minimum tax and can thus be judged as successful. A comprehensive evaluation plan could facilitate relevant data gathering in PFE and similar VAs and could, in doing so, improve accuracy and possibly reduce evaluation cost. Such a plan should give weight also to the organisational changes, with potential long-lasting effects, that these programmes are capable of promoting.

Keywords Energy-intensive industry · Voluntary agreement · PFE · Energy management system · Policy evaluation · Bottom-up method

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Introduction

Manufacturing industries account for one-third of global energy demand and nearly 40% of carbon dioxide (CO_2) emissions (IEA 2009). In EU-27, the sector accounts for 28% of final energy demand and 22% of CO_2 emissions due to its fuel use (EC 2010a).[1] Consequently, it is crucial that industries contribute to targets like 20% primary energy savings of the EU Action Plan on Energy Efficiency and the long-term objective to reduce GHG emissions by 80–95% by 2050. Decision makers will need to engage the industrial sector in constructive ways to meet the

[1] When including the indirect CO_2 emissions from industrial electricity use, this share will increase.

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challenge. This paper examines the Swedish voluntary agreement (VA) Programme for improving energy efficiency in energy-intensive industries (hereafter referred to as PFE or the programme) to assess whether this can serve as a good practice example among policy initiatives. As in many other VAs, the industrial companies are motivated by a tax rebate to enter into a multi-year legally binding agreement and pursue certain measures for energy efficiency improvement (Price 2005; Krarup and Ramesohl 2000). PFE is thereby guided by the dual ambition of facilitating competitiveness while governing industry towards political goals on energy efficiency improvement.

The development of effective energy efficiency policies as well as practices for monitoring and evaluating their results has become increasingly important with the target setting at different political levels. In National Energy Efficiency Action Plans (NEEAPs) the EU Member States shall list and quantify the impact from those national measures (e.g., policies or market mechanisms) that are planned for reaching the Energy Service Directive (ESD) target of 9% energy savings by 2016 (ESD Article 4 and 14, 2006).[2] The ESD has also triggered the challenging task of developing EU-harmonised evaluation methods (ESD Annex IV, 2006; EMEEES 2009).

The first 5-year period of PFE was concluded in 2009, and the main purpose of this paper is to evaluate the programme both in terms of its process and impact. Swedish industrial energy use and the PFE policy design section provides a background on Swedish industrial energy use and describes the main elements of PFE. Features of the inherent policy theory and how programme activities have progressed in relation to these are discussed in Process evaluation section. In Impact evaluation section, the impact evaluation brings forth programme results in terms of quantified energy savings and cost-effectiveness; common criteria for judging the success of policy instruments. The combination of perspectives aims at contributing to the deeper understanding of PFE which is found necessary for interpreting its results. In Discussion and remarks on policy implications section, we discuss the results and its implications for energy efficiency policy.

[2] ESD does not involve energy use in the trading sector, of the EU ETS, to which some energy-intensive industries belong. But, as made evident in later sections, due to the underlying definition of energy-intensive business there are also companies from the non-trading sector participating in PFE. The ESD target and related evaluation methodologies is therefore relevant for the case of PFE.

Swedish industrial energy use and the PFE policy design

Industrial energy use in Sweden

Since 1970 the Swedish energy system has made a notable shift away from oil as the dominating primary energy source. Nuclear capacity has been scaled up to the extent that hydro and nuclear power provide almost equal shares, and together some 90% of total electricity production (i.e., 146 TW h in 2008). CHP, foremost biomass-fuelled, provide most of the remaining generation capacity and a substantial heat supply via the extensive district heating grid. The industrial sector, including mining and quarrying and the manufacturing industries, has contributed to the development by shifting its energy end-use away from oil products towards more electricity, as shown in Table 1. Biomass has become increasingly important in the energy demanding pulp and paper industry (PPI). In 2007, 78% of its fuel consumption was covered by internal biomass sources, primarily black liquor and bark (Wiberg 2007).

Induced by a scheme of tradable renewable electricity certificates the PPI auto-produced 5.9 TW h electricity in 2008, which represents a 40% increase since the scheme was launched in 2003 (SFIF 2011). This corresponds to 25% of the electricity demand of the entire PPI (i.e., 22.6 TW h in 2008). The industrial use of natural gas and district heating has increased steadily since the 1980s when these energy carriers were introduced in the sector. Consumption of coal and coke has been more or less constant due to its function in reducing iron oxides in the blast-furnace process of iron manufacturing.

The Swedish industrial sector has a record of decreasing energy intensity. Industrial final energy demand has been around the same level since 1970, while the total value added has increased by a factor of about 2.5 (SEA 2009b). When considering the primary energy demand of electricity production the decoupling effect appears somewhat less pronounced. Assuming 40% generation efficiency the industrial primary energy use has increased by 30.5 TW h, or

Table 1 Swedish industrial energy use 1970–2008

Industrial energy use TW h (PJ)	1970	1980	1990	2000	2008
Electricity	33.1 (119.2)	39.8 (143.3)	53.0 (190.8)	56.9 (204.8)	55.5 (199.8)
Oil products	74.2 (267.1)	54.8 (197.3)	20.8 (74.9)	21.6 (77.8)	16.0 (57.6)
Coal and coke	14.2 (51.1)	14.8 (53.3)	16.9 (60.8)	15.6 (56.2)	16.4 (59)
Natural gas	–	–	3.2 (11.5)	3.4 (12.2)	5.4 (19.4)
District heating	–	3.1 (11.2)	3.6 (13)	4.0 (14.4)	5.6 (20.2)
Biomass and peat	32.7 (117.7)	35.2 (126.7)	42.8 (154.1)	51.7 (186.1)	52.2 (187.9)
Ind. final energy use	154 (555)	148 (532)	140 (505)	153 (552)	151 (544)
Ind. primary energy use[a]	204 (734)	207 (747)	220 (791)	239 (859)	234 (844)

Source: SEA (2009a)

[a] The electricity generation efficiency is assumed to be η=0.4

15%, over the same period due to increasing electricity demand. The trend of decreasing electricity intensity starts first in the early 1990s. Over the past decades, the less energy-intensive types of manufacturing industries have become increasingly important to the Swedish economy. In 2005, almost 50% of the industry's value added was generated in the engineering industry, including for instance manufacturing of machinery, electronic and optical components, and transport equipment (Johansson et al. 2007). The same engineering industry accounts for less than 10% of industrial final energy use. Indeed, structural change is an important factor behind the decrease in specific energy consumption but decomposition analysis has also identified that Sweden has had an industrial energy efficiency improvement of 14% between 1990 and 2005 (Odyssee 2009).

Policy making for industrial electricity efficiency

In terms of policy making for industrial energy efficiency, there are certain reasons for focusing on electricity. Over the years, it has become the dominating energy carrier in the sector (see Table 1). In previous decades, Swedish energy-intensive industries have had a competitive advantage from low electricity prices but after the deregulation of the electricity market in 1996, an increased integration with continental Europe and the introduction of EU-ETS, the situation has been altered. For these companies, being export-oriented and subject to international competition, the increase in wholesale electricity prices from the low level of year 2000 until today has become a serious concern (Nord Pool Spot AS 2011). Cost-cutting by improving electricity efficiency can reduce the exposure to increasing and volatile electricity prices.

Industrial competitiveness is a prioritized political goal. Hence, a policy that obligates the sector to act will typically be combined with an economic incentive (e.g., a tax reduction). This is complicated by the fact that Swedish energy-intensive industries are largely exempted from energy related taxes. The general energy tax on fuels is set at zero for manufacturing processes and the carbon tax on fossil fuel use is significantly reduced for energy-intensive industries. Since fossil CO_2 emissions from many of these facilities are controlled under the EU-ETS cap and trade, further policy interference would be futile in terms of short-term emission reductions (Henriksson and Söderholm 2009). Moreover, industrial electricity consumption was untaxed for many years but in 2004 this received criticism from the European Commission for being incompatible with the common market (EC 2004). Hence, the Swedish government was forced to promptly remove the illicit state aid of zero taxation by introducing the minimum tax of 0.5 Euro/MW h on industrial electricity use.[3] The Energy Tax Directive (ETD), however, can provide the opportunity of reduced taxation for energy-intensive businesses if these enter into agreement on energy efficiency improvement (ETD Article 17 2003). Thus, to enable the tax exemption for energy-intensive companies and to stimulate their energy and in particular electricity

[3] Exceptions are made for manufacturing processes in the sectors: metallurgy, electrolysis and chemical reduction.

efficiency improvement, Sweden launched PFE in 2005.[4]

The PFE outline

PFE is intended for energy-intensive companies as defined by the criteria: (1) purchases of energy products and electricity amount to at least 3% of the production value and/or (2) the energy-, carbon dioxide-and sulphur tax on energy products and electricity used by the company amount to at least 0.5% of the added value (§ 4 of SFS 2004:1196; ETD Article 17 2003). Companies from the sectors pulp and paper, mining, iron and steel, non-metal minerals and industrial chemicals are typical candidates. In some cases also food processing industries, saw mills and engineering industries can qualify as energy-intensive. From January 2005 and onwards the programme period starts when the company is accepted for participation and lasts for the 5 subsequent years.[5]

During the first 2 years, the company has to introduce and obtain certification for a standardized energy management system (EnMS)[6] and carry out an energy audit and analysis. The audit report describes the plant's energy use and proposes energy saving measures based on an analysis of energy demand in short- and long-term perspective (SEA 2004). This work is concluded with a list of identified electricity saving measures. Those listed measures with payback periods of less than 3 years have to be implemented while measures with lower rate-of-returns are pursued on a voluntary basis. The list is submitted to and approved by the Swedish Energy Agency (SEA), which is the administrating agency. During the first 2 years, the company also has to introduce routines for procurement of high-consumption electrical equipment as well as routines for energy efficient project planning. The core purpose of these routines is that the company shall acknowledge the life cycle cost in its procurement and investment decisions and thus give preference to energy efficient equipment (SEA 2006).

After the first 2 years the participating company must submit its first report to SEA demonstrating how the requirements have been met and what level of electricity savings to be expected from the listed measures. During the following 3 years, the company shall implement the measures and continuously apply the EnMS as well as the routines for procurement and project planning. At the end of the programme period the company must submit its final report in which the impact of all electricity efficiency improvement measures has to be assessed. Each company must achieve an improvement in electricity efficiency which broadly speaking is equivalent to the improvement that would have been achieved if the tax (i.e., 0.5 Euro/MW h)[7] had been imposed instead of PFE (§ 11 of SFS 2004:1196). As a consequence, the programme builds on the theory that the attention-raising effect of its components (e.g., the EnMS and the routines) will offset the impacts of the removed tax on electricity.

PFE can be classified as a medium-term VA in which companies are incentivised by the tax rebate to enter the programme, fulfil its binding obligations and thereby improve energy efficiency.[8] Hence, in the taxonomy of VAs suggested by Price (2005), PFE fits into the category of programmes that are implemented in conjunction with existing energy/GHG emissions tax policy or with strict regulations. The agreement is signed and entered by individual companies comprising one or several production sites. The programme is regulated by a law (SFS 2004:1196) that defines the binding commitments of all parties and leaves little room for negotiation. Divergence from regulations needs to be reported and tested. The SEA reviews the

[4] The policy planning and formulation process for a Swedish long-term agreement started some years earlier. The process can be tracked through a series of policy documents: Ds 2001:65 2001; Prop. 2001/02:143 2002; Ds 2003:51 2003; Prop. 2003/04:1 2003; Prop. 2003/04:170 2004; SFS 2004:1196 2004. The smaller scale EKO-Energi scheme (1994–1999) can perhaps be seen as a Swedish precursor to PFE. Policy makers also took inspiration from VAs implemented abroad.

[5] The companies that applied before 31 March 2005 were entitled a tax reduction backdated to 1 July 2004 and could thus conclude their first 5-year programme period in July 2009 (SEA 2005). A continuing, second programme period, was launched in 2009.

[6] Initially the participating companies used the Swedish Energy Management System standard SS 627750. This document was later replaced by European standard EN 16001.

[7] Throughout this paper, 1 Euro is the equivalent of 10 Swedish kronor (SEK).

[8] Voluntary agreement (VA) and Long-term agreement (LTA) are two designations commonly used for these kinds of programmes. We prefer the former to describe PFE since: 1) it underlines the voluntary approach and 2) the 5 year programme period is medium term rather than long term.

companies' reports and occasionally conducts site visits to monitor compliance. Companies are liable to the regulations and the threat in case of non-compliance is that participation is terminated and the minimum tax is repaid for the entire period. In its structure and details of procedures PFE is rather advanced and goes beyond being a gentlemen's agreement. It is also rich on programme components. Rather than being one policy instrument, PFE provides a packaged mix of instruments, which also complicates the task of evaluation.

Process evaluation

Methodological remarks

This analysis of PFE takes inspiration from the process-oriented approach of Theory-Based Evaluation (TBE) (Weiss 1972; Chen and Rossi 1983; and others). Theory should be understood as "the set of beliefs and assumptions that undergird program activities" (Weiss 1997, p. 503). Thus, the policy theory constitutes the basis for how programme activities are expected to bring about the desired changes. Advocates of TBE claim it is superior to a conventional impact evaluation in that it can answer to not only if, but also why, targeted impacts are achieved. For energy efficiency policies the impact will typically be defined as the quantified energy efficiency improvement and/or energy savings. In case this impact is found uncertain or insufficient the TBE should obtain answers about where in the chain of activities that the policy programme failed to function as expected. If, on the other hand, prior expectations are met or even exceeded a TBE should pinpoint the activities that explains the success. Impact can arise also by other paths than those presumed by the policy theory and to estimate additionality is an important, yet difficult, task of evaluation.[9] TBE can contribute in solving this issue through its system analytical procedure of assessing the programme by: separating its components; examine these; and communicate the interpretations. Eventually, the evaluation may fulfil its virtue of supporting programme administrators in determining what, if any, modifications that are needed for a forthcoming effective operation.

The research method applied to understand PFE and its policy theory includes in-depth studies of official policy documents and previous evaluations. These have been conducted over a longer period of time, almost 2 years, and have evolved with the programme period as new records about its results have become available. Also, at several occasions, to make details clearer, conversations have been held with staff at the SEA. PFE is pushing for rather multifaceted changes (e.g., technology, actor and market related) but delimitations are necessary to avoid the myth of an all-purpose evaluation (Weiss 1972). The process perspective here given can only give attention to a few aspects and it serves foremost as a supplement to the impact evaluation. In the following we will analyze two areas of essential importance for understanding—and evaluating—the effectiveness and cost-effectiveness of PFE: (1) the eligibility and coverage of PFE and (2) the programme goals and achievement.

Eligibility and programme coverage

All energy-intensive industrial companies are eligible for PFE (§ 4 of SFS 2004:1196), which is about 1,250 companies (SEA 2005). In March 2007, 95 companies, comprising some 250 industrial sites, had submitted their second-year reports (SEA 2007a). Since then, another ten to 20 companies have entered, while a few have left the programme (SEA personal communication 2009a, b, c). Hence, less than 10% of eligible companies are participating in PFE. In Fig. 1, the numbers of eligible and actually participating companies are grouped by the size of their electricity use. Notably, the participation rate decline sharply for companies with an electricity use below 100 GW h/year. Since the size of the tax cut is proportional to the electricity use large consumers (>100 GW h/year) are highly motivated to attend.[10]

A result of the self-selection mechanism is that only 3% of eligible companies with lower electricity

[9] The additionality of a policy programme is the impact achieved by the programme per se, i.e., not resulting from autonomous changes.

[10] For companies with an electricity use of 1 TW h/year, the annual PFE tax rebate amount to 500,000 Euro, while companies using 10 GW h/year are granted a more modest amount of 5,000 Euro.

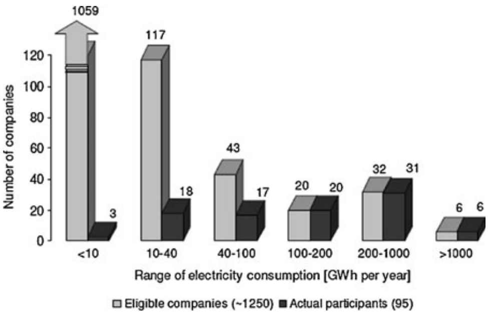

Fig. 1 Eligible and participating companies categorized by electricity consumption. Source: SEA (2005, 2007a)

demand (<100 GW h/year) have joined PFE. This shows that a tax relief below 50,000 Euro is often considered insufficient as a motivator and to cover for the compliance cost related to, for example, EnMS implementation and certification (Sjögren et al. 2007). The low overall participation rate may appear disappointing and staff at the SEA has stated they would like to see as many companies as possible in the programme (SEA personal communication 2008). In the early planning phase of PFE, the intended target group comprised 60 companies from the conventional energy-intensive sectors: pulp and paper; mining; iron and steel; non-metal minerals; and industrial chemicals (Ds 2001:65 2001). However, the previously mentioned criteria of energy-intensive business (ETD Article 17 2003) implicated that the much greater number of 1250 companies became eligible (including e.g., saw mills, food industry, engineering companies). With this distinction being made, it is clear that while participation rate is low compared to eligible companies, it actually exceeds the intended target group of the policy theory.

In terms of electricity consumption, the 10% participating companies account for 85% of the eligible electricity demand (i.e., 30 out of 35 TW h). Hence, in absolute numbers, PFE comprise most of the saving potential. It is possible though, as pointed out by Henriksson and Söderholm (2009), that PFE components like EnMS could do a better job in detecting cost-effective energy efficiency improvement measures among the 1150 non-participating companies, since these can be assumed to lack prior experience in energy management compared to the really energy-intensive companies. In practice, the administrative cost of having a full scale EnMS constitutes a barrier for these companies often being SMEs with lower energy cost shares (Sjögren et al. 2007). From a programme administration standpoint, the burden would increase multi-fold if all 1,250 eligible companies were to join. In this sense, the tax incentive has successfully attracted the lion's share of eligible electricity use, and thereby potential savings, while the total administrative burden has been kept at moderate level.

Goals and achievement

The evaluation of programme effectiveness can be carried out from the two perspectives of goal achievement and additionality (Krarup and Ramesohl 2000). While the former is discussed in the following, the latter is being analyzed in relation to the impact evaluation of Impact evaluation section. The existence of goals is essential for assessing goal achievement. It is problematic in this regard that policy instruments often lack quantitative targets and are governed by multiple but unclear objectives (AID-EE 2007). Evaluators may find it necessary to make independent interpretations and formulations of goals on the basis of the policy theory (Weiss 1972).

PFE does contain many requirements: the companies have to perform energy auditing and analysis, implement and certify their EnMS and adopt routines for energy efficient procurement and project planning. PFE has also proven successful considering that nearly 100% of the companies have complied with these obligations. Regarding the electricity savings impact no quantified target has been formulated.[11] There is, however, the requirement mentioned in The PFE outline section that: companies must submit a list of measures and later implement these so to reach electricity savings of the same level that would have been achieved if the minimum tax were to be applied over the same period. This counterfactual reference situation stems from the paragraph of the ETD stating what level of savings that an agreement in substitution for the tax must achieve (ETD Article 17(4) 2003). The potential saving impact from a fictive tax has not been estimated by the SEA or any other authority. The course taken by this paper is therefore to quantify the counterfactual situation, i.e.,

[11] High expectations on results, however, have been communicated based on the second year report (Ottosson and Petersson 2007; SEA 2007b).

to estimate the impact in terms of electricity savings due to a fictive tax and frame this as the level of savings that PFE ought to achieve (i.e., the programme's impact goal).

In the second- and fifth-year reports, the companies were asked whether their electricity savings could match the counterfactual situation. Different justifications were made and indeed there is no clear-cut answer to this question. A majority of companies, however, made the interpretation that cost reductions from electricity saving measures should at least equal and thus eliminate the cost-raising effect of a fictive tax (i.e., had it existed). Theoretically, this implies that the companies must report and implement electricity saving measures as if they were facing a unitary (−1.00) own price elasticity of demand for electricity. To exemplify: a tax of 0.05 Euro cent on an electricity price of 4 Euro cent per kW h results in a 1.25% cost-raising effect and thus a PFE company with this electricity price should in substitution for the tax achieve electricity savings and cost reductions of 1.25%.

On the basis of official policy documents (ETD 2003; SFS 2004:1196) and our examination of the companies' goal interpretations, the PFE impact goal is here being formulated as a target-level. Figure 2a and b plots, for 36 of the PFE companies, reported electricity savings against the cost-raising effect of the fictive tax.[12] The latter is decided by each company's electricity price, varying with power contract and exposure to the Nord Pool spot market. The target-level is decided by the simple relationship that a 1% cost-raising effect must be eliminated by a 1% electricity savings and cost reduction. While Fig. 2a contains the ex-ante deemed savings from measures that were reported in the second year, Fig. 2b contains more reliable ex-post data where the planned and additional measures have been implemented and estimated by the means of measurement or engineering calculations. In both cases, the percentage of annual electricity savings is compared to a base year, represented by the companies' electricity demand in 2004.

In the second-year report the planned measures for ten of the companies were inferior to reach the target-level. In the final report, however, many companies showed a significantly improved performance. Average electricity savings of the 36 companies increased from 3% to 5.1%, and some companies were even reporting savings in the high range of 15–20% (see Fig. 2b). In the next section, which evaluates the PFE impact, explanations are provided for this increased performance after the second-year report.

The target-level can also be expressed as a quantitative electricity saving target for the entire group of PFE companies. Given their yearly electricity demand of about 30 TW h, the tax exemption for all companies is 15 MEuro per year. To equal out the cost-raising effect, given the tax had existed, the programme should achieve 375 GW h of annual electricity savings (equal to 1.25%) when assuming an average electricity price of 4 Eurocent per kW h.[13] It is made evident by the impact evaluation in the next section that the reported electricity savings are well above this level. The PFE collective of companies has thus successfully fulfilled and surpassed the impact goal, as it is defined here. A few individual companies, however, did not the reach the targeted saving level (as illustrated in Fig. 2b) and stand the risk of being excluded from the programme. The lists of planned measures in the second-year report and implemented measures in the fifth-year report should reflect their level of ambition. These can be examined to determine if companies are reluctant of listing measures, although saving opportunities with short payback periods (<3 years) can be assumed to exist. Can such behaviour be justified within the framework of PFE? These are relevant issues in supervision.

Impact evaluation

Methodological remarks

The impact of an energy efficiency policy is the quantified energy efficiency improvement and/or energy savings expressed in whatever metric is appropriate. Several extensive guidelines for energy efficiency policy evaluation have been developed to support evaluators in quantifying impact (EMEEES

[12] The selection of 36 companies, about a third of the participants and the proportional electricity use, is delimited by the availability of data.

[13] This corresponds to the average Nord Pool spot price for Sweden between 2005 and 2009 (Nord Pool Spot AS, 2011), and is exclusive of grid costs.

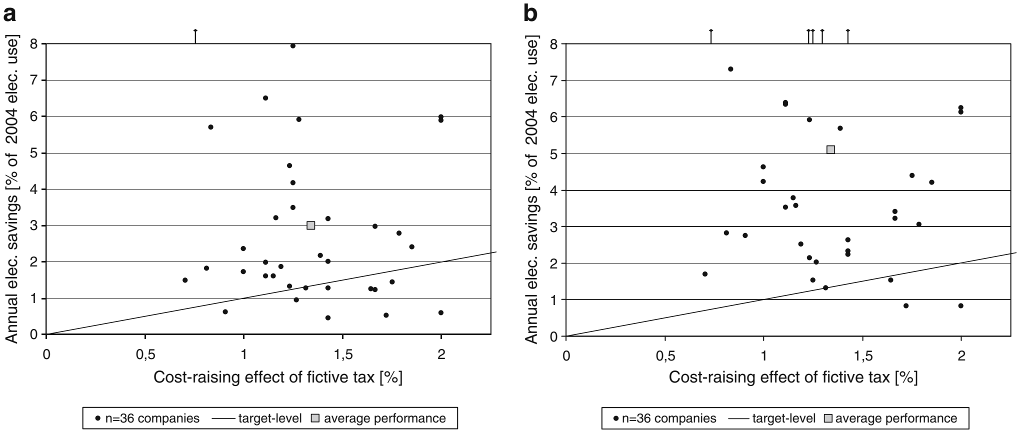

Fig. 2 **a** Ex-ante deemed electricity savings from listed measures of the second-year report, as compared to the cost-raising effect of a fictive minimum tax. Source: SEA (2007a). **b** Ex-post measured or engineering estimated electricity savings from listed and additional measures of the fifth-year report, as compared to the cost-raising effect of a fictive minimum tax. Source: SEA unpublished data (2010)

2009; IEA DSM 2005; SRCI 2001). It is foremost the guidelines for bottom-up calculations presented by the EMEEES project that have shaped the impact evaluation in this section. A distinction is made between gross and net impact. Gross impact refers to the quantification of all energy savings or efficiency improvements that are documented under the policy framework, without considering that other driving forces could have caused part of the impact. With a gross-to-net impact conversion, the evaluator seeks to solve the additionality issue by raising the question: How large energy savings would not have been achieved if the policy programme had not existed? Consequently, the net impact or additional savings refers to the quantified impact induced by the programme per se, not resulting from autonomous changes that would have taken place also without the programme. This has a clear relevance in the striving for effective and cost-effective energy efficiency policies.

Gross impact

This presentation of gross impact is aligned with the PFE reporting procedure that gathers data both from the second-year interim report and the fifth-year final report. While the former data set contains the ex-ante deemed savings from the reported lists of planned measures, the latter report concludes PFE with its ex-post estimates from all programme components (e.g., the adoption of routines and changes in operation and maintenance (O&M) as stipulated by the EnMS). The fifth-year report thus captures the total gross annual electricity savings that the companies have reported to the SEA under the PFE scheme. Table 2 compiles the technical and O&M measures from the two check-points. In the beginning of 2007, 95 companies had submitted their second-year reports comprising 860 measures equalling ex-ante deemed annual savings of 726 GW h. In 2010, when 101 companies had submitted their fifth-year final reports the number of measures had increased to 1,254 and the ex-post estimate of annual savings was 917 GW h; an increase by 191 GW h (or 26%) compared to the second-year data.[14] The measures have been subdivided into types of end-use technologies. A large part is motor-related, e.g., variable speed drive (VSD) installations. Measures that relate to pumping systems are also common due to the large participation of the pulp and paper industry that uses pumping equipment throughout the mills.

In addition to all the technical and O&M measures presented in Table 2, a few more categories of

[14] The few companies that had not submitted their final report by the end of 2009 will only make a marginal difference.

Table 2 Reported annual electricity savings from technical and O&M measures

Type of end-use technology	Second-year report			Fifth-year report		
	No. of measures	GW h elec. savings	% of savings	No. of measures	GW h elec. savings	% of savings
Production processes: large variety of measures, often involves optimization of motor-related processes	243	354	49	312	443	48
Pumping systems: VSD control and replacement of pumping equipment	214	142	20	289	154	17
Compressed air systems: sealing air leakage, measures on compressors and vacuum systems	78	76	10	118	94	10
Indirect elec. efficiency and other measures: electric boilers, phase compensation, control of motor heaters	65	64	9	107	93	10
Industrial motors: installation of efficient motors, VSD control	85	30	4	140	55	6
Fan systems: VSD control on different industrial fan applications, e.g., drying and de-dusting	58	22.5	3	90	34	4
Space heating and ventilation: heat recovery and demand controlled HVAC equipment	50	21	3	71	19	2
Cooling systems: optimization and replacement of cooling machines	19	10	1.5	26	15	2
Lighting systems: time and presence controlled lighting	48	6.5	1	101	10	1
Totals from technical and O&M measures	860	726	100	1254	917	100

Source: SEA (2007a, 2011a)

electricity savings measures have been reported by the companies. These are (SEA 2011a):

- Electricity savings due to the energy efficient routines: 174 GW h/year from project planning and 36 GW h/year from procurement practices
- Supplementary electricity saving measures: 323 GW h/year from a number of measures with large impact that for various reasons have been categorised separately

By summing up all these measures, SEA concludes that the total gross annual impact of PFE is 1,450 GW h (SEA 2011b). The result is quite remarkable considering the target-level of 375 GW h/year that was formulated in the previous section. It even exceeds the previous high expectations of 1,000 GW h annual electricity savings based on the second-year data (SEA 2007b). By comparing data from the two checkpoints, we can better understand the PFE process and how it corresponds to policy theory. The measures reported in the second-year report can be seen as a response to the legal requirement of conducting energy audit and analysis to identify profitable measures for implementation. The elevated, actually doubled, impact thereafter indicates that the companies did not stagnate in their efforts to implement measures. It also shows their willingness, with a few exceptions, to report more measures than the law requires. There are, at least, three complementing explanations for their behaviour.

The energy management system

The policy theory suggests that PFE components like the EnMS, including the routines, create an attention-raising effect that will offset the impacts of the removed tax on electricity. Since these programme components were fully introduced first after the second year, it is reasonable that the elevated impact of about 700 GW h is observed in the later years of the programme period. The companies have estimated the impact from the two categories of routines to be 210 GW h/year. The remaining 500 GW h of reported annual electricity savings are partly from technical and O&M measures implemented under the guidance of certified EnMSs. It is difficult to verify a direct causality between the EnMS and reported savings for each company and measure. In general, though, companies claim that the EnMS has helped establishing an organisational structure with a strong focus on energy efficiency. As many as 80% of the companies claim that the EnMS has introduced new methods for monitoring energy use that have been valuable for their energy efficiency improvements (Hörnsten and Selberg 2007).

A legally binding agreement

In a review of VAs worldwide Price (2005) concludes that the most effective ones are legally binding. The PFE legislation (SFS 2004:1196) should therefore be seen as a strong motive for compliance. As an example, the companies have taken it serious that the listed electricity saving measures must be implemented over the programme period. This requirement has facilitated the allocation of investment capital for PFE measures. It has also led some companies to be careful not to list measures that they were not sure about in the second year (Hörnsten and Selberg 2007). Thereafter, as measures have been analysed in detail and investment funds have been secured, companies have taken decision to implement additional measures.

Electricity price development

Variable but on the whole increasing electricity prices and the perceptions held by industry that future electricity prices will remain at high levels are fundamental reasons for energy-intensive companies to improve electricity efficiency. Thollander and Ottosson (2008) show that “cost reductions resulting from lower energy use” and “the threat of rising energy prices” is ranked as the first and fourth most important among 23 driving forces for energy efficiency improvement in the Swedish PPI.

Acknowledging the strong underlying motive of energy cost reductions in the energy-intensive firms the total gross impact cannot be attributed to PFE exclusively. The programme does, however, emphasize electricity efficiency rather than other factors of production as a prerequisite for industrial competitiveness. It also make requirements and provide tools for companies to overcome commonly cited barriers like “the lack of access to capital” and “the lack of time or other priorities” (Thollander and Ottosson 2008). It is therefore likely that PFE has realised energy savings that have been overlooked before. The following section will examine the importance of PFE by estimating its attributable share of reported savings, i.e., the net impact of PFE.

Net impact

In a bottom-up evaluation method the gross-to-net impact conversion is done by adjusting total gross annual impact with a number of correction factors as expressed in Fig. 3 and further explained below.

Owing to the PFE documentation and reporting procedures, it has been possible for the SEA to estimate a total gross annual impact of 1,450 GW h. To complete the equation the correction factors needs to be determined:

- *Free-rider coefficient*: expresses the share of savings, ranging between 0 and 1, that would have been implemented also without the support from the policy programme.
- *Multiplier coefficient (also called spill-over)*: expresses the savings that are indirectly caused by the programme in addition to what was targeted. Both participant and non-participants can implement measures without involvement (e.g., financial, technical or informative support) from the programme administration. The possible range is from 0 to in principle very large numbers.
- *Double counting coefficient*: expresses the potential effect from overlap and whether savings have to be shared between different policies and/or saving measures. The range is between 0 and 1, where 1 represents a situation without shared savings.

In an intermediate evaluation of PFE, an attempt is made to estimate the coefficients (Stenqvist and Nilsson 2009). Some factors of influence are discussed in a qualitative manner but the authors surrender the issue of quantifying all coefficients. Though there is still a lack of surveys, some new knowledge is added in the following which allows for a revision of previous estimates.

Free-rider

In the fifth-year report, the companies have answered for each measure belonging to the category of technical and O&M measures how it was identified. Of the 917 GW h/year of electricity savings it is claimed that: 43% was identified during the energy audit; 32% was known from before; and the remaining 25% was identified by other means. Hence, without the PFE requirement on energy auditing and net impact = gross impact x (1 – free-rider coefficient + multiplier coefficient) x double counting coefficient

Fig. 3 Bottom-up calculation for a gross-to-net impact conversion. Source: EMEEES (2009)

analysis the identification and implementation of 43% of these savings would not come about, or at least have been deferred. It is also assumed that the increased awareness and energy efficiency focus resulting from a certified EnMS can explain most of the savings that were identified by other means. Likewise, the adoption of energy efficient routines is considered to be a direct result of the PFE participation. On the other hand there are technical and O&M measures that were known already from before and these would probably have been implemented also without PFE. The last category of supplementary electricity saving measures involves rather large-scale upgrading of production processes that to a large extent is taken to be autonomous improvements.

With this reasoning, it is found that somewhere around 40% of the electricity savings can be free-rider savings and to express the uncertainty involved here the free-rider coefficient is estimated to be in the range [0.3,0.5].

Multiplier

Energy efficient choices made by PFE companies may have a transforming effect on the market if suppliers change their offers to stimulate non-participants in favouring energy efficient solutions. Market transformation studies (e.g., sales data analysis) are often recommended to identify such a multiplier effect (EMEEES 2009; IEA DSM 2005; SRCI 2001). In one survey, equipment manufacturers and retailers were asked about how PFE influenced their business in terms of awareness, demand, offers, sales, etc. (SEA unpublished report 2007a, b). The results give interesting, but ambiguous, insight to the business. A market structure with a lot of middlemen is revealed. Motor manufacturers, for example, could observe an increasing demand on energy efficient motors but since the end-users are unknown to them so are the reasons for the change in demand. Motor-related measures are common but PFE is technology-neutral and it is evident in Table 2 that the 1,254 measures are diverse. This complicates the focus of a market transformation study compared to a policy targeting a specific consumer product like cold appliances. A survey has to be well planned to target the relevant market actors and, more than impressions, collect actual sales data on the most important technologies. High efficiency motors and variable speed drive installations are measures standing out in terms of increased demand over the last years (SEA unpublished report 2007a, b). A survey would be needed to confirm the role of PFE and estimate the size of a possible multiplier effect behind a market transformation.

During the 5-year programme period, PFE companies, mostly in the pulp and paper industry, have increased their levels of auto-produced electricity with 15% (SEA 2009c). This development has been driven by the scheme of tradable renewable electricity certificates along with the price levels of electricity. It has little to do with PFE, however, and since this involves supply side measures it is not a case for multiplier effects. It is possible, anyhow, that EnMS practices have supported project planning for reaching optimised solution with regards to the back pressure turbines and the demand for steam. In such cases, whenever electricity savings has been an outcome, this can be reported as a result from routines for energy efficient project planning. There are some examples of such company reporting (SEA 2011a).

A multiplier effect can be derived from PFE participants that apart from electricity savings have made heat and fuels savings. Due to the tax incentive PFE only account electricity savings as programme impact. It can be argued, however, that the EnMS stimulates a general energy efficiency improvement concerning all energy carriers (SEA 2008). Case in point: in the fifth-year report 75% of the companies voluntarily reported measures related to other energy carriers than electricity (SEA 2011a). It is not possible, due to the diversity of measures and complexities involved (e.g., some measures are fuel shift rather than energy saving measures), to derive an impact for the complete data set. It is possible, however, to separate a subset of measures that are reported as implemented and for which the energy savings are clearly quantified (SEA 2011c). These measures represent heat and fuel savings in the size of 950 GW h/year. Taking this to be a potential result from having a certified EnMS, the multiplier coefficient can be somewhere in the range [0,0.65].

Double counting

There is no other policy instrument with influence on the PFE companies that, like PFE, specifically requires electricity saving measures to be identified, implemented, monitored and reported. The documentation and reporting procedure includes information about the companies, their sites and their implemented measures. This information can be cross-checked to avoid double-counting in case attempts are made to evaluate electricity savings from partly overlapping policies. For example, the promotion of energy efficient products through the EU Ecodesign Directive represents a support for industrial energy efficiency improvement. This policy interaction will probably be enhanced in the future as the revised Ecodesign and its respective requirements are being implemented. In a bottom-up accounting of national energy savings, the concerned agencies will have to deal with the double counting issue by allocating savings only to one preferred policy. In the case of the Swedish Environmental Code that can be used to mandate energy efficiency improvement (Johansson et al. 2007), the potential problem of overlapping regulation has been solved by a decree. This implies that PFE companies are considered to fulfill any requirement on energy conservation stipulated by the Code (SEA 2008). Thereby, the risk for double counting is reduced since the PFE companies only need to report their measures to one agency (i.e., the SEA).

The documentation and reporting procedures applied in PFE also helps to avoid double counting between categories of measures. The SEA explains that the implementation of technical and O&M measures should be an outcome of energy auditing and continuous energy management, that the procurement routines concern equipment that is acquired repeatedly, and that the routines for project planning involves larger scale restructuring (SEA 2006). Some companies have claimed it difficult to make a separation, but in the reporting they are required to allocate each measure to one or another category and state the method for verification. Adequate actions have been taken to reduce the risk of double counting, but because of the different measures involved (i.e., routines as well as technical measures) the occurrence cannot be fully excluded. We estimate that the double counting coefficient lies in the interval [0.95,1].

When the estimated correction factors are used in the formula of Fig. 3, the result is a net annual electricity saving impact between 689 and 1,015 GW h. In addition to this, PFE has caused a potential multiplier effect of up to 950 GW h/year of heat and fuel savings.[15]

Clarifications on gross and net impact

The preceding sections have estimated the PFE electricity savings in terms of gross and net annual impact, yet some clarifications can help to avoid misunderstandings about the meaning of these results. The gross annual impact of 1,450 GW h does not, by necessity, imply that the participants have decreased their absolute electricity use by that amount. On the contrary, the actual electricity demand of the PFE companies was almost 3% higher in 2008 compared to 2004 (SEA 2007a, 2011a). This is because plant throughput and other conditions typically fluctuate from year to year. Due to the latest economic downturn, for example, overall production level and industrial electricity use was much lower in 2009 than average over the last couple of years. Therefore it is more accurate to interpret impact as avoided demand rather than absolute savings.

To be precise, gross annual impact should only be understood as the estimated savings from the specific measures compared to the base situation of the prior operation. Since measures have been implemented over the whole 5-year period and measurement and verifications are done by each company, the total gross annual impact relies on a range of different base situations. To claim an aggregated PFE gross impact, a practical approximation is to consider the year before the programme started (i.e., 2004) as the common base year for all measures. Figure 4 shows the estimated impact from 101 companies as the percentage of avoided electricity use compared to the baseline representing the companies' electricity demand in 2004, which was 30 TW h.

[15] For reasons of clarity, we avoid mixing net electricity savings with the heat and fuel savings attributable to the potential multiplier effect.

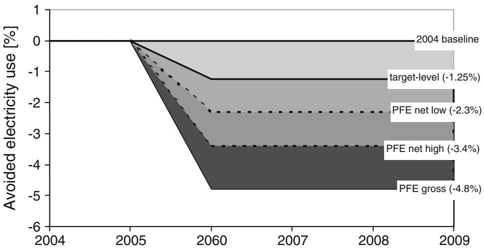

Fig. 4 Avoided electricity consumption from PFE measures compared to the 2004 baseline. Source: SEA (2007a, 2011a)

While the gross annual impact of 1,450 GW h equals almost 4.8% savings, the net annual impact interval 689–1,015 GW h correspond to 2.3–3.4% savings. The target-level of 1.25% is clearly exceeded by the collective PFE savings. Another ten companies can be expected to submit their final report for the first 5-year period. Since these are companies with lower electricity consumption they can only make a marginal contribution to the final programme impact.

The cost-effectiveness of PFE

The term cost-effectiveness in relation to energy efficiency policies can have dual meanings: the ratio of the cost per saved amount of energy (e.g., Euro/MW h) or; whether the energy efficiency improvement measures take place where they are the least expensive. Here the cost-effectiveness ratio for the PFE electricity savings is assessed from the perspective of society which includes programme costs for government and for end-users/companies. The main costs involved are:

- Companies' investments into electricity saving measures (2005–2009): 70.8 MEuro (SEA 2011a)
- Companies' administrative costs to comply with PFE regulations (2005–2009): 13 MEuro (NUTEK 2008)[16]
- SEA's costs for administrating PFE (2004–2009): 4.2 MEuro (SEA personal communication 2008)

From the perspective of society, the annual tax rebate of 15 MEuro is not considered a cost but a relocation of capital between government and end-users. The total cost for society is thus 88 MEuro between 2004 and 2009. The discount rate is set at 4%. A depreciation period of 12 years is selected based on simplifying assumptions about the persistence of energy savings. According to recommendations on measurement and verification methods in the framework of ESD many industrial energy efficiency improvement measures are assigned default saving lifetimes of 15 years.[17] The category efficient electric motors and variable speed drives, however, has a default saving lifetime of 12 years. Moreover, savings that arise from good energy management and monitoring have default saving lifetimes of 5 years (EC 2010b). Table 2 shows that the PFE impact is resulting from a variety of measures but that motor-related and VSD installations have been especially important. Also, the EnMS-related O&M measures and the routines applied are essential to PFE. It is a reasonable approximation to use a uniform 12-year saving lifetime and depreciation period to all measures. Thereby, the annualised cost for society is 9.4 MEuro. The gross annual impact implies a unit cost of 6.5 Euro/MW h. Based on the net annual impact interval (i.e., 689–1,015 GW h) the unit cost is 9.3–13.6 Euro per MW h of saved electricity, depending foremost on the presence of free-riders. This cost calculation compare very favourable to yearly average wholesale electricity prices which have been between 29 and 51 Euro/MW h in the period 2005–2009 (Nord Pool Spot AS 2011). Comparison can also be made with the cost for electricity production from new generation capacity which depends largely on the power technology and its related fees and subsidies. A study based on Swedish conditions, using a 6% discount rate and a 20-year depreciation period for commercial energy technologies, derives results between 16 and 110 Euro per unit of produced MW h (Hansson et al. 2007).

The second perspective on cost-effectiveness also deserves some attention. The companies have made significant investments and still the average payback period of all measures is less than 1.5 years (SEA 2011b). In interviews, companies have declared that

[16] Standard Cost Model (SCM) methodology has been applied to estimate the costs of administrative activities due to the PFE law (SFS 2004:1196 2004).

[17] The lifetime of energy savings can be a critical factor for determining policy target achievement. The ESD, for example, allows for existing policies and early actions to contribute to the savings target of 9% conditional a lasting effect exists by 2016 (ESD Annex I 2006).

PFE activities have raised their competence level in energy management for energy efficiency and that the EnMS has made them question their former routines (SEA 2009c). With a macroeconomic perspective this could indicate an occurrence of firm-specific information asymmetries prior to PFE. Based on this perspective it can be discussed whether addressing the measures has been overall economically efficient in the sense that the measures have been implemented where they are least expensive (see Henriksson and Söderholm 2009). Theory on information asymmetries implies that electricity taxes could do a better job in companies with a high electricity cost share while EnMSs and other attention-raising activities could be more effective in companies with a lower electricity cost share, since the latter are relatively less experienced with energy efficiency improvement (Ibid.). Given that there is a positive correlation between electricity demand and electricity cost share, Eligibility and programme coverage section has shown that PFE induces a reverse situation. The largest electricity consumers are eager to join and substitute the tax with the EnMS (and the other programme components) while companies using less electricity are typically facing the tax. The programme results partly support the theory. Some 40 companies with lower electricity demand (<100 GW h/year) did join PFE and their average gross annual impact is 9%. For those, about 60, companies with higher consumption (>100 GW h/year) the corresponding figure is 4%. A review of specific sectors shows that manufacturers of food products and beverages (NACE 15) have found the energy auditing and analysis to be most useful (Hörnsten and Selberg 2007). The sector as a whole reported gross electricity savings of 5.3%. Another less energy-intensive sector, the manufacturers of wood and wood products (NACE 20), reported gross electricity savings of 6.7%. This can be compared with the more energy-intensive sectors (i.e., NACE 21, 24, 25, 27 and 28) each of which reported gross electricity savings close to 3%. This indicates that the most energy-intensive companies, though they provide the large bulk of total savings, are less responsive to PFE and EnMS in terms of their reported percentage savings. Still, as demonstrated in Goals and achievement section, the 3% electricity savings exceeds the estimated impact of a minimum tax at 0.5 Euro/MW h. Consequently, PFE can do a good job in promoting electricity savings in all the concerned sectors.

Discussion and remarks on policy implications

This ex-post evaluation shows that the PFE gross annual impact (i.e., 1,450 GW h) as well as the interval of net annual impact (i.e., 689–1,015 GW h) greatly exceeds the estimated annual impact of a minimum tax (375 GW h) which is interpreted here as the programme's target-level. The evaluation also shows a cost-effectiveness ratio with a relatively low cost per saved amount of energy. Moreover, PFE has caused a multiplier effect of heat and fuel savings that can be as large as 950 GW h/year. On these merits PFE can be judged successful against its objectives to improve industrial electricity efficiency while safeguarding industrial competitiveness. EnMS procedures have been a key to the successful outcome, as indicated by the elevated programme impact after the second year. This result is promising and well-timed given the opportunity for worldwide EnMS implementation according to the international ISO 50001 standard being published in 2011. Stimulating industrial EnMS practices as a main ingredient of a VA can be a viable and cost-effective policy solution. All in all the continuing 5-year period of PFE is justified. It can be assumed, however, given the short average payback period of less than 1.5 years that many "low hanging fruit" measures were harvested during the first period. If significant energy savings are to be realised also in the future, the companies need to make continuous improvements as prescribed by the EnMS standard.

There is no officially declared PFE impact target. Hence, in order to evaluate the programme effectiveness the authors had to interpret and formulate a target-level. This assessment is complicated by the difficulty to envisage the impact on electricity efficiency improvement from a non-existing counterfactual situation. Even among non-participating companies, that are facing the minimum tax, it would be difficult to determine its influence on electricity consumption. The cost-raising effect is negligible in view of the increase in wholesale electricity price observed over the last 5–10 years. On the other hand, the tax rebate has been an important carrot incentive for companies to join PFE and undertake the agreed activities. This is evident among companies with annual electricity consumption above 100 GW h for which the programme coverage has been close to total.

Below, the 100 GW h/year threshold PFE is gradually becoming less attractive. As non-participating firms only account for 15% of eligible industrial electricity consumption the collective ineffectiveness from the missed-out savings should not be too large. Nevertheless, it is especially companies with lower electricity consumption (<100 GW h/year) that have reported large percentage savings. This shows that less energy-intensive industries have a lot to gain from the attention-raising activities that are typical for PFE and some other VAs (e.g., energy auditing and analysis, EnMS and routines). Hence, there should be a large potential also for non-participating companies to engage in the kind of energy management that has proved successful within all industrial sectors of PFE. It remains a major challenge for policy makers as well as commercial players (e.g., ESCOs) how to best stimulate these companies, with relatively high saving potentials, to make energy efficiency improvements. As an alternative policy instrument an industrial energy audit programme for SMEs was launched in 2010. It offers subsidized energy audits, requires companies to set up an energy plan and finally to report their implementation of measures (STEMFS 2010:2). Ex-ante estimates are expectant (Thollander and Dotzauer 2010) but since the scheme will remain for 5 years it is too early to evaluate its effectiveness.

Supported by the PFE documentation and reporting procedures, this paper used a bottom-up approach to evaluate gross and net impact. Another option would be a top-down approach to examine how the industrial electricity intensity has developed prior to and during the PFE period, then single out the actual electricity efficiency improvement and attribute an appropriate share to PFE. Given the heterogeneity between and within industrial sectors this methodology might not be feasible. At least it would require additional reporting by the companies and further data analysis by the administrating agency, which would increase administrative burden. Currently, the cost carried by the SEA for administration, which only partly goes to monitoring and evaluation (M&E), has equalled 5% of the total programme cost (see The cost-effectiveness of PFE section). Given that cost for M&E should be kept at reasonable level, the feasibility of such an evaluation effort would need to be more closely examined.

In addition, a bottom-up methodology needs to compromise between accuracy and evaluation cost. It is expressed by the net impact interval that the gross-to-net impact conversion suffers from uncertainties. Additional surveys could serve to improve the accuracy of the free-rider coefficient and provide better evidence for estimating a multiplier effect. Ideally, an evaluation plan is developed in the early phase of planning and formulating a policy instrument. In PFE such a plan could have served to integrate all necessary data into the overall documentation and reporting procedure, still with respect to the administrative burden shouldered by companies. In this way, relevant correction factors and other details would be given systematic attention and the need for supplementary surveys or making guesstimates could be avoided. An evaluation plan can also identify the forthcoming energy efficiency targets that the policy instrument should contribute to. The work of the EMEEES project on EU harmonised evaluation methodologies deserves some attention in this regards. To better pinpoint additionality is not only an issue about accountability against set targets. It also has a practical importance in strive for cost-effective policy implementation. The ESD does not explicitly require that only additional energy savings are counted against the 9% target of 2016. It does mention, though, that evaluation methods should be cost-effective and minimise administrative burden while reaching an acceptable level of accuracy. These considerations, i.e., reaching a cost-effective policy impact that can be monitored and evaluated by practical methods, is highly relevant also in view of the EU target of saving 20% of the projected primary energy demand in 2020.

With its process perspective, this evaluation has strived to go beyond the focus of quantifiable impact. Activities like the energy audit and analysis, the certified EnMS, the routines for energy efficient procurement and project planning, would unlikely come about in the absence of PFE. Neither would companies have been incentivised to document and report savings and thereby improve their practices for monitoring and verification. These are programme components with capacity to alter organisational structures around energy issues in the companies and at their industrial sites. PFE has been an impetus for such organisational changes that, in turn, can have long-lasting effect in terms of energy efficiency improvement.

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Paper II

Trends in energy performance of the Swedish pulp and paper industry: 1984–2011

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Abstract

The Swedish pulp and paper industry accounts for half of industrial final energy use in Sweden and 2% in EU–27. On the basis of a disaggregated set of physical production data a logarithmic mean Divisia index decomposition method is applied to disentangle the influence from activity, structure, and energy efficiency improvement on its fuel, electricity and primary energy use. An extended analysis tracks the fossil energy use and CO_2 emissions to discern past and present developments of industrial decarbonization. Between 1984 and 2011 the total production output increased by 49% while growth in primary energy use was limited to 26%. Compared to an activity-based scenario 50 PJ of primary energy use has been avoided through energy efficiency improvement and 6 PJ through structural change. The production has become oriented towards more electricity-intensive but less fuel-intensive segments. The electricity use efficiency improvement was negligible until year 2000 but sizeable thereafter as it started to outpace the counteracting impact from structural change. The analysis confirms results from previous bottom-up evaluations. The policy context is elaborated in a discussion about the role of relevant policies (e.g. energy management system obligation, EU ETS) in facilitating the enhanced energy efficiency improvement observed after year 2000.

Keywords: Energy-intensive industry; Decomposition; Energy efficiency; Decarbonisation

1 Introduction

At various political levels, from international high-level forums to national governments, there are expectations for energy efficiency improvement (EEI) to contribute to the achievement of various political objectives (IEA 2010; EC 2012; Wade et al. 2011). To unleash untapped EEI potentials across societal sectors is justified by studies which show the importance of this for reaching climate mitigation targets by 2050 and beyond (IEA 2013; IPCC 2007). In manufacturing industry, which account for a third of global energy demand, energy efficiency investments is among the least-cost options to reduce greenhouse gas emissions in the next decades (IEA 2010; Worrell et al. 2009). Through cost-cutting and improved competitiveness there can also be a strong business case for industrial EEI (IIP & IEA 2012).

EU's policy makers have manifested the importance of efficient energy use as exemplified by three policy frameworks: the energy services directive (EC 2006); the climate and energy package for 2020 (EC 2010); and most recently the energy efficiency directive (EC 2012). Each policy framework contains EEI targets; require contributions by Member States and sectors; involve monitoring and reporting procedures. For EEI or energy savings targets to be credible it is essential that the political process is informed by public authorities and independent research about the progress towards fulfilment, the impact and outcomes of policy instruments as well as autonomous change. Thus, the EEI development needs to be monitored and evaluated to ensure compliance, not the least when tax-funded incentives are applied for support, which is often the case for manufacturing industry. In EEI policy evaluation, two main approaches are commonly applied to estimate impact. Bottom-up methods assess and sum up the impact from individual EEI actions within a sector or certain policy target group, while top-down methods rely on statistical records over a relevant time period to estimate the aggregated EEI of a country or a sector (Thomas 2009).

In this paper a top-down decomposition approach based on physical indicators is applied to evaluate the trends in energy performance, i.e. energy use and energy efficiency improvement, in the Swedish pulp and paper industry (PPI) between 1984 and 2011. Being accountable for as much as half of the industrial and one fifth of the national final energy use (SEA 2012) it is essential that pulp and paper manufacturers contribute if Sweden is to make progress and achieve EEI targets and objectives at EU and national level.[1] A consistent and highly disaggregated data set allows for a quantification of the changes in the PPI's energy use due to the influence from the three factors: structure (i.e. production mix); activity (i.e. production volume); and energy intensity (i.e. specific energy consumption at product level). The analysis is conducted on the basis of data for fuel, electricity and primary energy use. In addition, though on a more aggregated level, it is examined how fossil fuel use and related CO_2 emissions have developed. The paper complements recent but methodologically different studies, about the influences from energy policies and market mechanisms on Swedish energy-intensive industries and especially the PPI (e.g. Stenqvist and Nilsson 2012; Henriksson et al. 2012; Ericsson et al. 2011; Lindmark et al. 2011; Ottosson and Magnusson 2013; Ottosson 2011). It provides a refined update to previous, less disaggregated, decomposition studies on energy use in Swedish PPI (Isacson et al. 1987, 70; Farla et al. 1997; Lindmark et al. 2011).

The purpose is to demonstrate, with precision and novelty, how the Swedish PPI's energy performance has developed over time. The development over the recent period (2000–2011) is related to that of the earlier period (1984–2000) to explore if the last decade of activities in the energy policy field has had impact on the Swedish PPI. It is assessed how the progress relates to EU, national and industry specific objectives and programmes for EEI, renewables and climate mitigation. The combination of quantitative analysis and informed discussions on potential cause and effect relationships of industrial energy policies are deemed important for the future of energy efficiency policy making.

The remainder of the paper has the following disposition. Section 2 treats methodological issues, describes the applied data set, and clarifies some constrains. Section 3 gives a background to the Swedish PPI and its physical production over the analysis period. Section 4 provides the results, first as a

[1] The Swedish PPI alone accounts for 2.3% of the entire EU–27 industrial final energy use (Eurostat 2013; SEA 2012). Moreover, as a large user and supplier of renewable energy it can influence the achievement of the binding EU targets on renewable energy supply and reduction of GHG emissions up to 2020 (EC 2010).

sector level analysis of energy use followed by the main results of the decomposition analysis. Complementing results fuel use and related CO_2 emissions are also provided. Section 5 provides a discussion about the influence of industrial energy policies and section 6 concludes.

2 Methodology

2.1 Method selection

A variety of analytical techniques have been developed and applied to analyse, model and forecast trends of industrial energy use and energy related emissions. To provide a categorization Greening et al. (2007) formulates research questions that energy analysts from different disciplines often seek to answer, and identifies five groups of purposeful analysis techniques. Decomposition analysis qualifies as a category applicable by analysts who seek to disentangle the influence of factors like activity, structural change and specific energy use on the aggregated energy trends in a country or in a certain sector of economy. Various decomposition methods have been proposed and applied for different purposes since the start of their use in the 1970s. In a survey Ang (1995) found 51 studies and in a later survey Ang and Zhang (2000) could identify 124 relevant studies published between 1978 and 1999. With the growth of empirical studies the field of applications has expanded, i.e. from foremost industrial energy demand analysis in the past to involve also industrial air-emissions (e.g. CO_2, NO_X and SO_2) and other sectors of economy like transportation and electricity generation. In a sector level analysis of manufacturing industry the influential factors can be described as (Phylipsen et al. 1998, 17):

- Activity (ACT): indicates the level and change in the sector's production of goods, either on the basis of physical indicators, like tonnes of products, or on the basis of monetary indicators, like industrial gross value added of production. Increased production volume will, ceteris paribus, result in a proportional increase in sector energy use.

- Structural change (STR): indicates the level and change in the sector's composition of products. Intra-sectoral activity alters the production mix and thus the overall energy intensity and energy use of the sector.
- Energy intensity (INT): indicates the level and change in specific energy use required for production at a certain level of disaggregation. Decreased energy intensity at the product level is taken as an approximation of actual energy efficiency improvement.

The influence from each factor on the energy use contributes to the total change in the sector's energy use $\Delta E_{t,T}$ between year t and T according to Equation 1:

$$\Delta E_{t,T} = \Delta E_{t,T(ACT)} + \Delta E_{t,T(STR)} + \Delta E_{t,T(INT)} \quad (1)$$

To determine the contributions of the three factors a decomposition method including a set of equations needs to be selected. The commendable work of Ang and co-authors has guided the methodological selection for this application study. Continuous studies have highlighted the latest methodological developments, categorized available methods, and provided recommendations to practitioners in the field of decomposition analysis (Ang 1995; Ang and Zhang 2000; Ang 2005; Ang and Liu 2007). As Greening et al. (2007) and others have pointed out no there is no universal or standard method for energy trend decomposition. However, some previously applied methods have been outperformed by new method proposals. The methodological framework of parametric Divisia index methods that was outlined in Ang (1995) is no longer a preferred choice in Ang and Zhang (2000). The residual term issue, representing an unexplained effect, is handled by the refined Laspeyres index method and the logarithmic mean Divisia index method (LMDI) which yields perfect decomposition results. This study applies a version of the latter approach, namely the LMDI I. It has been used by a growing number of studies since year 2000 and has several advantages (e.g. ease of application and flexibility) over other methods (Ang and Liu

2007). In the special case of an additive energy consumption approach, the LMDI I define each factor as given by the Equations 2–4 (Ang 2005):

$$\Delta E_{t,T(ACT)} = \sum_i \frac{E_i^T - E_i^t}{\ln E_i^T - \ln E_i^t} \ln\left(\frac{Y^T}{Y^t}\right) \tag{2}$$

$$\Delta E_{t,T(STR)} = \sum_i \frac{E_i^T - E_i^t}{\ln E_i^T - \ln E_i^t} \ln\left(\frac{S_i^T}{S_i^t}\right) \tag{3}$$

$$\Delta E_{t,T(INT)} = \sum_i \frac{E_i^T - E_i^t}{\ln E_i^T - \ln E_i^t} \ln\left(\frac{I_i^T}{I_i^t}\right) \tag{4}$$

With the variables defined as:

E_i^T = energy use in sub-sector *i* year *T*

Y^T = total industrial sector production volume year *T*

S_i^T = production share of sub-sector *i* year *T*

I_i^T = specific energy use of sub-sector *i* year *T*

$t = T - 1$

Thus, for each of the three decomposition factors the calculations are performed at every defined sub-sector level *i* and between the years *t* and *T*. The result is derived as the summation over all sub-sectors and all intermediate time-periods to cover the entire analysis period.

For studies on past developments Ang (1995) recommends either the energy consumption or the energy intensity approach. Distinction is also made between additive and multiplicative decomposition. As demonstrated by the Equations 2–4 an additive energy consumption approach has been selected, which means that results will be presented as the aggregated change in industrial energy use between the different years of the time-series. Such a presentation of results in terms of energy units, rather than energy intensity ratios or elasticities, which denote the change in energy use from each factor compared to the base-year, is likely to be understood by many readers (Ang 1995). With the input of the empirical data, described in the following section, the equations have been calculated in a standard spreadsheet software program.

2.2 Data used in the analysis

The main data source utilized is unique and highly suitable for this type of industrial sector micro-level analysis. Since 1973, on behalf of the Energy and Environmental Committee of the Swedish Forest Industries Federation, the energy analyst Rolf Wiberg has conducted systematic surveys and compiled detailed site and process level data on fuel, heat and electricity use from all mills of the Swedish PPI.[2] The selected analysis period (1984–2011) is covered by six surveys (Wiberg 1985, 1989, 1995, 2001, 2008; Wiberg and Forslund 2012). Additional statistics, mainly from the Swedish Forest Agency (SFA), the Swedish Energy Agency (SEA) and the Swedish Forest Industries Federation (SFIF) has contributed to the analysis.

A decomposition study can be carried out on the basis of physical indicators (e.g. GJ per tonne of a product) or monetary indicators (e.g. GJ per industrial value added). The physical approach is selected here as being the most useful for analysing the energy performance of the production in energy-intensive industry (Phylipsen 1998; Farla et al. 1997). Physical production data is also practical to use compared to monetary values since there is no need to adjust nominal values for inflation or convert currencies to allow for cross-country comparisons. Indeed, the choice between physical and monetary data also depends on the availability of data at a desired level of disaggregation. The Wiberg surveys attributes the use of different energy carriers to the manufacturing of 27 product categories, including 16 pulp products and 11 paper and board products.

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[2] In the EU system of industry standard classification the PPI is covered by the NACE code C17.1 – Manufacture of pulp, paper and paperboard.

At this level of detail – on the basis of final fuel use, electricity use and primary energy use[3] – the analysis of this paper is performed as a time-series decomposition between 1984 and 2011 with input data from the six survey years, and as a period-wise decomposition over the intermediate time-intervals. A period-wise decomposition is performed between the first year ($t = 0$) and the final year (T) of an analysis period, but does not include intermediate figures (e.g. changes at one-year interval). A time-series decomposition, on the other hand, is performed between pairs of intermediate data points ($t = 0, 1, 2 \ldots n$ and $T = t + 1$) and the final result is the sum of changes over the whole analysis period. The latter approach involves more efforts for data collection and processing and provides a more refined result. Available survey data enables a combination of the two approaches with the overall time-period of adequate length (i.e. 28 years) to generate a trend analysis. It should be considered in the interpretation of results that the intermediate time-periods are of variable length.

The Wiberg survey data is reported by staff at the mills via a data form which systematically compiles the same type of information. In each year the response rate has been between 98 and 100% of all mills. Absolute consumption data for external fuels and electricity have high reliability; the corresponding data for internal fuels, derived from delivered steam at estimated efficiency, have good reliability. In surveys from 1984 to 2007, fuel use data is expressed as litre of oil equivalents (Loe) based on lower heating values for different fuel types (e.g. 39 GJ/m^3oe for fuel oil). In the last survey, due to diminishing oil use, fuel use is expressed as kilowatt hours (kWh). Actual or estimated efficiencies have been applied to fuel-to-steam conversions. The specific energy consumption for different product categories has been

[3] *Final fuel use* is defined as all fuel used directly in the production processes and for steam generation, but not fuel used for on-site electricity generation (i.e. to avoid double-counting). *Electricity use* is defined as the sum of purchased electricity from the grid and the electricity which is generated on-site (less electricity sold to the grid). *Primary energy use* is defined as the sum of: (1) the final fuel use; (2) the use of grid electricity with a conversion factor of 2.5 applied (i.e. based on an estimated 40% conversion and grid transmission efficiency) and; (3) the use of internally generated electricity with actual fuel-to-electricity conversion factors applied for installed backpressure turbine systems.

metered at the level of detail allowed by the mill's sub-metering infrastructure. Improved metering infrastructure was implemented between 1979 and 1984, and successively thereafter, which has increased the reliability of firm's self-reported data in 1984–2011. Reported data has been converted to annual averages for all production sites and adjusted for influence from seasonal climate variations, production disruption etc. In case of conspicuous deviations, Wiberg has discussed reported values with responsible staff and made appropriate corrections. All survey years from 1984 to 2007 are characterized by high capacity utilization rates while the situation in 2011 was different. The impact from lower capacity utilization rates and shutdowns is addressed in the result section of this paper. (Wiberg 1985-2008; Wiberg and Forslund 2012)

Two surveys (Wiberg 1974, 1980) are excluded from the decomposition analysis period and inconsistencies in the product categorization are thereby avoided. In addition, since an objective of this study is to provide policy relevant results on energy performance over the post-2000 period in relation to the preceding period, the 1970s is less important. Previous developments in energy use and CO_2 emissions intensities in Swedish PPI have been decomposed in other studies (e.g. Farla et al. 1997; Lindmark et al. 2011). Some data from the early surveys is included in the aggregated analysis of fuel use and CO_2 emissions, which in addition to Lindmark et al. (2011) captures the development from 2006 to 2011.

3 Background

3.1 Industry trends

The Swedish PPI hold the positions as Europe's largest pulp producer and second largest paper and board producer after Germany (CEPI 2012). In 1984, 70 mills produced 16.5 Mt pulp and paper products (Wiberg 1985). By 2011, the number of mills had decreased to 52 while total production had increased to 24.5 Mt (Wiberg and Forslund 2012). Some trends over the analysis period are:

- Mergers, acquisitions and international expansion have characterized the growth strategy since the 1980s (Ojala et al. 2006). Consolidations have resulted in fewer but larger mills located in Sweden. Between each survey, two to five mills have been taken out of operation (Wiberg 1985–2008; Wiberg and Forslund 2012).
- There has been no real greenfield investment since the 1970s but upgrades of existing mills have incrementally increased production capacity (Wiberg 1985–2008; Wiberg and Forslund 2012).
- The nominal value added of production has gone from 21 to 35 billion SEK (SFA 1987, 2012). This corresponds to a decline in real values which reflects an increased competition, higher cost for raw materials, falling export prices for some product segments etc. (Ojala et al. 2006).
- The PPI has shrunk relative to the size of the manufacturing industry; its share of industrial value added decreased from 11% to 7.5% (SFA 2012).
- While the cost share for raw materials has increased the cost share for wages has decreased. The number of full-time employees was 30,000 in 2011 compared to 55,000 in 1984 (SFA 2012).

3.2 Physical production

Figures 1 and 2 demonstrate how the production divided into the 27 categories has developed in 1984–2011.[4] Total output has increased by 49% and until 2007 at an annual rate of 2%. However, the last period (2007–2011) demonstrates a production decline of 5%, which is partly attributed to the permanent shutdowns of five production sites (Wiberg and Forslund 2012).

For pulp grades Figure 1 demonstrates that pumped thermo-mechanical pulps (TMP & CTMP) and bleached sulphate pumped pulp, being produced and

[4] This categorization includes all paper and board products, market pulp as well as pumped pulp (Wiberg 1985–2008; Wiberg and Forslund 2012).

refined to paper products in integrated mills, have had the largest growth since 1984. After 2007 it is foremost the production of bleached sulphate market pulp and recovered fibre pulp that have declined. The former is due to a mill shutdown and the latter to increased export of recovered paper to markets with higher willingness to pay (SFA 2012). Due to the access and reliance on virgin fibre the recovered fibre utilization rate remains low in Swedish PPI (10–20%) compared to PPI in other countries (40–80%) (Farla et al. 1997; IEA 2007).

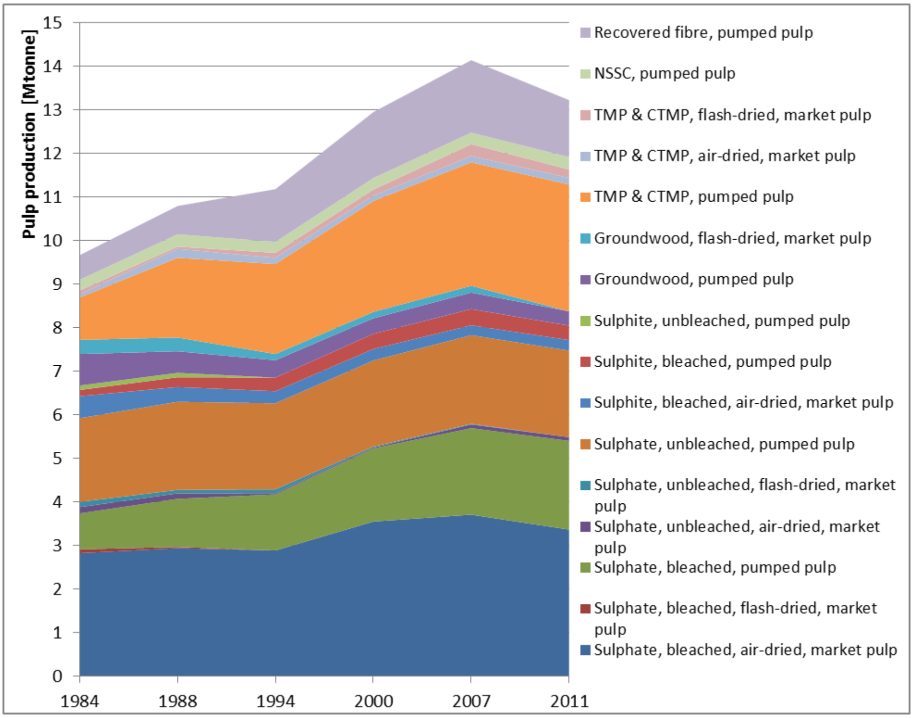

Fig. 1 Production of pulp grades 1984–2011. Source: based on data from Wiberg (1985–2008) and Wiberg and Forslund (2012)

For paper and board grades Figure 2 demonstrates that the production of kraft board, newsprint and magazine paper have increased the most since 1984. Since 2007, there has been a decreased production of carton board, kraftliner and fine paper due to shutdowns of some smaller sized mills. The production of newsprint, a segment which has suffered from diminishing market demand

and excess capacity, started to decrease after 2007. Further cutbacks in the capacity for graphic papers (i.e. newsprint, magazine paper) have been announced and executed in 2012–2013. These segments will be reduced by some 1.2 Mt or 30% and related production declines in pumped TMP can be expected (Danske Bank 2013).

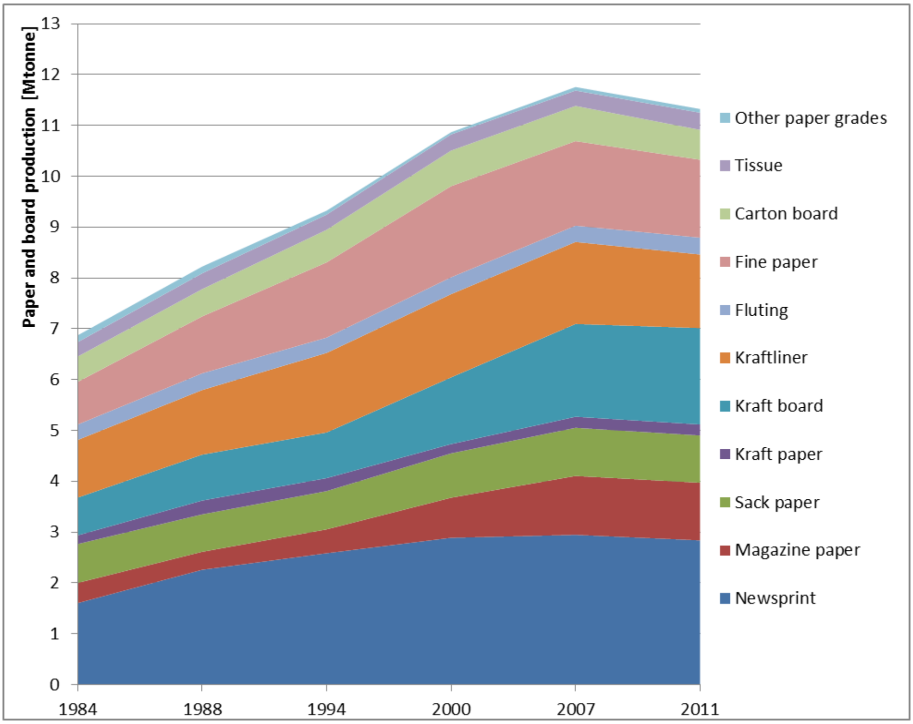

Fig. 2 Production of paper and board grades 1984–2011. Source: based on data from Wiberg (1985–2008) and Wiberg and Forslund (2012)

4 Results

4.1 Aggregated energy analysis

The total final energy use of Swedish manufacturing industry (i.e. 534 PJ in 2010) is dominated by a few energy-intensive sectors of which the PPI accounts for more than half (276 PJ in 2010) (SEA 2012). Figure 3 demonstrates how categories of the PPI's fuel use, electricity use and primary energy use has developed over the survey years, e.g. ranging from a 17% growth in final fuel use to a 44% growth in total electricity use. The gap between total and final fuel use corresponds to the fuel allocated for internal electricity generation which has increased substantially both in installed capacity and in operation of back pressure turbine systems.[5] Although internal electricity generation has curbed the demand, purchased grid electricity has increased by 3.4 TWh/12 PJ (27%) to reach 15.8 TWh/57 PJ in 2011.

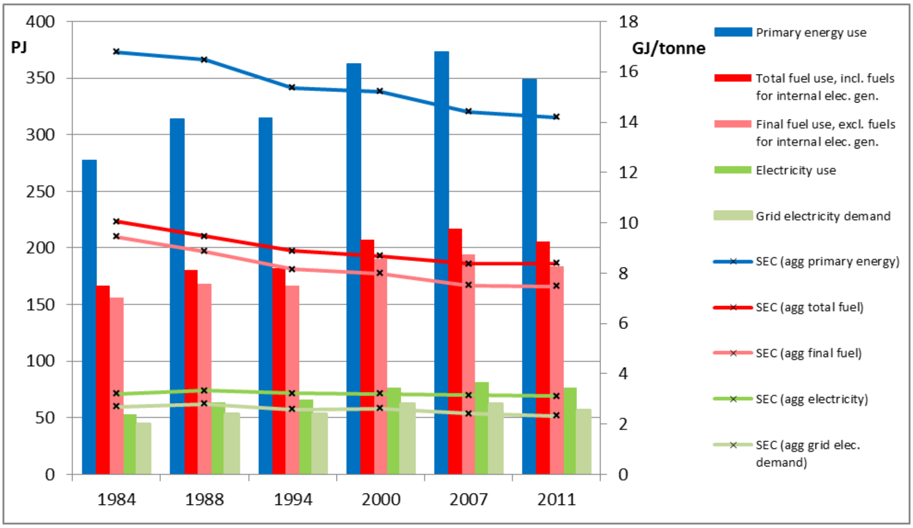

Fig. 3 The development of total (primary y–axis) and specific (secondary y–axis) fuel use, electricity use and primary energy use (1984–2011). Source: based on data from Wiberg (1985–2008) and Wiberg and Forslund (2012)

The growth in physical production exceeds the growth of all categories of energy use (1984–2011). At aggregated level the specific energy consumptions (SECs) have developed as follows:

- $SEC_{agg\ total\ fuel}$: -17% (-0.7% per year)

[5] Between 1984 and 2011, internal electricity generation increased from 2.4 TWh to 5.7 TWh (i.e. 140%) and its share of the total electricity use increased from 16 to 27% (Wiberg and Forslund 2012).

- $SEC_{agg\ final\ fuel}$: -21% (-0.9% per year)
- $SEC_{agg\ electricity}$: -3%, (-0.1% per year)
- $SEC_{agg\ grid\ electricity}$: -14% (-0.65% per year)
- $SEC_{agg\ primary\ energy}$: -17% (-0.7% per year)

The recent period (2007–2011) demonstrates an absolute reduction in all categories of energy use. It reflects the production decline due to the permanent shutdown of five mills and the lower capacity utilization rate, estimated 3% lower in 2011 compared to 2007.[6] The fact that $SEC_{agg\ primary\ energy}$ has decreased despite a lower capacity utilization rate indicates that energy efficiency improvement and/or structural change has generated absolute primary energy savings since 2007, in addition to the decreased activity.

4.2 Decomposition analysis

In this section Figures 4, 5 and 6 show the results of the decomposition analysis of the PPI's final fuel use, electricity use and primary energy use. Period-wise results are displayed on the left-hand side (lhs) and time-series results for the whole analysis period are displayed on the right-hand side (rhs). As a complement and to enable benchmarking the Appendix compiles the product level SECs for some survey years.

4.2.1 Final fuel use

Final fuel use increased by almost 27 PJ (or 17%), from 156 PJ in 1984 to 183 PJ in 2011. Figure 4 (rhs) demonstrates that 41 PJ (or 60%) of the hypothetical increase in final fuel use expected from increased activity was

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[6] Official statistics does not provide capacity utilization rates at sub-sector level. The capacity utilization rate of the entire Swedish manufacturing industry was 91% in 2007 and after levels of 75–80% in 2009 it recovered to 88% in 2011 (SCB 2013a). An estimated 3% decrease for the PPI is supported by production data (Wiberg and Forslund 2012) in combination with data on production capacity of the closed mills (SFIF 2013).

avoided. The contribution from fuel use efficiency improvement was 26 PJ of final fuel savings while 15 PJ was avoided by structural changes.

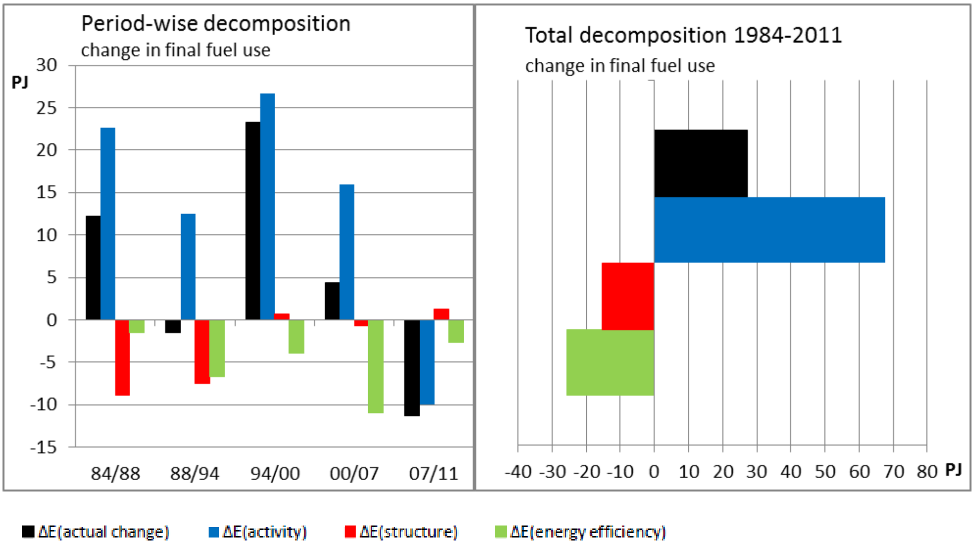

Fig. 4 Decomposition of change in final fuel use, period-wise (lhs) and over the analysis period (rhs)

Structural change of relevance occurred 1984–1994 when shifts in production mix had a clear downward impact on fuel demand. Over this period, the production volumes and relative shares of the segments pumped TMP, recovered fibre pulp, and newsprint increased substantially (see Figure 1 and 2). These segments are produced in integrated mills with low specific fuel use. For pumped TMP which requires no fuel for drying the $SEC_{final\ fuel}$ is 0.4–0.6 GJ/t and for recovered fibre pulp the $SEC_{final\ fuel}$ is only 0.3 GJ/t. Newsprint, being a final product, does require fuel for drying but the $SEC_{final\ fuel}$ at 4–5 GJ/t is the lowest among paper and board products (see Appendix).

For 19 of the 27 product categories the $SEC_{final\ fuel}$ decreased 1984–2011. For all the paper and board products, except the residual category of other paper, $SEC_{final\ fuel}$ decreased; from -5% for kraftliner to -36% for fine paper. As a weighted average for paper and board grades, the specific final fuel use reduction was -23%. Among pulp grades, for 9 of 16 products the $SEC_{final\ fuel}$

decreased; from -1% for pumped unbleached sulphate to -41% for air-dried TMP. For some grades (e.g. TMP pumped and bleached sulphite market pulp) the $SEC_{final\ fuel}$ increased by 20–30%. As a weighted average for 15 pulp grades, excluding recovered fibre pulp[7], the specific final fuel use increased by 1.5% (1984–2011).

Fuel use efficiency improvement occurred to some extent in all periods but particularly in 2000–2007 when 11 PJ was saved through efficiency measures. The largest segment, bleached sulphate market pulp, demonstrates a $SEC_{final\ fuel}$ reduction of -6% in this period. For six large paper and board products (i.e. fine paper, kraft board, kraftliner, magazine paper, sack paper and carton board) which accounts for two thirds of the paper and board production the $SEC_{final\ fuel}$ decreased by 8–20% in 2000–2007.

4.2.2 Electricity use

Electricity use increased by 6.5 TWh (or 44%), from 15 TWh in 1984 to 21.5 TWh in 2011. Figure 5 (rhs) demonstrates that 0.7 TWh (or 10%) of the hypothetical increase in electricity use expected from increased activity was avoided. The contribution from electricity use efficiency improvement was 1.4 TWh of savings while structural change increased demand by 0.8 TWh.

[7] Recovered fibre pulp has an exceptionally low specific final fuel use in 1984 compared to later survey years (see Appendix). This category has been excluded to avoid distortion of the weighted average for the pulp grades.

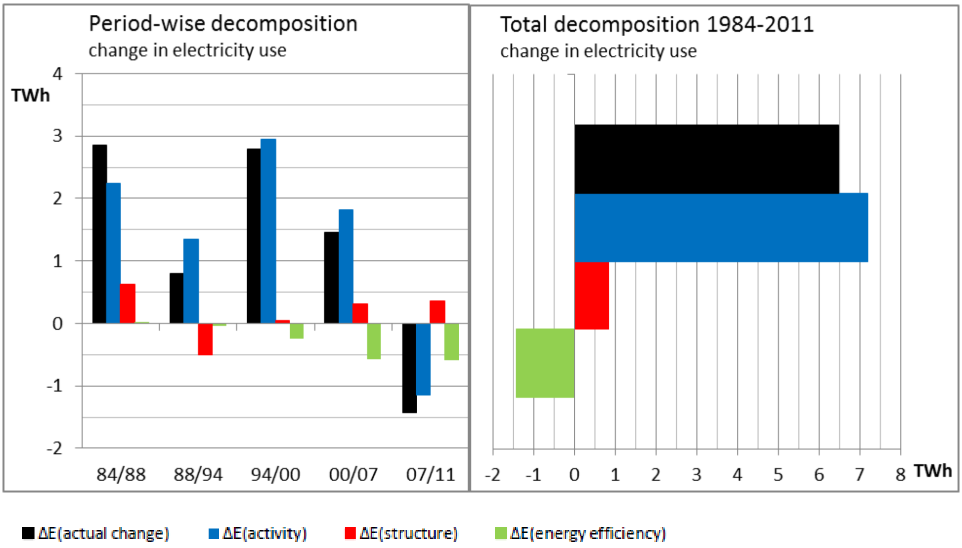

Fig. 5 Decomposition of the change in electricity use, period-wise (lhs) and over the analysis period (rhs)

Structural changes, which have increased electricity use are (see Appendix):

- The production share of pumped TMP has doubled since 1984; at 12% in 2011 it was the second largest segment. With its high $SEC_{electricity}$ at 2208 kWh/t this segment accounts for 30% of the PPI's electricity use. Production increased most rapidly 1984–1988 as made evident by the period-wise impact on electricity demand.
- The production shares of relatively electricity-intensive segments like magazine paper and kraft board increased from year 1994.
- Production of bleached pulp segments has increased while unbleached segments have been constant or in decline. Delignification and bleaching requires additional electricity use, e.g. for pumped sulphate the $SEC_{electricity}$ is 30–50% higher for bleached pulps.

Despite increased production shares for electricity-intensive segments electricity use efficiency improvements counteracted the impact from structural change and prevented a growth in specific electricity use. For 17 of

27 products the $SEC_{electricity}$ decreased 1984–2011. Among paper and board, for 8 of 11 products the $SEC_{electricity}$ decreased; from -2% for fluting to -29% for kraft board. For some products (e.g. tissue, fine paper, carton board) the $SEC_{electricity}$ decreased by 15–25%. As a weighted average for paper and board grades, the specific electricity use reduction was -10%. Among pulp grades, for 9 of 16 products the $SEC_{electricity}$ decreased; from -5% for the two largest segments (i.e. TMP pumped, bleached sulphate market pulp) to reductions of 25–35% for the minor segments of TMP market pulps. For the electricity-intensive ground-wood pulps the $SEC_{electricity}$ increased by 15–30%. However, due to shutdowns the production share of ground-wood pulps was only 1% in 2011 compared to 6% in 1984; a structural change which reduced electricity demand foremost in 1988–1994. As a weighted average for the 16 pulp grades the specific electricity use decreased by -5% (1984–2011).

Electricity use efficiency improvement was negligible in 1984–1994. However, since year 2000 1.2 TWh has been saved through efficiency measures. For the large segment unbleached sulphate pumped pulp the $SEC_{electricity}$ was reduced by -16% in this period, and for some paper and board grades (e.g. kraft board, kraftliner, fine paper) the $SEC_{electricity}$ was reduced by -10%.

4.2.3 Primary energy use

Primary energy use increased by 71 PJ (or 26%), from 278 PJ in 1984 to 349 PJ in 2011. By the application of different conversion factors for grid and on-site generated electricity, the EEI from increased on-site generation is incorporated in the primary energy use analysis.[8] Figure 6 (rhs) demonstrates that 56 PJ (or 44%) of the hypothetical increase in primary energy use expected from increased activity was avoided. The contribution from energy efficiency improvement was 50 PJ of primary energy savings while 6 PJ was avoided by structural changes.

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[8] Chemical pulp mills generate electricity on-site with high-pressure recovery boilers and backpressure turbines. Exhaust lower-pressure steam is utilized for process heating like drying market pulp or paper in integrated mills. According to the allocation procedures used in Wiberg (1985–2008) and Wiberg and Forslund (2012) the efficiency of internal electricity generation corresponds to a fuel-to-electricity conversion factor of 1.17–1.25.

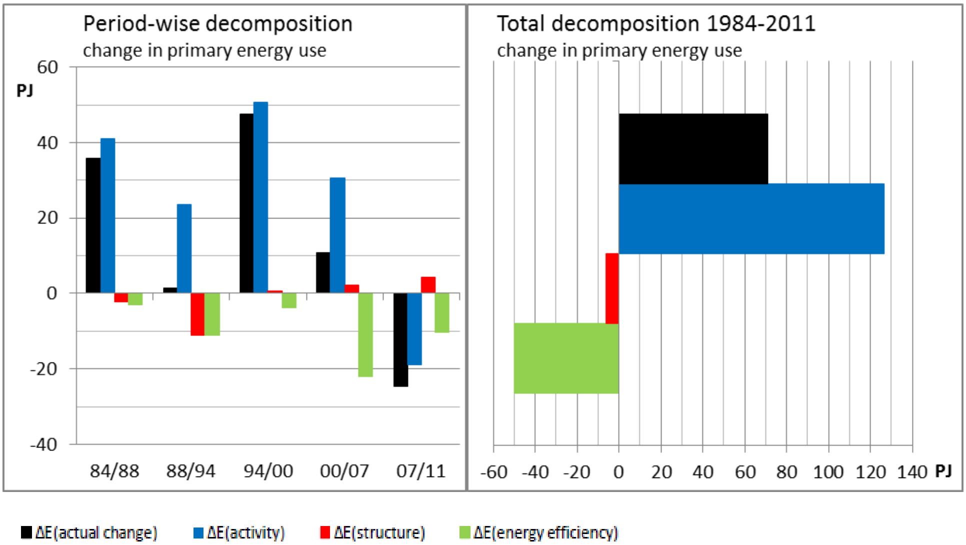

Fig. 6 Decomposition of primary energy use, period-wise (lhs) and over the analysis period (rhs)

Structural change influenced primary energy use foremost in 1988–1994 when the production share of recovered fibre pulp almost doubled. The $SEC_{primary\ energy}$ for recovered fibre processing is a low 3–4 GJ/t compared to virgin pulp routes that require 15–20 GJ/t. The decreased production share of groundwood pulps has also influenced the primary energy use in this period (Wiberg 1985, 1989, 1995; Appendix).

For 20 of 27 products the $SEC_{primary\ energy}$ decreased in 1984–2011. For all paper and board grades, except other paper grades, the $SEC_{primary\ energy}$ decreased; from -3% for kraftliner to 30-35% reductions for kraft board and fine paper. As a weighted average for paper and board grades, the specific primary energy use reduction was -20%. Among pulp grades, for 10 of 16 products the $SEC_{primary\ energy}$ decreased; from -4% for pumped TMP to -38% for air-dried TMP. As a weighted average for the 16 pulp grades the specific primary energy use decreased by -6% (1984–2011).

The primary energy use savings from EEI was a sizable 22 PJ in 2000–2007. The pattern of period-wise primary energy use efficiency improvement resembles the pattern of period-wise fuel use efficiency improvement (see

Figure 4), but the electricity use efficiency improvement clearly contributes after 2000. In 2007–2011, primary energy use decreased by 25 PJ as a function of production declines and EEI especially in electricity use.

4.3 Fossil fuels, biofuels and CO_2 emissions

Figure 4 shows a final fuel use EEI of 26 PJ (1984–2011). Due to the opportunities to substitute fuels it is not justified to perform a separate decomposition analysis for a certain fraction of fuel use, e.g. fossil fuels. The results would be complicated by the fact that the "efficiency improvement" from reduction of one fuel type (e.g. oil) is counteracted by increased use of other fuel types (e.g. spent liquor, bark etc.). However, to extend the scope from industrial energy demand to environmental impact, a decomposition approach could be used to analyse energy related emissions. Such methodological frameworks have been proposed and applied to analyse industrial CO_2 emissions (Ang 2005; Diakoulaki and Mandaraka 2007). It requires that fuel-mix at sub-sector level and fuel specific emission factors are incorporated in the analysis. At the level of the 27 products the Wiberg surveys do not provide sufficient data on fuel-mix to execute a decomposition analysis of related emissions.[9]

However, on an aggregated level it can be examined how total fuel use and fossil CO_2 emissions, the main contributor of human induced climate change (IPCC 2007), has developed over the analysis period. The reduction of fossil fuel use in favour of biofuels in Swedish PPI is a development which has been examined before (e.g. Lindmark et al. 2011; Ottosson 2011). However, due to restricted time-series such studies have not analysed the latest development. Thus, Figure 7 demonstrates how total fuel use and CO_2 emissions of the Swedish PPI have developed between 1973 and 2011.[10] The fossil fuel fraction

[9] The Swedish PPI uses up to 20 different fuel types. On the product level these fuels are merged into the main categories: external fuel oil; external other fuels; internal spent liquor; internal bark; internal other fuels. The large category external other fuels represent a mix of several fuels, fossil and non-fossil (Wiberg and Forslund 2012).

[10] Compared to final fuel use, total fuel use includes fuels for on-site electricity generation (see Figure 3). Thus, the numbers are somewhat higher, e.g. 166 vs. 156 PJ (1984) and 217 vs. 195 PJ (2007).

has decreased from 85 PJ (or 43%) to 14 PJ (or 7%) with the most drastic reduction in 1979–1984. Fossil fuel use was more or less constant in 1984–2000 but the decarbonisation in absolute numbers was resumed after 2003.

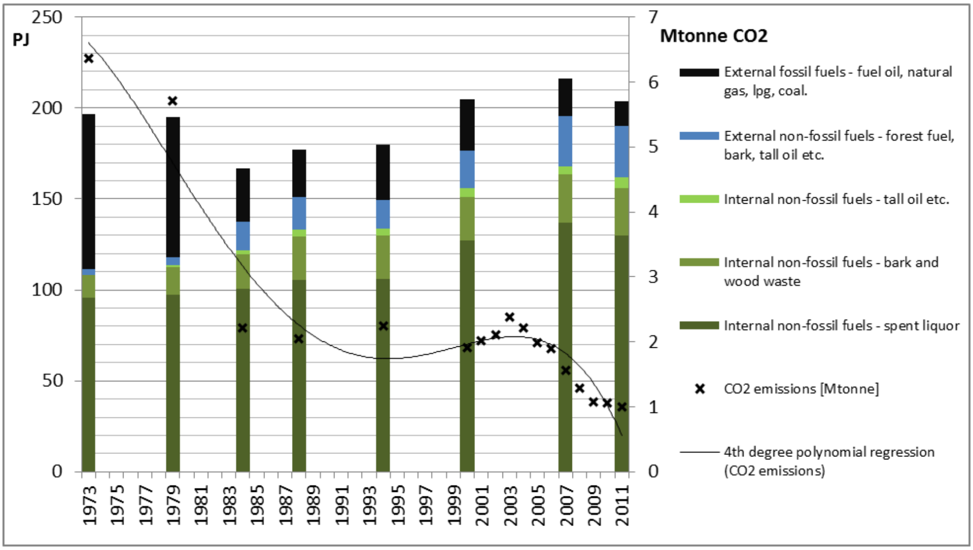

Fig. 7 Total fuel use (primary y-axis) and related CO_2 emissions (secondary y-axis). Source: based on data from Wiberg (1974–2008), Wiberg and Forslund (2012) and SFIF (2013)

As a result of fuel-shifts and fuel use efficiency improvements the direct CO_2 emissions have been reduced by 85%, from 6.4 Mt to 1 Mt in 1973–2011. In international comparisons the Swedish PPI stands out as the most CO_2 efficient (IEA 2007); defining CO_2 intensity as direct CO_2 emissions from fossil fuel combustion and indirect emissions from purchased electricity in relation to the volume of paper and paperboard produced and pulp exported. In 2003, the CO_2 intensity was 130 kg CO_2/t for the Swedish PPI while the weighted average for the PPI in thirteen OECD countries was 470 kg CO_2/t (Ibid). Considering the absolute emissions reductions since 2003, the Swedish indicator reached 100 kg CO_2/t in 2011.[11]

[11] The estimate is based on an emission factor of 0.036 kg CO_2/kWh purchased electricity, being representative for the Swedish grid electricity mix in 2008 (Gode et al. 2011, 119).

5 Discussion

The paper has analysed and provided results on the development of physical output, energy demand and CO_2 emissions, energy efficiency improvement (EEI) and structural changes in the Swedish pulp and paper industry (PPI). Between 1984 and 2011, compared to an activity-based reference scenario, it is estimated that EEI led to the avoidance of: 26 PJ (or 38%) of final fuel use; 1.4 TWh (or 19%) of electricity use; and 50 PJ (or 40%) of primary energy use. Structural changes had lesser impact than EEI on the PPI's energy use as it led to the avoidance of 15 PJ (or 22%) of final fuel use and 6 PJ (or 5%) of primary energy use, and caused electricity demand to increase by 0.8 TWh (or 11%). Thus, production has become oriented towards somewhat more electricity-intensive and less fuel-intensive segments. Another observation is that EEI is more pronounced among paper and board segments than pulp segments.

While electricity efficiency improvement was negligible in the first half of the analysis period there has been period-wise electricity savings of around 0.6 TWh both in 2000–2007 and 2007–2011. It corresponds to 3% of annual average savings in relation to the electricity use in respective base-year. The top-down derived result in this paper are consistent with previous ex-post bottom-up evaluations based on firm's self-report electricity savings under the Swedish policy programme for energy efficiency improvement in energy-intensive industries (PFE).[12] In the first PFE period (2005–2009), participating firms from PPI reported 0.67 TWh of gross annual electricity savings from technical replacements, O&M and energy efficient procedures (SEA, 2009). It has been estimated that 50–70% of these savings are additional, i.e. attributable to PFE (Henriksson et al. 2012; Stenqvist and

[12] PFE is a voluntary agreement in which participating firms are required to: conduct energy audits; have certified energy management systems conform to ISO 50001; adopt procedures for energy efficient procurement and project planning; implement and report electricity savings actions. Firms are incentivised by an exemption from the minimum tax on industrial electricity use (i.e. 0.5 Euro/MWh) introduced by the EU Energy Tax Directive and are required to achieve electricity savings at a level which would be expected had the tax been in place (Stenqvist and Nilsson 2012). PFE will expire in 2014 due to revisions of the EU state-aid rules for environmental protection.

Nilsson 2012). Ex-ante bottom-up assessments of the second PFE period (2009-2014) indicate that the PPI will achieve 70% of the total deemed 0.8 TWh annual electricity savings for industry as a whole (SEA 2013a). Fuel use EEI has occurred in all periods but especially in 2000–2007 when it led to the avoidance of 11 PJ final fuel use. The enhanced EEI in this period has also been facilitated by the firm's energy management systems (EnMS) and energy auditing activities under PFE. In addition to electricity saving actions, 40% of the PPI's sites voluntarily reported 3.5 PJ of fuel and heat savings under the first PFE period (SEA 2013b). This participant spill-over effect is consistent with the enhanced fuel use EEI observed by the period-wise decomposition (2000–2007).

In terms of CO_2 emissions the Swedish PPI has resumed its phase out of fossil fuels in the last decade. Remaining oil use exists mostly in the lime kilns of the sulphate pulp process. The biofuel lime kiln is considered a long-term solution for the European PPI to achieve 80% GHG emission reductions by 2050 (CEPI 2011, 26). The Swedish PPI is currently adopting this technology and in 2007–2011 the fossil fuel use in lime kilns was reduced by 25% (Wiberg and Forslund 2012, 42). The installation of a large lime kiln fueled with crushed sawdust pellets was completed in 2011 (Gulbrandsen and Stenqvist 2013a) and additional installations are underway (Haaker 2013). The full impact of these investments in terms of CO_2 emission reductions will be apparent in the next few years but it shows that Swedish PPI is moving towards a close to complete decarbonization. Another outlook is that structural changes are awaited as large shares of production capacities for electricity-intensive segments like newsprint, magazine paper and pumped TMP have been closed in 2012–2013. Thus, the past trend of structural change towards more electricity-intensive and less fuel-intensive segments observed in 1984–2011 will be interrupted. Without alternative production the announced cutbacks could reduce the Swedish PPI's electricity demand by 3 TWh.[13]

The results confirm that the case for EEI has been strengthened in the Swedish PPI over the post-2000 period. Interacting factors, policy-driven and

[13] This estimate of 3 TWh corresponds to some 2% of Swedish electricity use and the annual electricity generation from the country's oldest operating nuclear reactor.

autonomous changes, have contributed to make EEI actions and investments more attractive than before. Real prices on fuel oil and electricity have increased compared to historically low price levels in the late 1980s. Between 2000 and 2006 Swedish industrial electricity prices doubled and the relatively high price levels were maintained until 2010, after which there has been a downward trend (SCB 2007, 2013b). The EU emissions trading scheme (EU ETS) has contributed to the electricity price increase, which the PPI perceives to be the main influence of the scheme (Gulbrandsen and Stenqvist, 2013a). However, the intended main mechanisms of EU ETS, the cap and trade, have been undermined by the overly generous allocation of CO_2 emission allowances, a low demand of the same and an overall weak price signal (Ibid). Since the start of EU ETS the Swedish PPI has had a considerable surplus of allowances and this situation is not expected to change. On the contrary, in the third period the benchmark based free allocation to Swedish PPI has increased the surplus to levels far above actual emissions.

The PFE incentives and obligations have reinforced the Swedish PPI's capacity to identify, plan, implement and monitor its EEI actions (Stenqvist and Nilsson 2012; Wiberg and Forslund 2012, 3; Wiberg 2008, 47). Concurrent with PFE, expectations about high energy prices have improved the cost saving potentials of EEI actions and placed energy efficiency among the strategic issues in some PPI firms. Out of the ten largest PPI firms in EU, seven have communicated group-level EEI objectives. Four of these international firms, all with headquarters and/or production sites in Sweden, have set quantified targets to reduce specific energy use by 1–2% annually (Gulbrandsen and Stenqvist 2013b). Another policy influence on Swedish PPI is the scheme for tradable renewable electricity certificates. Since 2003 it has provided economic incentives and supported the PPI's investments in new capacity for electricity generation from renewable sources (Ericsson et al. 2011; Ottosson and Magnusson 2013). The results show that on-site electricity generation has increased substantially. Demand for purchased grid electricity has thereby decreased by almost 10% since year 2000 which has contributed to EEI in terms of primary energy use.

Despite positive connotations and political advocates who speak warmly about the role of industrial energy efficiency (e.g. to address environmental issues, foster resource efficiency, increase competitiveness etc.) the Swedish government has not formulated a national EEI target for the industrial sector. Besides the indicative target under the EU energy service directive (EC 2006) there is only an economy wide target to reduce primary energy use in relation to GDP by 20% between 2008 and 2020 (Regeringskansliet 2012, 42).[14] However, the Energy and Environmental Committee of the Swedish Forest Industries Federation has agreed that Swedish pulp and paper mills should reduce energy use with 15% in relation to production output and increase internal electricity generation with 2 TWh until 2020 (Wiberg and Forslund 2012, 1). The first target corresponds to a 1.2% annual reduction of specific energy use, which is ambitious considering that $SEC_{agg\ final\ fuel}$, $SEC_{agg\ primary\ energy}$ and $SEC_{agg\ electricity}$ improved at annual rates of 0.9%, 0.7% and 0.1% respectively (1984–2011). The second target is also ambitious as it implies that internal electricity generation grows at the same high rate observed since year 2000. Thus, the industry association envisions potentials for further energy efficiency improvement and renewable energy investments despite an eventful last decade for Swedish PPI.

6 Conclusions and policy implications

Since 1984, it is estimated that EEI in Swedish PPI has led to savings of: 26 PJ (or 38%) of final fuel use; 1.4 TWh (or 19%) of electricity use; and 50 PJ (or 40%) of primary energy use (i.e. compared to an activity-based reference scenario). Structural change has, though with a lesser impact than EEI on the PPI's energy use, altered the production mix to consist of more electricity-intensive and less fuel-intensive product segments. The decomposition analysis confirms that EEI has been strengthened in the post-2000 period.

Electricity use EEI, which was negligible before, reached levels near 3% annual electricity savings after year 2000. Results are consistent with previous bottom-up impact evaluations of PFE which provide important evidence for the accuracy of firm's self-reported data and the role of the programme components in stimulating foremost electricity savings but also final fuel use

[14] The Swedish target is less ambitious and not compatible with EU's target for 2020 which can be interpreted as 13% reduction of primary energy use in relation to 2005 (Ecofys and Fraunhofer 2010, 4).

savings. The combined policy influence on Swedish PPI has successfully facilitated EEI and increased internal electricity generation. Such cause and effect relations have been discussed in previous studies and are supported by the quantitative evidence provided in this paper.

Fossil fuel use and related CO_2 emissions have been reduced by half between 2000 and 2011. The Swedish PPI has resumed a fossil decarbonisation in absolute numbers which is comparable to the rapid reduction observed in the early 1980s and thus strengthened its position as the world's most CO_2 efficient PPI. Due to restricted time-series previous studies have not been able to demonstrate this recent and encouraging development. The continuation of a versatile industrial energy policy package to overcome barriers to energy efficiency and to further stimulate renewable energy investment is recommended for complete decarbonisation. Especially in light of the situation with EU ETS which requires major reforms to obtain its intended functions.

After three decades of absolute growth in production output and energy demand the period 2007–2011 represents a trend break in the Swedish PPI. Additional shutdowns and structural changes are currently underway. In parallel, higher ambitions for EEI are indicated by the targets formulated by PPI firms and industry associations. These are important developments in the PPI, which accounts for half of industrial and one fifth of Swedish final energy use, and ought to be quantified and fed into projections of the future national energy balance. Doing so, it should visualize the political space and opportunities to upgrade currently modest energy efficiency ambitions on national level. Objectives on energy supply and climate mitigation should then also be reconsidered. Aligned with objectives, targets and credible baseline scenarios, it is suggested that a new energy efficiency programme, building on the success of PFE, is designed to facilitate further EEI in the PPI and other industrial sectors. For further studies, the suggested features for programme improvement could be examined more closely: inclusion of additional participants and areas of energy use; differentiated incentives and obligations for firms with diverse expertise in energy management; participant networks for knowledge transfer, explicit targets and objectives and, finally, the suitable design of an evaluation plan and customized reporting procedures.

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Appendix

Table A.1: Specific energy consumption (SECs) for 27 pulp, paper and paperboard products in the Swedish pulp and paper industry in the years 1984, 2000 and 2011. The SECs represents annual average values based on all production sites, stand-alone as well as integrated mills (Wiberg 1985, 2001; Wiberg and Forslund 2012).

Products	$SEC_{final\ fuel}$ [GJ/t product]			$SEC_{electricity}$ [kWh/t product]			$SEC_{primary\ energy}$ [GJ/t product]		
	1984	2000	2011	1984	2000	2011	1984	2000	2011
Pulp products									
Sulphate: bleached, air-dried, market pulp	18.64	18.80	17.23	841	798	796	23.88	23.42	21.15
Sulphate: bleached, flash-dried, market pulp	17.51	n p	n p	888	n p	n p	24.64	n p	n p
Sulphate: bleached, pumped pulp	13.81	12.52	12.03	828	664	673	20.82	17.56	16.53
Sulphate: unbleached, air-dried, market pulp	19.46	18.49	17.63	815	633	761	26.58	22.44	22.04
Sulphate: unbleached, flash-dried, market pulp	19.85	13.77	n p	673	720	n p	23.72	17.48	n p
Sulphate: unbleached, pumped pulp	10.06	10.41	10.00	526	591	494	14.35	14.91	13.07
Sulphite: bleached, air-dried, market pulp	15.91	17.16	20.26	856	1137	1147	22.31	26.04	30.11
Sulphite: bleached, pumped pulp	11.51	11.93	11.97	792	877	849	17.46	18.40	17.65
Sulphite: unbleached, pumped pulp	9.32	n p	n p	589	n p	n p	13.66	n p	n p
Groundwood: pumped pulp	0.31	0.23	0.30	1761	2110	2306	16.14	19.20	21.04
Groundwood: flash-dried, market pulp	3.12	3.28	n p	1864	1 983	n p	19.86	21.03	n p
TMP & CTMP: pumped pulp	0.47	0.51	0.57	2316	2335	2208	21.29	21.50	20.43
TMP & CTMP: air-dried, market pulp	5.66	4.33	3.35	1981	1897	1308	23.35	21.10	14.54
TMP & CTMP: flash-dried, market pulp	4.02	4.49	4.77	1885	1904	1425	20.72	21.62	17.60
NSSC: pumped pulp	4.76	4.72	5.70	449	501	383	8.75	8.78	8.16
Recovered fibre: pumped pulp	0.04*	0.31	0.36	333	310	364	3.03	3.08	3.60
Paper products									
Newsprint	5.85	4.60	4.78	580	594	593	10.78	9.68	9.85
Magazine paper	8.58	7.10	5.79	825	711	776	15.94	12.86	12.43
Sack paper	8.85	8.15	6.56	1004	1002	858	17.66	16.58	13.15
Kraft paper	9.63	7.84	7.78	1219	1057	1034	20.31	16.87	16.33
Kraft board	10.02	7.41	6.73	888	726	633	17.53	13.23	11.38
Kraftliner	5.30	5.38	5.06	440	535	483	8.90	9.77	8.59
Fluting	6.98	6.98	6.28	470	420	463	11.13	10.11	9.31
Fine paper	8.70	6.90	5.61	772	651	591	15.30	12.20	10.34
Carton board	7.33	5.62	5.55	708	613	567	13.69	10.85	10.08
Tissue	8.50	7.37	6.99	1178	1125	936	19.08	17.50	15.32
Other paper grades	12.09	18.52	13.65	1223	1738	1591	22.91	33.66	26.80

n p: no production

* The $SEC_{final\ fuel}$ for recovered fibre pulp is very low in 1984 compared to later years which could represent an error. However, the specific fuel consumption for recovered fibre processing does depends on the requirements of the intended final product, e.g. newsprint, kraftliner, tissue etc. (Wiberg 1995, 23).

Paper III

Energy management in Swedish pulp and paper industry – the daily grind that matters

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efficiency, pulp and paper industry, energy management system, competitiveness, EN 16001, ISO 50001

Abstract

The Swedish pulp and paper industry (PPI) accounts for almost 50 percent of industrial final energy use. It is an energy-intensive industry and process optimization is seen as prerequisite to compete on the global market. This alone should motivate company boards and on-site organisations to put energy management high on the agenda. Definitely, from time to time, energy issues (e.g. fuel shifts, selling of generation capacity, and more lately increasing auto-produced electricity) have been managed with respect to the combined effects of policies and market forces. Yet, it was first after 2004 that the industry implemented energy management systems (EnMS), with particular focus on energy efficiency, and received certification according to the Swedish and later the European standard. This was required by the Programme for improving energy efficiency in energy-intensive industries (PFE), a five-year voluntary agreement in which some 100 companies reported gross annual electricity savings of 1.45 TWh, equal to 5 percent of base year consumption. This result highlights the potential role of an EnMS in raising awareness and facilitating investments. In this paper we analyse the case of the Swedish PPI; its relation to energy issues in previous periods and the formalised EnMS practices of recent years. We pose the questions: How are standardised EnMS structured and put into practice? What are there measurable effects and other discernible outcomes? The results are based on in-depth interviews with energy management coordinators at eight pulp and paper mills. The experiences with EnMS are found to be predominantly positive. EnMS has changed organisational structures and created greater focus on energy efficiency, which has resulted in quantified energy savings. Considering that EnMS implementation and certification is at a pioneering stage and that the international ISO 50001 standard is currently being developed, these are important results for the future of EnMS in industry.

Introduction

Close to a third of global energy use and almost 40 percent of the carbon dioxide emissions are attributable to the manufacturing industries (IEA, 2009). Energy efficiency improvement can be a means to several ends but from the business perspective held by industry representatives it serves foremost to gain competitive positions. This is not to say that energy efficiency is always prioritised across industry and this is important to consider for the achievement of societal goals like energy saving and climate mitigation targets. In fact, it is absolutely necessary for fulfilment that all sectors of society, not the least energy-intensive industries, make substantial contributions. Exploiting the full potential of energy efficiency improvement requires continuous and systematic attention. To facilitate such corporate management many national Energy Management System (EnMS) standards have evolved over the last decade.

In Sweden, a national EnMS standard was introduced with the voluntary agreement Programme for improving energy efficiency in energy-intensive industries (PFE) which is administrated by the Swedish Energy Agency (SEA). Since

2004, through its combination of incentives and obligations[1] PFE has stimulated some 100 energy-intensive[2] companies to implement and become certified for their use of EnMSs.[3] After 2009, when the first five-year programme period was concluded, PFE was cited as a success (SEA, 2011a). The companies reported 71 MEUR of investments into electricity savings measures that, in combination with many zero-cost measures, generated gross annual electricity savings of 1.45 TWh (i.e. almost 5 percent of their annual electricity demand). The average straight payback period of these measures was less than 1.5 years (SEA, 2011a). The cost for society has been estimated at a low 6.5 Euro per MWh of saved electricity, thus being clearly favourable compared to market electricity prices and cost of new generation capacity (Stenqvist & Nilsson, 2011). Considering that many PFE companies belong to truly energy-intensive sectors (e.g. pulp and paper, chemical industry, manufacture of basic metals) the observed results are rather intriguing and in contradiction to economic theory stating that the market place alone creates a high and persistent energy consciousness within energy-intensive firms. According to some scholars, the use of energy efficiency programmes to stimulate an attention-raising effect among energy-intensive firms is viewed unnecessary (Brännlund & Kriström, 2010). Their solution for an effective climate policy is rather a global tax or an emissions trading scheme to internalise the externality (i.e. carbon dioxide emissions). Also in practice on an EU policy level there are expectations on EU ETS and the Energy Taxation Directive to encourage take-up of remaining energy savings opportunities in energy-intensive firms (EC, 2011). The European Commission does, however, also recognise that some obstacles need to be addressed by other measures. For large companies the Commission plans to propose regular energy auditing to become mandatory and it also recommends Member States to incentivise the implementation of standardised energy management systems (EC, 2011).

Previous experiences from voluntary agreements that include obligations on energy management practices in energy-intensive firms show that these provide cost-effective energy savings beyond business-as-usual (Worrell et al., 2009). The Swedish PFE provides another example that allows us to challenge the hypothesis of adequate energy consciousness in energy-intensive firms and more specifically to analyse the potential contribution from standardised EnMS practices.

1. Participants are exempted from the EU minimum tax on electricity of 0.5 Euro per MWh. In return, each company is required to: conduct an energy audit and analysis; identify and invest in profitable electricity saving measures; implement and certify an EnMS; introduce routines for energy efficient procurement and project planning; report their progress to the SEA.

2. According to the definition of the EU Energy Taxation Directive (2003/96/EC) a company is energy-intensive if: (1) purchases of energy products and electricity amount to at least 3 percent of the production value and/or (2) the energy-, carbon dioxide- and sulphur tax on energy products and electricity used by the company amount to at least 0.5 percent of the added value. PFE companies belong to the following industrial sectors: pulp and paper; chemical products: steel and metal; mining and quarrying; mineral products: saw mills and manufacture of wood products; manufacture of food products.

3. Initially according to the Swedish SS 62 77 50 and then according to the European EN16001 standard.

PURPOSE AND RESEARCH QUESTIONS

Given the potential capacity of a standardised EnMS in raising awareness and facilitating energy efficiency improvement in energy-intensive firms (as well as other firms) it is important to study the practical implementation that makes such changes come about. In light of the development with many national EnMS standards being launched and now also consolidated into international standards it is of interest to study the response among industrial actors. Therefore, in this paper we present the case of standardised EnMS in the Swedish pulp and paper industry (PPI). The key questions being posed are: How is a standardised EnMS structured and activated? Which are the measurable effects and other discernible outcomes?

OUTLINE

In a first section of this paper some basic concepts related to energy management are presented. Then, as a point of reference we present results from previous research on industrial energy management practices, with preference for its occurrence within the Swedish PPI. Next, based on conducted interviews we are able to present how the more formalised EnMS practices in recent years have materialised in eight studied pulp and paper mills. For the reflections on measurable effects from certified EnMS a quantitative assessment illustrates the size of electricity savings implemented as well as the development of absolute and specific electricity consumption at the mills. In a final section we conclude the overall results and reflect about possible implications for the future of EnMS implementation and certification according to international standard.

Background and concepts

DEFINING ENERGY MANAGEMENT

The concept of energy management is defined by Capehart et al. (2008) as:

> *The efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions.*

While pointing out the objective of energy management this definition does not describe the procedures that constitute energy management. Certainly, for any profit-seeking organization, and especially one where the cost share for energy products is significant, this objective of energy management should be inherent in the business. This, however, does not ensure that appropriate energy management procedures are practiced. On the contrary, the existence of energy efficiency gaps indicates that such are often absent across sectors of energy end-users (Jaffe & Stavins, 1994). In Sweden, the energy saving potential in some energy-intensive sectors[4] has been estimated at 10 percent by the year 2016. This means that a forecasted increase in industrial energy demand can be avoided through a more efficient energy use (SOU 2008:110, 2008, p. 215). The estimate is conservative since it only takes into account savings from technical measures and not behavioural changes (i.e. O&M), the latter being central in EnMS practices. Moreover, the un-

4. The sectors of: iron and steel, pulp and paper, refineries and petrochemicals.

derlying assumptions on energy prices levels from 2005 and onwards has been greatly exceeded by actual developments. Energy efficiency improvement should therefore have become even more attractive than expected.

The emphasis on efficient energy use as the means to maximize shareholder value is an important to make. It can certainly be imagined a firm in which the increased energy use enables higher production levels and thus improved profits. However, if the increased production capacity has deficient energy performance the same firm will become more exposed to increasing energy prices and the shrinking profit margins that follow. In situations with low market demand or increasing energy prices the poorly performing production capacity ought to be suspended first. At stake here is to keep a constant focus on maintenance and further improvement to attain energy efficient production processes and auxiliary systems that will allow the company to minimize its energy use per unit of output (monetary or physical) and thereby uphold a competitive position.

In one or the other way energy related issues is always being managed but with an EnMS that prioritizes the efficiency aspect, the company can avoid the risk that other objectives take overhand. Moreover, even if there is a clear focus on energy efficiency, as with everything else, management can be poor. With an EnMS an industrial company is helped to structure and incorporate its energy management ambitions into the daily operations. The basic principles are the same as for other types of management systems, e.g. environmental management systems like ISO 14001. Following the cyclic "Plan-Do-Check-Act" approach, as depicted in Figure 1, the company shall: establish goals and procedures that correspond to the energy policy and requirements of relevant stakeholders (plan); implement the necessary procedures (do); monitor the manufacturing processes with regards to the policy, the significant energy aspects and specified targets and also report the results (check); take actions to continuously improve the performance of the processes (act) (SIS, 2003).

A proper EnMS implementation requires documentation and activation of an organisational structure including the work planning to identify tasks and responsibilities (SIS, 2003). Internal revisions should be conducted regularly to make sure that work keep up with requirements set by the standard document and the energy policy. External revisions performed by an accredited auditor can give further recognition as the company receives a certification according to the standard. It is evident from at least ten national EnMS standards released over the last decade, from Denmark in 2001 to China in 2009, that there are prospect for EnMSs to facilitate industrial energy efficiency improvement (Kahlenborn, 2010). The European EN 16001 was released in 2009 and there is ongoing work to conclude the international ISO 50001 in 2011. By time the numerous national standards are likely to be phased out in favour for the internationally agreed documents. In the Swedish PFE, for example, EN 16001 substitutes for SS 62 77 50 since 2009, and when the ISO 50001 is available it will probably succeed.

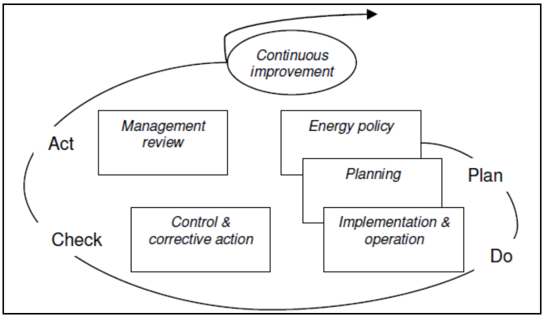


Figure 1. The PDCA approach of a standardised EnMS. Source: SIS (2003)

ENERGY AND THE PULP AND PAPER INDUSTRY

The energy use in the PPI varies considerably depending on the production process. There are many different pulping processes but the two main routes are mechanical and chemical. In electricity-intensive mechanical pulping, wood chips are processed in large grinders and nearly all the wood ends up in the pulp which is used for paper such as newsprint. In an integrated mill the heat is recovered from the mechanical pulping process and the steam produced is used for drying the paper and other processes. Chemical pulping is used to produce stronger high quality fibres and involves dissolving the lignin in a chemical cooking process. About half of the wood ends up in the spent pulping liquor that is concentrated in evaporators. The resulting black liquor is combusted in chemical recovery boilers and the bark component can also be combusted in separate boilers. The high pressure steam produced is used for CHP generation, enough to meet all the steam and electricity demands of a modern chemical pulp mill. In 2008, the Swedish PPI consisted of 56 mills. Their fuel use was 218 PJ of which 94 percent was bio-energy, mainly in the form of black liquor. The total electricity demand amounted to 22 TWh[5] of which back pressure turbines auto-produced 6 TWh, equal to 25 percent of the demand. (SFIF, 2011)

Energy is clearly an integral part of the energy-intensive PPI. Management of energy issues has thus been important to respond to changes in relative energy prices and various environmental and energy policies. In the 1970s, the dramatic increase in oil prices set off a fuel switch in the PPI from oil to biomass and partly electricity. The oil substitution, which is still ongoing, has later also been motivated by the Swedish carbon tax that was introduced in 1991 and more recently the EU ETS that was introduced in 2005. Fossil fuels now account for only 6 percent (2008) of the fuel consumption in the PPI (SFIF, 2011), which aims to phase out all fossil fuels from the production processes by 2020. The introduction of the Swedish carbon tax also created a market for wood fuels and the forest industry (i.e. subsidiaries within the PPI groups) started to deliver wood chips, pellets and other fuels on a large scale to outside buyers, in particular the district heating sector. Over the past decades there has also been a steady growth in the number of pulp and paper mills that deliver waste heat to neighbouring district heating systems. In 2007, 22 pulp and paper mills delivered 1495 GWh of heat to district heating systems (Wiberg, 2007).

5. To put this in perspective it is equal to 16 percent of Sweden's electricity demand (SEA, 2009).

Another, more recent, development in the PPI is the great interest in electricity-related investments. There have been substantial investments in process-integrated electricity production and many companies have announced ambitious investment plans for wind power. These investments, which are described in Ericsson et al. (2011), represent a fundamental trend break to the 1990s and early 2000s, during which the PPI divested many of its off-site power assets (hydropower and nuclear power). According to Ericsson et al. (2011) this reorientation follows from policy driven changes in the underlying economic conditions in the sector, in particular the increase in electricity prices and expectations of permanently higher electricity prices in the future. Since the early 2000s, the PPI has faced increasing electricity prices following the electricity market reform and the introduction of the EU ETS. The reorientation has, however, also been driven by the opportunities created by the Swedish quota obligation scheme with tradable renewable electricity certificates (TRECs) that was introduced in 2003 (Ibid). The additional income from sales of TRECs has greatly improved the profitability of investments in biomass-based CHP.

EXPERIENCES IN ENERGY MANAGEMENT

The previous section showed that for the last decades the PPI has been heavily involved in strategic considerations and decision making concerning the supply of different energy carriers. More related to the concept of energy management is that apart from driving investments in new power assets increasing electricity price has become a trigger for increased focus on energy efficient production processes. Due to the historical low electricity prices that created a competitive advantage to the PPI and Swedish industry in general, the issue has become more acute in the post 2000 period than before (Trygg & Karlsson, 2005).

A relevant study is Thollander and Ottosson (2010) that examines, based on a questionnaire sent out in 2007, some aspects of energy management practices in the Swedish PPI. At that time the industry had been participating in PFE for two years and had just received certification for their EnMSs. Aspects considered by Thollander and Ottosson (2010) were: the strictness on payback criteria for energy efficiency investments; the existence of long-term energy strategies; and procedures on energy cost allocation. These indicators were then used to categorize how successful the mills were in their energy management practices. On a rather rough three grade scale 40 percent out of 40 responding mills were categorized as successful. Hence, there seems to be some potential for improvement. Nevertheless, all the mills did receive EnMS certification from authorised third-party auditors. Since the three aspects used by Thollander and Ottosson (2010) to judge success are not explicitly mentioned in the Swedish EnMS standard this does not appear contradicting. Questions can be raised about how EnMS practices are best evaluated in addition to the stamp of approval issued by external auditors. Therefore, in this point of time when the same mills have applied their EnMSs for another four years as required by the PFE participation, it is motivated to complement previous studies to describe the current status of EnMS practices in Swedish PPI.

Methodology and empirical base

THE RESEARCH METHODOLOGY

A main objective for introducing a standardised EnMS is to facilitate a management around energy efficiency so to enhance the competitive position of the firm. In this regard a measurable energy efficiency improvement that is assumed to be cost-cutting at the plant or company level can be viewed as one, though not the only, indicator of successful EnMS practices. A specific technical measure such as replacement of an industrial motor of poor efficiency with one of higher efficiency class generates instant electricity savings that depending on various conditions may persist to deliver annual savings for several consecutive years (CEN, 2007). Technical measures alone does little, however, to arrange an organisation for giving preference to energy efficiency and making it a core value for enhanced competitiveness and so shifting the mindset of management and staff. Yet being difficult to measure there should be large potential for such changes to influence energy efficient decision making and behaviour in the longer run (e.g. in terms of procurement procedures). The measurable impact in terms of energy efficiency improvement may arise long after such organisational changes are undertaken.

Based on this reflection we argue that multiple indicators must be used to describe the status and judge the success of EnMS practices. Since these are the intentions of this paper, the empirical base is both of a qualitative and quantitative nature. This dual approach is found necessary to obtain answers to the key questions posed in the introduction. Qualitative, and partly quantitative, data was gathered by the means of site visits including interviews with appointed energy management representatives at eight different mills. These in-depth and semi-structured interviews concerned issues on EnMS structure and activation at the mills. The answers from respondents provided enough material to frame five headlines that, inspired by literature (e.g. Capehart et al., 2008), highlights key issues on how an EnMS is structured and put into practice. The results from the interviews are presented under the following headlines: Energy management coordinator; Management and staff commitment; Energy cost allocation; Monitoring and reporting; and Training.

THE INTERVIEWED FIRMS

The empirical base of this paper originates from eight pulp and paper mills of varying size, type and geographic location. The selection of mills was done according to a few criteria. All respondents should participate in PFE that requires companies to implement and certify EnMSs. From 2005 to 2009 PFE has engaged about 100 energy-intensive firms and in total some 250 industrial sites in different industrial sectors. This study is focusing on the pulp and paper industry, which in Sweden covers about 45 companies and almost 60 mills.[6] At a conference arranged for PFE companies one author of this paper attended and established contact with representatives from several mills. After some correspondence the representatives of the eight mills, being presented in Table 1, accepted to be respondents.

6. It is common in the PPI that each mill operates as a separate business unit with an individual company registration number.

Data was collected during site visits that included interviews with appointed persons and shorter round tours at the production site. All visits, that lasted between one and three hours, were made over a period from February to June 2010.

QUANTITATIVE DATA SOURCES

For the eight mills, in order to enable interpretations of measurable effects from EnMS practices, the following data has been compiled and analyzed: electricity consumption; specific electricity consumption; and reported electricity savings during the course of PFE. The focus on electricity is due to the accessibility of such data. The requirement on EnMS implementation was introduced with PFE that in particular targets electricity savings in its substitution for the EU minimum tax on electricity (Stenqvist & Nilsson, 2011). For this reason the companies have only been obliged to identify and report their electricity savings measures to the SEA which in turn has provided this data (SEA, 2011b). Other energy savings measures (i.e. heat and fuels) have also been implemented under the guidance of the EnMS as made evident by the voluntarily reporting made by some companies.

The data on absolute and specific electricity consumption has been compiled from publicly available data provided by the Swedish Forest Industries Federation (SFIF, 2011). Its member companies from the entire PPI annually reports physical production as well as energy and emission related figures. The analysed time period (2005-2009) equals the period during which standardised EnMSs have existed at the mills.

Energy management practices at the mills

ENERGY MANAGEMENT COORDINATOR

To implement, develop and activate the EnMS a competent employee needs to be appointed with responsibility for coordination and thus become the Energy Management Coordinator (EnMC) at the company or industrial plant (Capehart et al., 2008). At all the mills there were one employee in such position and he or she was also among the persons being interviewed. Though their job titles varied (e.g. process engineer, energy manager, energy management coordinator etc.) it became clear as they described their work tasks that they were in the EnMC position at the mill. Coordination in the multi-divisional structure common for a pulp and paper mill involves work planning, communication and following up the progress. Internal communication was conducted with appointed staff members and also, though less frequently, with management representatives, i.e. production manager, energy manager, the manager of the mill. External communication involved the EnMC reporting to authorities according to regulations on energy and environmental matters. Common for all mills was that the EnMCs were not solely occupied with work on energy management as they all had multiple tasks to handle. A substantial part of their work, however, equalling about 25 percent of full-time, was devoted to EnMS activities.

MANAGEMENT AND STAFF COMMITMENT

The commitment from management is considered crucial for successful EnMS operation (Capehart et al., 2008). For some mills the EnMS was represented by a person in the top management group who was also the signatory of the energy policy. In other mills the EnMC, though not being member of management, was the appointed management representative. In any case, the interviews with the EnMCs confirmed that top management was supportive in the work for energy efficiency improvement. The participation in PFE was an important incentive in this regard. Mills that belonged to larger company groups with strong production bases in Sweden were often involved in group-wide activities about energy efficiency to exchange experiences and knowledge build-up.

Table 1. The interviewed mills.

Mill	No. of employees	Prod. [kt] p=pulp / pp=paper	Electricity use [GWh]
◆	355	p: 380	284
■	720	p: 170, pp: 335	504
▲	150	p: 30, pp: 55	67
×	950	p: 555, pp: 600	820
⋇	900	p: 625, pp: 830	2036
●	190	p: 40, pp: 30	88
+	870	p: 600, pp: 495	718
▬	400	p: 403	486

Data from 2008 or 2009. Source: SFIF (2011)

Given the complexity of a pulp and paper mill, i.e. production processes that involve people with advanced technology and are fuelled with different energy carriers through an infrastructure of conversion and distribution technologies, the EnMC cannot independently keep control over the entire EnMS domain. Also, given the number of staff in these large size plants, often between 500 and 1000 employees plus some contracted personnel, it is impossible for a sole EnMC to directly communicate and engage with the entire work force. For energy management practices to spread across the mill staff in various positions and with different competences will have to be engaged to support the EnMC.

It was clear from the visited mills that all EnMCs had certain contact persons within the organisation. Most often the EnMC had appointed contacts at each important production step which in an integrated pulp and paper mill typically includes the following divisions: wood preparation and debarking; pulping; bleaching; paper making (often by multiple paper machines). In three of the mills these contacts were referred to as division-level EnMCs which clearly indicates their connection to the EnMS. In other mills, without making this designation, it was an agreed task of process engineers to report to the overhead EnMC whenever needed (e.g. in case of deviation from normal operation).

The EnMS teamwork can be organised in different ways, but Capehart et al., (2008) recommends a structure with one technical committee and one steering committee. The former consist of people with strong technical background that can assist the EnMC and division-level staff in specific situations and also keep the organisation updated on the advancement of energy efficient solutions. The role of the steering committee should be to assist the EnMC in guiding the EnMS activities and raise awareness at division-level. None of the interviewed mills had established two distinct committees. Instead, in all the mills there were at least one and sometimes several energy management groups of mixed composition. In practice the basic function appears to be the same. A group typically consisted of the EnMC, division-level process engineers and technical experts enrolled from the maintenance as well as from the project department. They met regularly a few times per year in order to evaluate the list of proposed energy efficiency measures and prepare decisions on implementation.

To quantify the total staff involvement, the EnMCs were asked to estimate the number of employees directly involved in work related to the EnMS and energy efficiency improvement, either from time to time or on a more regular basis. The estimates varied from 6 to 50 persons, which depending on the size of the mill corresponds to between 2 and 5.5 percent of the entire staff.

ENERGY COST ALLOCATION

A common barrier to energy efficiency is the split incentive situation that arises when end users are not held accountable for the costs of their energy use. In a manufacturing industry this occurs when energy costs are accounted for as part of the general overhead, which will give less incentive for a division in the plant to reduce its energy use. To overcome the potential split incentive barrier, the plant's energy use should be sub-metered to enable cost allocation based on the actual consumption of each division or important process that constitutes a cost centre. In their study Thollander and Ottosson (2010) examined the status of energy cost allocation in the Swedish PPI and concluded that: 66 percent made energy cost allocation based on sub-metering; 8 percent based on square meters; and 5 percent based on number of employees. The remaining 21 percent made no allocation at all.

The interviews confirmed that sub-metering and related energy cost allocation, as well as energy revenue allocation (e.g. some divisions supply others with steam) can be a complex issue in a pulp and paper mill, which is probably the case also for other heavy process industries. On the basis of their production processes all the mills are organised into divisions and in all but one mill each division also represents a cost centre. A category of five mills claimed to be allocating energy costs based on the actual usage controlled by adequate sub-metering systems for electricity and steam, consisting sometimes of up to 80 metering points. Some of these mills could also express the specific consumption of different fuel types (e.g. bio-energy, fuel oil, and diesel) down to division-level. These five mills were rather content with their sub-metering system but could anyway express some difficulties concerning the precision of the electricity metering as some processes were simultaneously fed from several low voltage switchgears. This was a greater concern for a second category of two mills. Their number of switchgears was insufficient for doing an electricity cost allocation based on constant sub-metering. Instead the energy invoice was approximately allocated to the division level by the help of periodic use of portable metering equipment. Improvement of the metering system was planned by one of these mills. One mill was organised as a single cost centre. It was anyhow divided into larger production processes and equipped with an adequate sub-metering system to monitor the specific energy consumption of each such process. This represents an interesting case where the information on process level energy consumption is accessible and visible to staff and management, while the economic incentives for division level energy efficiency improvement are not as apparent.

A special case for several mills was compressed air, an energy carrier often regarded as a common resource. Hence, the cost allocation to the divisions needs to be done by some other means than a consumption based rate. It is stated by at least three mills that the common ownership of the compressed air system, with the maintenance department being responsible for service, makes it difficult for staff at the division level to identify measures on this equipment. These mills also stated they have implemented none, or only a few, measures related to compressors or sealing of air leakage.

MONITORING AND REPORTING

In addition to cost allocation it can be discussed how a sub-metering system can support monitoring of specific energy consumption and the assessment of the production's energy performance. With a capacity to gather substantial amount of energy related data it is also of interest how such data is being transferred and reported internally, and perhaps externally, to stimulate energy efficiency improvement. Moreover, whenever an energy efficiency improvement measure is implemented, the EnMS should make sure that energy savings are estimated and verified in an appropriate manner.

Five mills had automatic meter reading to assimilate real-time data from the metering devices (mainly for electricity and steam) and transfer it to a database accessible via the companies' intranet. Depending on the size of these mills the number of meters, for electricity and steam consumption, varied between 20 and 80. The energy consumption data was combined with physical production data to provide the specific consumption of different energy carriers (e.g. kWh/ADMt[7]). Continuous monitoring was used to confirm that acceptable levels were maintained. At one of the mills there was an alarm being triggered upon significant deviation. This called for a prompt reaction from the responsible process engineer to find an explanation and possible solution to the abnormity. Another mill mentioned a procedure of reporting eventual deviations at daily meeting and shift changes to facilitate a follow-up on such information. Several mills mentioned that data on specific consumption was used to keep track on processes identified as significant energy aspects by the EnMS. The electricity-intensive thermo mechanical pulping process provided one example where sub-metering data was used to compare the performance of refiners and make evident, for example, a need for replacing refiner plates. At all mills the EnMCs compiled reports to make annual comparisons of the specific energy consumption for different energy carriers. This was done on the plant level and, whenever sub-metering allowed for it, at the division or process level. Two of the mills mentioned that this was done even on a monthly basis.

Due to their participation in PFE, all mills are required to identify and implement electricity savings measures with a

7. ADMt stand for air-dried metric tonnes of pulp.

payback period of less than three years. In their reports to the SEA they also have to estimate the size of achieved savings. For answering to this but also driven by internal company demands the mills had developed methods to assure evaluation of their measures. To some extent such methods was practiced also before the EnMS, but most mills claimed they had made advancements. In a survey of the whole PFE collective, 80 percent of the PFE participants claim that the EnMS has introduced new methods for monitoring energy use that have been valuable for the energy efficiency improvement (Hörnsten & Selberg, 2007).

The interviewed mills described their methodologies applied for evaluating electricity savings as a combination of engineering estimates using on-site data and direct metering of the end-use load. For energy efficiency measures on motors, portable metering equipment has been used to meter the electricity consumption during a couple of days before implementation. After the installation the equipment has been metered again and the difference in load has been multiplied by the normalised annual hours of operation. The result constitutes the annual electricity savings. When direct metering has not been feasible the electricity savings have been estimated based solely on theoretical calculations. Sometimes this is the preferable method (i.e. being more accurate) as can be the case for pumping equipment with an intermittent operation.

TRAINING

Training is another aspect and requirement of a standardised EnMS. Staff in different divisions and with specific work tasks will have diverse opportunities to influence the energy performance of the manufacturing processes. Supportive training may be essential if this is to be realised in the best possible way. As part of the EnMS it should be identified what type of training that is needed and for what staff. Since energy efficiency improvement can be achieved from different angles (e.g. operation & maintenance, procurement, project planning etc.) several target groups may benefit from training. Since organisations are changing (e.g. staff is being replaced) and technical systems are being altered (e.g. new technology is being installed) training needs to be given continually.

The interviews gave diverse answers concerning the training that had been conducted since the EnMSs had been introduced. A distinction should be made between actual training sessions and dissemination of information. To the former category belongs both examples on broad training or lecturing targeting awareness raising among all employees, but also more specialized training for certain operators of equipment. At all mills the EnMCs had spread the information to all employees about the existence of an EnMS to facilitate energy efficiency improvement. This action cannot be considered training but rather a call for everyone to be aware and support the work. At these occasions, the staff have been encouraged to identify and give own proposals on energy efficiency measures.

At two of the mills all employees, more than being informed, had received a few hours lecture on energy and environmental issues of importance to the mill. Included in these sessions were facts about policies at the national (e.g. PFE, environmental regulations etc.) as well as the international (e.g. EU-ETS) level, and how these affect the activities and business. These broad training sessions were intended to build an understanding among the staff for the energy related goals formulated by the organisation. The aim was to stimulate staff to become more cooperative and take personal responsibility for improved energy efficiency, for example, by being alert on the operation and condition of equipment (e.g. to avoid unnecessary idle running). The Swedish EnMS standard state that the need for training should be identified and satisfied among employees in positions to influence the significant energy aspects. Several respondents expected international EnMS standards to make more explicit specifications and could thus foresee that efforts for training and awareness-raising would need to be improved in the future compared to current practices.

At five mills it was mentioned that they offered specialised training for staff with larger influence on the energy performance of manufacturing processes. Courses were held in optimised operation of the most energy demanding equipment such as pumps and boilers. A few mills pointed out that such training was carried out also before the EnMS implementation. On the other hand, at some mills it was claimed that the role of operators had become more autonomous over the last years. On the basis of their educational and practical skills they are expected to steer their work according to best practice.

Quantified electricity savings

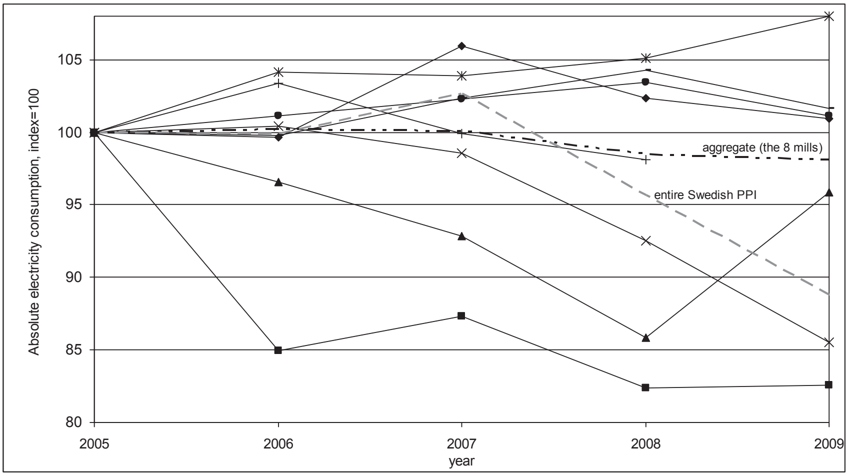
After five years participation in PFE (i.e. 2005-2009), companies were required to report their achieved electricity savings from different categories of measures. The main category includes technical and other operation and maintenance (O&M) measures. Some measures were identified through the required energy auditing activities that were undertaken in the first two years of PFE. Other measures were identified thereafter as a result of the EnMS practices that received certification in the second year of the programme. Technical measures typically involve replacing or improving certain equipment, which in the PPI often relates to pumping systems. There are also many examples of zero-cost measures like shutting down unnecessary equipment and improving operation practices. Another category of measures are the routines for energy efficient procurement and project planning that PFE requires. The purpose is that companies should acknowledge the life cycle cost (LCC) in its procurement and investment decisions and possibly give preference to energy efficient alternatives (SEA, 2006). Procurement routines should be applied to electrical equipment (e.g. motors, pumps and fans) that is using more than 30 MWh per year. Project planning routines should guide the investment decision in case of larger renovations at the production site. These kinds of assessments were partly new to the mills when they entered PFE, but eventually have become integrated in their EnMS practices. For the interviewed mills Table 2 shows the size of reported annual electricity savings from the different categories. The total of reported annual electricity savings for a mill is commonly around three percent, though the sample's high and low deviates quite much.

Figure 2 displays, for the eight mills, the absolute electricity consumption over the period 2005-2009. Four mills have decreased their electricity consumption, of which two with a substantial amount of about 15 percent. On the other hand, the other four mills have increased their electricity consumption, of which one with about 8 percent. The aggregated result for the eight mills shows a moderate decrease compared to the aggre-

Table 2. The mill's reported annual electricity savings under PFE.

Mill	Categories of reported annual electricity savings			Sum of annual elec. savings	
	Technical and O&M measures [MWh]	Procurement routines [MWh]	Project planning routines [MWh]	[MWh]	Relation to 2004 elec. demand [%]
◆	6571	8	1787	8366	2.9
■	26016	554	270	26840	4.4
▲	8044	63	5	8112	8.6
×	32384	380	390	33154	3.5
✳	57701	794	1509	60004	3.2
●	1115	100	63	1278	1.5
+	26710	300	2500	29510	4.0
▬	11887	199	377	1763	2.7
Sum	170 428	2398	6901	179 727	3.5 (3.85 in average %)

Source: SEA (2011b)



Source: SFIF (2011)

Figure 2. Electricity consumption for the eight mills (2005–2009).

gate for the entire Swedish PPI, which decreased its electricity consumption by 10 percent over the period. With regards to the figures in Table 2 there is no general consistency between the size of reported annual electricity savings and the development of absolute electricity consumption. This can be due to several reasons since different conditions influence the energy consumption of an industrial plant, the most evident being production volume, production mix and weather conditions. During 2008 and 2009, for example, many mills experienced low production volumes following the global recession. Also, depending on production mix and periodic variations in energy markets a mill may favour one fuel input over another, for example, to increase steam production from an electric boiler. Varying conditions like these will cause annual energy savings to differ from pre-estimated values. In their engineering estimated values the mills have commonly normalised the annual hours of operation, but the fact that equipment run on variable loads may be more difficult to adjust for.

In order to take account of physical output Figure 3 displays, for the eight mills, the specific electricity consumption (SEC) over the period 2005-2009. The physical output of each mill is defined as the annually produced tonnes of market pulp and final paper products. Three mills have decreased their SEC while five mills have experienced an increase. For some mills it might be a disappointment that despite hard work with electricity efficiency improvement under PFE, their SEC is increasing. The period 2008-2009 has been exceptional, though, due to the low production volumes at many mills. Because of the idling losses such situations tend to drive up the SEC. This is noticeable for three mills and since these are large size mills this has also shaped the aggregated result.

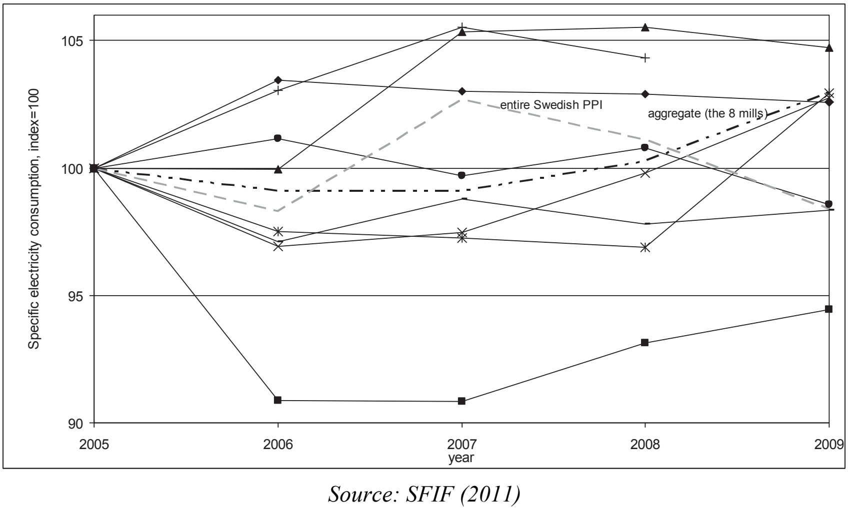


Figure 3. Specific electricity consumption for the eight mills (2005–2009).

In their EnMS the mills can of course formulate SEC-targets based on different base and target years. Some mentioned 2003 and 2010 respectively and hence their prospects for target achievement could be much better than made evident by Figure 3. For some mills it has not been an EnMS target to reduce specific electricity consumption. Therefore it is possible that other EnMS targets like the reduction of specific fuel oil consumption may result in a shift to electricity.

Conclusions

The interviews exposed some differences in how the mills had structured their EnMS practices. Though the standard document provides a common guideline, there is no uniform model for how an EnMS is realised in an organisation. Still, each mill has received certification from an authorised third-party auditor. This explains the underlying idea of management systems, that objectives are set by management to reflect the ambition level with respect to context and challenges (e.g. cost structure, demand from customers and other stakeholders, physical infrastructure, previous experience, and perception about the future).

All mills had an appointed person, an EnMC, being responsible (though only at part-time) for coordinating the EnMS activities. By arranging and chairing regular meetings with division-level staff the EnMC has a central role in structuring the EnMS. The mills with appointed division-level EnMCs have further enhanced this structure. This way of embedding the EnMS throughout the organisation is reasonable, not the least in large multi-divisional mills, where each division represents a cost centre and thus have to take decisions about implementation of energy savings measures. Support from the main EnMC and technical expertise from maintenance and project departments is provided by the EnMS framework.

The allocation of staff and resources to support the EnMS is a management issue. The fact that a quite a share of the work force (between 2 and 5.5 percent) has been directly involved in EnMS activities shows that mill management have been committed to the task. It is difficult to state an optimal level of staff involvement. As a minimum, all employees should be aware of the existence of the EnMS and whom to direct for related issues. As a guideline for a large process industry that plans to implement a standardised EnMS, an effective operation will require direct (though at a moderate part-time) engagement from 3-5 percent of the work force.

Inadequate energy cost allocation could provide a barrier to improving division-level energy efficiency improvement. The issue is closely connected to the issue of sub-metering that enables more precise energy cost allocation. A few mills lacked the satisfactory infrastructure and it should be an EnMS objective to make improvements on this area. Mills with advanced sub-metering systems have the advantage of being able to set specific targets on process levels and continuously monitor the progress of such energy aspects. For the majority of mills the practices on monitoring and reporting energy savings have improved since the introduction of the EnMS. It remains a challenge how to further improve these practices, for example, in the case of compressed air systems which is viewed as a common resource and therefore attracts less attention at the division-level.

The training of staff is an EnMS activity that has been treated differently by the mills but overall it has not been highly prioritised. Improvements could be made to identify the actual target groups for specialised training. Especially the routines on procurement and project planning that to some extent introduced new ways of thinking in the mills could be areas to address. This would involve procurement and project departments more heavily in the EnMS and could probably be motivated for keeping pace with the advancements of energy efficient technologies.

The Swedish as well as the European standard does not include any explicit specifications about issues concerning energy efficient project planning and/or procurement. For the mills these requirements were introduced as part of PFE and the results show that these routines were able to attain sizeable amounts of energy savings at some mills, though less at other. In the forthcoming ISO 50001 the need for evaluating energy performance in the design of new or renovated facilities as well as for procurement of equipment and services will become highlighted. The mills are thus prepared for a transition to the international standard. For a complete newcomer that plan to implement an EnMS according to the international standard the introduction of design and procurement routines will likely become challenging though potentially rewarding.

Reported annual electricity savings shows that the EnMS practices have resulted in actual savings, commonly about 3 percent compared to the electricity demand of the base year. Yet, when studying how absolute and specific electricity consumption was developing over the period 2005-2009, the impact from these measures was not always evident. This analysis is partly disturbed by the low production volumes in 2008-2009. A more complete picture of how energy intensity has developed in the PPI would require an analysis of the primary energy use. Also, the delimited five-year period is too short to deduce any real trends in electricity intensity. A comprehensive top-down study could be performed to examine the energy intensity over a longer time period. With a decomposition approach it could be estimated to what extent that energy efficiency improvement has influenced the development.

Since the European standard was published in 2009 and the international ISO 50001 will become available in 2011, the short-term future will tell if standardised EnMS is to be introduced by companies on a global scale. Though it might seem rational for companies to do so, they may not actually adopt EnMS on its own merit. This means that government's executive agencies within the framework of energy policy implementation will need to consider whether or not to incentivise an uptake of EnMS in different industrial sectors. In countries where national EnMS standards have already been developed, the dissemination has often been facilitated through voluntary or long term agreement on energy efficiency. The Swedish PFE provides one example on how to combine a moderate financial incentive with regulations to promote a rich set of attention raising activities including EnMS. Apart from the cost-effective savings achieved, an important result is that 100 companies and 250 industrial sites now have certified EnMSs. Some of these can provide good practice examples for other companies to follow.

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Paper IV

Evaluating industrial energy management systems – considerations for an evaluation plan

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Abstract

Since year 2000 a number of national energy management systems (EnMS) standards and specifications have been developed. To support EnMS implementation in industry some governments have launched agreements centered around energy management practices. National experiences show that such policy programs can achieve significant energy efficiency improvements. Implementation of industrial EnMSs has gradually increased and uptake can be expected to accelerate as the international standard (ISO 50001) gains further recognition. Since EnMS complements, or replaces, other energy or climate policies (e.g. emissions trading, energy or carbon taxes) it makes sense to systematically evaluate its implementation in industry. Accurate information needs to be compiled and rated against relevant criteria to confirm desired impact. In their assessments evaluators need to address several issues. Firstly, EnMS are embedded in a context which makes it difficult to attribute results. Secondly, a principle of EnMS is that firms set internal targets to improve energy performance, but these targets might not be consistent with societal objectives. Finally, EnMS certification issued by external auditors gives approval according to standard but cannot guarantee a desired impact. These and other aspects are analyzed and also proposed to be considered in EnMS evaluation. The methods include literature studies, stakeholder consultations to gather empirical input from practitioners, and quantitative data assessments of energy performance. The main contributions are documented experiences from industrial EnMS implementation in Sweden and based on these a set of considerations to be addressed by policy makers and academics in developing a plan for industrial EnMS evaluation.

Introduction

Close to a third of global energy use and 40 % of carbon dioxide (CO_2) emissions are attributable to manufacturing industry (IEA 2010). Thus, it is vital that the industry sector contributes with a fair share towards the achievement of ambitious climate mitigation, energy savings and renewable energy targets. According to the European Commission's roadmap for a competitive low carbon economy the industry sector's CO_2 emissions need to be reduced with the heroic numbers of 83-87 % by 2050 compared to 1990 (EC 2011a). In a step towards this long-term challenge EU's climate and energy package has set a binding greenhouse gas (GHG) emissions target of at least 20 % reduction by 2020 compared to 1990.[1] To mitigate climate change and to achieve ambitious targets by 2050 and beyond, international studies cite energy efficiency improvement to be the least cost measure (IEA 2010). Especially for manufacturing industries, energy efficiency can be seen as a cost-cutter and thus a means to increase profits in competitive markets. By structuring a firm's energy related affairs an energy management system (EnMS) can, if well implemented, be a facilitator for continuous improvement of energy performance. Thus, for industry and especially energy-intensive firms, the implementation of an EnMS should be a compelling business case; especially in periods with relatively high energy prices and when prices are expected to increase. Despite the good motives for energy efficiency improvement, EU's target of 20 % primary energy savings will not be achieved without the implementation of new and effective policies and measures (EC 2011b). Though it seems rational for manufacturing industries they

[1] Other EU targets for 2020 are: to increase the share of renewables in the energy mix to 20 %; to achieve 20 % primary energy savings compared to baseline projections (still a non-binding target).

do not seem to implement EnMS on its' own merit. Industry will thus miss out the attention-raising effect from an EnMS and fail to invest in cost-effective energy efficiency improvement actions. A policy implication is that authorities, to address the market failure of imperfect information, could encourage the uptake of EnMS which conform to standard. However, with a decision to use public funds to stimulate EnMS the issue of evaluation needs to be addressed. EnMS evaluation raises many questions and some dealt with in this paper are: Why and under what circumstances should industrial EnMS be evaluated? What are the objectives for EnMS implementation from a private and a public perspective? Which are the essential EnMS practices? Which indicators could be considered for monitoring and rating the success of an industrial EnMS?

The structure of the paper is as follows. The next section gives a background to EnMS, describes its role in industry and provides examples of countries which have promoted industrial EnMS implementation and certification. The methodology section presents the sources of information that have provided input for the discussions and findings on EnMS evaluation. The empirical findings are presented in the section of results. The final section concludes with considerations to address when evaluating industrial EnMS or energy efficiency programs with EnMS as a main component.

Background to EnMS

The role of industrial EnMS

Energy services are of particular importance for energy-intensive industries where energy represents a significant share of total production cost. In the past, access to low cost energy supply has involved strategic considerations in response to changes in relative energy prices and environmental policy making. For instance, for Swedish pulp and paper industry (PPI) the high oil market prices of the 1970s initiated a fuel switch from oil to biomass and electricity. This preference has been supported by national energy and carbon taxes and more lately the EU ETS. Between 1973 and 2007 the Swedish PPI reduced its share of fossil fuels from 43 % to just below 10 % of total fuel consumption; an absolute reduction of 66 PJ (or 75 %) and 4.5 Mton CO_2 emissions (Wiberg 2007). A recent development and trend break is the renewed interest and investments in electricity generation (e.g. back pressure turbines and wind power). In the 1990s the PPI divested its off-site power assets (e.g. hydro and nuclear power). The strategic reorientation follows from policy driven changes in underlying economic conditions of the PPI (Ericsson et al. 2011).[2] Correlated with the main goal of industrial EnMS practices (i.e. to reduce a firm's energy costs) is that increasing energy prices over the post year 2000 period has motivated an increased focus on energy efficiency improvement besides fuel shifting. Energy cost reduction is seen as the most important driver for industrial energy efficiency (Thollander & Ottosson 2008) but it is also essential that energy efficiency is made a strategic issue in organizations (Cooremans 2012). It implies that upper management decision makers, in addition to process engineers, embrace energy efficiency and enable such investments and related organizational changes to improve the competitiveness of the firm (Cooremans 2012). The importance of the strategic dimension is supported by the evidence that "people will real ambition" and existence of a "long-term energy strategy" is ranked as the second and third most important drivers for energy efficiency in the Swedish PPI (Thollander & Ottosson 2008). To make energy efficiency a strategic issue the Plan-Do-Check-Act approach and the EnMS standard requirements provide a comprehensive tool, tested also in other areas of management (e.g. quality and safety).

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[2] Three main energy policies at play are: the electricity market reform in 1996; the scheme of tradable renewable electricity certificates since 2003; and the introduction of EU ETS in 2005.

National experiences and promotions of industrial EnMS

As a policy option for public governance of industrial energy and environmental issues standardized EnMS has evolved rather recently. Though there are companies that have practiced energy management activities in the past, national EnMS standards and specifications started to evolve first after year 2000. To be compatible with procedures of established management systems they derived from standards like ISO 90001 and ISO 14001 (McKane 2009). Table 1 describes experiences from three countries where EnMS standards have been applied over the last decade. More recently, in 2009, EU consolidated national standards with EN 16001, and in June 2011 the internationally recognized ISO 50001 was published (ISO 2011). International organizations (e.g. UNIDO and IEA) promote EnMS implementation globally. As one of 25 Energy Efficiency Policy Recommendations IEA advise governments to require energy-intensive industries and stimulate other industrial energy end-users to implement EnMS which conform to ISO 50001 or equivalent (IEA 2011).[3]

Table 1. Some national experiences of industrial EnMS promotion and uptake.*

Country / EnMS standard	**EnMS promotion activities and industrial uptake**
USA / ANSI MSE 2000:2008	After the first, year 2000, version of the U.S. EnMS standard the standard development organization Georgia Tech Energy and Environmental Management Center made updates in 2008 to facilitate increased implementation (Kahlenborn et al. 2010). The Department of Energy has encouraged energy management practices by provision of tools and guidelines, but the use of the standard per se has not been emphasized so far. The industrial uptake has been low, it is estimated that less than 5 % of the industrial energy use is covered by standardized energy management practices (McKane 2009). Literature make evident that some large U.S. companies have long experiences from energy management and achieving substantial energy intensity improvements (Capehart et al. 2008). Currently the Superior Energy Performance Program is launched to stimulate ISO 50001 uptake and certification and so far some 30 large companies have announced their participation.
South Korea / KSA 4000	South Korea published an EnMS standard in 2007 to complement its industrial voluntary agreement (VA) for energy conservation and GHG emission reduction. Companies formulate their individual energy savings targets, plan and implement measures for fulfillment. The government support consists of providing energy assessments as well as financial support. Since the introduction the EnMS standard is intended to play a key role for companies' target achievement, but so far the uptake is low. Through a pilot program, eight companies had achieved EnMS certification between 2008 and 2010 (Kahlenborn et al. 2010).
Sweden / SS 627750	The EnMS standard was introduced in 2004 in conjunction with a VA for energy efficiency in energy-intensive industry (PFE). PFE grants eligible companies a tax exemption of 0.5 Euro per MWh electricity use (ETD Article 17 2003). In the first PFE period (2005-2009) companies were obliged to achieve EnMS certification (according to 627750 or EN16001) and fulfill other program requirements (e.g. auditing, identify and invest in electricity savings, report progress, adopt procedures for procurement and project planning). Some 100 companies and 250 industrial plants participated. Since companies are energy-intensive EnMS certification has reached a market penetration of 70 % of total industrial sector energy use. Bottom up evaluations of companies' reporting estimate gross annual electricity savings to be 5 % of the base year electricity use (SEA 2011). In the ongoing second period, companies will implement ISO 50001 and certification of about 90 companies is underway.

* In addition, there are various EnMS experiences in other countries: Japan stipulate legal requirements on industrial energy management practices since 1979; Ireland has an Energy Agreement scheme since 2006 which provide technical and informative support to companies, 70 sites have achieved EnMS certification conform to Irish standard (Cahill 2011); in Denmark at least 100 companies have ten years of experiences from a VA for industrial energy efficiency which involves tax rebates, EnMS certification and other requirements (Reinaud et al. 2012); Spain has a national standard since 2007 but uptake has so far been low (Kahlenborn et al. 2010); the Netherlands has experience from long-term sector agreements on energy efficiency which stipulate EnMS practices but until now without requiring certification.

[3] By January 2012 some 100 organizations in 26 countries had achieved ISO 50001certification (ISO 2012).

Methodology

The aim of this paper is to explore and identify aspects of EnMS evaluation to be addressed by evaluators (i.e. energy authorities and contracted partners or free standing energy policy researchers) which are to evaluate impact and outcomes of industrial EnMS practices. The methods include stakeholder consultations, literature studies, and quantitative data assessments. The stakeholders belong to three categories of actors with different roles in the Swedish PFE. Firstly, through personal communication, staff at the Swedish Energy Agency (SEA) responsible for program operation and evaluation has shared views on evaluation. Secondly, semi-structured interviews were conducted with EnMS coordinators at eight pulp and/or papers mills. For more than five years, these mills have had certified EnMS that conform to Swedish or European standard. Relevant for the scope of this paper are answers provided on objectives and target setting under the EnMS framework, as well as the monitoring practices at the mills.[4] Thirdly, certification companies that conduct external audits and issue EnMS certification have been addressed, through secondary sources and personal communication. Input from certification companies has been useful to identify essential EnMS practices, and to understand what an external audit includes and if the stamp of approval can secure the desired impact of improved energy performance. The energy performance concept is further investigated with the eight mills as an empirical base. Three potential indicators of energy performance have been analyzed to test the improvement under the EnMS framework. Numbers on physical production, energy use, and CO_2 emissions have been compiled from a database of the trade association Swedish Forest Industries Federation (SFIF 2012).

Results

EnMS evaluation

In Sweden, as in Denmark and Ireland, a comprehensive program approach has been effective to promote and support industrial EnMS uptake and certification (see Table 1). The IEA and the Institute for Industrial Productivity (IIP) recommend governments to launch such energy management programs (EnMP) with EnMS at the core and provides a checklist for implementation (Reinaud et al. 2012). Given these recommendations and the release of ISO 50001, it can be anticipated that governments will initiate and enhance policy activities to promote and incentivize EnMS. Thus adequate evaluation practices to assess the contributions from EnMPs, and EnMS in particular, will become increasingly important as:

- EnMPs may complement or replace alternative energy and environmental policy instruments like taxation, pricing of emissions, energy efficiency regulations (e.g. Denmark and Sweden).
- Evaluation is required to revise and adapt policy programs (Reinaud et al. 2012).
- Also when freestanding industrial EnMS implementation and certification is promoted without an EnMP approach, evaluation may be beneficial.[5]
- Whenever public funds are involved there is a justified demand for knowledge on results and effectiveness.
- For the broad category of less energy-intensive SMEs it sometimes argued that a full EnMS implementation and certification is exaggerated but there is little knowledge about the practical implementation of EnMSs in SMEs.

[4] In a previous paper we have investigated how a standardized EnMS is structured in this industry (Stenqvist et al. 2011).
[5] The *U.S Superior Energy Performance* is a relevant example, by which industrial EnMS certification is promoted without economic incentives for companies and at a moderate level of federal funding for administration and technical assistance. There are intentions to evaluate the energy performance improvement of certified companies through a detailed best practice scorecard methodology, and thus give recognition to successful companies (Georgia Tech 2011).

An important issue in the policy planning and evaluation phase is why governments at all need to intervene in the private sphere with economic incentives for business to implement EnMS? EnMS standards are designed to help companies improve their energy performance in accordance with their internal objectives. Policy makers need to ask themselves, which are the desired social benefits from industrial EnMS and improved energy performance that motivates the use of public funds to stimulate such implementations? These questions deserve attention due to some main findings of theory-based evaluations of 20 energy efficiency policy instruments in a number of countries (Harmelink et al. 2008). Firstly, energy efficiency policies often have multiple and unclear objectives, lack quantitative targets and clear time frames. Secondly, an important success factor is the existence of clear goals and mandates for the implementing agency. Thirdly, monitoring information is often insufficient to determine impact on energy saving, cost effectiveness, and target achievement (Harmelink et al. 2008).

EnMS evaluation in the case of PFE

The SEA is responsible for operation and evaluation of the Swedish PFE, which has the overall objective to stimulate industrial energy efficiency and in particular electricity efficiency (SFS 2004:1196 2004). In addition to this objective there are a number of requirements related to the different program components. There is no quantified impact target for PFE, but due to the tax exemption the companies must submit a list of planned actions and later implement these so to achieve electricity savings of the same level that would have been achieved if the tax were to be applied over the same period.[6] The SEA admits it is a challenge to evaluate impact (e.g. energy efficiency improvement) and other intended outcomes of the PFE (Moberg 2012). Among a rich set of program components (e.g. legal requirements, tax rebate, EnMS, tools, networks and recognition etc.) it is difficult to isolate the main drivers for desired change and to conclude what this change consists of. Similarly, it is difficult to identify program components that fail to generate desired change, due to being unnecessary or deceptive. The SEA has progressively carried out a variety of monitoring and evaluation activities to identify and demonstrate program results (Moberg 2012; Reinaud et al. 2012):

- To assess program impact (i.e. the level on energy efficiency improvement) a bottom-up methodology has been applied. Based on companies' reports the SEA has compiled data on e.g.:
    - gross annual electricity savings from required actions and procedures
    - value of investments and straight pay back periods
    - gross annual energy savings from voluntary reports of other non-required actions
- Through a number of interviews and surveys directed to different stakeholders qualitative information about EnMS implementation and compliance has been collected.
- Correction factors like free-rider, spill-over, double counting have not been estimated by the SEA, but attempts have been made in academic evaluations (Stenqvist & Nilsson 2012).
- The isolated impact (i.e. energy efficiency improvement) from specific program components, like the EnMS, has not been estimated.

The SEA regards the EnMS to be a tool which contributes to the companies' achievement of the overall PFE objective. The program context makes it difficult to separate and attribute results solely to the EnMS. Moreover, it is a principle of EnMS that companies set their internal energy performance targets of relevance. The certification provides a best available quality check of the implementation. In case a PFE company submits a poor report to the SEA, examination of the audit protocol can be motivated as part of the assessment of that company's compliance (Moberg 2012).

[6] For an analysis and interpretation of this counterfactual situation see Stenqvist & Nilsson (2012).

The conclusion after the first five year period is that PFE has generated cost-effective gross annual electricity savings of almost 5 % (or 1.45 TWh per year) compared to a 2004 baseline situation (SEA 2011; Stenqvist & Nilsson 2012). Almost all of the 100 companies complied with the program requirements including the EnMS certification. Reports from the ongoing second period, during which companies will implement ISO 50001, show that companies plan to slightly increase their investments in electricity savings actions compared to the first program period (Moberg 2012). These experiences have led the SEA to promote energy management also outside PFE. The interest for EnMS appears to be on the rise but there is still resistance among SMEs against full scale implementation and certification. Some of the SEA promotion activities include: an energy audit program for SMEs; manuals for systematic energy management; a communication platform for energy efficiency in industry; a Lean Energy training course (Moberg 2012).

Input from certification companies

To obtain views from the standard certification companies about PFE and EnMS implementation the SEA commissioned an operational evaluation. At the time, in 2008, the first five year program period of PFE was more than half way through and almost all the 100 participating companies had received their EnMS certification according to Swedish standard. Six out of seven authorized certification companies were interviewed and shared their experiences in the evaluation report (Franck & Nyström 2008). To complement this information, an interview has been conducted with an EnMS auditor (Modig 2012).

At the outset, the PFE tax exemption of 0.5 Euro per MWh of electricity use was imperative to attract managements' attention and will to participate and comply with the program requirements. The EnMS implementation was at first, from a management perspective, seen as a necessary obligation to receive the tax rebate (Franck & Nyström 2008). At the same time, the EnMS requirement was well-timed with underlying conditions of increasing energy prices. The interest for strategic and systematic energy management was on the rise and the EnMS was gradually given enhanced attention throughout many organizations (Modig 2012). According to certification bodies the most important EnMS practices have been (Franck & Nyström 2008):

- **Energy audit and analysis:** the energy audits revealed large and profitable energy saving potentials which strengthened the business case for energy efficiency improvement in many companies. The EnMS framework has resulted in more thorough technical and economic analysis of potential measures, especially as firms have identified significant energy aspects. When energy audits have been conducted entirely by external consultants the results have sometimes been less useful for the firm's practical implementation. For some companies there could be a stronger focus on energy efficiency improvement from operation and maintenance measures.
- **Roles and responsibilities:** EnMS coordinators are appointed by top management and take responsibility for facilitating compliance with PFE and standard requirements. In many companies the EnMS coordinators feel they have support and a clear mandate from management to perform their tasks. This has been important for the EnMSs to become established and continuously maintained in the companies. Especially at larger industrial plants the chief EnMS coordinator has access to division level EnMS coordinators (i.e. process engineers) and together with other staff (e.g. technical experts from maintenance department) they form an EnMS team.
- **Dissemination in the organization:** with EnMS the awareness of energy issues has spread across the organizations. The EnMS teams hold regular meetings to plan the implementation of actions (Modig 2012). EnMS practices have also involved new categories of employees like production/process developers, maintenance engineers, and staff working with procurement. Some companies have trained their staff to raise general awareness on energy related issues as

well as specialized knowledge among operators who influence significant energy aspects.

- **Life cycle cost (LCC) procedures for energy efficient procurement and project planning:** PFE requires that companies use LCC procedures to evaluate their purchase of new electrical equipment, and to plan larger investment projects like plant retrofits. These new procedures have sometimes been difficult to communicate within organizations, between purchasing and maintenance division. The service from equipment suppliers has gradually improved upon the demand for LCC information. ISO 50001 requires such procedures which are expected to become increasingly important (Modig 2012).

In principal all the EnMS requirements are reviewed by the external auditor at yearly site visits. Ideally the external auditor is a person with technical degree and long experience from working with energy analysis in manufacturing industry. The auditor plans the visit by preparing a relevant audit program based on examination of previous audit protocols, the energy balance of the plant, and other relevant documents provided by the company. Depending on the size and complexity of the plant the external audit can last between one and three days. At the opening meeting a number of company staff attends like the EnMS coordinator, parts of the EnMS team and top management. Thereafter the auditor goes through different divisions to observe ongoing practices and ask different employees about their role and influence under the EnMS framework. In a final meeting the auditors delivers a statement about the compliance with the EnMS standard and describes any identified abnormalities in relation to requirements, the company's energy policy and procedures. Serious abnormalities must be explained by the company to be acceptable or the company can lose the EnMS certificate. For instance, the companies' energy performance targets and monitoring practices are tested. If a company fails to meet its targets the deviation needs to be explained, for instance, by demonstrating how a temporary shutdown has altered the baseline energy use. (Modig 2012)

The companies in general request a critical assessment and expect the external auditor to be knowledgeable and in position to scrutinize and challenge existing EnMS practices. The conclusion among certification companies is that the EnMS standard, with few exceptions, has been well received and implemented by the companies (Franck & Nyström 2008). Compared to the Swedish standard the ISO 50001 puts further emphasize on some essential issues like the role of the EnMS team, the commitment from top management, the possibility to include transport related energy use in the EnMS, the objective to reduce GHG emissions (Modig 2012).

Input from industrial energy end users on EnMS target formulations

Interviews were conducted with EnMS coordinators at eight pulp and/or paper mills that participate in PFE.[7] The respondents were asked about strategies, objectives, targets, and monitoring practices under the EnMS framework. The mills are organized under larger company groups, sometimes with global business activities, but each mill operates as an independent business unit. Each mill is organized into multiple divisions, and each division typically represents a cost center (Stenqvist et al. 2011). Consequently, targets and monitoring can exist on different hierarchical levels, from group-wide to site-level, at division and for certain production processes:

- **Group-wide:** the mills are often subordinated group-wide strategies and targets. Six mills declared group-wide targets to reduce specific energy use (i.e. production related) which were quantified and with clear time frames. Typical levels of targeted reductions are 1-2 % per year, or

[7] At all mills the EnMS coordinator was the representative appointed by top management. In some cases also other staff members of the EnMS team participated in the interviews (see ISO 50001 for definitions).

5-10% when targets cover periods of about five year. It is also common with group-wide strategies and targets to reduced specific CO_2 emissions. The mills should contribute to overarching targets, but need to formulate their site-level strategies and targets that are dictated by their production and energy related situation and outlook.

- **Site level:** the site-level EnMS objectives vary between different mills, but usually the EnMS strategy is focused on reduced specific energy use. While some mills declare explicit target levels other only monitor the development. Some mills also set targets for separate energy carriers, e.g. to reduce specific electricity, steam or fossil fuel use. Other site-level EnMS objectives for some mills are: increased internal electricity production; increased use of biomass fuels; and increased energy deliveries to adjacent society (e.g. waste heat and/or electricity).
- **Division and process level:** each major production process represents a division and for a large integrated pulp and paper mill it involves: wood preparation; debarking; pulping; bleaching; paper making (often by multiple paper machines). Five mills have automatic meter readings to assimilate data from electricity and steam meters at the division and process level. The sub-metering systems allow these mills to identify significant energy aspects at process level and to track specific energy use of individual installations. An example is refiners used in thermo-mechanical pulping, for which the specific electricity use is monitored to ensure that acceptable levels are maintained. Monitoring data is used to compare performance and analyze opportunities for improved energy performance, e.g. by changing refiner plates. Process level monitoring thereby contributes to site-level EnMS target fulfillment.

This examination of targets formulations demonstrates that the EnMS framework is used to improve energy performance in different ways, as summarized in Table 2. Energy efficiency through reduced specific energy use is one common interpretation of improved energy performance, but the EnMSs also contain supply side oriented strategies and targets. In one occasion the respondent had low awareness of the existence of EnMS targets and a few mills lacked quantified targets with clear time frames. This is not acceptable and needs to be improved for compliance with ISO 50001.

Table 2. The presence of EnMS objectives and targets among eight pulp and paper mills.

Group-wide Reduce specific energy use	Site level Reduce specific energy use (for all or certain energy carriers)	Site level Increase use of biomass fuels	Site level Increase energy supply to adjacent society	Site level Increase internal electricity production	Site level Low awareness of targets
6	7	2	2	5	1

Indicators of energy performance

According to ISO 50001, energy performance is the measurable results related to any of the three aspects: energy efficiency; energy use and energy consumption. Results are measured against the organization's energy policy, objectives and targets. Thus companies can manage a variety of energy performance activities under their EnMS, as demonstrated for the eight mills in the previous section. For these mills, three indicators are used to analyze how the performance has developed with EnMSs between 2005 and 2010, compared to a baseline period represented by the average annual performance between 2001 and 2004 (i.e. prior to the EnMS implementation). The three energy performance indicators, based on the physical output of tonnes market pulp and final paper products, are: specific total final energy use; specific final electricity use; and specific fossil CO_2 emissions.[8]

[8] The data is retrieved from the Environmental Database of the Swedish Forest Industry Federation, to which the companies report their annual production volumes, energy use, emission to air and water etc. (SFIF 2012).

Figure 1 demonstrates how the specific total final energy use has developed for the eight mills. In 2010, the energy intensity had increased for six mills between 1 and 12 % and decreased only for two mills by 6 and 14 % respectively. Since the latter two mills have large production volumes the aggregate for the eight mills is a decrease in energy intensity by 2 %. Given that seven mills have site-level objectives or targets to reduce specific energy use the development is rather discouraging. One explanation can be low production outputs in 2008-2009, which tends to increase specific energy use. Another issue is the potential target conflict between increased use of biofuels and internal electricity production on the one hand, and reduced total specific energy use on the other. Fuel shifts from fossil fuels to biofuels of diverse qualities tend to increase total energy use. In addition, some mills have, in accordance with their site-level objectives, improved boiler and turbine installations to increase internal electricity generation from biofuels and thus expanded production beyond pulp and paper products.

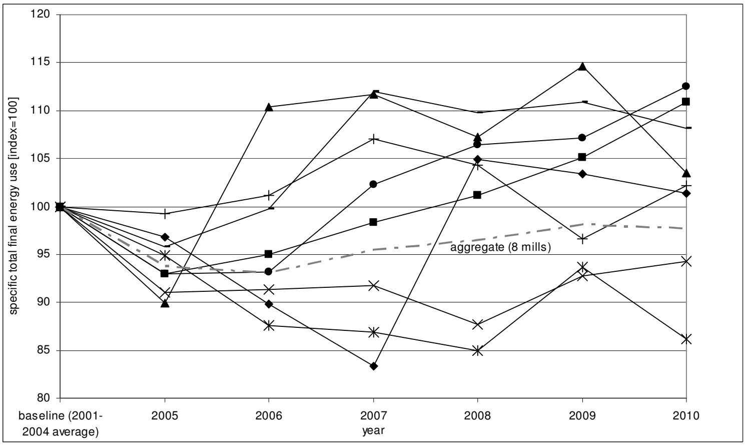

Figure 1. Specific total final energy use for eight mills (2005-2010). Source: SFIF (2012)

Figure 2 demonstrates how the specific final electricity use has developed for the eight mills. Decreased electricity intensities can be expected as PFE requires electricity savings in particular and the mills have reported bottom-up estimated electricity savings of between 1.5 and 9 % compared to their 2004 electricity demand (Stenqvist et al. 2011). In 2010, the electricity intensity had decreased for six mills; by 0.5-4 % for five mills and an extraordinary 21 % for one mill. For the two remaining mills the electricity intensity increased by almost 5 %. The aggregate for the eight mills is a decrease by 1 %. Again, for some mills low production outputs 2008-2009 can explain deviations from expected performance.

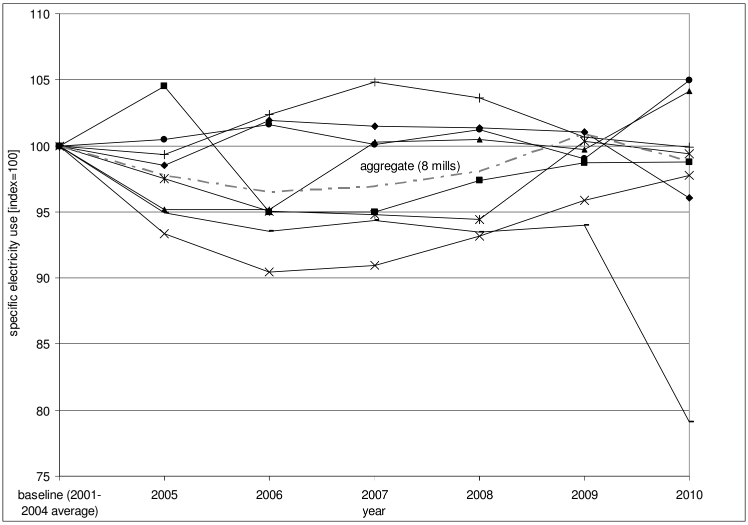

Figure 2. Specific final electricity use for eight mills (2005-2010). Source: SFIF (2012)

Figure 3 demonstrates how specific fossil CO_2 emissions have developed for the eight mills, which is closely related to their fossil fuel use. For this indicator an overall improvement is evident. In 2010, seven mills had decreased the CO_2 intensity with between 12 and 90 % and the aggregate for the eight mills was a 33 % specific reduction. In fact, over the period and compared to baseline, the aggregate fossil fuel use and related CO_2 emissions have decreased by 30 % in absolute numbers. For one mill the CO_2 intensity increased by 21 %. Notably, this is the same mill that decreased its electricity intensity by 21 % (see Figure 2). Thus the explanation appears to be a fuel shift from electricity to fossil fuels over this period. Interviews with EnMS coordinators could clarify the technical and economic conditions at the mill and thus improve the understanding about priorities of energy carriers and fuels.

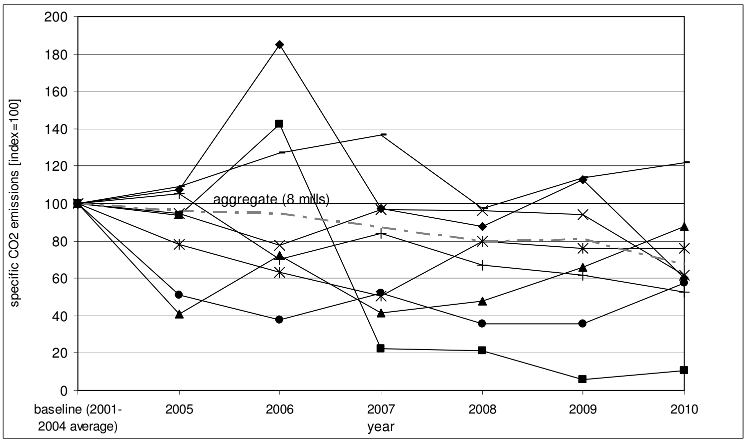

Figure 3. Specific CO_2 emissions for eight mills (2005-2010). Source: SFIF (2012)

Conclusions

With ISO 50001 and policy recommendations to stimulate industrial EnMS, through policy programs or somewhat less comprehensive measures, EnMS evaluation has come to fore. To monitor and verify desired impact is important for companies as well as public agencies. Companies need to ensure that efforts put into EnMS practices pay off, and from the public perspective the societal objectives behind EnMS implementation need to be defined, communicated and achieved. Non-quantified objectives like energy efficiency or improved energy performance appear as vague in this regard. Furthermore, such objectives are rather means to achieve other goals than goals in themselves. The actual societal goals, i.e. GHG emission reductions, increased industrial competitiveness, job creation etc., will have to be defined already in the planning phase and take count of the national context and political priorities. Ideally the societal objectives (formulated by policy makers) are consistent with the firm internal objectives of improved energy performance (formulated by the companies). Verification requires, at the minimum, that the constituents of improved energy performance are defined by the administrating agency as well as the company, and then monitored accordingly to ensure continuous improvement towards mutual objectives. Clear target formulations from the start will enable cost-effective monitoring and evaluation based on relevant performance indicators that are tracked through companies' reporting over the program period.

Requirements on companies to achieve certification can be motivated for several reasons and especially when companies are offered economic incentives to join an EnMP and introduce an EnMS. The external auditor validates that the EnMS conform to standard and thereby share the responsibility with the administrating agency to verify program compliance. Given that responsibilities are clearly defined the external auditor can play an important role in the overall evaluation plan. From a company perspective the critical test performed by a skilled external auditor is often appreciated. In the case of SMEs, for which there are concerns about the cost for certification, the potential benefits need to be examined as well. The scope of the external audit is of course adapted to the needs of the specific company/client with regards to its size, technical complexity etc.

Among EnMS requirements the external auditor reviews the company's energy performance in relation to energy policy and target formulations. However, the EnMS certification cannot guarantee improved energy performance in all regards. The data analysis demonstrated that several certified mills, despite EnMS targets to reduce specific energy use, have increased their energy intensity. In some cases this can be explained by increased use of biomass fuels and internal electricity generation, which are other site-level EnMS targets. In the Swedish case of PFE, bottom-up evaluations conclude that the program has been successful in generating large and cost effective electricity savings. However, the data analysis demonstrates that specific electricity use has increased for individual mills. In order to cross check companies' program compliance an evaluation plan could combine bottom-up methods with the use of top-down indicators. For the CO_2 intensity indicator the development is clearly positive. Specific and absolute fossil CO_2 emissions have decreased significantly for all but one mill. Though being managed and facilitated under the EnMS framework these achievements cannot be attributed solely to EnMS and PFE. A combination of market and policy related driving forces have influenced the decarbonisation of the Swedish PPI.

Essential among EnMS practice is the activity of the EnMS team. A cross-functional and multi-person team can be a key for energy management and improved energy performance to become a strategic issue in top management and across the organization. For evaluators, the organizational structure and documented activity of the EnMS team could be an indicator of the progress and the existence of real ambitions for energy efficiency improvement and other low-carbon solutions.

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Paper V

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The limited effect of EU emissions trading on corporate climate strategies: Comparison of a Swedish and a Norwegian pulp and paper company

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HIGHLIGHTS

- We examine corporate responses to the EU ETS in two pulp and paper companies.
- Rising electricity prices are perceived as the strongest influence from the scheme.
- The scheme has reinforced commitments to reduce CO_2 emissions.
- The CO_2 price tag supports some investments but has limited effect on innovation.
- The effect of the scheme is mediated by both market factors and production factors.

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ABSTRACT

This article examines to what extent and how the EU ETS has influenced the climate strategies of two Nordic pulp and paper companies: Swedish SCA and Norwegian Norske Skog. Rising electricity prices are perceived to be the greatest effect of the scheme. The EU ETS has served to reinforce commitments to improve energy efficiency and reduce CO_2 emissions in both companies studied. Procedures like monitoring of CO_2 emissions and accounting for CO_2 prices have become more significant since the introduction of the EU ETS, but the scheme has not triggered a search for innovative, low-carbon solutions. Due to differences in market factors and production factors, SCA has been more active than Norske Skog in investing in and implementing CO_2-lean actions. Future studies of climate-mitigation activities, strategies and innovations in the pulp and paper industry should involve more in-depth investigation of the interactions between such factors and the EU ETS.

1. Introduction

The EU Emissions Trading System (ETS) was the first international policy instrument to introduce regulation of fossil CO_2 emissions of pulp and paper companies in Europe. Of 11,500 installations introduced to the system, about 900 were pulp and paper mills. In terms of allocated EU Emission Allowances (EUAs) the pulp and paper industry (hereafter PPI) represents two per cent of EU ETS (Hyvärinen, 2005: 40). Can the ETS induce companies in the PPI and other energy-intensive industries to adopt proactive climate strategies? That will represent a crucial test of the EU's ability to achieve a low-carbon economy. Further, how can divergent corporate climate strategies be explained? Examination of this question can shed light on the conditions under which different corporate climate strategies emerge.

This article examines to what extent and how the ETS has influenced the climate strategies of two specific pulp and paper companies and the European PPI more generally. One of the few works on this topic is Rogge et al. (2011), whose study, based on survey data of paper producers and technology providers in Germany, found their innovation activities to be governed mainly by market factors, not the EU ETS or other climate policies. As the EU ETS is the first EU-wide regulation to target PPI CO_2 emissions, we were puzzled by the finding that the scheme apparently had scant effect on innovation activities, and suspected that the methodological approach of Rogge et al. had bypassed important aspects of corporate responses to the ETS. Complementary interview-based studies with relevant company representatives can identify more nuanced perceptions about corporate climate strategies, including the possible influence of the EU ETS on innovation activities. This has motivated our approach to examining the effect of the EU ETS by analysing the status and changes

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in climate strategies in two comparable yet different pulp and paper manufacturing companies: Svenska Cellulosa Aktiebolaget (SCA) and Norske Skog, with headquarters in Sweden and in Norway, respectively. Both companies appear to have progressive climate strategies, having been ranked as the best Swedish and the best Norwegian company in the 2010 Carbon Disclosure Project (CDP) appraisal. The two companies display some variation in climate strategies and development over time, with SCA apparently experimenting more with innovative abatement projects than Norske Skog. Further, Norske Skog specializes in newsprint production, and is smaller and less diversified than SCA. Due to the market situation with surplus production capacity of newsprint, Norske Skog has recently sold assets to reduce debts, and has shut down several mills to cut costs (Norske Skog, 2011).[1] By contrast, SCA develops, produces and markets a broad portfolio of products and ranks among the world's leading forest industry companies. This variation in company type and performance enables exploration of the conditions under which different corporate climate strategies may emerge.

This article proceeds as follows. Section 2 presents the analytical framework and methodology applied in this study. Section 3 examines the corporate climate strategies of SCA and Norske Skog in presence of EU ETS. In Section 4 we analyse the link between the EU ETS and the changes in corporate climate strategies in light of three causal mechanisms that shed light on corporate responses to regulation. Section 5 explains the divergence in corporate climate strategies of SCA and Norske Skog. In the final Section 6, we identify some patterns in the complex process of EU ETS adaptation in the two companies and reflect on the future outlook of EU emissions trading and the PPI.

2. Analytical framework and methodology

The concept of 'corporate strategy' has been defined variously in the management literature. Building on scholars like Mintzberg (1987) and Leong and Ward (1995), we view corporate climate strategy as being composed of three main constituents:

1. recognition of the problem of anthropogenic climate change and acceptance of responsibility in mitigating greenhouse gas (GHG) emissions
2. manifestation of company responsibility for problem-solving, expressed by a target for reducing GHG or CO_2 emissions and related monitoring practices
3. actions or a pattern of actions: investments or implementation of technical and organizational abatement measures for climate–target achievement.

These constituents have guided our research and interview questions, and serve as indicators, framed as headings in this article, under which empirical results are described and analysed. In analysing the influence of the EU ETS on corporate climate strategies, we see three complementary causal mechanisms as providing explanatory power. First, the EU ETS may influence the cost-benefit calculations of companies. According to a rational-calculative model of corporate behaviour grounded in the mainstream economic view of the firm as a unitary profit-maximizing agent (e.g., Gravelle and Rees, 1981), the principal function of emissions trading is to *restructure incentives* by putting a price on CO_2 emissions. A unitary profit-maximizing actor with full information on the relative costs of various alternatives will rank the different alternatives according to cost, phasing in the lowest-cost option first. If the allowance price is low, or expected to be low in the future, the company will prefer minor, low-cost adaptation such as trade in allowances. Many studies of the effects of the EU ETS are explicitly or implicitly based on this understanding of corporate behaviour (e.g., Egenhofer, 2007; Hoffmann, 2007; Ellerman at al., 2010).

Second, drawing on Porter (1990) and Porter and Van der Linde's (1995) seminal work on the link between environmental regulation, innovation and competitiveness, we propose that the EU ETS may trigger exploration, experimenting and learning across companies. In line with this Porter Hypothesis, the key assumption is that the EU ETS may alert and educate companies to the benefits of reducing emissions, raising the likelihood that product and process innovations will be environmentally friendly. Lack of 'stringency' is the factor most often mentioned when scholars seek to explain why the EU ETS induced relatively little innovation in the first phases (De Bruyn et al., 2010; Ellerman at al., 2010; Rogge and Hoffmann, 2010; and Martin at al., 2011). According to the Porter Hypothesis, environmental regulations can – if stringent enough – stimulate companies to be innovative, adopt and develop new technologies and practices, and gain competitive advantages. The main implication is that companies *need* regulation in order to recognize new and innovative opportunities that may pay off in the short or long term (Porter and van der Linde, 1995).

Third, drawing on neo-institutional theory, we expect that companies may internalize norms and rules about appropriate conduct by participating in schemes like the EU ETS. Sometimes referred to as 'the logic of appropriateness' (March and Olsen, 1989), this internalization of norms and rules constitutes the prime causal mechanism seen as connecting institutions and policy instruments to behavioural change. Studies have shown that institutions and regulations can create new norms of responsibility based upon the matching of situation and role rather than on cost-benefit calculations (Vogel, 2005; Barth and Wolff, 2009; Flohr et al., 2010). This literature questions the profit-maximization motive and opens up for intrinsically norm-driven behaviour to explain why some companies go beyond compliance with environmental regulations (see, e.g., Flohr et al., 2010, Gulbrandsen, 2010). Companies guided by the logic of appropriateness can be expected to invest in long-term carbon solutions beyond minimum compliance measures, once they have recognized the climate change problem and responsibility for contributing to problem-solving efforts.

Our research methods include interviews, surveys of company documents and reports, and quantitative data analysis. Semi-structured interviews were conducted with company management representatives responsible for strategic and operative matters concerning environmental impacts, including climate change and other sustainability issues. Some complementary interviews were conducted to obtain representation from other stakeholders in the European pulp and paper industry and EU ETS policy experts. Company documents and reports (annual reports, sustainability reports etc.) have been used to examine the companies' external communications and outside recognition. Data, originally from the Community Transaction Log (CITL, 2011), on allocated allowances and verified emissions under the EU ETS have been analysed to examine the relation to cap from the initiation of the scheme until 2011. By combining methods we have been able to cross-check the consistency in company statements, reported actions and compliance with the system. In addition, since the EU ETS is one of many factors that may influence corporate climate strategies, the effects of other relevant variables have also been taken into account. We have

[1] The Follum mill in Norway was sold in March 2012 and the Parenco mill in the Netherlands in August 2012; during the period studied here, Follum and Parenco were fully owned by Norske Skog.

examined how the EU ETS and other EU policy instruments as well as domestic-level policy instruments interact and co-produce outcomes. The use of these different methods has proven practical in informing the analysis of factors that have conditioned corporate responses to the EU ETS.

3. Corporate climate strategies

3.1. Company backgrounds

SCA was founded in 1929 through a merger of several Swedish forest companies. The internationalization of the company started in the 1960s; today it ranks among the world's leading forest industry companies. It develops, produces and markets a broad portfolio of products within the main segments of personal care (e.g., baby nappies and incontinence care); tissues (e.g., toilet paper and napkins); packaging material; publication paper and newsprint; and solid-wood products (SCA, 2011). In 2011, SCA operated some 250 production facilities, of which 45 were larger pulp and/or paper mills, in 60 countries, and sold its products in more than 100 countries. Europe represents a strong base, with 75% of total net sales (€11.7 billion for 2011), 75% of the total number of 44,000 employees, and 75% of group-wide energy use (fuel, heat and electricity) (SCA, 2012; Isaksson, interview 2011).[2]

Norske Skog is Norway's only major pulp and paper company. It was founded by Norwegian forest owners in 1962 to refine national timber resources. During the 1990s, the company grew internationally, first in Europe and expanding further through the acquisition of newsprint and magazine paper mills in Asia, Australasia, and South America (Sæther, 2004). Since the mid-2000s, a difficult market situation with surplus capacity of newsprint has been challenging for the company. Between 2005 and 2011, global production of newsprint decreased by almost 20% (FAO, 2012). In recent years, Norske Skog has closed or downsized some of its production units and sold others; production has fallen by 37% since 2006 (Norske Skog, 2012). The company has shown negative results for several consecutive years and has debts. However, with an annual production of 4 million tons it is still among the world's largest producers in its segment of publications paper. In 2011, the company operated 13 wholly-owned mills located in 10 countries, with annual sales around €2.6 billion, and had 5075 employees worldwide. The European part of Norske Skog's business is represented by seven mills and accounts for 70% of total production capacity (Norske Skog, 2012).

3.2. Recognition of the climate change problem

At an early stage both SCA and Norske Skog expressed acknowledgment of the climate change problem and their responsibility for contributing to problem-solving (SCA, 1999, 2002; Norske Skog, 2002). The companies already had considerable experience of dealing with local air and water pollution at their mills, and were thus prepared for developing corporate climate strategies when the climate change problem emerged on the international agenda. Norske Skog and SCA have monitored and reported their CO_2 emissions since 1996 and 1998, respectively–much earlier than many other PPI companies. They were also relatively quick to express support for intergovernmental efforts to reduce GHG emissions, like the Kyoto Protocol (SCA, 1999; Norske Skog, 2002). Among companies based in Norway and Sweden, Norske Skog and SCA scored highest on carbon accounting in the 2010 Carbon Disclosure Leadership Index (CDP, 2010). Our expectations that the two companies would be PPI frontrunners were confirmed by examination of the corporate climate strategies of the 10 largest pulp and paper companies in Europe, which indicated that the big Nordic forest companies–Stora Enso, SCA and UPM–have adopted more ambitious climate policies and programmes than have companies from other countries (Gulbrandsen and Stenqvist, 2013).[3]

In the planning and formulation phase of EU ETS, SCA and Norske Skog were positive to the idea of a carbon trading scheme, i.e., conducting climate-mitigation efforts where most cost-effective, although they would have preferred a global scheme. By contrast, the broader European PPI sector, represented by the Confederation of European Paper Industries (CEPI), initially opposed the ETS, arguing that its design 'raises several concerns for the competitiveness of EU industry' (Hyvärinen, 2005: 41). There has been significant focus on the regulatory risk of the system due to carbon intensity and international competition in the PPI. Nordic pulp and paper companies have a higher share of renewables in their energy mix than most other European pulp and paper companies, which means they face lower regulatory risk.[4]

For SCA, expectations as to the allocation of EUAs were generally fulfilled. Due to international competition it was expected that EU member states, in their National Allocation Plans (NAPs), would propose generous allocations to domestic industries (Isaksson, interview 2011). Indicative of the political importance of getting the scheme up and running, the NAPs were also approved by the European Commission (Convery and Redmond, 2007). For many pulp and paper companies, including SCA (although not Norske Skog), this resulted in 'long' positions (whereby the cap of allocated EUAs clearly exceeded verified fossil CO_2 emissions) in the first trading period.[5] In the course of the EU ETS, both SCA and Norske Skog have anticipated successive reductions in allocated EUAs. For individual installations this has sometimes been the case, but the aggregate amount of allocated EUAs has increased for both companies from the first to the second trading period (see below).

While generally content with the allocation procedures, both companies still perceive the risk of carbon leakage as a weakness of the EU ETS, and would prefer a global emissions trading scheme (interviews, Strandqvist 2011 and Carlberg 2011). Another issue that SCA and Norske Skog noted also prior to the introduction of EU ETS concerned the potential effects on electricity prices. Moreover, the companies had warned decision-makers of the risk of windfall profits in the power sector (interviews, Isaksson 2011 and Carlberg 2011).[6] Norske Skog and SCA share frustrations concerning electricity prices: sales of surplus allowances have not compensated for the rise in electricity prices; and the higher costs cannot be passed on to consumers because of the sharp competition in many market segments, especially newsprint.

[2] In 2012, SCA announced its decision to divest itself of its main operations in the packaging segment. When implemented, this will significantly alter the company portfolio (SCA, 2012).

[3] Data on file with authors. See also Gulbrandsen and Stenqvist (forthcoming).

[4] However, all mills in Norway were excluded from the scheme in the first trading period–a government decision that Norske Skog disagreed with (Norske Skog 2005).

[5] In the first and the second period of EU ETS, the EUAs were allocated to the PPI by means of 'grandfathering' based on recent historical baselines of fossil CO_2 emissions. Due to significant use of biofuels, the industry also has biogenic CO_2 emissions, which are not regulated by EU ETS.

[6] According to economic theory, the power generators will pass on the opportunity costs of their largely freely allocated emission allowances to electricity consumers. The extra costs of fossil-fuel-based power generation thus impact on wholesale electricity prices, in line with the carbon intensity of the marginal production unit (Sijm et al., 2006).

3.3. Manifestations by target formulations and monitoring practices

In 2001, SCA made a group-wide commitment to reduce CO_2 emissions from fossil fuels in relation to production levels (SCA, 2002). This commitment was strengthened in 2008, when SCA announced it would reduce the CO_2 emission intensity per unit of product from fossil fuels and from purchased electricity and heat by 20% by 2020, compared to 2005 (SCA, 2009). In 2011, SCA reported a reduction of 7.3%, so it has been making progress towards its target (SCA, 2011). Recently, the company also adopted a target of 14% improvement in specific energy use between 2010 and 2020 (SCA, 2012). While some of SCA's other environmental and social commitments have been changed or replaced over the years, its commitment to mitigate climate change has remained firm since 2001.[7] In the late 1990s, the SCA resource management system (RMS) brought in monitoring and reporting practices for CO_2 emissions–as well as other emissions to air, water and various material flows (SCA, 1999). This system was introduced due to internal driving forces, independent of any expectations about a future emissions trading scheme (Isaksson, interview 2011). The RMS has since been used and developed for group-wide bottom–up compilation of GHG emissions data from most production sites (SCA, 2012).

Norske Skog has also, since 2001, made clear its objective of reducing GHG emissions. In 2007, this objective was quantified: the company announced it would reduce direct emissions from pulp and paper production and indirect emissions from purchased energy by 25% by 2020, compared to 2006 (Norske Skog, 2010). As of 2011, GHG emissions (including CO_2, CH_4 and N_2O) had been reduced by 18.2% (Norske Skog, 2012). Whereas SCA's target is production-related (as is common practice in the industry), Norske Skog has set an absolute emissions-reduction target. Such targets leave less room for manoeuvring than production-related targets, but can prove tactical when a production decline can be foreseen. The fact that Norske Skog has reduced its total production level by almost 40% since 2006 has contributed directly to progress towards its target.

In connection with the companies' targets formulations it is relevant to assess their CO_2 emissions and cap of allocated EUAs as regulated by EU ETS. The development of emission levels indicates whether progress is consistent with group-wide targets. The ratio between verified emissions and allocations indicates to what extent EU ETS incentivizes companies to reduce CO_2 emissions.

Fig. 1 shows the CO_2 emissions and EUA allocations for 41 of SCA's installations, all covered by the EU ETS. During the first trading period, the emission-to-cap ratio remained unchanged at around 90%. With some acquisitions introduced in the second trading period, emissions reached a high of 1.52 Mt CO_2 in 2008 (Sandbag, 2012; communication with Eriksson 2011). These new installations entitled SCA to additional EUAs in the second period. In 2011, the EUA surplus was 450,000 t CO_2 and the emission-to-cap ratio was 75% (Sandbag, 2012). For unknown reasons, one particular SCA mill, Mannheim (Germany), received a large surplus in the second period, compared to its stable CO_2 emissions between 2005 and 2011 (Sandbag, 2012).

For the third trading period, which will span the period January 2013 until December 2020, SCA expects a decrease in allocated allowances compared to earlier periods (Isaksson, interview 2011). Allocation in line with best-practice benchmarks means that mills with less favourable fuel mixes will receive fewer EUA allowances than currently needed (Strandqvist, interview 2011).[8] That should provide strong incentives for those mills to implement abatement actions in the third trading period. SCA as such may still receive a surplus of EUAs, since some of its larger mills are heavily reliant on biomass fuels (Fält, interview 2011). As SCA has a diverse product portfolio with major operations in up to ten EU ETS countries, a more in-depth analysis would be required to assess the group-wide situation for 2013–2020.

Turning to Norske Skog, Fig. 2 shows CO_2 emissions and EUA allocations for the seven installations covered by the EU ETS. From an initial emission-to-cap ratio close to 100%, the allocation of EUAs increased as the Norwegian mills joined the EU ETS in the second trading period. Over the period 2005–2011 Norske Skog's direct CO_2 emissions decreased by about 10%, due partly to low production output in recent years (Norske Skog, 2006, 2011). In 2011, Norske Skog had a total EUA surplus of 90,000 t CO_2 and an emission-to-cap ratio of 83% (Sandbag, 2012). Almost 90% of the CO_2 emissions from its European mills stem from Parenco (Netherlands) and Bruck (Austria)–where electricity for the production processes is not purchased but produced on-site from natural gas (co-generation of heat and power). Under the EU ETS, CO_2 emissions from the production of electricity are allocated to these mills, not to the power companies. The CO_2 emissions from Norske Skog's three Norwegian mills are very low compared to mills elsewhere in the PPI, and this relates to energy and fuel mix. The Norwegian mills account for more than 30% of the company's total production capacity, but their direct emissions (onsite fossil fuels) and indirect emissions (those arising from purchased energy) are less than 5%. These mills get most of their electricity from hydropower, and cover only around 1% of their energy demand by fossil fuels.

Norske Skog is likely to receive a group-wide surplus of EUAs in the third trading period, partly because of the low emission levels of its Norwegian mills. Table 1 shows direct and indirect emissions from purchased energy for Norske Skog's European mills in tons of CO_2 equivalents per ton of paper.[9] Only direct emissions are reported under the EU ETS. As the product benchmarks for these mills will be close to 0.3 allowances per ton of paper in the third trading period (DG CLIMA, 2011; EC, 2011), two mills–Bruck and Parenco–will have to purchase emission allowances; the other mills will receive a surplus of free allowances (Carlberg, interview 2011).

Somewhat paradoxically, the mill with the biggest carbon footprint–Walsum–will have a considerable surplus of emission allowances in the third phase of the EU ETS. This mill has a large carbon footprint because it purchases electricity from a coal-fired power station, but emissions from producing this electricity are accounted for by the power-plant under the EU ETS, not by the mill (see Table 1). In sum, Norske Skog appears well-positioned for the third trading period, when a considerable surplus of free allowances can be expected.

3.4. Actions for abatement

In its external communication SCA reports on several recent and on-going CO_2-lean investment projects and some innovative abatement actions. The company strategy is to maintain and improve its installations with the most suitable technology in terms of fuel usage and energy performance (Strandqvist, interview 2011). A group-wide programme, ESAVE, has been

[7] Since 2006, SCA has had the following environmental and social commitments: reducing CO_2 emissions from fossil fuels; not using wood fibre from controversial sources; improved water usage; compliance with the universal Code of Conduct (SCA, 2011). In 2011, SCA further extended the number of sustainability targets (SCA, 2012).

[8] The starting point for setting performance benchmarks for free allocation of EUAs (2013–2020) was to be the average performance of the 10% most efficient installations in a sector in 2007/2008 (EC 2011).

[9] Norske Skog's mills produce primarily newsprint and coated fine paper.

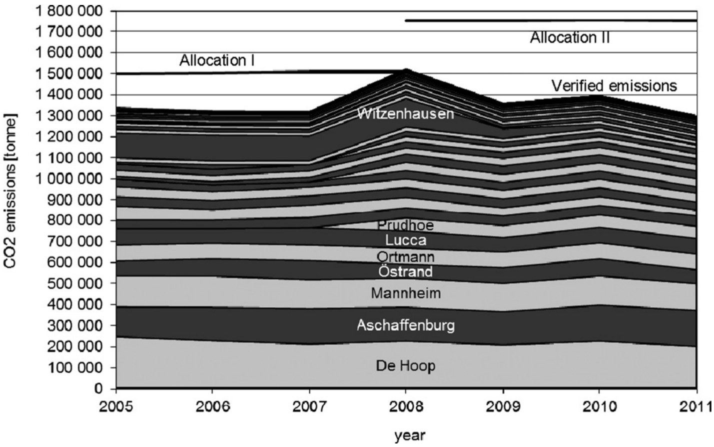

Fig. 1. Allocations and CO_2 emissions for SCA's 41 installations under EU ETS. Source: Sandbag (2012).

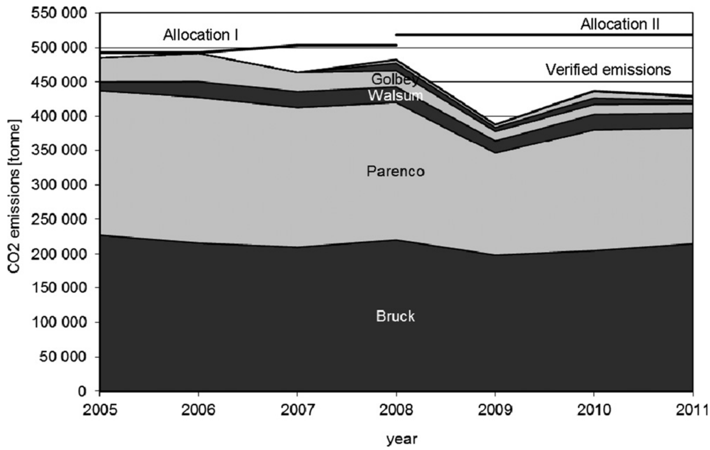

Fig. 2. Allocations and CO_2 emissions for Norske Skog's 7 installations under EU ETS. Source: Sandbag (2012).

Table 1
Direct and indirect emissions from Norske Skog's European mills in 2010, measured as tons CO_2 equivalents/tons of paper. Source Norske Skog (2011).

Mill	Bruck (AT)	Follum (NO)	Golbey (FR)	Parenco (NL)	Saugbrugs (NO)	Skogn (NO)	Walsum (DE)
CO_2-e direct	0.55	0.01	0.04	0.72	0.02	0.02	0.06
CO_2-e indirect	0.05	0.02	0.12	0.07	0.02	0.02	1.29

established to provide a structured approach to identifying and implementing energy-efficiency improvement actions. Since 2003 this programme has resulted in 1700 smaller-scale projects with an estimated annual reduction of 120,000 t of CO_2 (SCA, 2012). In 2010, responding to the demand for biofuels and renewable electricity, SCA formed the new business unit SCA Energy to coordinate activities like fuel from logging residues, refined biofuels and wind-power (Fält, interview 2011). Larger projects include investments in new or retrofitted energy installations with the potential to generate significant CO_2 emissions reductions:

- In 2006 the Östrand chemical pulp mill (Sweden) made a €160 million investment in a recovery boiler and a back-pressure turbine which doubled the capacity for biofuel based auto-produced electricity and made the mill a net provider of electricity and heat (SCA, 2009). In 2011, after a €50 million investment, Östrand installed a new lime kiln which will be fuelled with crushed sawdust pellets and will reduce oil consumption by 17,000 m^3 per year, and fossil CO_2 emissions by 80% or 50,000 t per year (Fält, interview 2011).

- At the Witzenhausen mill (Germany), an external partner has invested €127 million in a combined heat and power (CHP) plant for incineration of industrial by-products and refuse-derived fuel (Isaksson, interview 2011). The mill has phased out its old gas installations and outsourced electricity and heat production to the operator of the CHP plant, thereby reducing direct CO_2 emissions by 90% or 100,000 t per year (Sandbag, 2012).
- The joint venture Statkraft SCA Vind AB has been formed to implement wind-power installations of up to 1200 MW in SCA's Swedish forest holdings (Vindkraft Norr, 2011). SCA grants the land area while the Norwegian power company Statkraft undertakes the €1.6 billion investment. Through the wind-power installations partly underway, SCA will be ensured affordable and long-term electricity supply for its electricity-intensive Ortviken mill (SCA, 2011).

Norske Skog reports that climate-change issues are integrated into its business strategy in various ways–including management and projection of operational costs; identification of investment options; relations with employees, customers and other stakeholders; and its engagement with governments and regulators (CDP, 2011). The focus is on short- and long-term abatement plans in order to achieve its emissions-reduction target. As examples of abatement actions, the company has highlighted:

- Participation in a consortium investigating the possibilities to develop and produce second-generation biofuel.[10]
- Several mills are conducting feasibility studies into greater use of biofuel, as investments in new assets or upgrades of existing assets.
- Reduced energy use and GHG emissions by increasing the capacity of the company's Skogn mill in Norway to incorporate clay fillers in its paper products (CDP, 2011). The clay can substitute virgin pulp and reduce process energy demand for pulp production in an integrated mill.

4. Effects of EU ETS on corporate climate strategies

4.1. The cost-benefit perspective

The EU ETS may influence company cost-benefit assessments by increasing the benefits of cutting CO_2 emissions and by adding costs to not doing so. Companies will rank the available abatement alternatives, phasing in the lowest-cost options first. Low EUA prices should not be expected to trigger offensive strategies involving new investment practices and engagement in long-term R&D to drive large-scale and high upfront-cost solutions.[11]

Both SCA and Norske Skog recognize that EUAs represent potential costs or revenues in every investment decision. New staff categories, like project departments responsible for major process changes at the mills, are now involved in CO_2 accounting, as the price of emissions must be integrated in investment appraisals. However, the companies do not perceive the role of the EU ETS as a particularly important impetus for investments (interviews, Isaksson 2011 and Carlberg 2011). The CO_2 price-tag on fossil-fuel use represents one of several factors that can underpin industrial investment decisions (Fält, interview 2011). Rising electricity prices are seen as a stronger influence from the EU ETS. Access to abundant and affordable electricity is essential to the PPI; thus, the EU ETS has made it increasingly important to make projections about future electricity prices and account for this in investment and business plans. This 'indirect' effect of EU ETS overshadows the more 'direct' effect of establishing a price-tag on CO_2 emissions from internal fossil fuel use. Interest in electricity generation from wind-power and industrial CHP has grown, and greater efforts are being made to establish secure and affordable electricity supplies. This is demonstrated by SCA's abatement actions, organizational restructuring (e.g., the establishment of SCA Energy) and search for alternatives to the electricity spot market.

Rising electricity prices are also a driving force for process changes to reduce specific electricity use. Both SCA and Norske Skog claim that they continuously maintain and replace equipment to improve their energy performance and reduce CO_2 emissions. Primarily SCA has implemented large high upfront-cost investments expected to generate significant future CO_2 emissions reductions. These investment decisions have been announced at various points in time over the EU ETS periods (2005–2012), without apparent association with the EUA market price or expectations as to future prices. Hence, the variable but generally low EUA price level does not appear to have been important in motivating companies to adopt more offensive investments.

The impact of the EU ETS on investments is expected to increase in the third trading period. The newly installed lime kiln at SCA's Östrand mill has shown that the EU ETS can contribute positively to a large CO_2-lean investment. The estimated emissions reduction of 50,000 t CO_2 per year represents revenues of €0.5–1.5 million per year from selling EUAs, depending on the future price level (here assigned a range of €10–30). For the €0.5 billion investment, this revenue stream will constitute a considerable share of the depreciation value.

4.2. Regulation, innovation and competitiveness

As applied to the EU ETS, the Porter Hypothesis rests on the following logic: companies (board, management and staff) in the trading sector will have to deal with the introduction and implications of EU ETS; the EUA cap-and-price signal will raise awareness of the business advantages of achieving CO_2 emissions reductions; early adopters of CO_2-lean products and process innovations will gain a first-mover advantage over their competitors.

With current emissions-to-cap ratios of 75–85%, both SCA and Norske Skog have some operating space in relation to their caps. In a group-wide perspective, neither company risks having to purchase EUAs. In terms of the size of the cap, the regulation of CO_2 emissions cannot be considered stringent. Neither do today's low price levels (€5–10), due partly to generous allocations, send a clear signal to companies to develop offensive strategies and invest in innovative solutions. For Norske Skog the situation was somewhat different in the first trading period, when its emissions-to-cap ratio was close to 100% and the EUA market

[10] Financial constraints have halted this project, but Norske Skog reports that the accumulated knowledge base will be valuable for similar projects in the future.

[11] Over the second period (2008–2012) the EUA price has ranged between €27 (in 2008) and low levels of €5–10 (2011–2012). The economic downturn and generous allocation over the second period will generate a transferable surplus which will depress the price in the third period. As of August 2012, estimates based on EUA futures indicated price levels between €8 and €12 over the third period 2013–2020 (EEX 2012).

price was around €20–30. The allocation increased after the Norwegian mills were included in the second period, which established Norske Skog's long position. It can be argued, as held by Norske Skog, that the company was disadvantaged in being partly excluded from the EU ETS and the framework conditions faced by its competitors (Norske Skog, 2005). In relation to other PPI companies, Norske Skog's cap appears to have exerted some pressure on the company in the first trading period (Sandbag, 2012). However, it is primarily market factors like newsprint overcapacity that have led Norske Skog to reduce its CO_2 emissions since 2005. The Parenco mill in the Netherlands has reduced its CO_2 emissions by 20% in absolute figures since 2005 as a result of a paper machine shutdown in 2009 which decreased annual production by 40% (Norske Skog, 2010). The CO_2 intensity of this mill's production has thus increased by 30%.

A common standpoint among industry representatives is that energy and climate policies need to provide long-term stable conditions to facilitate investments. Perceived uncertainties may lead to dropping or postponing investments due to lack of decision support (Fält, interview 2011). SCA has to a greater extent than Norske Skog undertaken large projects and investments over the EU ETS period. We find no instances where the EU ETS as such has led SCA to refrain from making investments, but neither is the system perceived as a major force behind business-driven investments (Isaksson, interview 2011). In expectation of the third period, with allocation based on performance benchmarks, SCA is content with the long-term horizon provided by the scheme. In addition to the phase-out of expensive fuel oil, the lime kiln investment at the Östrand mill will generate annual revenues from EUAs, at least until 2020. This may give the mill a first-mover advantage, as lime kilns are often considered a fossil-fuel-dependent production process (Ecofys, 2009). In their road-map to a low-carbon bioeconomy, the Confederation of European Paper Industries (CEPI, 2011) categorize biofuel lime kilns as one of the long-term solutions up to 2050. The project is innovative with regard to the large volumes of fuel-oil replacement and the advanced requirements of the biofuel combustion process (Fält, interview 2011). If successful, this could pave the way for further installations in the PPI. To coordinate its business activities in renewable energy, SCA established SCA Energy. The intention is to scale up existing segments (like supply of wood pellets) and develop new innovative segments (like automotive fuels)–both likely to influence SCA's R&D strategies.

4.3. Internalization of norms and rules

Drawing on neo-institutional theory, we proposed that companies may internalize norms and rules about appropriate conduct through their participation in schemes like the EU ETS. Whereas companies are likely to seek the least costly adaptation to the ETS in the short term, they may internalize norms and rules for appropriate conduct as socially responsible companies in the longer term. Our interviews confirmed that the EU ETS has raised awareness of the climate-change issue among company staff and management alike. Media coverage and public debate have made the ETS a reality that both SCA and Norske Skog must take into account. The scheme also requires companies to monitor and report CO_2 emissions and integrate the cost of emissions in their financial procedures. As noted, while SCA and Norske Skog had monitored and reported emissions data before the introduction EU ETS, the scheme has resulted in slightly more resources being put into site-level administration and reporting of GHG emissions data. Project departments have also become involved in integrating CO_2 prices in investment appraisals.

Although commitments on emissions reductions had been made earlier, it was only in 2007/2008, after the introduction of the EU ETS, that the companies formulated and communicated quantified CO_2 emission reduction targets. Political targets associated with the ETS, like the EU's GHG emissions target of at least 20% reduction by 2020 compared to 1990, spur companies to formulate their own targets with timeframes and ambition levels that appear both reasonable and socially responsible (Isaksson, interview 2011). SCA has stressed the importance of adapting its group-wide climate mitigation target to the circumstances of various EU member states and other regions of the world. In each country, operations experience differing conditions, such as variable feedstock, energy supply, and policy contexts. Consequently, opportunities for reducing CO_2 emissions vary significantly from country to country.

Norm-driven company behaviour may certainly be triggered by mixed motivations, including the desire to 'do the right thing' while also reaping reputational benefits and building credibility in the marketplace. However, we have found little evidence of norm-driven behaviour in the PPI and the companies studied. Rather, our analysis of the influence of the EU ETS on corporate climate strategies shows that some activities, like energy-efficiency improvement actions, can be attributed to other policy programmes or an autonomous development. In this kind of action-oriented perspective, the EU ETS can be seen as one factor among others, but one which has as yet had rather little influence on normative commitments to develop proactive climate strategies.

5. Explaining divergent corporate climate strategies

We have seen that both SCA and Norske Skog recognize the problem of anthropogenic climate change. Apart from aspects perceived to have negative impacts on business (e.g., electricity price increases and the risk of carbon leakage), they have welcomed the EU ETS. The companies have manifested their responsibility for problem-solving with their CO_2 emissions-reduction targets and related monitoring practices, and have made progress towards their respective targets. Compared to pulp and paper companies in other European countries that rely on fossil oil, coal and natural gas for much of their electricity and process heat needs, a relatively large share of production capacity of our two case companies is located in Sweden and Norway, with ready access to renewable electricity and CHP based on biofuels. This helps to explain why Norske Skog and SCA were more positive towards the EU ETS than were pulp and paper companies in other European countries, although it must be noted that only 8 out of 41 SCA installations covered by the ETS are located in Sweden.

On the other hand, there are some divergences that call for further analysis. One evident difference between the company strategies lies in target formulation. Norske Skog's target is formulated as an absolute reduction, whereas SCA has adopted an intensity-based reduction target, following the common practice of reduction related to production level. As noted, Norske Skog's progress towards its target has been facilitated by its closure of some mills in recent years. These restructurings of operations were probably foreseen when targets were formulated, which may explain the rationale for adopting an absolute target.

SCA is more active than Norske Skog in investing and implementing CO_2-lean actions. One explanation and important difference here is access to forest land. As Europe's largest forest owner, SCA can take advantage of its vast forest resources (2.6 million hectares) through activities like biofuel production, electricity generation from biomass sources, and experimentation with large-scale wind-power installations. By contrast, Norske Skog has sold off most of its forests and cannot experiment with innovative activities requiring large tracts of forest land.

The viable options for larger investments and climate-related innovation activities are heavily dependent on the infrastructural and organizational context surrounding the mill. The SCA Östrand mill (Sweden), for example, is located in the vicinity of the company's forest assets. At a site nearby, the business unit SCA BioNorr produces refined biofuels of residuals from sawmilling operations under SCA Timber. This integration creates a supply chain and a logistic solution that ensures reliable and affordable access to fuel pellets, making possible the investment in the biofuel-based lime kiln (Fält, interview 2011). Projects undertaken at the Östrand mill show that production factors (access to natural resources, raw materials, infrastructure etc.) clearly matter for the types of innovative and CO_2-lean investment solutions that can be accomplished. These factor conditions, however, are not entirely inherited or given, but have been exploited and refined by SCA together with other actors (cf. Porter, 1990).

SCA has aligned several operations to interplay in something like an industrial cluster in the area around the Östrand mill. In Witzenhausen (Germany), by contrast, SCA has outsourced electricity and heat production and contracted a company to cover the whole 'waste-to-energy' value chain, to ensure the long-term energy supply. More generally, it is easier to use and switch to less carbon-intensive fuels in some countries than in others, and the national situation clearly matters when it comes to electricity supply and the availability of biomass to replace fossil fuels. Mills in some countries can rely on affordable hydropower (as in Norway) or on CHP from biomass fuels (as in Sweden), while elsewhere in Europe mills often rely on fossil natural gas for much of the electricity and process heat required in production.

Production mix and financial situation are other aspects that make possible different actions. As noted, problems of overcapacity and decreased demand for newsprint have put pressure on Norske Skog. In this situation it is probably difficult for Norske Skog to see long-term stability in the segment, which can explain why the company has refrained from investments and instead focused on paying its debts. By contrast, SCA has a more diversified production portfolio, dominated by the hygiene segment (tissue and personal care products), where demand is steadily growing. Between 2005 and 2011, the global production of household and sanitary paper increased by almost 25% (FAO, 2012). Besides being less vulnerable to shifts in market demand, a diversified production portfolio requires different types of process equipment, which in turn makes possible a variety of energy supply- and demand-side measures.[12]

The pulp and paper companies of Sweden and neighbouring Finland are known for their long history of product and process innovations (see e.g., Waluszewski, 1990; Smith, 1997; Laestadius, 1998). According to recent rankings of the top 1000 EU companies by level of R&D investment, Stora Enso (Finland), SCA (Sweden) and UPM (Finland) are the three highest-ranked forest industry companies (JRC EC, 2011). By comparison, Norske Skog was not a technological frontrunner in the past, nor does it rank among the companies with the highest R&D investments. However, it has been relatively quick to adopt new technology developed in collaboration between equipment manufacturers and the Swedish (and Finnish) PPI. In the 1970s, for example, Norske Skog dealt with air and water pollution with equipment developed and delivered by Swedish companies (Sæther, 2000: 190).

To summarize, the effect of EU ETS is conditioned by various factors at the national and regional level, including access to biomass, electricity supply, and policy context. Our case studies have shown that both company-internal and -external factors influence corporate responses to the EU ETS and help to explain why SCA has initiated more innovation activities and CO2-lean investment projects than Norske Skog.

6. Conclusions

The EU ETS was the first mandatory climate regulation targeting the PPI in Europe. The PPI sector initially opposed the ETS, arguing it would entail competitive disadvantages for European industry. The rational-calculative model of corporate behaviour captures well the opposition to the EU ETS in the PPI and the short-term, cost-minimizing adaptation to the EU ETS by European pulp and paper companies. The pulp and paper industry generally appears to focus on continuous improvements in operations and reductions in energy use, rather than long-term, innovative solutions. Corroborating this observation, our study has shown that emissions trading had a rather limited effect on the climate strategies of SCA and Norske Skog. For both firms, company-wide CO_2 emission objectives existed prior to the introduction of the scheme, as did systems for site-specific emissions monitoring. The value of CO_2 emissions is recognized and accounted for by SCA and Norske Skog, but the EUA price-tag is a minor incentive among the many factors that underpin industrial investment decisions.

However, the observation that SCA and to some extent Norske Skog have engaged in low-carbon activities for the longer term does not fit with the model of cost-minimizing, short-term adaptation to the EU ETS. By influencing electricity prices, the scheme has reinforced commitments to improve energy efficiency and reduce CO_2 emissions. Indeed, rising electricity prices are perceived as the strongest influence of the EU ETS and have led to strategic decisions to investigate the alternatives to the wholesale electricity market. Electricity-intensive pulp and paper companies are showing greater interest in investing in power assets, on their own or in various constellations; in making bilateral agreements for long-term power contracts; and engaging in energy-supply contracts.

Compared to Norske Skog, SCA appears more attuned to exploring new opportunities. One explanation is company variation in factors of production that constrain or facilitate specific innovative and CO_2-lean investment solutions. Illustrative is SCA's extended search for new biomass-based energy solutions to reduce emissions. The situation for Norske Skog is different, as the company has less need for CO_2-lean innovation for its mills in Norway, which receive the bulk of their electricity needs from hydropower. Two additional factors seem to explain the greater willingness of SCA than Norske Skog to invest in low-carbon solutions: availability of human and financial resources, and dynamic capabilities. SCA is not only a far bigger company than Norske Skog; it is also one of Europe's largest owners of forests that can be used for innovation and emissions-reduction purposes. SCA also has a long history of product and process innovation and ranks among the top three innovators in the industry.

We must conclude, however, that the EU ETS so far has had little effect in triggering the search for *innovative*, low-carbon solutions. Even a frontrunner like SCA has maintained a low profile with regard to possible long-term abatement technologies like black liquor gasification and CCS. Hence, our study does not lend support to the Porter Hypothesis–i.e., that the EU ETS would

[12] For instance, SCA Östrand's investments in a new recovery boiler and a back pressure turbine which made the mill a net supplier of renewable electricity could not be have been made by any of Norske Skog's mills, which are all based on the thermo-mechanical pulping process (see Section 3.4 for examples of different measures implemented by SCA).

alert and educate companies to the benefits of reducing emissions, and raise the likelihood of product and process innovations achieving high environmental performance. In our analysis, the limited effect of the EU ETS on innovation emerges as due primarily to surplus of allowances and a low EUA price.

Finally, the proposition that companies may *internalize* norms and rules about appropriate conduct through their participation in the EU ETS receives limited support in our study. Both SCA and Norske Skog had recognized their responsibility in mitigating GHG emissions before the introduction of the ETS. Moreover, their actions do not appear to be norm-driven but seem motivated primarily by economic motives, taking their social responsibility into account.

As part of the EU 2020 strategy there are high expectations for the EU ETS to become the key policy instrument in delivering cost-effective climate mitigation in energy-intensive industries. The cap for 2020 represents a 21% reduction of emissions compared to 2005, when the EU ETS was first implemented. Thereby the EU ETS, alongside with the effort-sharing decision, is intended to ensure that the EU meets its binding target of 20% reductions of GHG emissions by 2020 compared to 1990. However, this does not imply that EUA prices will be sufficiently high to directly stimulate investments, climate strategies and innovations in the trading sector and more specifically in the PPI. Estimates based on EUA futures indicate that EUA prices will remain low throughout the third period. Although price projections are uncertain, the economic downturn combined with generous allocations during the second trading period is set to create a surplus of EUAs which can be transferred to the third period. Thus, it is possible that access to EUAs will be inflated compared to actual emission levels of the PPI–which would lessen the need for companies to purchase any EUAs over the initial years of the third period, and further delay investment in innovative strategies to reduce GHG emissions. For the system to have greater influence on company investment decisions in the future, the enforcement of a stringent cap and a high EUA market price will be necessary.

7. List of interviews

Georg Carlberg, Norske Skog, Vice-President Environment, 13 June 2010 and 30 June 2011, and email communication 28 June and 27 October 2011
Per-Erik Eriksson, SCA, Vice-President Energy, 11 October 2011 (email communication)
Christer Fält, SCA, Environmental Manager SCA Forest Products, 15 April 2011
Patrik Isaksson, SCA, Vice-President Environmental Affairs, 20 April 2011
Marco Mensink, CEPI, Energy and Environment Director, 28 January 2011
Yvon Slingenberg, European Commission, 27 January 2011
Kersti Strandqvist, SCA, Senior Vice-President Corporate Sustainability, 19 April 2011
Tomas Wyns, CAN Europe, EU ETS Policy Officer, 27 January 2011

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Paper VI

Difficulties of free allocation within EU ETS – a critical analysis of key sectors in the third trading period

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Abstract

In this paper we analyse the allocation procedures of the 3rd period of EU ETS and the difficulties involved with distributing free allowances in a fair and understandable way. The assessment covers two energy-intensive sectors and their industrial activities in three Member States (MS); the cement industry (CEI) and the pulp and paper industry (PPI) located in the UK, Sweden and France. Will the intended mechanisms of EU ETS come into effect and improve its environmental effectiveness? Will sectors in certain MS be more or less influenced? Could outcomes be influential for the implementation of low-carbon solutions? The empirical basis consist of official data on installation's past and present emissions and allocations and proposed 3rd period allocations according to MS's National Implementation Measures (NIMs). Results show that the new allocation procedures are better suited for the CEI, a relatively homogenous sector, for which the allocation is expected to decrease in a consistent manner in all three MS. For the PPI – with diversities in product portfolios, technical infrastructure and fuel mix – the new allocation procedures will cause dispersed outcomes. Lack of benchmark curves, biased selection of references values for fuel-mix and specific energy use, and fall back approaches leads to allocations to the PPI which do not represent the average performance of the 10% most efficient installations. Examples of conspicuous, however endorsed, over-allocations will reduce harmonization in PPI, within and between MS.

Keywords: EU ETS; Third period; Allocation; Cement; Pulp and paper

1 Introduction

Climate change has been cited *"the greatest market failure the world has ever seen"* (Stern, 2007, 1). The external effects of anthropogenic carbon dioxide (CO_2) emissions are not valued in the economic decision making and as fossil reservoirs are increasingly extracted and combusted, it leads to a steady increase of global CO_2 emissions and atmospheric concentration. The warming of the climate system is unequivocal; since the 1950s many of the observed changes are unprecedented over decades to millennia (IPCC, 2013). Many aspects of climate change will persist for many centuries even if CO_2 emissions are stopped (IPCC, 2013). Tremendous negative impacts and high social costs can be expected from global warming, and to avoid the worse scenarios prompt actions have to be taken to reduce current global emission levels by about 50% until 2050 (Stern, 2007). By defining climate change as a market failure economic theory view correct pricing of CO_2 emissions as the first-best policy option. The price tag should send a clear signal to the market actors (i.e. the polluters) and stimulate them to reduce emissions without dictating the specific means. Based on these principles of a market-based and technology neutral policy instrument the EU emissions trading system (EU ETS) was introduced in 2005 to *"promote GHG reductions in a cost effective and economically efficient manner"* (EC, 2003).

Since the start, EU ETS has been subject for scrutiny by different stakeholders, e.g. industry associations, academics, NGOs, think-tanks etc. Some authors have called the implementation a remarkable achievement given its scope, timing and novelty (Ellerman et al., 2007). Indeed, EU ETS is the first multinational policy and trading scheme to impose a CO_2 price and to regulate CO_2 emissions from major point sources such as energy generation and energy-intensive manufacturing (Ellerman et al., 2007). EU ETS has also been hit by criticism following the first "trial period" (2005–2007) and the second "Kyoto period" (2008–2012) due to unresolved issues. In brief, the scheme has managed to impose a cap of emission allowances (EUAs) but the resulting price has been volatile and far below the expected level. Thus, EU ETS has not managed to induce the long-term stabile and stringent price signal needed for inducing investment in low-carbon technologies within the trading sector (see e.g. Laing et al., 2013). Nonetheless, the European Commission (EC) and the

Directorate General for Climate Action (DG CLIMA) put trust into EU ETS as the flagship of efforts to achieve its GHG emissions targets e.g. the Kyoto target, the 20% target by 2020 and possibly even more long-term targets (Hedegaard, 2011). In the revised ETS directive several reforms have been introduced for the 3rd period (2013–2020). In terms of allocation, the share of auctioning has increased to about half and with exceptions for eight member states (MS) it should apply to all power generators. Remaining EUAs are to a large extent allocated for free in 2013 and beyond. However, allocation to manufacturing industry is no longer based on grandfathering of past emission but determined by EU common performance benchmark rules and grandfathering based on production output.

Theoretical underpinnings and practical experiences of allocation procedures from previous ETS periods have been subject to several studies (e.g. Hepburn et al., 2006; Zetterberg et al., 2012; Demailly and Quirion, 2006). Fewer studies have been published about the recent, but delayed, implementation of the 3rd period benchmark-based free allocation to EU's manufacturing industry. Cló (2010) argues that the EC's deficient assessment of the carbon leakage risk has authorized the continuation of free allocation as the dominant allocation procedure, rather than auctioning, with adverse effect on harmonization of EU ETS. An analysis by Lecourt et al. (2013) concludes that the 3rd period allocation will substantially reduce free allocation to benchmarked sectors compared with the 2nd period, reward installations with better CO_2 emission performance, and redistribute EUAs foremost between installations within MS. Lecourt et al. (2013) provides a methodologically robust and extensive empirical assessment of all benchmarked sectors in 20 different MS. However, we suspect that the analysis has bypassed some interesting outcomes of benchmark-based allocation procedures at sector and installation level, which requires disaggregated examination to be detected.

Our comparative study covers two key sectors, the cement industry (CEI) and the pulp and paper industry (PPI) in three different MS (UK, Sweden and France). The cement sector is homogenous in terms of processes and products and is concentrated to few large company groups; it is a highly fuel- and carbon-intensive industry in monetary terms. The pulp and paper sector is heterogeneous with a diversified product portfolio and a relatively large number of companies; it is a highly energy-intensive but less carbon-intensive industry. Our aim is to analyse the outcomes of the new allocation procedures in these two different sectors and to discuss related critical aspects of the use of EU common benchmarks introduced in the 3rd trading period. Will the allocation provide incentives for reductions in GHG emissions and energy efficient techniques (EC, 2009, Art. 10a)? Will sectors located in certain MS be more or less influenced than others? If so, could such outcomes be important for the implementation of low-carbon solutions? From these questions, lessons can be drawn about the difficulties of free allocation in terms of environmental effectiveness and EU harmonization. The empirical material consists of the National Implementation Measures (NIMs) and the European Union Transaction Log (EUTL).[1] Section 2 briefly describes the development of EU ETS. Section 3 presents the amendments following the last ETS directive and reviews the 3rd period allocation rules that have been developed and applied to the PPI and CEI. Section 4 compiles the results of the assessment and presents the outcomes in each sector and MS. Section 5 provides a discussion of results and section 6 concludes.

2 Background

2.1 Preparations, implementation and the first trading period 2005–2007

The flexible mechanisms that were introduced by the Kyoto Protocol in 1997 put emissions trading on EU's agenda. After having overcome an initial scepticism the EC took initiative to develop a trading scheme that could be linked to the international climate regime and the binding Kyoto commitments. The preparations were concretized by the EC's green paper on GHG emissions trading (EC, 2000). After a few years of reviews and amendments to the initial proposal (EC, 2001) the first ETS directive was

[1] By September 2011, MS were required to submit their list of installations covered by the ETS directive in the 3rd period. These lists, referred to as NIMs, comprise the proposed benchmark-based free allocations to concerned sectors and installations. As of April 2013 the NIMs of Sweden, France and UK were among the few MS NIMs that were available to the authors, which confined our assessment to these three MS. EUTL is the official registry of allowances and verified emissions under EU ETS.

endorsed in 2003 (EC, 2003).[2] The implementation in 2005, according to the time plan, has been judged remarkable given the scope (i.e. some 11,000 power producers and energy-intensive industry installations covering half of EU's CO_2 emissions), the timing, and the novelty of the project (Ellerman et al., 2007).

Already in the initial design of EU ETS it was provided for separate trading periods. The first three-year period served to establish infrastructure and build experiences among stakeholders (e.g. beneficiaries, brokers, EU and national authorities etc.) about the new concept of emissions trading. The decentralized approach, with free allocation of allowances based on grandfathering of historical emissions determined by the MS's National Allocations Plans (NAPs), enabled a smooth implementation (Skjaerseth and Wettestad, 2009). It offered a situation close to status-quo which could be accepted by the participants (Zetterberg et al., 2012). National authorities were generous with handing out free allowances to domestic industries and because of the political prestige of getting the scheme launched on time EC accepted the NAPs without too much revisions (Convery and Redmond, 2007). A few MS applied auctioning as a subsidiary allocation method and only Denmark auctioned a full 5% of total allowances in the 1st period (Ellerman et al., 2007).[3]

Upon implementation, the EUA price increased to almost 30 Euro within the first year. However, as MS reported their verified emissions for 2005 the situation of over-allocation became evident which caused a major price drop in April 2006. The decline was further enhanced by the prohibition against transferring surplus allowances from the 1st "trial period" to the 2nd trading period, the "Kyoto period" (Convery and Redmond, 2007). The growing awareness that the surplus would lose its value in the coming period did, justifiably, make the EUA spot price approach zero as the 1st period was coming to an end.

[2] For thorough reviews of the origin and evolution of EU ETS see for instance Skjaerseth and Wettestad (2009) and Convery (2009).

[3] The MS should allocate at least 95% of the allowances free of charge while the remaining 5% could be auctioned (EC, 2003, Art. 10).

2.3 The second trading period 2008–2012

Ellerman (2008) praised the 1st period invaluable to develop institutional capacities and provide opportunity to correct deficiencies before the important 2nd period, which linked with the Kyoto commitment period and its flexible mechanisms for international emissions trading via the Clean Development Mechanism (CDM) and Joint Implementation (JI).[4, 5] The cap was set 6.5% below the 2005 level in order to be consistent with EU's Kyoto commitment. Grandfathering, with special provision for new entrants and closures, became the main allocation procedure as MS ought to allocate 90% of allowances for free while 10% could be auctioned (EC, 2003). The latter option was applied much less in practice as only seven MS reported intentions to auction altogether 3% of the total cap (EC, 2013a). The free allocations via the NAPs were based both on historical emissions and also on the expected growth the coming years. All the NAPs had to be approved by the EC and consistent with the overall cap. Thus, the 2nd period allocation procedure included a degree of national flexibility and autonomy for including national priorities in the allocation process.

Auctioning is supported by scholars with the arguments that it: conforms best to polluter pays principle, ensures transparency and simplicity, reduces administrative costs and enables reinvestments of government auctioning revenues (e.g. Hepburn et al., 2006).[6] On the other hand, there are political-economic dimensions which oppose auctioning, i.e. industry and MS lobbying asserts it could seriously harm firm's international competitiveness and ultimately threaten manufacturing industry to relocate and give rise to a carbon leakage (Markussen and Svendsen, 2005; Makipaa et al., 2008). Thus, volumes of auctioned EUAs have been negligible in favour for grandfathering,

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[4] EU-15 has a target to reduce GHG emissions by 8% as an annual average for 2008–2012, compared with 1990. According to the latest submission of EU's GHG inventory to UNFCCC the emissions were 14.9% below the 1990 level (EEA, 2013a).

[5] The trading sector has used the opportunity to procure and surrender international offset credits, CERs and ERUs, instead of EUAs. The price spread between the assets has been beneficial (Mansanet-Bataller et al., 2011).

[6] In the 3rd period, at least 50% of government's auctioning revenues ought to be used for mitigation or adaptation to climate change in EU or elsewhere (EC, 2009, Art. 10.3).

which has nevertheless been criticized. From the perspective of manufacturing industry, it has been blamed for causing negative redistributive effects between producers and consumers of electricity (Cló, 2010). The Confederation of European Paper Industries (CEPI) called it a real flaw in the initial design of EU ETS that it was possible for power generators to pass on the opportunity costs and earn windfall profits as the value of freely allocated EUAs was added to the market price of electricity (Hyvärinen, 2005). Studies on EU ETS and power prices confirm that a major part of the opportunity cost is passed over to the wholesale electricity price (e.g. Sijm et al., 2008), which, however, has been found to be economically correct (Woerdman et al., 2007).

The cap did become stricter in the 2nd period but it influenced foremost the power generators, which experienced a 13% decrease in allocation (EEA, 2013b). For many manufacturing industries the free allocation did in fact increase, e.g. by 8% in pulp and paper, and 13% in cement and lime (Ibid). Sector-level EUA surpluses grew even larger in the 2nd period as the economic downturn caused production declines and reduced CO_2 emissions across manufacturing industry.[7] When designing the EU ETS none had anticipated that the economy could fluctuate so violently to create an oversupply of magnitude and depressing prices (Karpestam and Andersson, 2011). Manufacturing industries have also, to some extent, been compensated via over-allocation from "race to the bottom" domestic industry policies based on overoptimistic growth numbers in the 2nd trading period NAPs. In contrast to the polluter pays principle, free allocation based on historical emissions has *"had the perverse effect of providing more free allocation to the highest emitting installations"* (EC, 2010, 2). The cement and lime industry accumulated a surplus of 282 million EUAs between 2008 and 2012, equal to a monetary value of 2.8–4.2 billion Euro at a EUA price of 10–15 Euro. For the PPI, corresponding figures are 53 million EUAs with a monetary value of 0.5–0.8 billion Euro (EEA, 2013b).

Representatives of the PPI claim that revenues from selling surplus EUAs have been negligible compared with the increased cost for electricity experienced in

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[7] It is a challenge to assess and attribute abatement due to EU ETS. Laing et al. (2013) list examples of foremost econometric studies. Skjaerseth and Eikeland (2013) provide a recent and systematic study of corporate responses to EU ETS covering five sectors.

the same period (Gulbrandsen and Stenqvist, 2013a). This could be the case for some electricity-intensive segments such as thermo-mechanical pulp, which has a specific final electricity use of around 2200 kWh/t (Worrell et al., 2008). On the other hand, fuel-intensive segments and potential net producers of electricity like chemical kraft pulp mills can benefit from increased electricity prices. The homogenous production process of the CEI is in general less electricity-intensive than the heterogeneous PPI. In 2011, the EU-27 weighted average specific final electricity use was 107 kWh/t of grey cement and the world's best practice for Portland cement is estimated 59–62 kWh/t (CSI, 2013; Worrell et al., 2008). Thus, in spite of claims from industry (Raaum Christensen, 2013, 173f), the value of the CEI's EUA surplus should largely exceed the potential ETS induced cost increase on electricity.

The EUA price reached levels of 30 Euro in 2008, but then fell to 10–15 Euro and later to around 5 Euro. Since transfers of EUAs and international credits to the 3rd period was permitted, an accumulated surplus of almost 2 billion allowances continues to press down carbon price levels as made evident by the trading in EUA futures (EEX, 2013).

3 The third trading period 2013–2020

3.1 General amendments

EU ETS in its 3rd period is characterized by some important changes (EC, 2009):

- A community-wide cap has been introduced based on the EU target of reducing total CO_2 emissions with 20% by 2020. Allowances issued each year from 2013 shall be reduced by a linear factor of 1.74% compared with the average annual amount of allowances of the 2nd period.[8]
- From negligible shares of auctioning in the 2nd period about half of allowances will be auctioned but primarily to power generators. For a

[8] By 2020 the allocation to fixed installations shall be 21% below the emission levels of 2005 (EC, 2013c).

few sub-sectors not deemed exposed to carbon leakage a gradual phase-in of auctioning will apply.

- The decentralized approach with free allocation based on past emissions via MS's NAPs is replaced by free allocation based on past production volumes and EU harmonized benchmarks for manufacturing industry and heat installations via MS's NIMs. Sectors and installations deemed exposed to a significant risk of carbon leakage receive free allowances at 100% of their benchmark values.

In the assessment of MS's NIMs the EC had to ensure that the proposed annual preliminary amounts (PAs) of free allowances did not exceed the linearly decreasing maximum amount (MA) as dictated by the community-wide cap (EC, 2009, Art. 10a(5)). If so, a cross-sectoral correction factor (CSCF) should be applied to adjust the sum of PAs with the MA and thereby determine the final free allocation. The decision, originally due in February but eventually announced September 5 (2013), clarified that the CSCF will imply a 5.7% reduction in 2013 growing to a 17.6% reduction by 2020. As of September, a couple of months of administrative procedures were expected before the free allowances are finally transferred to the installations' individual accounts (EC, 2013b).

3.2 Benchmark-based free allocation

The benchmark methodology dates several years back. By order of the EC a trio of energy research and consultancy organizations (i.e. Ecofys, Fraunhofer Institute and Öko-Institut) developed a first proposal for allocation methodology (Ecofys, 2009a). After two years and an "unprecedented" amount of consultation with industry associations and other stakeholders the EC reached a final benchmark decision including 52 product benchmarks plus three more for fuel and heat consumption and certain process emissions (EC, 2011). In determining the total amount of free allocation to an installation its different benchmark-related sub-installations are first defined. If activities are not covered by a product benchmark the alternative heat and fuel benchmarks can be applied but each sub-installation must not receive allocation according to more than one benchmark (DG CLIMA, 2011a). The general formula for determining the final free allocation to a sub-installation is:

Free allocation = BM x HAL x CLEF x CSCF

BM: product/fuel/heat specific emission intensity benchmark value.

HAL: historic activity level as median production volume (or heat/fuel use or prod.) in 2005–2008 or 2009–2010.

CLEF: carbon leakage exposure factor, which is 100% for installations at risk of carbon leakage.

CSCF: cross-sectoral correction factor to adjust free preliminary allocation with the maximum annual amount.

The product benchmark values are supposed to represent the average performance of the 10% most efficient installations in a sector or sub-sector in 2007–2008 (EC, 2009, Art. 10a(2)). It has been disputed if efficient should mean GHG efficient or energy efficient (Ecofys, 2009c). In general, with the PPI being one exception, the benchmark values have been derived from benchmark curves covering CO_2 emission intensities of EU's existing installations (EC, 2011). The heat and fuel benchmarks, of 62.3 and 56.1 EUAs/TJ respectively, are based on natural gas as the reference fuel and a 90% fuel-to-heat conversion efficiency. Special guidelines are provided for cross-boundary heat flows. When heat is transferred between two ETS installations the free allocation is given to the heat consuming installation but when heat is exported from an ETS installation to a non-ETS installation the heat producer receives the free allocation according to the heat benchmark (DG CLIMA, 2011b).

3.3 Benchmarks for the pulp and paper industry

Over the 2nd period there were about 900 pulp and/or paper installations in EU ETS.[9] As an annual average over the 2nd period, they emitted 29.6 Mt

[9] The NACE code of the sector is C17 – Manufacture of paper and paper products.

CO_2 and were allocated 40.3 million EUAs (EEA, 2013b). Thus, the aggregated average emission-to-cap ratio has been 73%, including variations from 82% in 2008 to 68% in 2012.

The European PPI has relatively low CO_2 emissions in relation to its overall energy flows, as more than half of fuel consumption comes from biomass sources (CEPI, 2013). However, the fuel-mix is geographically diverse, in some MS biomass account for 75–90% of fuel consumption (e.g. Sweden and Finland) while it is negligible in MS where natural gas account for 90% or more (e.g. Italy, Netherlands and UK) (Ecofys, 2009b). It is also a technically diverse industry that produces numerous products with different degrees of integration between pulp grades (i.e. virgin or recycled fibre) and paper and board products.

Though the PPI represents only 2% of the EU ETS emissions 11 out of 52 product benchmarks have been developed for the sector, as shown in Table 1. It was a main priority for the PPI that the benchmark methodology could differentiate among its range of products. According to CEPI the PPI should ideally have 64 product benchmarks but politically that was not feasible and eventually CEPI could accept the 11 product benchmark in combination with the heat and fuel benchmarks (Gulbrandsen and Stenqvist, 2013b, 133). Separate values for pulp and paper products enables allocation to stand-alone pulp mills that produce market pulp as a final product. To avoid double-counting, the allocation to pulp benchmark sub-installations is based on the share of production that is exported since pumped pulp in integrated mills is not entitled allocation. The PPI is deemed exposed to a significant risk of carbon leakage and receives 100% free allocation up to benchmark values.

Table 1. Official benchmark values for the 11 pulp and paper products. See EC (2011, Annex I) for definitions of products, processes and emissions covered.

Product	Carbon leakage exposure	Benchmark value (EUA/air-dried t)
Short fibre kraft pulp	Yes (CLEF 100%)	0.12
Long fibre kraft pulp	Yes (CLEF 100%)	0.06
Sulphite, thermo-mechanical and mechanical pulp	Yes (CLEF 100%)	0.02
Recovered paper pulp	Yes (CLEF 100%)	0.039
Newsprint	Yes (CLEF 100%)	0.298
Uncoated fine paper	Yes (CLEF 100%)	0.318
Coated fine paper	Yes (CLEF 100%)	0.318
Tissue	Yes (CLEF 100%)	0.334
Testliner and fluting	Yes (CLEF 100%)	0.248
Uncoated carton board	Yes (CLEF 100%)	0.237
Coated carton board	Yes (CLEF 100%)	0.273

Instead of using benchmark curves the values first proposed by Ecofys (2009b) were derived from literature values on best practice specific energy consumption (SEC) in non-integrated mills with natural gas as reference fuel. The finally decided and official benchmarks values of Table 1 differ somewhat from those proposed by Ecofys (2009b), which could be due to slightly modified SEC values or a different reference fuel-mix. Either way, the benchmark methodology implies that also biogenic CO_2 emissions have become entitled free allocation in the 3rd period, which will become evident for PPI in countries like Sweden and Finland where biofuels (e.g. black liquor, bark etc.) dominates the fuel-mix. In addition to physical production some mills and foremost stand-alone pulp mills will be rewarded, via the heat benchmark for their biofuel-based district heating deliveries. In cases when there are no suitable product benchmarks the heat or fuel benchmark approach is also applied, but in this case from an installation's heat consumption perspective.

3.4 Benchmarks for the cement industry

Over the 2nd period there were around 270 cement installations in EU ETS and with 8% of total CO_2 emissions it is the second largest emitting sector (Ecofys, 2009c).[10] As an annual average over the 2nd period, cement installations emitted 129.5 Mt CO_2 and were allocated 176.5 M EUAs (EEA, 2013b). The oversupply has increased substantially, from an emission-to-cap ratio of 91% in 2008 to 64% in 2012.

The cement manufacturing process follows the three main steps of raw material preparation, clinker production, and cement grinding, of which the clinker production is the most energy- and CO_2-intensive, accounting for 90% of emissions (Ecofys, 2009c).[11] A main issue in the development of product benchmarks was whether such should be formulated on the basis of clinker production or cement production. With a cement benchmark a carbon leakage risk could arise; a producer could theoretically import clinker from outside EU, refine it to cement within EU, and sell all excessive free allowances. However, a cement benchmark would also provide a clear incentive to reduce the clinker content of cement by the use of substitutes that substantially reduce the specific CO_2 emissions compared with ordinary Portland cement, with 95% clinker content. A clinker benchmark does not provide the same incentive and thus excludes the largest abatement potential. Eventually, a clinker benchmark was proposed and motivated as a more practical approach (Ecofys, 2009c). The majority of EU's CEI, represented by CEMBUREAU, favoured a clinker benchmark. However, individual firms specialized in clinker substitution and composite cements, argued for a cement benchmark (Raaum Christensen, 2013, 174).

Another issue was if there should be separate product benchmarks for grey and white clinker of which the latter is produced in small volumes but at a higher SEC than conventional grey clinker (Ecofys, 2009c; CSI, 2013). Insufficient

[10] The NACE code for the sector is C23.5.1 – Manufacture of cement.

[11] The high temperature calcination process converts limestone ($CaCO_3$) to lime (CaO) and releases 55% of total CO_2 emissions per tonne cement. Remaining CO_2 emissions come from fuel combustion in the cement kiln (40%) and indirectly from electricity use in raw material and clinker grinding, conveying etc. (5–10%) (Ecofys, 2009c).

data on white clinker producers and the foremost aesthetic difference motivated Ecofys to propose one single clinker benchmark applicable to both grey and white clinker (Ecofys, 2009c). From an emission intensity curve covering at least 94% of the kilns in EU-27 a benchmark value of 780 kg CO_2 per tonne clinker was derived. CEMBUREAU defied and argued for a benchmark value of 837 kg CO_2 per tonne clinker based on energy-intensity levels and a fixed fuel-mix with coal as reference fuel (Ecofys, 2009c). Eventually, in the final benchmark decision EC adopted two product benchmarks, one for grey cement clinker at 0.766 EUA per tonne clinker and one for white cement clinker at 0.987 EUA per tonne clinker (EC, 2011). Though literature demonstrates a relatively high cost pass-through capacity in the cement sector, due to high transport costs resulting in a regional market, it also qualified as exposed to a significant risk of carbon leakage by the EC.

4 Results

4.1 Pulp and paper industry

The assessment of the PPI in UK, Sweden and France covers 20% of installations, 22% of allocations and 17% of CO_2 emissions of the sector's representation in EU ETS. The industrial structure varies between the MS. Swedish PPI has a high reliance on virgin raw material and has the largest production capacity, dominated by large integrated paper mills (>600,000 t) and stand-alone pulp mills (>400,000 t). Also in France there are some larger size mills but generally the PPI in France and UK is characterized by medium (~300,000 t) and smaller size (~100,000 t) producers of paperboard and publication paper with high reliance on recovered paper as raw material.

4.1.1 United Kingdom

The PPI in UK is Europe's 8th largest paper and board producer with 5% of production but it accounts for less than 1% of pulp production (CEPI, 2013). In the 3rd period of EU ETS, 36 installations are participating compared with 50 in the 2nd period (UK NIM, 2012; EUTL, 2013). Figure 1 shows the development of CO_2 emissions and allocation since 2008.[12] Aligned with shutdown related production declines the CO_2 emissions have been reduced by 15% (EUTL, 2013; FAO, 2013). Thus, there has been no improvement of specific CO_2 emissions.

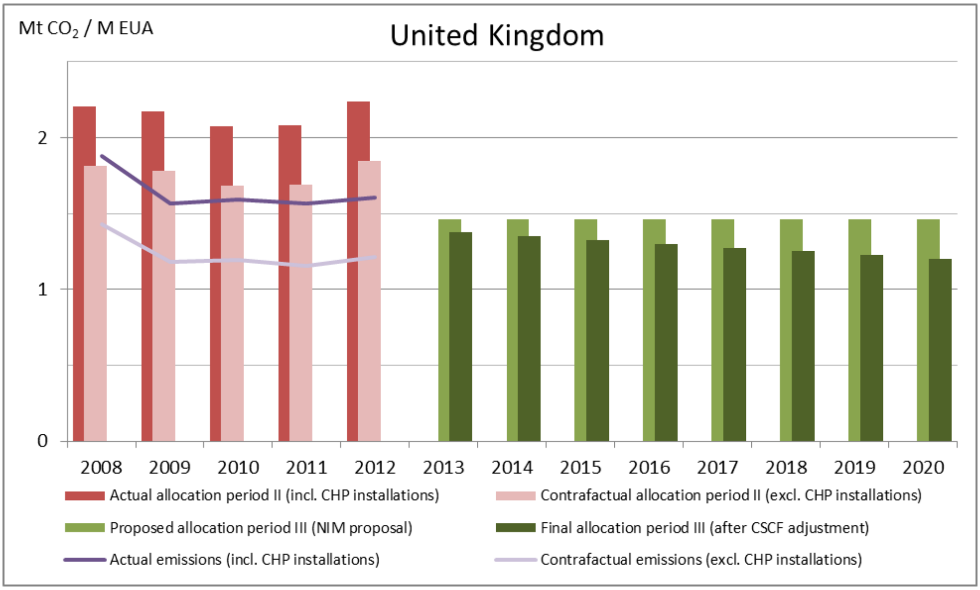

Figure 1. Emissions and allocations to PPI in UK, inluding all installations within each period. Data Source: EUTL (2013) and UK NIM (2012)

Besides shutdowns the difference in allocation between periods can be attributed to changes in allocation procedures for heat installations, as illustrated in Figure 1 with an actual and a contra-factual situation. In the 2nd period, some energy contractors – that deliver steam and electricity from natural gas fired combined heat and power plants (CHP) – have been categorised and allocated EUAs as if they belonged to the PPI. This is represented by the base case of actual allocations and emissions in period II (incl. CHP installations). However, in the 3rd period, the rules for cross-boundary heat flows between ETS installations imply that the heat consuming

[12] Since 90% of UK's PPI was excluded from the 1st period there are no records for 2005–2007.

installation (i.e. the paper mills) is allocated according to the heat benchmark (see Section 3.2). The contra-factual case depicts a situation where allocations and emissions attributed to external CHP installations are subtracted from the actual situation, while estimated allocations and emissions for the relevant paper mills are added. This exercise provide a better comparison between the two periods and shows that the proposed 3rd period allocation to UK's PPI will not be reduce by 40% as it appears in the base case but 25% as estimated in the contra-factual situation.

When accounting only for the 36 installations that are listed in the UK NIM the allocation in 2013 of almost 1.4 M EUAs, after CSCF adjustment, is a reduction by 16% compared with the allocation in 2012. However, it is still estimated to be 10–30% above the emission levels observed over the 2nd period. Thus, the sector as a whole does not face a imminent risk to be in a short position. However, this is due to generous allocations to a few of the larger installations while for more than half of individual installations short positions are expected already in 2013. However, the effects of tranferred EUAs provides compensation.

4.1.2 Sweden

The Swedish PPI is Europe's largest pulp producer and 2nd largest paper and board producer, accounting for 31% and 12% of the respective segments (CEPI, 2013). In the 3rd period of EU ETS, 52 installations are participating compared with 58 in previous periods (SE NIM, 2012; EUTL, 2013). Figure 2 shows the development of CO_2 emissions and allocation. Between 2005 and 2012, CO_2 emissions have been reduced by half while total production volume, despite structural changes, has been almost unchanged (EUTL, 2013; FAO, 2013). Thus, there is a clear trend of fossil decarbonisation.

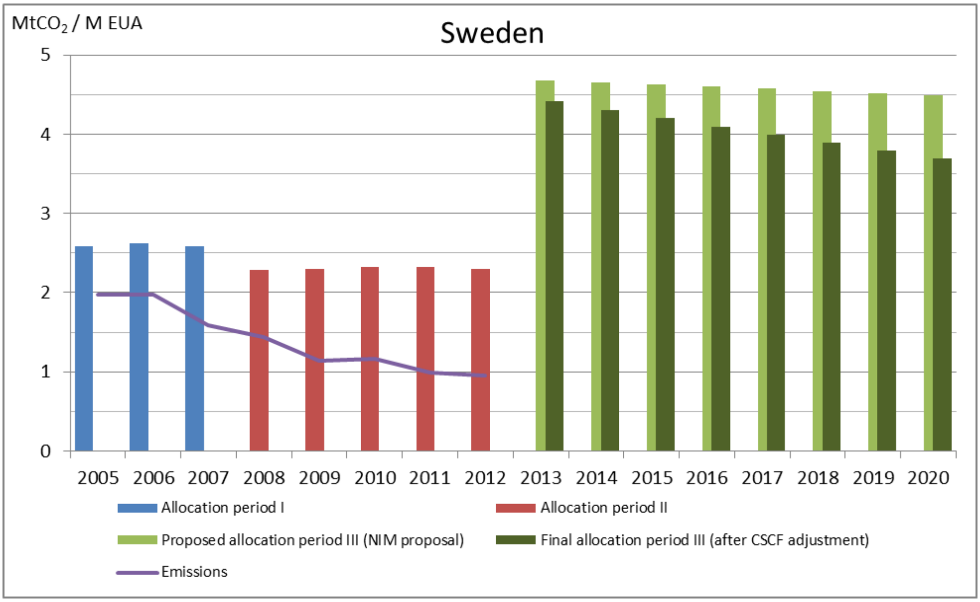

Figure 2. Emissions and allocations to PPI in Sweden, inluding all installations within each period. Data source: EUTL (2013) and SE NIM (2012)

So far, annual allocation has been around 2.5 M EUAs, which is well above last year's CO_2 emissions and closer to levels in 2003–2004 (Stenqvist, 2013). Due to abatement the emission-to-cap ratio reached a low level of 40% in the 2nd period and generated large amounts of transferable EUAs. Nevertheless, the 3rd period allocation will double and reach 4.5 M EUAs in 2013, which is five times the current emission level (SE NIM, 2012). The effect of the CSCF adjustment is negligible in this context.

There are at least four explanations behind the conspicuous outcome in the 3rd period. Firstly, several large and integrated mills are much rewarded by the product benchmarks which are based on non-integrated mills. Secondly, biofuels account for more than 90% of total fuel demand in Swedish PPI whereas benchmark values are based on natural gas (Ecofys, 2009b). Thirdly, several mills are heat exporters and receive free allocations for biomass-based heat deliveries to district heating grids. Finally, when product benchmarks have not been applicable (e.g. for dissolving pulp, kraft paper etc.) fall back approaches for heat or fuel use have rewarded mills for their large biomass-based energy flows.

4.1.3 France

France is Europe's 5th largest paper and board producer and 6th largest pulp producer, accounting for 9% and 5% of the respective segments (CEPI, 2013). In the 3rd period of EU ETS, 87 installations are participating compared with 100–120 installations in previous periods. Figure 3 shows the development of CO_2 emissions and allocation. Between 2005 and 2012, CO_2 emissions have been reduced by 40% while physical production has been reduced by 23% (EUTL, 2013; FAO, 2013). Thus, there has been some improvement in specific CO_2 emissions.

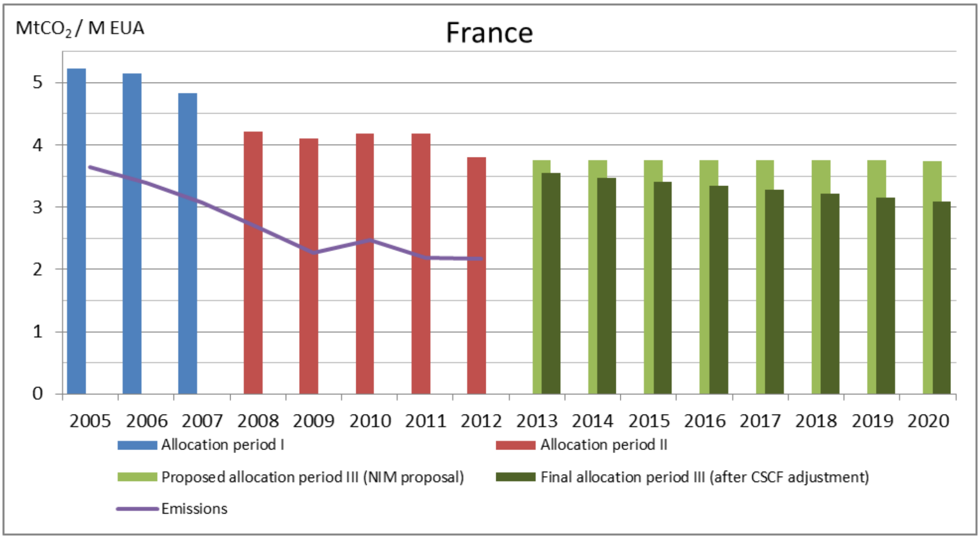

Figure 3. Emissions and allocations to PPI in France, inluding all installations within each period. Data source: EUTL (2013) and FR NIM (2012)

Annual allocation decreased from around 5 million EUAs in the 1st period to 4 M EUAs in the 2nd period. Apart from shutdowns and decreased production output, a few cases of outsourced heat and power supply have contributed to CO_2 emissions reductions in combination with more tangible abatement measures (EUTL, 2013). After CSCF adjustment the allocation will be 3.6 M EUAs in 2013. When accounting only for operating installations listed in the French NIM it represents a reduction by 4% compared with the allocation in

2012 (FR NIM, 2012). The emission-to-cap-ratio is expected to be 50–70% in the coming years, but successively it will be offset by the CSCF adjustment. However, a large amount of transferable EUAs is expected to increase the surplus. Thus, there will not be a short position on aggregated level though for a third of installations it could be the case already in 2013.

4.2 Cement industry

The assessment of CEI in UK, Sweden and France covers about 17% of the sector's ETS installations, CO_2 emissions and allocated EUAs (Ecofys, 2009c). The cement sector is relatively homogenous in terms of its products and processes and is concentrated to a handful of large international firms, which supply domestic demands by operations throughout EU. While domestic annual cement production is commonly 400–600 kg/capita, production in UK, Sweden and France was 120 kg/capita, 300 kg/capita and 280 kg/capita respectively in 2010, in correlation with low domestic per capita consumption (CEMBUREAU, 2013a).

4.2.1 United Kingdom

UK's CEI accounts for 5% of cement production in EU-27 (CSI, 2013). Twelve installations are participating in the 3rd period of EU ETS compared with 17 in the 2nd period (UK NIM, 2012; EUTL, 2013). Four cement works have been shutdown and one gas-fired power station must no longer receive free allocation (UK NIM, 2012).[13] Figure 4 shows the development of CO_2 emissions and allocation since 2008.[14] The CO_2 emissions have been reduced

[13] In the 2nd period, this power station was categorised under the cement sector and received 585,000 EUAs per year in free allocation (EUTL, 2013).

[14] Records for 2005–2007 are excluded since half of UK's CEI was exempted from the 1st period.

by 30% while physical production decreased by 25% (EUTL, 2013; CEMBUREAU, 2013b).[15] Thus, specific emissions have improved slightly.

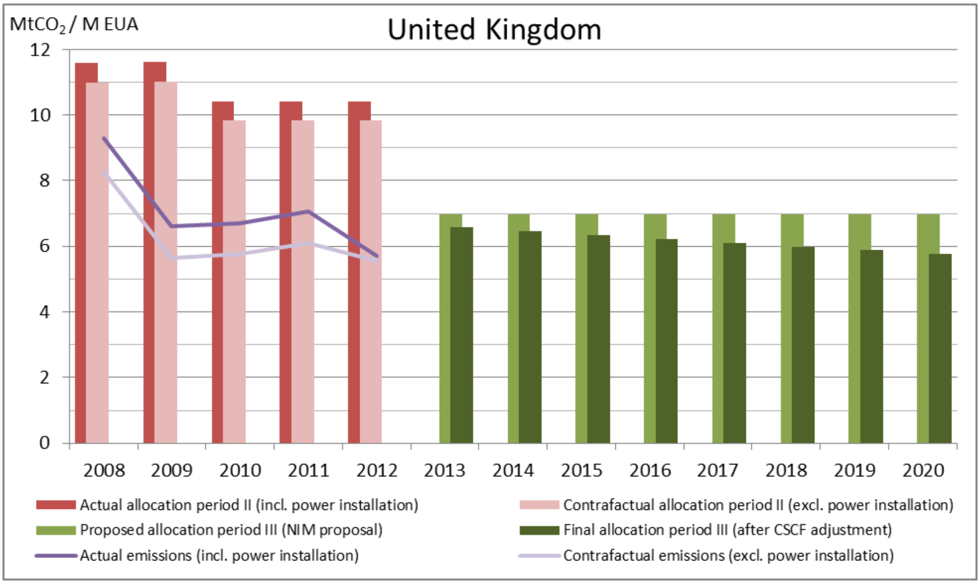

Figure 4. Emissions and allocations to CEI in UK, inluding all installations within each period. Data source: EUTL (2013) and UK NIM (2012)

The emissions-to-cap ratio has been 55–80% in the 2nd period. Similar to the case of UK's PPI two scenarios are used to demonstrate the sector's allocation and emission levels with or without inclusion of records for one power station (EUTL, 2013). The latter scenario is preferable for comparing the size of allocation between the two periods. After the CSCF adjustment the allocation of 6.6 M EUAs in 2013 represents a reduction by one third compared with 2012. When accounting only for the twelve operating installations listed in UK's NIM the 2013 allocation is reduced by 25% compared with 2012. However, it is still 20% above the emission level in 2012. With transferable EUAs the sector should be able to recover from its downturn without facing a

[15] Self-reported company data to the Cement Sustainability Initiative (CSI) shows that fuel-mix carbon-intensity and specific gross CO_2 emissions per tonne clinker improved by 5–7% in 2008–2011 (CSI, 2013).

short position in the coming years, but succesively the situation becomes stricter.

4.2.2 Sweden

The Swedish CEI accounts for 1–2% of cement production in EU-27 (CSI, 2013). In the 3rd period, as in previous periods, the sector is represented by three cement works of the same company group (EUTL, 2013; SE NIM, 2012). Figure 5 shows the development of CO_2 emissions and allocations. Between 2005 and 2012 the CO_2 emissions increased by 12%, which could reflect a relatively large production output in 2012 at unchanged levels of specific emissions (EUTL, 2013). However, the Swedish CEI does not report to CSI and production data is insufficient for this period.

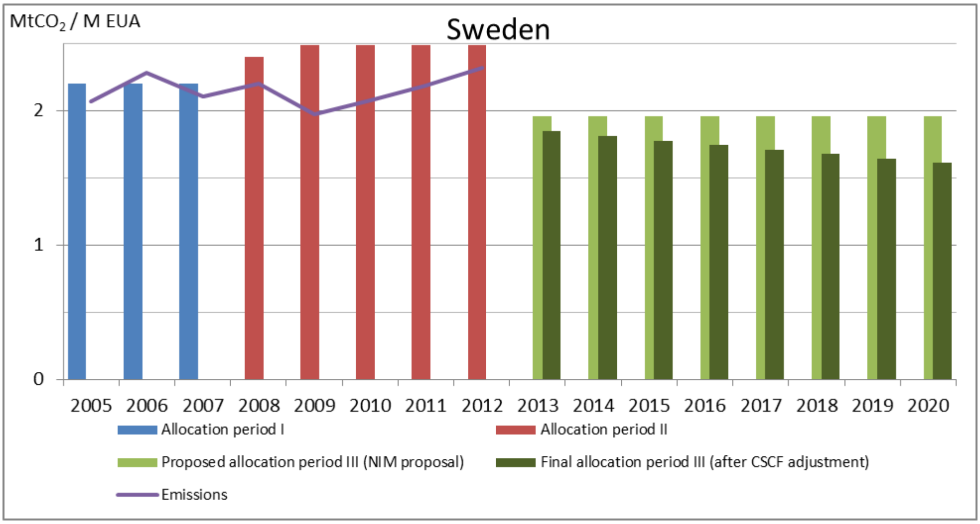

Figure 5. Emissions and allocations to Swedish CEI, inluding all installations within each period. Data source: EUTL (2013) and SE NIM (2012)

From an emission-to-cap ratio around 100% in the 1st period, increased allocation led to ratios of 80–90% in the 2nd period (EUTL, 2013). In 2013, after CSCF adjustment, the allocation will be 25% below the allocation and

20% below the emissions of 2012. It can be expected that all Swedish installations will experience short postions in the 3rd period.

4.2.3 France

In 2011, the French CEI accounted for 11% of cement production in EU-27 and was the third largest producer (CSI, 2013). As in previous periods 30 cement works are proposed to participate in the 3rd period (EUTL, 2013; FR NIM, 2012). Figure 6 shows the development of CO_2 emissions and allocations. Between 2005 and 2012, both CO_2 emissions and physical production decreased by about 15% (EUTL, 2013; CEMBUREAU, 2013b). Thus, there has been no change in specific CO_2 emissions.[16]

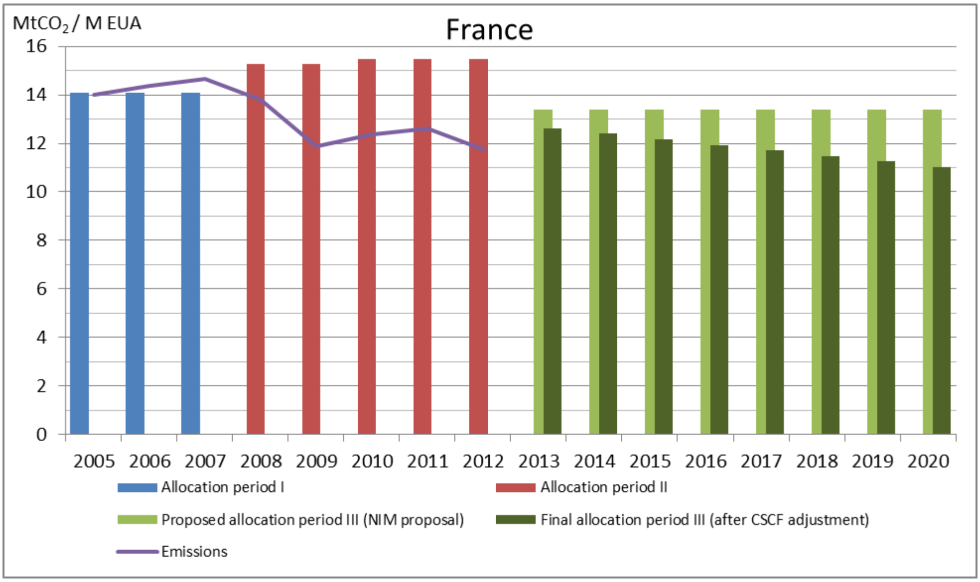

Figure 6. Emissions and allocations to French CEI, inluding all installations within each period. Data source: EUTL (2013) and FR NIM (2012)

[16] Self-reported company data to CSI shows that the fuel mix carbon-intensity and the specific gross CO_2 emission per tonne clinker is almost unchanged in 2005–2011 (CSI, 2013).

Similar to the Swedish case, the emission-to-cap ratio changed from around 100% in the 1st period to 80–90% in the 2nd period (EUTL, 2013). In 2013, after CSCF adjustment, the allocation will be 18% below the allocation but 7% above the emission level of 2012. With transferable EUAs the sector as a whole does not face an imminent risk to be in a short position but for one fifth of the installations it is more likely to occur.

5 Discussion

The procedures for allocating allowances to participating companies in the EU ETS were changed after the 2nd commitment period following an extensive review process. Two of the most contentious issues with the previous methods for free allocations were the use of grandfathering based on historical emissions and the lack of harmonization across MS. Both of these aspects were criticized for being both unfair and creating perverse incentives resulting in redistributive effects and over-allocation.

In view of the annually decreasing cap (currently set at -1,74%/year) the issue of over-allocation could be viewed as minor issue for the overall effectiveness of EU ETS with the argument that the economic incentive, via the alternative CO_2-cost, is equal to all participants on the margin. However, experiences from previous trading periods and arguments from behavioral economics suggest that an oversupply of emission allowances will pacify firms and dampen their responses in terms of innovation and investments in low-carbon solutions and thereby decrease the efficiency of the system (Laing et al., 2013). In the 3rd trading period, the share of auctioning was increased to include the majority of all power producers. Further, the methods used for allocation of the remaining allowances for free to industries were changed to a system based on EU-wide benchmarks. Together, these two changes should improve the EU ETS to be more in line with the "polluters pay principle" and increase the incentives for cost effective mitigation actions among participating industries.

The aim with the benchmark methodology for allocation of emission allowances for free was, in general, to allocate less allowances than needed putting most firms in a short position and thereby forcing them to engage actively in either trading or mitigation. The new allocation method in the 3rd trading period resulted in lesser allocations to industry compared with the 2nd period. For the EU´s PPI, the 2013 allocation is 33.6 M EUAs after CSCF adjustment, which is 17% below the average annual allocation in the 2nd period (40.3 M EUAs). For EU's CEI the corresponding figure is 151 M EUAs in 2013, which represents a 15% reduction (EC, 2013d; EEA, 2013b). However, reducing the allocation does not necessarily mean that regulated sectors are put in short position in the 3rd trading period. A closer look at the CEI and PPI reveals that both sectors will probably continue to be in long positions during the 3rd period due to either production declines (the CEI) or a still too generous allocation (the PPI).

For EU's CEI the 2013 allocation is 5% below the relatively high emission level of 2008 (159 Mt CO_2). However, due to large production declines, the projected allocation in 2020 (127 Mt CO_2) is still 11% above the emissions levels of 2012 (114 Mt CO_2). For the collective of EU MS that report to CSI, cement production decreased by 21% in 2008–2011, which is closely correlated with absolute CO_2 emissions reductions by 22% over the same period (CSI, 2013). Thus, this analysis hardly reveals any evidence of abatement. In our sample of countries, the emission-to-cap ratios changed from stringent in the 1st period to generous in the 2nd period as production declines imposed long positions for CEI foremost in UK and France. While UK's CEI has improved specific CO_2 emissions by 5% since 2008 our analysis provide no evidence in support for abatement in Sweden or France (CSI, 2013). When comparing the emission levels in 2012 with expected 3rd period allocations the Swedish CEI, which has maintained a relatively stable production output over the post 2008 recession period, appears more prone to be in a short position. The production output of CEI in all three MS is directly dependent on domestic construction markets. Only if construction activity increases sharply will CEI in France and UK recover to reach the high levels of output observed in 2005–2008, the years that define the historic activity level.

For EU's PPI, the 2013 allocation is 5% above its record high emission level of 2008 (32 Mt CO_2) and only by 2020 do projected allocations reach the currently representative emission level of 2012 (28.3 Mt CO_2). European production of pulp and paper decreased by 6% in 2008–2012, which correlates with a reduction of direct CO_2 emissions of almost 6% in the same period (CEPI, 2013). Thus, at EU level the PPI has hardly improved its specific CO_2 emissions over this period. For our sample of countries, the emission-to-cap ratios have not imposed direct emission constraints for PPI in any of the three MS. However, despite over-allocations there is evidence of abatement in Sweden and France, where specific CO_2 emissions have been improved by 50% and 20% respectively in 2005–2012 (FAO, 2013; EEA, 2013b). In Swedish PPI, the fuel oil use was reduced with 20% between 2007 and 2011 and with 30% when accounting also for the closure of five mills (Wiberg and Forslund, 2012). With only 7% of fossil fuels in the fuel mix the Swedish PPI is currently moving towards complete decarbonisation (Stenqvist, 2013). In UK, on the other hand, emission reductions are only correlated with production declines since 2008 (FAO, 2013; EEA, 2013b). Representatives of European PPI perceive increased electricity prices as the strongest influence of EU ETS, not the carbon price tag on internal fuel use, and downplay the role of EU ETS in triggering innovative low-carbon solutions (Gulbrandsen and Stenqvist, 2013a). If so, the future driving force, beyond economic motives, for industrial decarbonisation will be complementary policies directed towards e.g. energy efficiency improvement, process integration, renewable energy supply and high efficient CHP based on bio-fuels or other less carbon-intensive fuels.

Abandoning the National Allocation Plans and introducing EU-wide benchmark methodology in the 3rd period implied a strong harmonization across the EU MS, which means that all installations will receive the same treatment with no national flexibility. This will mitigate concerns over perverse incentives and strategic behavior from national authorities and eventually result in a more fair and acceptable allocation.

For the relatively homogeneous CEI in the EU this seems to have worked well. However, our detailed analysis points to conspicuous outcomes in the PPI that could question the fairness. Compared with the coherent outcomes for the CEI, the assessment of the 3rd period allocation in PPI gives three distinguishable outcomes. In UK, the allocation will become stricter. In France, the situation is close to business-as-usual with a continued long position. Finally in Sweden, the allocation reaches a conspicuously high level; twice as large as the 2nd period allocation and five times larger the actual emission level (see Figure 2). The main explanations of the dispersed outcomes of the benchmark rules are the use of biomass fuels and the economies of scale in integrated mills. The over-allocations reflect the biomass′ share of the PPI's fuel-mix which is about 90% in Sweden, 50% in France and 5% in UK (Ecofys, 2009b). Thus, a major change in the 3rd period is that the PPI's biogenic CO_2 emissions have become entitled free allocation since natural gas has been the reference fuel for determining product, heat and fuel benchmarks, of which the product benchmarks are derived from literature values and not curves (Ecofys, 2009b; EC, 2011).

Regarding size and process integration, benchmarks together with grandfathering based on production volume clearly rewards large producers; for integrated mills, which are potential net producers of steam, the benchmark values based on non-integrated mills represents a windfall gain. The Swedish situation is illustrative. For the ten largest producers of which nine are integrated mills the average emission-to-cap ratio is expected to be 20% in 2013, and for outliers even 5% [sic!]. For the ten smallest producers six stand-alone mills are expected to be in short positions in 2013. Sweden's favorable factor conditions for a low-carbon production of pulp and paper products (e.g. the access to raw materials and renewable energy) and the fact that its PPI started to phase-out fossil fuels already in the 1970s (Lindmark et al., 2011) are generously rewarded in the 3rd period of EU ETS. In international comparisons the Swedish PPI do stand out as the most CO_2-efficient (IEA, 2007). Seen from this perspective the new allocation procedures will reward the best performing installations in terms of specific CO_2 emissions. However, the product benchmark values for pulp and paper products do not represent the average performance of the 10% most GHG efficient installations in 2007–2008 (EC, 2009, Art. 10a(2)). For Swedish PPI, one would have to go back to the early years of the 1980s in order to find emission levels that correspond to allocation levels determined for the 3rd period. Since then fossil fuel use and related CO_2 emissions have been reduced by 80% while physical production has increased by 50% (Stenqvist, 2013).

A general problem with the EU ETS is the difficulty of managing structural changes in the economy as this can create unexpected "bubbles" of oversupply resulting in depressed EUA prices (see e.g. Karpestam and Andersson 2011). This problem is currently being discussed for the EU ETS in general but the effects of structural changes in the economy has also effects on the free allocation methodology, especially how to manage closures, new entrants or significant changes in capacity in existing installations.

Allocating allowances for free based on historical emissions (grandfathering) is the main concern here and this method was abandoned in the 3rd period. However, a certain degree of grandfathering is still present. Both the production volumes and CO_2-performances, to the extent that product benchmark curves have been applied, are determined on historical prerecession records. This is especially important for the PPI which is in a transformative stage with many closures, downsizing and structural changes in production capacity that will put to test the regulated provisions for closures regarding continued free allocation (DG CLIMA, 2011c). In particular the newsprint segment has suffered from diminishing market demand and excess capacity. In Europe, as well as in Sweden and France, newsprint production fell by 20% between 2007 and 2012 (FAO, 2013). Firms of the Swedish PPI, which accounts for one fifth of EU's newsprint production, have announced additional temporary or permanent shutdowns of paper machines in this segment (Stenqvist, 2013). For five large integrated mills expected production declines are in the range of 20 to 50% reductions compared with the levels of 2007 (Danske Bank, 2013). Acknowledging the bleak prospect for newsprint and to some extent other publication segments, it is unlikely that the historic activity level (2005–2008) will be relevant for the future production levels until 2020. In cases like these, MS's authorities will have to decide whether reduced production is a case of partial cessation or a case of significant capacity reduction (DG CLIMA, 2011c). If the former should apply it is expected that installations, even at halved activity levels, will maintain their initial levels of free allocation over the third period, because of the generously set thresholds for adjusting allocation. Thus, over-allocations, in terms of low emission-to-cap ratios, are likely to persist and be further enhanced in the PPI over the 3rd period.

6 Conclusions

The new allocation rules for the EU ETS have managed to reduce the allocation compared with the 2nd period, which was expected. However, as our example shows, the new rules are not likely to put analysed sectors in short positions in the coming years, with the potential exception being Swedish CEI. In the CEI the outcome is foremost due to the large production declines observed since 2005–2008. In the PPI the main reason for this outcome is the apparent inability of the benchmark rules to provide a stringent representation of the (fossil) CO_2 emissions intensities in this heterogeneous sector where the biomass share of fuel mix ranges from 0 to above 90% in different MS.

Harmonizing the methodologies have been good but have been more easily and fairly adopted in homogeneous sectors. Our example demonstrates large differences between the homogeneous CEI and the more difficult and diverse PPI. The outcomes of the new allocation procedures in CEI are much more coherent than in PPI; the 3rd period allocation will result in stricter allocations to CEI in all three MS compared with the 2nd period allocation.

Another problem that has been highlighted is how to deal with structural change. In the PPI the problems with structural change is very relevant, while the CEI is expected to display a stable development. The EC has issued a set of rules and procedures for the treatment (i.e. adjustment of allocation) of closures, capacity reductions and partial cessation of operations. The compliance of MS and installations in all sectors will be essential to avoid subsidies and to successively increase the share of auctioned allowances.

For the current and future debate on structural reformation of the EU ETS it should be worth looking into how to solve problems with the free allocation based on harmonized benchmarks for a selected number of industries as one might expect that free allocation will continue to be used in some ways.

Acknowledgements

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