Implications of an Energy Efficiency Obligation Scheme for the Swedish Energy Intensive Industries – an evaluation of costs and benefits

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Highlights

- A Swedish energy efficiency obligation scheme would result in a positive benefit-to-cost ratio.
- The break-even cost ranges from 83.3 €/MWh to 86.9 €/MWh in different scenarios for energy and emission allowance prices.
- An energy efficiency obligation scheme can be attractive for energy intensive industries.
- Implementing an efficiency obligation scheme could help Sweden meet the target of the European Energy Efficiency Directive.

Abstract

The EU Energy Efficiency Directive (EED) aims at improving energy efficiency by implementing actions in all sectors of the economy in the EU. Article 7 of the EED sets the target of 1.5% cumulative annual energy end-use savings. An energy efficiency obligation scheme (EEO) is one of the policy mechanisms proposed to reach this target. This paper assesses the impact of implementing a Swedish EEO, and the implications that such a scheme may have for Swedish energy intensive industries. The assessment was based on Cost-Benefit Analysis (CBA) methodology. The Benefit to Cost Ratio (BCR) ranges from 1.56 to 2.17 and the break-even cost ranges from 83.3 €/MWh to 86.9 €/MWh with sensitivity analyses performed for the emission allowance prices and eventual costs of the EEO. The annual energy savings potential is estimated to be 1.25 TWh/year. A Swedish EEO could motivate investments in energy efficiency measures, and thus help Sweden reach the energy efficiency targets set in the EED.

Keywords: energy efficiency obligation scheme, cost-benefit analysis, industrial energy efficiency, Energy Efficiency Directive, Sweden

1. Introduction

The European Commission's Directive 2012/27/EU on energy efficiency, also known as the Energy Efficiency Directive (EED), aims at improving energy efficiency by implementing actions in all sectors of the economy in the EU. Article 7 of the EED sets a general binding target of 1.5% energy end-use savings for energy suppliers and distribution network operators in all EU Member States, excluding the transport sector (European Parliament 2012). For Sweden, this amounts to 3 TWh/year (Swedish Energy Agency 2012a).

The EED recommends implementation of an energy efficiency obligation scheme (EEO) with trading of white certificates as an option for achieving the additional energy savings required for complying with Article 7 of the EED. The EEO is a regulatory mechanism that introduces an energy efficiency obligation for specific energy market parties, which can be delivered by the parties themselves or procured among eligible subcontractors (Joshi 2012). The EED opens for alternative policy instruments other than the

List of abbreviations: BCR – Benefit to Cost Ratio; CBA – Cost Benefit Analysis; EED – Energy Efficiency Directive; EEO – Energy Efficiency Obligation; EII – Energy Intensive Industries; EUA – EU Emissions Trading Scheme (ETS) emission allowance; HPI – High Policy Intensity; PFE – Program för Energieffektivisering (Program for improving Energy Efficiency)

EEO, if these are considered more suitable for particular Member States. Alternative instruments could be energy or carbon taxes; financial instruments or fiscal incentives; regulations or voluntary agreements; standards and norms; labeling schemes; as well as training and educational initiatives. It should be noted that any alternative instruments need to be additional to existing EU minimum requirements and should lead to an equivalent amount of energy savings as per the EED targets. Furthermore, all instruments shall be subject to the methods of monitoring and verification of the energy savings as suggested by Appendix V of the EED (European Parliament 2012). Four of the EU Member States will only use EEO for achieving the energy savings required by the EED, while fourteen will use a combination of EEO and alternative policy instruments (Bertoldi et al. 2015). Ten Member States will only use alternative policy instruments and Sweden is one among them.

Sweden has communicated its implementation plan for Article 7 of the EED to the European Commission in December 2013. In this plan, Sweden aims to achieve the cumulative energy savings required by the EED using a combination of new and established instruments, though not an EEO. The main instrument to be used for achieving energy efficiency improvements is increased taxation (Ministry of Enterprise Energy and Communications 2013).

Prior to the notification to the European Commission, the Swedish Energy Agency (2012a) analyzed the consequences of implementing a quota system for energy efficiency in the Nordic context, and calculated the costs of a potential Swedish EEO. These costs were estimated based on the Danish EEO costs. We argue that the Swedish Energy Agency (2012a) did not fully assess the cost-effectiveness of a possible Swedish EEO, as the analysis lacks a proper assessment of the benefits of such a scheme and a detailed presentation of the energy savings potential of the various sectors affected. One example could be the energy intensive industrial sector.

The industrial sector accounts for one third of the total energy use and 80% of the emissions in Sweden (Swedish Energy Agency 2012b). For comparison, the average share of emissions from energy intensive industries in the EU is 40% (Swedish Energy Agency 2013a). The majority of the energy intensive industries in Sweden are part of the EU ETS system. In the context of energy efficiency policies, the engagement of the energy intensive industries (EII)[1] is particularly important, since they are responsible for nearly 80% of the energy used in the Swedish industrial sector (Swedish Energy Agency 2012b; Thollander and Ottosson 2010). Energy costs are significant in the overall costs of EII, and thus energy cost increases may affect the sector's international competitiveness (IVA 2013). In the past ten years, the Swedish electricity prices have already increased threefold, causing concern among industries (Thollander et al. 2013).

Meanwhile, the Swedish Energy Agency (2012a) identified significant energy savings potential among the EII, and estimated that incentives for investments in energy efficiency improvements could promote energy savings of 15 TWh until 2020. The energy savings potential among Swedish EII is approximately 80 % of the total energy savings potential of the Swedish industrial sector (Fraunhofer ISI et al. 2009a). The Royal Swedish Academy of Engineering Science estimates that industrial energy use relative to value added can decrease by 50 % by 2050 if the technical energy efficiency potential of Swedish industries is fully exploited (IVA 2013). However, there is a gap between technical and economic potential, meaning that a measure might be technologically possible to implement, but not feasible from an economic perspective. Furthermore, the economic potential can be further reduced due to the "*energy efficiency*

[1] According to Swedish Energy Agency, energy intensive industries are whole companies or parts of companies active in industrial manufacturing that use on average at least 190 MWh of electricity per million SEK (eq. to 116.550 €) of value added in their industrial production processes (Swedish Energy Agency 2012d).

gap", which leads to cost effective measures not being implemented (Hirst and Brown 1990). Incentives for cost-effective energy saving actions could motivate these improvements.

This paper provides an assessment of costs and benefits of utilizing the energy savings potential of the EII under an EEO to reach the EED target. Our assessment is based on cost-benefit analysis (CBA) methodology. We aim at answering two key questions: (i) *can the implementation of an EEO in Sweden be justified from a benefit-to-cost perspective;* and (ii) *what would be the implications of an EEO for EII?*

Section 2 provides an introduction to the European and Swedish energy efficiency policy context. The methodology for performing a CBA for environmental policy evaluation is presented in Section 3, along with a justification of the relevance of the methodology for energy efficiency policy evaluation. The CBA calculations, data sources and estimations used for carrying out this study are also explained in Section 3. Section 4 presents the results of the CBA and discusses the implications of an EEO for the EII. The final section presents conclusions and policy recommendations based on the results of the analysis.

2. Energy efficiency policy instruments in the EU and Sweden

EEOs are already in place in some EU Member States. Table 1 shows the different paths and targets chosen among different countries. The monitoring of achievements also varies, as well as the introduction or not of white certificates trading. The regulatory framework, targets and context of operation can be different. The issue of lifetime for measures taken within the EEO, for example, is addressed differently in the countries that currently have EEOs. In France, cumulative and discounted energy savings are counted while, in Denmark, first year energy savings are counted (see Table 1). Counting lifetime savings is a more complicated method compared to counting first year energy savings, and the latter can encourage low-cost short lived measures. To tackle this problem, the Danish regulating authority encourages measures with a lifetime over 15 years giving them a 50% premium, while savings with a lifetime of less than 4 years are cut by half (ea Energy Analyses 2014).

Table 1: Comparison of characteristics of EEOs in chosen countries of the EU (VITO et al. 2015)

Country	**Energy savings target**	**Obligated parties**	**Sectoral coverage for eligible projects**	**White certificates trading**	**Compliance regime**
France	kWh cumac (cumac = cumulative and actualized – discounted for measure's lifetime)	All energy suppliers	All final energy consumers	Certificate trading or bilateral exchange	Penalty of €0,02/kWh cumac shortfall in energy savings
Italy	Million white certificates, including lifetime (accounting both annual primary energy savings and anticipated energy savings for measures with lifetime over 5 years)*	Electricity and gas distributors	All final energy consumers, except electricity generation	Certificate trading or bilateral exchange	Non-compliance penalty justified on case-by-case basis
Denmark	First-year savings relative to annual final energy consumption	Electricity, gas, oil and district heating distributors	All final energy consumers, with selected types measures eligible for the transport sector	Certificate trading allowed among obligated parties, transfer between different program phases	Fines posed on a case-by-case basis for obligated actors that have not complied with agreements

UK	Measured in reduction of CO_2 emission equivalent (lifetime CO_2 equivalent) Heat cost reduction (vulnerable households only)	Electricity and gas suppliers	Residential only	Certificate trading allowed among obligated parties, transfer between different program phases	Regulator can impose fine to obligated parties of up to 5% of global turnover

* Up to 2013 the target was expressed as yearly primary energy savings.

[b] The UK EEO scheme focuses on the residential sector only. Since our analysis focuses on the industrial sector, the UK EEO has been excluded from the comparison.

Lees (2012) and Eyre et al. (2009) show that EEOs have been cost-effective to implement. They can remove market barriers to energy efficiency, and effectively stimulate the creation of a market for energy services. Moreover, energy efficiency measures do not only provide benefits in terms of energy demand reduction, but also bring additional benefits to the companies engaged. The IEA calls this additional value "*multiple benefits of energy efficiency*", which might include energy security, health and well-being, job creation and lower costs of compliance with stringent environmental regulations (IEA 2014). Although these benefits affect both energy suppliers and consumers, they are not commonly accounted for in impact assessments. Since the methodology for quantifying multiple benefits of energy efficiency is still at early stages of development, we do not apply such analysis in this paper.

Eyre et al. (2009) claim that concerns about energy price increase in the context of an EEO are not justified as the price increases are outweighed by the reduction obtained through lower energy use. Increases in energy prices are expected to stimulate actors to implement energy savings measures (Fraunhofer ISI et al. 2012). On the other hand, Rosenow et al. (2013) point to potential regressive outcomes, such as the pass-through of EEO costs to end-users, which can affect poor households disproportionally. This is obviously an aspect to consider when designing energy efficiency schemes. Since the focus of this paper is on the energy intensive industrial sector, this type of direct regressive outcome will not be discussed further.

In line with the subsidiary character of European energy policies, the EED leaves the choice of obligated actors to the Member States, which can be either energy suppliers or distributors. The Swedish Energy Agency (2012a) suggests that the energy efficiency obligation should be placed on the energy distributors, as in the case of Denmark. Bertoldi et al. (2013) suggest that end-users in the industrial and commercial sector might be better poised to be the obligated actors in an EEO. For now, the EED indicates that only energy suppliers or distributors could be the obligated parties in the scheme and the decision is left to the Member States. In any case, there is not enough evidence to favor the choice of one or the other (Bertoldi et al. 2015). The decision depends more on the goals aimed at with the scheme.

The obligated actors are not restricted to delivering energy savings directly from their own operations; they can also make agreements with eligible end-users of energy to deliver the required energy savings (Eyre et al. 2009). The latter stimulates the energy services market, as any company in the position to deliver eligible energy savings can act as a third party company.

Sweden has taken action towards improving industrial energy efficiency. A voluntary agreement program, PFE (Program for Improving Energy Efficiency), was started in 2004 focusing on EII. Table 2 gives overall information about the size, duration and achievement of the program. PFE aimed at electricity savings and the implementation of energy management systems (EnMS) in EII. The program offered tax rebates in exchange for fulfillment of obligations in the program. PFE showed impressive results in terms of achieved energy savings. However, the tax rebates offered by the program were considered capital transfers between the state and the end-users (here, the participating EIIs), and they were almost equal to the costs incurred by the EIIs (Stenqvist & Nilsson, 2011) (see Table 2). After two implementation periods, PFE can no longer be continued as this capital transfer via tax rebates violates the EU regulations on government subsidies (Swedish Energy Agency 2012c).

Table 2: Facts on the PFE - Swedish Program for Improving Energy Efficiency (Stenqvist and Nilsson 2011).

About PFE (Program for Improving Energy Efficiency)	
Program description	Voluntary agreement for EII offering tax rebates in exchange for introduction and operation of energy management systems, and investments on energy efficiency improvement measures. The program only considered electrical efficiency measures.
Duration	First program period from 2004 to 2009, second program period from 2009 to June 2014.
Participating companies	110 EII in both periods (accounting for 85% of PFE eligible electricity use, eq. to 30 out of 35TWh)
Energy savings	1,450 GWh/year (gross impact per year of program), 689-1,015GWh/year (net impact per year of program) in first period
Program costs for participating companies	79M € in first period (eq. to 708 MSEK[2]) (15.8 M€/year)
Tax rebates offered	84 M € in first period (eq. to 750 MSEK) (16.8 M €/year)
Cost-effectiveness	10.4 – 15.2 €/MWh of saved electricity (eq. to 93– 136 SEK/MWh)

In addition, the PFE has been criticized for strong government regulation and for information asymmetry. The latter occurs when the involved parties do not have access to the same amount of information, resulting in market imbalances (Mansikkasalo et al. 2011). This refers to knowledge about energy efficiency improvement potential that the actors involved with the program may have, which is not disseminated to actors that are not part of the program but could possibly have a considerable energy efficiency improvement potential, i.e. non-energy intensive industries. It should be noted that the issue of information asymmetries in voluntary agreements has been generally considered a constraint to their cost-effectiveness (Glachant 1999). Also the short payback periods of the measures implemented in PFE could possibly mean that the implementation focused on "low-hanging fruits" in the first period (Stenqvist and Nilsson 2011). Focusing on "low-hanging fruits" is not something that is negative per se. However, the cost-effectiveness of such measures cannot be fairly compared with a more ambitious program, aiming at higher efficiency gains.

A report evaluating the impacts of Swedish energy efficiency initiatives within industry, particularly PFE, points out deficiencies when defining goals, and accounting for energy savings (Swedish National Audit Office 2013). In general though, the PFE served to engage the Swedish EII in energy efficiency measures. The implementation of Energy Management Systems (EnMS) in the context of the program gave the industries the opportunity to identify their potential for energy efficiency improvement. As a next step, alternative instruments have to be considered for replacing PFE and enhancing the engagement of the

[2] All costs are translated into Swedish currency (SEK) using the exchange rate of 8.97 SEK/€ (5 year average currency –Source: oanda.com)

whole industrial sector in actions to improve energy efficiency. These instruments should be in line with national and EU guidelines, and an EEO is among the alternatives to consider.

3. Methods

3.1. *Cost- Benefit Analysis (CBA)*

Decision-makers have recognized the importance of performing ex-ante and ex-post (after implementing the scheme) evaluations of policy instruments (Pearce et al. 2006). The most widely used method for policy evaluation in the context of environmental policies is Cost Benefit Analysis (CBA), whereby costs and benefits are expressed in monetary terms so that they can be compared under a common unit of measurement (European Commission 1997).

CBAs combining the evaluation of economic cost-effectiveness with social efficiency in the form of optimal distribution of resources in the society are at the basis of evaluations of energy efficiency policies (Gillingham et al. 2006). Oikonomou et al. (2007) did an ex-ante evaluation of a white certificates scheme for the Dutch residential sector. Fraunhofer ISI et al. (2012) investigated the costs and benefits of various policy schemes for energy savings in Germany. Tol (2012) evaluated the EU 20/20/20 package using CBA. Suerkemper et al. (2011) and Clinch and Healy (2001) evaluated energy efficiency programs in the domestic sector for France and Ireland respectively. Furthermore, a benefit and costs assessment was performed for the EEO and white certificate schemes' implemented in France, Italy and UK by Giraudet et al. (2012). In these studies, CBA has been used to assess energy efficiency policy instruments at the national level, often including all energy consuming sectors. Some include qualitative analysis (Fraunhofer ISI et al. 2012; Tol 2012) or environmental social benefits (Giraudet et al. 2012), while others focus on specific sectors (Suerkemper et al. 2011).

However, CBA is associated with uncertainties. Some of the benefits of the scheme or project under evaluation are difficult to monetize since they may be intangible benefits or non-marketable goods and services, i.e. avoided costs, environmental benefits etc. (Cellini and Kee 2010). Assessing the costs also includes uncertainty due to the effect of *spillovers* (Gillingham et al. 2006). Also, since information asymmetries may exist in performing ex-ante evaluations, cost pessimism or cost optimism may distort the results of the analysis (Pearce et al. 2006). Sensitivity analyses can alleviate some of the uncertainty concerns, especially those related to assumptions made when defining the benefits and the costs (Cellini and Kee 2010).

One alternative method to CBA is Cost-Effectiveness Assessment (CEA). In CEA, the benefits of the policy are measured in environmental units (energy, CO_2 emissions etc.), in a cost-effectiveness ratio (U.S. Environmental Protection Agency 2008). The CEA can only be used for comparative purposes. Multi-Criteria Analysis (MCA) resembles the CEA and CBA, but integrates multiple indicators applying different weights to a selection of criteria defined by the decision-maker. In contrast to CBA, MCA does not require all criteria to be expressed in monetary terms. Similar to CEA, MCA cannot be used to conclude whether a policy is worth implementing, but rather shows the highest possible effectiveness per given unit of cost (Pearce et al. 2006). For the case of MCA, regardless of the comprehensiveness of the analysis, the results may be biased due to arbitrary choices of the criteria and their weight (Ackerman 2008). Assessing environmental impacts and risks related to policy implementation is out of the scope of this paper. Here, we focus on the balance between overall economic costs and benefits and, therefore, choose the CBA.

3.2 Evaluating a Swedish EEO using Cost-Benefit Analysis (CBA)

A CBA was carried out for a potential Swedish EEO, focused on prospective energy efficiency improvements and savings among Swedish EII. In addition to the direct benefits of the scheme, which are translated into avoided costs for energy use, the indirect monetized benefits resulting from energy efficiency improvements were included in the form of potential reductions of CO_2 emissions. Thus the CBA focused on straightforward monetized benefits for Swedish EII, the reason why social and market aspects that are not relevant to the EIIs are not considered. From a social perspective, reduced energy demand due to energy efficiency improvements may lead to lower energy prices in a competitive wholesale market, thus creating a benefit for all end-users of energy. However, this social perspective is excluded from the present analysis. The analysis can be considered as a financial CBA, investigating the profitability of an EEO only for the involved actors: the state, the obligated actors and the end-users of energy, in this case the EII.

There are two financing mechanisms in the context of an EEO (see Figure 1). One is the cost-recovery mechanism of the scheme, which operates by eventually transferring the investment costs to the end-users of energy (individuals or organizations). The costs are passed to the end-users either by the state through taxation (indirect costs) or by obligated actors through energy supply or distribution price increases as per choice of obligated actor (direct costs). The other mechanism of the scheme is related to the potential supply of subsidies from the obligated parties to the EIIs for investing in energy saving measures for the fulfillment of the obligation.

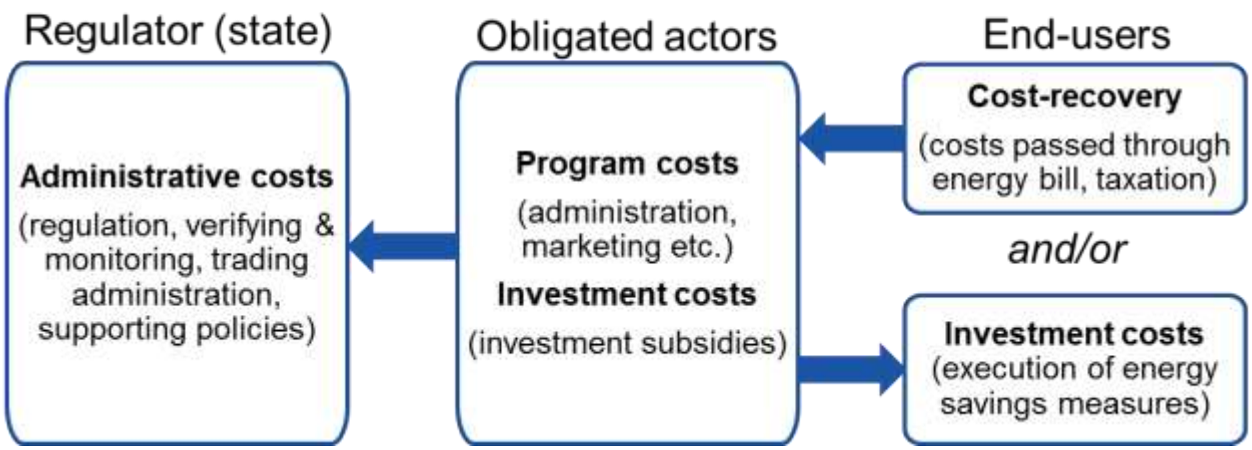

Figure 1: Schematic illustration of financing flows within an EEO

The total costs of an EEO are divided into administrative, program and investment costs (see also Figure 1). The administrative costs include costs borne by the state for the general administration of the EEO implementation, costs for verification of the energy savings achieved, administrative costs of trading certificates (if applicable) etc. The program and investment costs include costs on the obligated actor's side. The program implementation costs include what can be *transaction costs* for the obligated parties*, i.e.* technical support to the scheme's implementation, marketing of the energy savings measures, costs for setting up agreements, monitoring performance and reporting energy savings etc.

The administrative costs, C_{adm}, are estimated at 0.25 €/MWh (eq. to 2.30 SEK/MWh) by the Swedish Energy Agency (2012a) for a potential Swedish EEO. The European Commission (2011) provides an alternative estimation, which is only one tenth of the one provided by the Swedish Energy Agency, (2012a). However, the source of this estimation lacks transparent calculations, while the estimation made by the Swedish Energy Agency (2012a) is based on actual experience from the Swedish green certificate scheme[3]. One should take into account that administration costs (on the state's side) represent only around 1% of the overall costs of the scheme. Thus variations within a reasonable range only cause negligible differences to the overall costs.

The investment costs refer to the investment costs incurred for the realization of the energy savings measures. Obligated parties contribute to the investment costs subsidizing the implementation of measures. The remaining part of the investment is borne by the end-users. According to Giraudet and Finon (2015), it is very difficult to identify the share of the cost borne by the obligated parties. Giraudet and Finon (2015) and Giraudet et al. (2012) define investment costs as "direct costs", which are categorized as "obligated parties direct costs" or "customer direct costs". From their estimations based on publicly available information and stakeholder interviews, the share of obligated parties to the total costs, including investment costs, was around 10% in France, meaning that the scheme was mainly financed by end-use consumers. On the contrary in Great Britain, where the EEO aimed at the residential sector, that share was 73%. No such information is available for Italy or Denmark. For a small EEO in the state of Vermont in the US, the obligated parties' contribution to investment costs varied between 10-40% (ea Energy Analyses 2014). Since the available data is insufficient for concluding about the investment costs share borne by obligated actors and the cost to beneficiaries and end-users, we do not make this distinction in this study.

To alleviate uncertainties related to CBA, two types of sensitivity analysis were applied in this study: (i) *partial sensitivity analysis* and (ii) *break-even analysis*. In the *partial sensitivity analysis,* one variable is subject to variations and the impact of these variations is analyzed. Critical variables in this context are price dynamics (e.g. energy prices, inflation), investment costs, operating costs, demand data etc. (European Commission 2008). Here, this is taken into account by applying sensitivity analysis for varying CO_2 emission allowance prices under two different scenarios for energy prices. The same method was used for the costs by altering the costs of the scheme within a range of values observed for the EEO costs in other EU Member States.

A *break-even analysis* is used when it is difficult to estimate the effects of a policy or when available studies are not fully comparable to the case studied. The present study is ex-ante and an EEO has not been introduced in Sweden, so there is no ex-post analysis of the costs. The PFE addressed only electricity savings and, therefore, utilizing PFE's costs for this analysis could be misguiding. The only available information on the costs of EEO is from the schemes applied in other EU countries. These cost values can be used and are comparable to a certain extent, but uncertainties remain. By using break-even analysis we determine the maximum costs for the scheme to achieve neutral impact, meaning benefits equaling costs. In this way, although the precise costs for a Swedish scheme are not given, with the break-even analysis we can indicate the maximum level that costs can reach, above which the scheme's implementation is no longer justified.

3.3 Calculating the Benefit-to-Cost Ratio

The Benefit-to-Cost Ratio (BCR) was estimated for the EII: iron and steel, non-ferrous metals, chemical, non-metallic mineral products and pulp and paper sector, as indicated in Equation 1.

$$BCR = \frac{benefits}{costs} = \frac{avoided\ energy\ costs + avoided\ CO_2\ emission\ costs}{costs\ of\ the\ EEOS} =$$

[3] The electricity certificate system aims at increasing the electricity production of renewable energy in Sweden. Electricity produced from renewables (wind, solar, wave, geothermal, some biomass and some hydro sources) are awarded green certificates. Electricity suppliers and some electricity users are then obligated to buy electricity certificates equivalent to 17 % of their electricity use (Swedish Energy Agency 2010).

$$= \frac{\sum_{i=1}^{n} [E_p \cdot Sh_i \cdot \left(Pr_{E_i} + \left(f_{CO2_i} \cdot Pr_{CO2} \right) \right)]}{E_P \cdot C_{total}} \quad (1)$$

where

i = energy carrier,
E_p *= total energy savings potential for all sectors considered in the analysis in kWh,*
Sh = share of energy carrier in energy mix,
Pr_E *= price of energy carrier per kWh (for end-users),*
f_{CO2} *= CO2 emissions factor of energy carrier in tons* CO_2 *per kWh,*
Pr_{CO2} *= price of CO2 emissions per kWh; and*
C_{total} *= total costs per KWh of energy saved(*$C_{total}=C_{administrative}+C_{program}+C_{investment}$*).*

If the BCR is larger than one (BCR > 1), the benefits outweigh the costs and the scheme is economically attractive for implementation. Here, the annual benefits and costs were estimated corresponding to the period up until 2020 to harmonize with the EU2020 goals. In the next sections, the methodology for calculating each separate component of the BCR as shown in Equation (1) is presented. Figure 2 in the end of this section summarized the BCR components' values and sources of the estimations.

Benefits of the scheme

The benefits of a Swedish EEO were quantified based on the avoided costs for purchased energy and the avoided costs for CO_2 emissions. Both were estimated based on projected energy savings potentials, E_p, for the EII. In the case of avoided costs for CO_2 emissions, the savings of energy correspond to an amount of CO_2 that would otherwise be emitted during the combustion of fuels in energy production or in the industrial processes. Hence, the avoided costs of emissions were translated into benefits for EII through the avoided costs for acquiring the emission allowances (EUAs) required by the EU Emissions Trading System (EU ETS).

For calculating the avoided costs of energy, the potential energy savings, E_p, need to be identified first. Fraunhofer ISI et al. (2009a and 2009b) provide raw data on the energy savings potential for various sectors of the economy for each EU Member State. The energy savings potential has been estimated for three policy scenarios, disaggregated by sector, fuel type and Member State: *Low Policy Intensity (LPI), High Policy Intensity (HPI)* and *Technical Scenario (TS)*. We choose to consider the HPI as the energy savings scenario which would be closest to the introduction of a policy instrument such as an EEO. The High Policy Intensity Scenario contains instruments that would be cost-effective at the national level and from the end-user's perspective (Ecorys and ECN 2012). The LPI scenario implies high barriers to energy efficiency improvement, which are not properly addressed. These barriers are removed under the HPI scenario not least as low discount rates for investments are introduced. The TS scenario represents the energy savings potential that would be achieved if all Best Available Technologies (BAT) were implemented in all sectors of the economy, regardless of their costs, thus is less likely to occur (Fraunhofer ISI et al. 2009a).

The discount rate assumed for the industrial sector in the HPI scenario by Fraunhofer ISI et al. (2009) is 8% with inflation deducted, and lower discount rates imply cost-effective scenarios from an economic point of view. The discount rates for the benefits used in this paper relate to socio-economic impact, which consists of benefits affecting welfare and economic growth among a reference group of population. However, to apply this broad definition in practice, we only take into account the socio-economic impact that is directly connected to the relevant actors and objectives we have defined for this specific CBA, as described in the beginning of Section 3.2. These definitions are in line with the European's Union guide on CBA, which discusses methods and best practices for assessing socio-economic impact and CBA objectives (European Commission/Directorate-General for Regional and Urban policy 2014).

However, the energy savings potential provided by Fraunhofer ISI et al., (2009a and 2009b) needs to be adjusted, because it is based on scenarios included in the 2005 report on European Energy and Transport Trends to 2030 (Mantzos and Capros 2006) and not the updated version from 2009. The updated report included additional measures and new policies that were already being implemented, thus resulting in lower energy use (Fraunhofer ISI et al. 2009a). Therefore, an update of the energy savings potential is needed before the CBA calculations. We update the energy savings potentials in the HPI scenario for the Swedish EII as provided in the database by Fraunhofer ISI et al. (2009b) using the actual energy use for the base year 2010 provided by Eurostat (2013). The estimation of the energy savings potential was done by multiplying the energy use in the base year with the rate of reduction in energy use indicated in the HPI scenario. The energy savings potential was thus calculated to reach 1.25 TWh/year for the EII in total. Table A.1 in the Appendix shows the energy savings potential as calculated per sector. As suggested by Ecorys and ECN (2012)), the correction of the HPI energy savings potential is necessary to improve accuracy. This is essential also as we monitor the changes resulting from various energy efficiency policies being implemented in the EU.

Fraunhofer ISI published a new report in 2014 on energy savings potential for the EU countries (Fraunhofer ISI et al. 2014). The study calculates the energy savings potential for the four basic sectors (residential, industry, tertiary, transport) but not sub-sectors. The same case applies for the ODYSSEE database on EU Member States energy savings potential. The energy intensive industries are a part of the industrial sector. In the case of Sweden, the energy intensive industries represent a large share of the industrial's sector energy use, but not all of it. Therefore, we keep the more precise, sector-based calculation based on the previous study from Fraunhofer ISI and ensure the validity of the results by applying the corrections described previously.

The energy savings potential is counted in annual energy savings. However, the cost-effectiveness of a measure is taken into account under the energy savings potential scenario. If a longer-lived measure is cost-effective, then it will be implemented and its energy savings counted in the EEO. Thus we can assume that in the scenario used for this analysis, annual savings resulting from longer-lived measures are included, even though we do not distinguish the share of these savings. Long lifetime measures are not related to the actual savings potential but rather related to the design of the EEO and the incentives given for investing in long-lived measures instead of low-hanging fruits.

The effect on energy savings from the latest decision of Sweden on the implementation of the EED Article 7 is not included in the HPI scenario. Nevertheless, including taxation increases beyond the baseline is not in the scope of the estimations under the HPI scenario. We aim to showcase how an "EEO pathway" would function for Sweden, instead of the "alternative measure pathway" that has been chosen. As the Implementation Plan for the EED for Sweden shows, the cumulative energy savings expected from taxation in the industrial sector under the EU ETS are equal to 11.99 TWh until 2020 (Ministry of Enterprise Energy and Communications 2013). This estimation is close to our own estimation under the HPI scenario. It should be noted though that the Swedish Energy Agency's calculation might be overestimating the effects of taxation on energy savings, especially since the calculation is "*contrafactua*l", i.e. in order to calculate the impact of taxation on energy savings, the tax levels as of January 2014 were lowered to those of the EU's minimum tax levels, which would have been the case had an EEO been introduced.

The next step in our analysis is to extract data on the shares of each energy carrier in the total energy use, *Sh.* The energy carrier shares in the Swedish EII were estimated based on the average share in the final energy use for the period 2002-2011, using primary data from Eurostat (2013) (see Table A.2 in the Appendix). For simplicity, it was assumed that the shares of each energy carrier would remain stable for the analyzed period, which is consistent with the Swedish Energy Agency's (2013) long-term prognosis for the energy mix in the Swedish industrial sector. The technological shifts needed to switch between energy carriers require large investments and radical changes in industrial plant configurations, which are not foreseen in the time frame of this analysis.

The energy savings potential per each energy carrier share needs to be multiplied with the respective future energy carrier prices in order to monetize the benefits of avoided energy use in the CBA. Thus, an estimation of the development of energy carrier prices in the time frame of the analysis is needed. The Swedish Energy Agency (2013) provides two scenarios for future energy prices, Pr_E: a *Reference Scenario* and a *Higher Fossil Fuel Prices Scenario* (see Table A.3 in the Appendix). The Swedish Energy Agency's prognosis is based on the forecast of fuel prices conducted by the International Energy Agency (IEA) (Swedish Energy Agency 2013b). Since the Swedish demand and global share in the fossil fuel market is relatively small, it is assumed that changes in Swedish demand for these fuels do not affect prices (Swedish Energy Agency 2013b).

The energy carriers selected for the analysis were the ones most widely used by Swedish EII: *coal, natural gas, electricity, LPG, fuel oil no. 1, fuel oil no. 2-5* as well as *wood and wood residues*. These energy carriers represent 95 % of the final energy use of the Swedish industries in 2011. District heating is not considered in the analysis since its share is relatively low for the industry, or approximately 3 % of the final energy used by Swedish industries (Swedish Energy Agency 2012b). However, the Swedish Energy Agency (2013) lacks a price projection for LPG. Here, the price projection for LPG was estimated using the European average price after refining, transportation and distribution (Energy EU 2013) and imposing the Swedish energy tax for LPG (Svenska Petroleum och Biodrivmedel Institutet (SPBI), 2013). The LPG price was assumed to follow the future trend seen for natural gas. As shown in Table A.3 of the Appendix, these scenarios imply significant rises in the energy prices, with average rates reaching 26% and 28% for the Reference and Higher Fossil Fuel Price scenarios respectively.

It should be noted here that wood and wood residues are classified as energy for own use in certain cases and are excluded from the transposition of Article 7 of the EED by Sweden, as stated in the implementation plan for Article 7 of the EED. We choose to include wood and wood residues as an energy carrier in the analysis, as they represent a large share in the fuel mix. Excluding them from the analysis might be closer to the current Swedish plans, but would also exclude a large energy savings potential from the analysis. With this choice, the importance of wood and wood residues as an energy carrier that can be targeted for energy efficiency improvement in the future is also highlighted.

After calculating the benefits of avoided energy use, we proceed calculating the benefits from avoided CO_2 emissions. The avoided costs for CO_2 emissions were estimated by multiplying the emission factors, f_{CO2}, with the EUA price, Pr_{CO2}. The emission factors, f_{CO2}, were chosen using the standard IPCC approach (see Table A.4 in the Appendix) (European Commission 2010). The large volume of free EUAs available in the EU ETS led to a significant decrease in the EUA price, $Pr_{CO2,}$ during recent years (Bruyn 2013).

The European Commission has decided to use backloading as a short-term measure to restore the effectiveness of the EU ETS. In this case, backloading means to postpone the auction of 900 million allowances until later in the current phase of ETS, i.e 2019-2020 (European Commission 2012). Under the EU 2030 framework for energy and climate policies, the EU ETS will be reformed. This means that the ETS cap in Phase 4 will be lowered by 2.2% annually from 2021, instead of the current 1.7% (European Commission 2014, 2015a). Moreover, a market stability reserve for placing surplus allowance will be established as of 2018 as a long term solution (European Commission 2015b). Estimations (including scenarios with and without backloading) of the future EUA price up until 2020 range from 5.75 €/tCO_2 to 13.61 €/tCO_2 (eq. to 51.6 SEK/tCO_2 and 122 SEK/tCO_2).

The EUA prices gradually increased after the decision for backloading up to 9 €/tCO_2 in the end of 2015, only to decrease again close to 5 €/tCO_2 in January 2016 (Intercontinental Exchange 2016). We assume that the price estimations used for the sensitivity analysis range for this study are in line with the current situation and its possible development in the future. The avoided CO_2 costs were used undiscounted in the estimation of the benefits since CO_2 emissions reductions represent a social benefit which is then removed from the system once the reductions are achieved (Giraudet et al. 2012).

Costs of the scheme

The BCRs were calculated using the range of costs indicated in Table 3. We take these values as given, based on the estimations provided from the relevant sources. The case of the UK was excluded since the UK EEO is applied only in the residential sector (see Table 1). The costs presented are already discounted. Furthermore, we calculate the break-even value for the costs, by assuming BCR=1 for the two scenarios for future energy carrier prices.

The costs of EEOs in various Member States have been evaluated in different studies. Since EEOs are a relatively new policy instrument, in most of these studies it was challenging to obtain detailed cost estimations. For example, the obligated actors in France prefer to keep the scheme costs confidential (Giraudet and Finon 2015; VITO et al. 2015). The most recent and detailed record of cost-efficiency estimates for EEOs in the EU is provided by the ENSPOL (Energy Saving Policies) report, which is a program co-funded by the EU (VITO et al. 2015). Since the evidence is not sufficient in order to be conclusive, we do not separate administration, program and investment costs, but use a total cost of the energy savings measures within the EEO per MWh of energy saved, as included in the ENSPOL report (see Table 3).

It should be noted that the estimation of the Swedish Energy Agency for the administration cost is in line with initial evidence from the EEOs in Denmark and France, where the administration costs fell within the same range (Giraudet et al. 2012; Mikkelsen 2012). Moreover, administration and program costs are thought to be maximum 20% of the total costs of the EEO for the case of France (VITO et al. 2015). Further data collection and analysis are needed in order to conclude with certainty about the division of administration, program and investment costs, as well as the division of costs to beneficiaries and obligated actors.

Table 3: EEO costs – Data from the Danish, Italian and French EEOs (data obtained from VITO et al. (2015))

Country	Denmark	Italy	France
Costs of EEO in €/MWh (eq. to SEK/MWh)	52.0 (466)	40.0 (359)	53.6 (481)

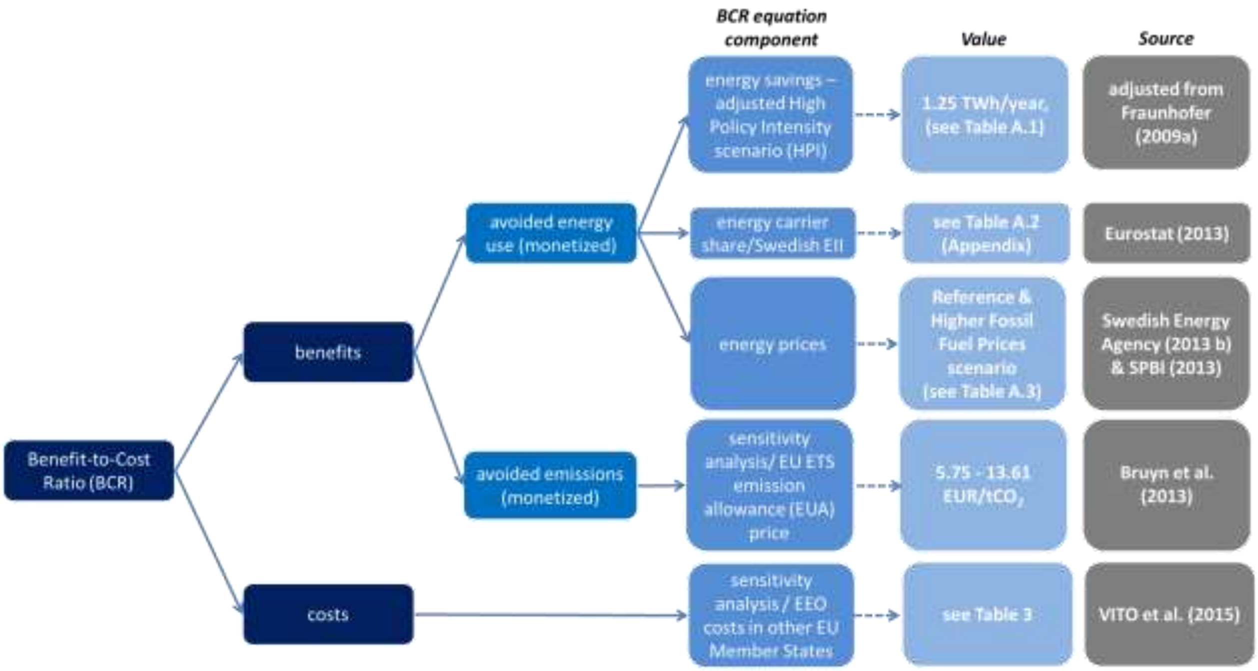

Figure 2: Cost-Benefit Analysis (CBA) for EEO implementation in Sweden – components and values used for calculations
Sources: Bruyn et al. 2013; Eurostat 2013; Fraunhofer ISI et al. 2009a; SPBI 2013; Swedish Energy Agency 2013b; VITO et al. 2015

4. Results and Discussion

The engagement of industrial actors is vital for the success of any scheme designed to improve energy efficiency, and to achieve the targets stipulated by the EED. Implementing an EEO in Sweden results in annual energy savings of 1.25 TWh, according to the adjusted secondary data in the High Policy Intensity (HPI) scenario of Fraunhofer ISI et al., (2009a). These energy savings lead to annual avoided carbon emissions of 0.29 Mt CO_{2eq}. The energy savings potential shown in this analysis indicates that the Swedish EIIs energy efficiency improvements would be able to cover more than one third of the energy savings target at national level (3 TWh/year). The benefits of the EEO result from the avoided energy costs and the purchases of emission allowances (EUAs) from the industries. These, in turn, are the result of the energy efficiency improvement, which leads to decreased energy use and CO_2 emissions in the industrial sectors considered in the analysis.

The avoided energy costs used in the CBA depend on energy prices in the future. Using Equation (1), the avoided energy and CO_2 emission costs range from 104 M€/year (eq. to 932 MSEK/year) to 106 M€/year (eq. to 952 MSEK/year) for the Reference scenario of energy prices, and from 106 M€/year (eq. to 950 MSEK/year) to 108 M€/year (eq. to 970 MSEK/year) for the Higher Fossil Fuel Prices scenario (see Table 4). The differences between the estimated energy prices in the two scenarios are not very large; therefore the interval of costs is relatively small.

The costs per MWh of energy saved are higher in an EEO than what has been observed within PFE. Thus the EEO is more costly than a voluntary agreement such as PFE. It should be noted that the level of energy savings achieved in the EEO and PFE is comparable for the EII, since the companies participating in PFE represent around 85% of the total energy consumption of the energy intensive sector (Stenqvist and Nilsson 2011).

The costs then range from 50 to 67 M€/year (eq. to 447 to 599 MSEK/year). The break-even cost ranges from 83.3€/MWh (eq. to 748 SEK/MWh) to 85.3€/MWh (eq. to 765 SEK/MWh) under the Reference scenario and from 85.0 €/MWh (eq. to 763 SEK/MWh) to 86.9 €/MWh(eq. to 779 SEK/MWh) under the Higher Fossil Fuel Prices scenario (see Table 4). These break-even costs exceed the actual costs observed in other countries (see Table 3). They are also around 8 times higher than the costs per MWh of energy savings observed in PFE.

Table 4: Benefit to Cost Ratio (BCR) and break-even costs of an EEO for Sweden with focus on the EII under different energy price scenarios provided from Swedish Energy Agency (2013)

CBA component	Reference Scenario	Higher Fossil Fuel Prices Scenario
Avoided Energy and CO_2 Emission costs M€ /year (eq. to MSEK/year)	**104-106 (932-952)**	**106-108 (950-970)**
Total costs of scheme M€/year (eq. to MSEK/year)	**50 – 67 (447 – 599)**	
BCR	**1.56 - 2.13**	**1.62 - 2.17**
Break-even cost of scheme in €/MWh (eq. to SEK/MWh)	**83.3-85.3 (748-765)**	**85.0 - 86.9 (763-779)**

In general, the scheme is cost-effective under the varying parameters assumed in this analysis (see Table 4). The BCRs range from 1.56 to 2.13 under the Reference energy price scenario and from 1.62 to 2.17 for the Higher Fossil Fuel Prices scenario. The BCRs are in line with previous studies done for other European EEOs. In fact, previous studies show that the ratio of the BCRs range from two (2) to six (6) (Mundaca & Neij 2009; Lees 2010; Bertoldi et al. 2010). The cost-effectiveness analysis from a national perspective for the French scheme in the period from 2006 to 2009 showed a BCR of 2.14 when excluding CO_2 emissions savings, and 2.60 when these savings were included in the calculation (Giraudet et al. 2012). As for this study, higher BCRs are expected when the analyses are performed ex-post and economy-wide, in comparison with the results of the present analysis, which focused specifically on EII and are based on an ex-ante analysis.

The sensitivity analysis of the BCRs indicates that the results are robust against shifts in future energy carrier prices, and more sensitive to variations in the costs of the scheme. However, since the costs as well as the benefits are based on the energy savings potential, there is an endogenous proportionality between the two variables used for calculating the BCR (see equation 1). Because of that, the weighting of the benefits against the costs of the scheme for different scenarios of energy savings potential (for example the LPI and Technical scenario that were mentioned in Section 3) would have the same results as for the HPI scenario. The absolute effect in terms of benefits and costs is obviously different and this should always be considered when evaluating policies with the CBA methodology.

For the purpose of the analysis, it was assumed that the whole energy savings potential is reached under the HPI scenario. However, it should be noted that the ex-ante calculated energy savings potential does not necessarily equal the energy savings that are actually achieved (Giraudet et al. 2012; Thollander et al. 2013). Externalities such as information asymmetry or regulatory failures may cause the energy savings to be lower than the estimated values (Giraudet et al. 2012). In an ex-ante policy evaluation, the expected effects of the EEO are estimated based on the achievable energy savings potential. In contrast, ex-post evaluation analyzes the real effects of the scheme. The ex-ante projections should be compared with ex-post measurements after the policy instrument is introduced. In this way, a rate of realization of the actual energy savings in relation to the potential identified can determine the rate of success of the scheme once audits have been performed (Kaufman and Palmer 2011).

Our method for assessing a potential Swedish EEO differs from the initial evaluations from the Swedish Energy Agency (2012a) because of two reasons. First, the evaluation of benefits is an integral part of the assessment, not only the costs. Second, we focused on the industrial sector as opposed to a wider EEO implementation. The basic argument against the EEO was the understanding that sufficient instruments exist in Sweden for addressing energy efficiency improvement. However, without the PFE, the situation is different. An EEO might be now an alternative for motivating energy efficiency improvement by the industry. The first report of the Energy Agency on EEO did not include the benefits, but estimated the costs on a similar basis as this study, i.e. based on experience from other countries that have implemented the scheme. In a more recent report by the Energy Agency, the potential of an EEO is put again in discussion and the benefits and costs of such a scheme aimed at the industrial sector are now discussed based on indicative estimations from Sweco (2014) and Xylia (2013).

Moreover, recent discussion addresses the fact that most of the "low-hanging fruits" in the residential sector have already been implemented due to other existing EU legislation (Bertoldi et al. 2015). That being said, the focus of the EEOs might shift in the future from the residential sector, as has been the case with earlier implementation in other countries, to the industrial sector where higher cost measures with longer and higher energy savings impact can be obtained. This observation makes the current evaluation of an "industry-focused" EEO for Sweden even more relevant for future decisions on the introduction of new policy instruments, especially taking into account the large share of the EII in the total final energy consumption of the country.

The implications of an EEO are numerous, and the scheme is likely to affect all stakeholders of the energy market, i.e. the obligated actors and the end-users of energy. The industry's perception of an EEO relates to doubts on the effects that a possible pass-through of the EEO costs to all end-user sectors including the industry might have on the sector's competitiveness. Meanwhile, despite concerns among industries, new policy schemes for fostering energy efficiency are not necessarily viewed with skepticism. There is interest in the implementation of energy savings at the systems level, incentivized through a certificate scheme, e.g. for increased use of waste heat for district heating, among other services (Jernkontoret 2014). In fact, third party access (TPA) of industries to the monopolized district heating market is seen as a vital step for Sweden to achieve the energy efficiency improvements needed for reaching the EU2020 goals (Thollander et al. 2013). TPA can be an opportunity within an EEO which can alleviate the high upfront costs of investments for energy savings measures, a major barrier to energy efficiency in the industrial sector.

The investments of EII in energy efficiency improvements represent the largest share of the costs of the scheme. Hence, a decisive factor for achieving energy efficiency improvements in the Swedish industrial sector is the general investment climate and the business environment. There are concerns from the industry that investments may be redirected to outside Sweden, if the investment climate inside the country is not attractive, and if operating conditions compromise profitability.

On the other hand, it could be argued that energy efficiency can greatly enhance industrial productivity. Instead of perceiving energy savings a "side-effect" of other investments, they should be seen as a "*central value generating proposition*" (IEA 2014) and its multiple associated benefits should also be taken into account (e.g. enhanced competitiveness, production and product quality, improved work environment, reduced costs of operation and maintenance). According to the IEA (2014), *"the value of* *the productivity and operational benefits derived can be up to 2.5 times (250%) the value of energy savings (depending on the value and context of the investment)"*, which can greatly reduce payback time for investments. A good economic policy with a long-term vision needs to be put in place by Swedish political authorities in order to facilitate investments in the industrial sector (IVA 2013). This can be achieved with long-term payback policies and public and private loans for large investments. The industries have indicated that secure supply of energy at competitive prices is one important factor in this context.

The experiences of Member States that have implemented EEOs indicate that investment costs to improve energy efficiency measures have generally short payback periods (Lees 2012; Bundgaard et al. 2013). The Danish EEO was particularly successful among companies within the industrial sector. The reasons for the Danish success are the specific instruments that are used for encouraging energy savings in the industries. These instruments are mainly consultant services offered to industries serving as third parties in the EEO, and subsidies given per kWh saved for various energy efficiency measures. The Danish actors involved in the EEO consider industrial energy savings an attractive option since they result in large energy savings at relatively low administration costs (Bundgaard et al. 2013). Furthermore, the general evaluation of the Danish EEO in 2012 shows that the energy savings in the industrial sector are a cost-effective measure. It also states that the obligated actors are most likely to target industries as potential third parties for achieving their targets within the obligation as it is the most cost-effective option for improving energy efficiency (Bundgaard et al. 2013).

Many investments made by the Swedish EII within the scope of PFE also had short payback periods of approximately 1.5 years (Swedish Energy Agency 2012a). Moreover, the costs of energy savings measures are likely to decrease over time as a result of learning curves and economies of scale achieved with increasing market penetration of energy efficiency measures and technologies (Lees 2012).

Voluntary agreements, such as PFE, served well to motivate the industrial sector towards energy savings. However, the impact of a voluntary program like PFE in the long-term has not been investigated fully and there is no proof that the intensity of energy savings would be maintained once the "low-hanging" fruits gathered under the voluntary agreement have been picked. Thus, a more forceful policy, such as an EEO, may be justified, and help Sweden achieve energy savings and EU targets faster. The difference between PFE and EEO lies in the fact that an EEO is not strictly regulated by the government, but rather left to the market. It allows for the most cost-efficient measures to be picked first according to market preferences and opportunities. Including all energy carriers in the scheme, in contrast to the electricity focus of PFE, ensures higher potential savings of energy and higher flexibility for the industries to implement measures. However, for the EEO to be effective and significant energy efficiency improvement to be achieved, clearly defined eligibility criteria for energy savings measures are needed, as well as thorough monitoring and verification of savings obtained from different measures. This is an important role that the regulator of the scheme has to play. Identifying best practices from existing EEOs internationally would be beneficial for that purpose.

The costs of a voluntary agreement such as PFE are lower compared to an EEO. Voluntary agreements are more straightforward to implement, thus requiring lower administration costs than EEOs (Transue and Felder 2010). The participation of a relatively small number of energy intensive industries and the exclusive focus on electricity savings could have been a factor keeping the costs of the scheme low. In comparison to a potential EEO, fewer actors were involved in PFE, thus potentially reducing transaction costs.

In the scheme proposed in this study, the EEO targets industries that are part of the EU ETS, without considering these energy savings as eligible allowances in the ETS. There is no legal restriction for including industries that are part of the EU ETS in an EEO, as long as double-counting of the effects of the measures is avoided. The interaction between EEO and EU ETS depends on the design of the scheme and the main focus of the EEO in each country. In fact, both Denmark and France include savings from EU ETS sectors in the eligible savings under the EEO. As mentioned previously, Denmark has particularly targeted the industrial sector with the EEO. In 2013, 44.4% of the total energy savings under the EEO was attributed to the industrial sector. The energy savings in the Danish EEO are weighted per the lifetime of savings, impact on primary energy consumption and expected CO_2 impact (VITO et al. 2015). In contrast to that, the UK EEO that targets the residential sector has minimal interactions with the EU ETS.

The EED affects the EU ETS as EUAs are freed due to reduced energy demand. The magnitude of these effects depends on the energy mix of each country or even sector. In the case of the Swedish EEI for example, the share of fossil fuels in the energy mix is rather low (ca. 25% - see Table A.2 in the Appendix). Hence, in our analysis, the sensitivity of the benefit values to changes of the EUA price is low and including the avoided CO_2 costs only slightly increases the total avoided costs. This can be explained by the low EUA prices observed in the EU ETS. In addition, the low emission factor of Swedish electricity generation further reduces the emission contribution related to electricity use. The combination of low emission allowance price with low carbon electricity in Sweden results in lack of drivers for further energy savings and CO_2 emission reduction measures. Furthermore, exogenous impact to the EU ETS from the EED is small in relation to endogenous impacts that affect the EU ETS, such as the inclusion of international carbon credits or regulations at Member State level (e.g. carbon taxation) or the impact of the economic recession (Altmann et al. 2013).

The conflicts between the EED and EU ETS can be amplified if the EU ETS adopts a more flexible design of the emissions cap in the long-term, which would require changes in the ETS Directive. On the other hand, the EED could also be reformulated so as to completely exclude EU ETS sectors (Altmann et al. 2013). However, this would exclude the large energy savings potential from the industries that are part of the EU ETS, therefore eliminating opportunities above the “low-hanging” fruits, as previously discussed. Another option would be to actually translate energy efficiency improvement into emissions reduction, which would require the introduction of conversion factors and ex-ante estimation of the energy savings potential, in a similar manner as in this study, but to a much wider level. This could lead to increased administration costs though. The upcoming review of the EED (currently under public consultation) might provide some direction towards a solution to the potential overlappings with the EU ETS.

Combining an EEO with alternative policy instruments is not an option that should be excluded from discussion. On the contrary, the example of France combining the EEO with tax rebates in order to address higher cost measures was positive (Bertoldi et al. 2015). On the other hand, previous studies have shown that the combination of taxation with EEO might have negative effects (V. Oikonomou et al. 2010). Therefore, in the case of Sweden that has chosen taxation as the main policy instrument for energy savings but is considering the EEO option, the implications of interactions among policy instruments need to be evaluated.

5. Conclusions and policy implications

The requirements of the EED at EU level in combination with rising energy prices and stricter goals for GHG emissions reduction provide an incentive to look closer at the energy efficiency potential of the industrial sector, but also raise questions about the impact that policy instruments may have. In this paper, we chose CBA to estimate the benefits to costs for a potential Swedish EEO, focused on prospective energy efficiency improvements and savings among Swedish EII. The profitability of the scheme was expressed in Benefit-to-Cost Ratio (BCR). The annual savings potential for the EII are estimated to reach 1.25 TWh/year until 2020. Using two different scenarios for energy prices (Reference and Higher Fossil Fuel Prices scenario) provided by the Swedish Energy Agency (2013), we performed sensitivity analyses for the benefits and costs of the scheme, including varying ranges of EUAs (in the benefit component of the CBA) and program and investment costs of the scheme (in the cost component of the CBA). Since the analysis is ex-ante, we used the experience from other EU Member States that have implemented EEO for identifying the costs range in the sensitivity analysis, assuming that the costs for Sweden will be within similar levels.

The inclusion of the avoided costs for CO_2 emissions only slightly increases the benefits of the scheme due to the currently low EUA price. Certainly, benefits increase with higher EUA prices, but the emission caps need to be more stringent for the effect of avoided CO_2 emissions to be significant. The sensitivity analysis indicates that the results are robust against shifts in energy prices (affecting the benefits) and more sensitive to variations in the costs incurred with the scheme implementation.

The BCR ranges from 1.56 to 2.13 under the Reference scenario for energy prices and from 1.62 to 2.17 under the Higher Fossil Fuel Prices scenario for energy prices. The break-even cost ranges from 83.3 €/MWh (eq. to 748 SEK/MWh) to 85.3 €/MWh (eq. to 765 SEK/MWh) under the Reference scenario and from 85.0 €/MWh (eq. to 763 SEK/MWh) to 86.9 €/MWh (eq. to 779 SEK/MWh) under the Higher Fossil Fuel Prices scenario. These break-even costs are higher than the costs observed in other EU Member States so far, and also considerably higher than the costs of the voluntary energy efficiency improvement program (PFE) that was previously implemented in Sweden.

Although our findings show that an EEO is costly to implement in comparison to PFE, indications of higher energy prices for the Swedish industrial sector in the future justify the implementation of energy savings measures at a larger scale, as they result in high benefits within the scheme. However, the high upfront costs for investments in industrial energy efficiency should not be neglected, and finding ways to promote the investments will be important. Finally, a Swedish EEO could fill the gap for Sweden to reach the energy efficiency targets set in the EED.

Engaging the EII in a Swedish EEO is a cost-efficient way to reach the targets set on energy efficiency within the scope of the EED. The analysis showed that under a High Policy Intensity (HPI) scenario, the ex-ante energy savings from the EII represent around one third of the total energy savings required at national level. Wood and wood residues were included as part of this analysis, contrary to the current Swedish decision to exclude them as energy carriers from the transposition of Article 7 of the EED. Including wood and wood residues as energy carriers is important for maximizing the potential energy savings under the targets of the EED.

In the scope of this study, the investment costs have been estimated based on previous experience in other Member States. This can serve as an indication of the effects of a Swedish EEO, but more detailed validation of these values are certainly needed before a definite position can be given about the potential of EEO in Sweden . Nevertheless, our approach served to estimate the maximum costs that an EEO can have in order to break-even when the large benefits from energy efficiency improvements in the EII are accrued.

Due to the difference in estimation methods of the different Member States, as well as the structural differences of their industrial sectors, a bottom-up estimation of the Swedish investment costs would increase the reliability of the results. Additionally, an effort to quantify indirect benefits (e.g. economies of scale for energy efficient technologies, increased productivity, job creation) and costs (e.g. energy price increases for end-users as a cost recovery mechanism, cost to beneficiaries, social costs) of the scheme, and market externalities would be beneficial for providing a full assessment of the effects of the scheme.

This study suggests that the EEO as policy alternative for improving energy efficiency should be further investigated in Sweden. However, practically speaking, the introduction of an EEO at this moment cannot have dramatic impact to Sweden's goals for 2020. EEOs require several years from design until delivering significant energy savings, as experience from other EU Member States has shown (Bertoldi et al. 2015). Therefore, a potential implementation of an EEO in Sweden would bring more significant results if seen under a long-term horizon and with an eye towards the more ambitious energy and climate policy goals for 2030.

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References

Ackerman, F. (2008). *Critique of Cost-Benefit Analysis, and Alternative Approaches to Decision-Making* (Vol. 4). Medford: Friends of the Earth. http://www.ase.tufts.edu/gdae/Pubs/rp/Ack_UK_CBAcritique.pdf

Altmann, M., Zerhusen, J., Maio, P., Lanoix, J. C., Trucco, P., Egenhofer, C., et al. (2013). *Energy Efficiency and ETS* (No. IP/A/ITRE/ST/2012-11). http://onlinelibrary.wiley.com/doi/10.1002/cbdv.200490137/abstract

Bertoldi, P., Castellazzi, L., Spyridaki, N. A., & Fawcett, T. (2015). How is article 7 of the Energy Efficiency Directive being implemented ? An analysis of national energy efficiency obligation schemes. *ECEEE 2015 Summer Study proceedings*, 455–465.

Bertoldi, P., Labanca, N., Rezessy, S., Steuwer, S., & Oikonomou, V. (2013). Where to place the saving obligation: Energy end-users or suppliers? *Energy Policy*, *63*, 328–337. doi:10.1016/j.enpol.2013.07.134

Bertoldi, P., Rezessy, S., Lees, E., Baudry, P., Jeandel, A., & Labanca, N. (2010). Energy supplier obligations and white certificate schemes: Comparative analysis of experiences in the European Union. *Energy Policy*, *38*(3), 1455–1469. doi:10.1016/j.enpol.2009.11.027

Bruyn, S. De, Nelissen, D., & Koopman, M. (2013). *Carbon leakage and the future of the EU ETS market: Impact of recent developments in the EU ETS on the list of sectors deemed to be exposed to carbon leakage*. Delft: CE Delft.

Bundgaard, S. S., Dyhr-Mikkelsen, K., Larsen, A. E., & Togeby, M. (2013). Energy Efficiency Obligation Schemes in the EU - Lessons Learned from Denmark. *IAEE Energy Forum*, *2013*(3), 43–47.

Cellini, S. R., & Kee, J. E. (2010). Cost-effectiveness and Cost-benefit Analysis. In J. S. Wholey, H. P. Hatry, & K. E. Newcomer (Eds.), *Handbook of Practical Program Evaluation* (3rd ed., pp. 493–530). Hoboken, USA: Wiley:Jossey-Bass.

Clinch, J. P., & Healy, J. D. (2001). Cost-benefit analysis of domestic energy efficiency. *Energy Policy*, *29*(January 2000), 113–124.

ea Energy Analyses. (2014). *Best Practices in Designing and Implementing Energy Efficiency Obligation Schemes*. Copenhagen: ea Energy Analyses. http://www.ea-energianalyse.dk/reports/1436_best_practises_energy_efficiency_obligation_schemes.pdf

Ecorys, & ECN. (2012). *The Energy Efficiency Investment Potential for the Building Environment*. Rotterdam: Directorate General for Energy of the European Commission.

Energy EU. (2013). LPG and Heating oil prices. http://www.energy.eu/

European Commission. (1997). *Guide to Cost-Benefit Analysis of Major Projects*. Brussels, Belgium: European Commission.

European Commission. (2008). *Guide to cost-Benefit Analysis of investment projects*. Brussels, Belgium.

European Commission. (2010). *How to develop a Sustainable Energy Action Plan (SEAP) - Guidebook*. Luxembourg: Publications Office for the European Union.

European Commission. (2011). Impact Assessment Accompanying the document Directive of the European Parliament and of the Council on energy efficiency and amending and subsequently repealing Directives 2004/8/EC and 2006/32/EC. *Commission Staff Working Paper*. https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_0779_impact_assessment.pdf

European Commission. (2014). 2030 framework for climate and energy policies. http://ec.europa.eu/clima/policies/2030/index_en.htm

European Commission. (2015a). COMMISSION REGULATION (EU) No 176/2014 of 25 February 2014 amending Regulation (EU) No 1031/2010 in particular to determine the volumes of greenhouse gas emission allowances to be auctioned in 2013-20. Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0176&from=EN

European Commission. (2015b). DECISION (EU) 2015/1814 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 October 2015 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC. Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015D1814&from=EN

European Commission/Directorate-General for Regional and Urban policy. (2014). *Guide to Cost-benefit Analysis of Investment Projects*. Luxembourg: European Union Publications Office. http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

European Parliament. (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC. *Official Journal of the European Union EN L*, (October), 1–56.

Eurostat. (2013). Statistics Database/Energy statistics - supply, transformation, consumption. ttp://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

Eyre, N., Pavan, M., & Bodineau, L. (2009). Energy company obligations to save energy in Italy , the UK and France: what have we learnt? In *ECEEE 2009 Summer Study* (pp. 429–439). Stockholm,Sweden: eceee - European Council for an Energy Efficient Economy.

Fraunhofer ISI, ECOFYS, & Öko-Institut e.V. (2012). *Cost / benefit analysis of the introduction of market-oriented instruments for realizing final energy savings in Germany: Final report to the Federal Ministry of Economics and Technology - Executive Summary*. Karlsruhe, Freiburg, Berlin: Fraunhofer ISI.

Fraunhofer ISI, ENERDATA, ISIS, Technical University of Vienna, & Wuppertal Institute for Climate Environment and Energy. (2009a). Database on Energy Saving Potentials. http://www.eepotential.eu/esd.php

Fraunhofer ISI, ENERDATA, ISIS, Technical University of Vienna, & Wuppertal Institute for Climate

Environment and Energy. (2009b). *Study on the Energy Savings Potentials in EU Mem-ber States , Candidate Countries and EEA Countries*. Karlsruhe/Grenoble/Rome/Vienna/Wuppertal: Fraunhofer ISI. https://ec.europa.eu/energy/sites/ener/files/documents/2009_03_15_esd_efficiency_potentials_final_report.pdf

Fraunhofer ISI, TU Vienna, & PwC. (2014). *Study evaluating the current energy efficiency policy framework in the EU and providing orientation on policy options for realising the cost-effective energyefficiency/ saving potential until 2020 and beyond*. Karlsruhe/Vienna/Rome: Report on behalf of DG ENER. https://ec.europa.eu/energy/sites/ener/files/documents/2014_report_2020-2030_eu_policy_framework.pdf

Gillingham, K., Newell, R., & Palmer, K. (2006). Energy Efficiency Policies: A Retrospective Examination. *Annual Review of Environment and Resources*, *31*(1), 161–192. doi:10.1146/annurev.energy.31.020105.100157

Giraudet, L. G., Bodineau, L., & Finon, D. (2012). The costs and benefits of white certificates schemes. *Energy Efficiency*, *5*(2), 179–199. doi:10.1007/s12053-011-9134-6

Giraudet, L.-G., & Finon, D. (2015). European experiences with white certificate obligations: A critical review of existing evaluations. *Pre-print, Economics of Energy & Environmental Policy*. https://hal.archives-ouvertes.fr/hal-01016110

Glachant, M. (1999). The Cost Efficiency of Voluntary Agreements for Regulating Industrial Pollution: A Coasean Approach. In C. Carraro & F. Lévêque (Eds.), *Voluntary Approaches in Environmental Policy SE - 5* (Vol. 14, pp. 75–89). Springer Netherlands. doi:10.1007/978-94-015-9311-3_5

Hirst, E., & Brown, M. (1990). Closing the efficiency gap: barriers to the efficient use of energy. *Resources, Conservation and Recycling*, *3*(4), 267–281. doi:10.1016/0921-3449(90)90023-W

IEA. (2014). *Capturing the Multiple Benefits of Energy Efficiency*. Paris: International Energy Agency.

Intercontinental Exchange. (2016). EUA 2013-2016. *EUA FUTURES*. https://www.theice.com/homepage.jhtml. Accessed 9 February 2016

IVA. (2013). *Energieffektivisering av Sveriges Industri - Hinder och möjligheter att nå en halverad energianvändning till 2050*. Stockholm: Kungl. Ingenjörsvetenskapsakademien (IVA). http://www.iva.se/Documents/Publikationer/Projekt/201308-IVA-Energieffektivisering-rapport3-H.pdf

Jernkontoret. (2014). Energi- och energiförsörjning. http://www.jernkontoret.se/energi_och_miljo/energi_energiforsorjning/index.php

Joshi, B. (2012). *Best Practices in Designing and Implementing Energy Efficiency Obligation Schemes*. Stockholm: Regulatory Assistance Project (RAP), IEA DSM Secretariat. http://www.ieadsm.org/Files/AdminUpload/(1)RAP_IEADSM Best Practices in Designing and Implementing Energy Efficiency Obligation Schemes 2012 June(6).pdf

Kaufman, N., & Palmer, K. L. (2011). Energy efficiency program evaluations: opportunities for learning and inputs to incentive mechanisms. *Energy Efficiency*, *5*(2), 243–268. doi:10.1007/s12053-011-9130-x

Lees, E. (2010). *European and South American Experience of White Certificates*. Paris: World EnergyCouncil-ADEME.

Lees, E. (2012). *Energy efficiency obligations – the EU experience*. Stockholm: ECEEE-European Council for an energy efficienct economy.

Mansikkasalo, A., Michanek, G., & Söderholm, P. (2011). *Industrins energieffektivisering - styrmedlens effekter och interaktion*. Stockholm: Naturvårdsverket.

Mantzos, L., & Capros, P. (2006). *European Energy and Transport Trends to 2030 – update 2005*. Luxembourg: Office for Official Publications of the European Communities.

Mikkelsen, K. M. (2012). *Why obligation schemes are the solution for European Member States during the financial crisis*. Copenhagen: Danish Energy Association. http://www.danishenergyassociation.com/EU.aspx

Ministry of Enterprise Energy and Communications. (2013). *Plan for implementation of Article 7 of the Energy Efficiency Directive*. Stockholm, Sweden.

Mundaca, L., & Neij, L. (2009). A multi-criteria evaluation framework for tradable white certificate schemes. *Energy Policy*, *37*(11), 4557–4573. doi:10.1016/j.enpol.2009.06.011

Oikonomou, V., Flamos, A., & Grafakos, S. (2010). Is blending of energy and climate policy instruments always desirable? *Energy Policy*, *38*(8), 4186–4195. doi:10.1016/j.enpol.2010.03.046

Oikonomou, V., Rietbergen, M., & Patel, M. (2007). An ex-ante evaluation of a White Certificates scheme in The Netherlands: A case study for the household sector. *Energy Policy*, *35*(2), 1147–1163. doi:10.1016/j.enpol.2006.02.017

Pearce, D., Atkinson, G., & Mourato, S. (2006). *Cost-Benefit Analysis and the Environment: Recent developments*. Paris: OECD Publishing.

Rosenow, J., Platt, R., & Flanagan, B. (2013). Fuel poverty and energy efficiency obligations - A critical assessment of the supplier obligation in the UK. *Energy Policy*, *62*, 1194–1203. doi:10.1016/j.enpol.2013.07.103

SPBI. (2013). Statistik/Skatter årsvis. http://spbi.se/statistik/skatter/

Stenqvist, C., & Nilsson, L. J. (2011). Energy efficiency in energy-intensive industries—an evaluation of the Swedish voluntary agreement PFE. *Energy Efficiency*, *5*(2), 225–241. doi:10.1007/s12053-011-9131-9

Suerkemper, F., Thomas, S., Osso, D., & Baudry, P. (2011). Cost-effectiveness of energy efficiency programmes—evaluating the impacts of a regional programme in France. *Energy Efficiency*, *5*(1), 121–135. doi:10.1007/s12053-011-9112-z

Sweco. (2014). *Kvantitativ utvärdering av marknadsmisslyckanden och hinder. En rapport till Näringsdepartementet 19 december 2014*. Stockholm: Sweco.

Swedish Energy Agency. (2010). *Energiläget (The Energy Situation)*. Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2012a). *Konsekvenser av kvotplikt för energieffektivisering* (No. ER 2012:07). Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2012b). *Energiläget i siffror 2012*. Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2012c). *Energy Efficiency Policies and Measures in Sweden*. Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2012d). *Energiläget 2012*. Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2013a). *Energiläget 2013*. Eskilstuna: Statens Energimyndigheten.

Swedish Energy Agency. (2013b). *Långsiktsprognos 2012*. Eskilstuna: Statens Energimyndigheten.

Swedish National Audit Office. (2013). *Energy efficiency in industry - effects of central government action (RiR 2013:8) (Executive Summary)*. Stockholm: Riksrevisionen.

Thollander, P., & Ottosson, M. (2010). Energy management practices in Swedish energy-intensive industries Energy management practices in Swedish energy-intensive industries. *Journal of Cleaner Production*, (18), 1125–1133.

Thollander, P., Rohdin, P., Moshfegh, B., Karlsson, M., Söderström, M., & Trygg, L. (2013). Energy in Swedish industry 2020 – current status, policy instruments, and policy implications. *Journal of Cleaner Production*, *51*, 109–117. doi:10.1016/j.jclepro.2013.01.021

Togeby, M., Dyhr-Mikkelsen, K., Larsen, A. E., & Bach, P. (2012). A Danish case: Portfolio evaluation and its impact on energy efficiency policy. *Energy Efficiency*, *5*(1), 37–49. doi:10.1007/s12053-011-9117-7

Tol, R. S. J. (2012). A cost–benefit analysis of the EU 20/20/2020 package. *Energy Policy*, *49*, 288–295. doi:10.1016/j.enpol.2012.06.018

Transue, M., & Felder, F. a. (2010). Comparison of energy efficiency incentive programs: Rebates and white certificates. *Utilities Policy*, *18*(2), 103–111. doi:10.1016/j.jup.2009.12.003

U.S. Environmental Protection Agency. (2008). *Understanding Cost-Effectiveness of Energy Effi ciency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers*. Washington D.C.: U.S. Environmental Protection Agency. http://www.epa.gov/cleanenergy/documents/suca/cost-effectiveness.pdf

VITO, University of Oxford, Italian Federation for Rational Use of Energy, Agency, P. N. E. C., Danish Energy Association, & French Environment and Energy Management Agancy. (2015). *Energy Saving Policies and Energy Efficiency Obligation Scheme*. Joint Implementation Network - JIN Work. http://enspol.eu/sites/default/files/results/D2.1.1 Report on existing and planned EEOs in the EU - Part I Evaluation of existing schemes.pdf

Xylia, M. (2013). *Cost-effectiveness assessment of energy efficiency obligation schemes - implications for Swedish industries*. KTH - Royal Institute of Technology.

Appendix A

Table A.1: Corrected average annual potential energy savings (TWh/year) under the HPI scenario for the EII of Sweden based on secondary data from Eurostat (2013) and Fraunhofer ISI et al. (2009b)

Industrial sector	Average annual energy savings potential 2013 – 2020 (TWh/year)
Iron and Steel	0.10
Non-ferrous metals	0.02
Chemicals	0.04
Non-metallic mineral products	0.02
Pulp and paper	1.07
Total	**1.25**

Table A.2: Average share of investigated energy carriers in total energy usage of the Swedish EII for the years 2002-2011 (Eurostat 2013)

Energy Carrier	Average Share in total energy use for 2002-2011 (%)
Residual Fuel Oil 1	0.99%
Residual Fuel Oil 2-5	6.45%
Coal	11.9%
Natural Gas	2.14%
Electricity	35.0%
LPG	3.10%
Wood and wood residues	36.2%
Total	95.9%

Table A.3: Average fuel prices for the years 2010-2020 for two different price development scenarios (SPBI 2013; Swedish Energy Agency 2013b)

Energy Carrier	Reference fuel prices scenario €/kWh(SEK/kWh)	Price change 2010 and 2020 (%)	Higher fossil fuel prices scenario €/kWh(SEK/kWh)	Price change 2010 and 2020 (%)
Residual Fuel Oil 1	0.06(0.56)	33	0.08(0.70)	33
Residual Fuel Oil 2-5	0.04(0.39)	25	0.05(0.47)	26
Coal	0.02(0.17)	-2	0.02(0.18)	-2
Natural Gas	0.03(0.34)	27	0.04(0.41)	30
Electricity	0.05(0.44)	41	0.05(0.46)	44
LPG	0.11(0.98)	27	0.11(1.01)	30
Wood and wood residues	0.15(1.35)	34	0.15(1.35)	34

Table A.4: Standard CO_2 emission factors (European Commission 2010)

Type of energy carrier	Standard Emission factor (t CO_2/MWh)
Coal	0.354
Natural Gas	0.202
Electricity (for Sweden)	0.023
LPG	0.267
Residual fuel oil (fuel oil No. 1-5)	0.279
Wood and wood residues	0.403