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Quantifying the extended energy efficiency gap

- evidence from Swedish electricity-intensive industries

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Abstract

Energy efficiency is one of the major means of reducing CO_2 emissions resulting from industrial use of energy. Both from a societal as well as business perspective it is of great importance to reduce industrial energy end use (EEU). The implementation of energy-efficient technologies as well as increased focus on energy management practices has been stated by previous research to be the two most important methods of improved industrial energy efficiency. To date, however, there are few (if any) studies that have analyzed the proportion of industrial energy savings that derive from implementation of new technology versus from continuous energy management practices. By analyzing substantial data from the Swedish PFE program this paper aims to quantify what previously has been referred to as the extended energy efficiency gap. Results show that about 61% of the analyzed 1,254 energy efficiency measures are derived from the implementation of new technology, and the rest stems from management and operational measures. The results presented in this paper are of outmost importance for industrial energy managers and energy auditors as well as industrial associations and policy-makers in order to cost-effectively address these no-regret measures.

Keywords: Energy management; energy efficiency gap; extended energy efficiency gap; PFE; energy efficiency measures

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1. Introduction

Improved industrial energy efficiency is becoming increasingly important, from the point of view of environment, public economy and business. Improved energy efficiency is considered to be one of the most promising means to reduce CO_2 emissions resulting from the use of fossil fuels (IPCC, 2014) as well as having direct economic benefits such as increased competitiveness and higher productivity (Worrell et al., 2003; Hirst & Brown, 1990). It is especially relevant for many companies in mature and energy-intensive industries that face energy costs often well over 30% of total production costs and need to prioritize energy efficiency in order to stay competitive in the future.

Despite the existence of cost-effective energy efficiency technologies on the market these are not always implemented due to various barriers to energy efficiency such

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as split incentives, principal-agent relationship, and information imperfections and asymmetries (Jaffe & Stavins, 1994a). The discrepancy between the optimal level of energy efficiency, assuming rational decision-making, and the actual level of energy efficiency has been referred to by Hirst & Brown (1990) and Jaffe & Stavins (1994a) as the energy efficiency gap or the energy paradox. In order to overcome the gap and improve energy efficiency in industry, governments have instituted different public policies and supporting schemes. In such policies the diffusion of more energy-efficient technologies has gained a great deal of attention (for example, energy labeling schemes and the European Eco-Design Directive) (EU, 2009). Recent research (Backlund et al., 2012b) has shown, however, that solely focusing on the implementation of new and more energy-efficient technologies is not enough to reap the full potential for improved energy efficiency. Backlund et al. (2012b) argue that it can be problematic to reach the full potential for improved energy efficiency by only concentrating on changing to more efficient technical equipment and omitting other important aspects such as continuous monitoring and maintenance, which constitute energy management practices. Moreover, since energy management practice is "less capital intensive and rather requires knowledge, attention and awareness" they can increase the knowledge about where energy is used at a company and how it can be saved (Backlund et al., 2012b). Knowing where energy is used in industry and where the improvement potential can be found can further facilitate investments in energy efficiency. Some work has been done by Fleiter et al. (2012) and Trianni et al. (2014), but there is a need to develop a common classification scheme for energy efficiency measures (EEMs).

By combining investments in more energy-efficient technology with continuous energy management practices, companies have the potential to bridge what has previously been termed the extended energy efficiency gap (Backlund et al., 2012b). Some attempts have been made to quantify the magnitude of energy efficiency improvements that go beyond the classical technology diffusion model, or in other words, what proportion of industrial energy savings derives from implementation of new technology versus from continuous energy management practices. In one sector, the shipping industry, energy management practices hold an important position in terms of energy efficiency potential (Johnson, H., 2014). Caffall (1995) in a number of international case studies stated that half of the energy efficiency improvements were found in management and half in technology. Recently, research in Swedish industry found the estimated potential from technology for non-energy intensive companies to be 20% and from energy management practices –13% (Backlund et al., 2012a). For energy-intensive industries, the energy efficiency potential from technology is 5% which is slightly lower than potential from energy management practices, which is 6% (Backlund et al. (2012a). Brunke et al. (2014) also studied the Swedish steel industry and asked them to rank the potential for energy efficiency emanating from energy management practices and found that about 25% of the potential was from energy management. It should be noted that different parameters have been studied in the different studies above, explaining in part the differences in energy management potential. In summary, it is apparent that previous research has found that there is additional potential apart from solely technology diffusion, and moreover that this potential is in the range of 25-50% of the full energy efficiency potential depending on the sector studied.

So far however, no study has studied real measures from a full national industrial energy policy program with the aim of quantifying the size of the energy management gap. By means of analyzing substantial data from the Swedish industrial energy program called the Program for Improving Energy Efficiency in Energy Intensive Industries (PFE), this paper aims to quantify the magnitude of energy efficiency improvements within Swedish energy-intensive industry that goes beyond the diffusion of technology model. The paper contributes to the classical diffusion of technology model and leads to an improved understanding of industrial energy efficiency deployment. The paper provides evidence of significant importance to the research community, companies (managers and auditors) and policy-makers.

This paper is organized as follows. The paper begins with an introduction and continues with a theoretical overview of the research field. The subsequent section presents the Swedish energy-intensive industries, followed by a method chapter, and then a result chapter. Finally, the paper ends with a concluding discussion.

2. Potential for improved energy efficiency

The objective with this section is to present a review of previous research on improving energy efficiency in industry, related to the scope of this study. As stated by Jaffe & Stavins (1994a), improved energy efficiency is not a primary aim for EEMs. It is a means to efficient allocation of, in this case, energy resources. This explains why an economic approach is common for estimating the potential for improved energy efficiency as well as for outlining public policies for improved energy efficiency. Public intervention in a market economy is primarily used in order to tackle market failures and imperfections.

Depending on how market barriers and imperfections that hinder investments in more energy-efficient technologies are viewed, the outline of public intervention to tackle these barriers and imperfections will be affected (Jaffe & Stavins, 1994a; Hirst & Brown, 1990). Firstly, public policies can be oriented to tackling only market failures (DeCanio, 1998). Market failures are those market barriers that arise from violation of the characteristics intrinsic to a perfect market and perfect competition: unlimited number of buyers and sellers, perfect information about prices and assets, zero transaction costs, absence of externalities, and homogenous products (Pihl, 2007). The market failures related to improved energy efficiency are mainly imperfect and asymmetric information in the form of principal-agent problems, split incentives and adverse selection, as well as imperfect competition and incomplete markets.

Secondly, there are also market barriers that do not belong to the category of market failures and thus cannot be solved by public policy intervention using the abovementioned theoretical basis (e.g. barriers related to behavior of energy users and explained, for example, by hidden costs and uncertainties about future energy prices) (Jaffe & Stavins, 1994a; Sorrell, 2004). Hidden costs are represented by the full spectrum of costs related to a particular energy-efficient measure that often can be neglected (Ostertag, 1999; Sorrell, 2000). These costs can be categorized into the costs related to the investment in the energy-efficient option, the overhead costs of consequent energy management procedures, as well as the costs for the lost benefits due to implementation of the energy-efficient option (Nichols, 1994). Thus, the examples of hidden costs are all the costs ranging from looking for information about an energy-efficient option, costs related to installation, connection, rebuilding, monitoring, production interruptions, and even the costs of staff needed to perform maintenance activities connected to the new energy efficiency option.

Thirdly, there can be one more category of market failures that do not cause the energy paradox but can be tackled by public policy intervention anyway (pricing by average cost instead of marginal, environmental externalities) (Jaffe & Stavins, 1994a).

Depending on the barriers, the potential for improved energy efficiency can be viewed differently. Jaffe & Stavins (1994a) distinguish between the economist's economic potential to energy efficiency which can be achieved by removing market failures and the technologist's economic potential which also includes elimination of various market barriers such as risk, uncertainties and environmental externalities (Figure 1). These also set the hypothetical potential for improved energy efficiency beyond these two which accounts for any "additional efficiency resulted from getting energy price right." To achieve the hypothetical potential the public policies should account for all the market barriers (Jaffe & Stavins, 1994a). Jaffe & Stavins (1994a) argue though that this can result in that the implementation costs of these policies may be too high to justify them. Thus, the narrow social optimum corresponds to removal of the barriers that pass a cost/benefit test while the true social optimum accounts for the environmental externalities as well. From all that is stated above, it can be concluded that the size of the energy efficiency gap thus depends on how the potential for improved energy efficiency is defined.

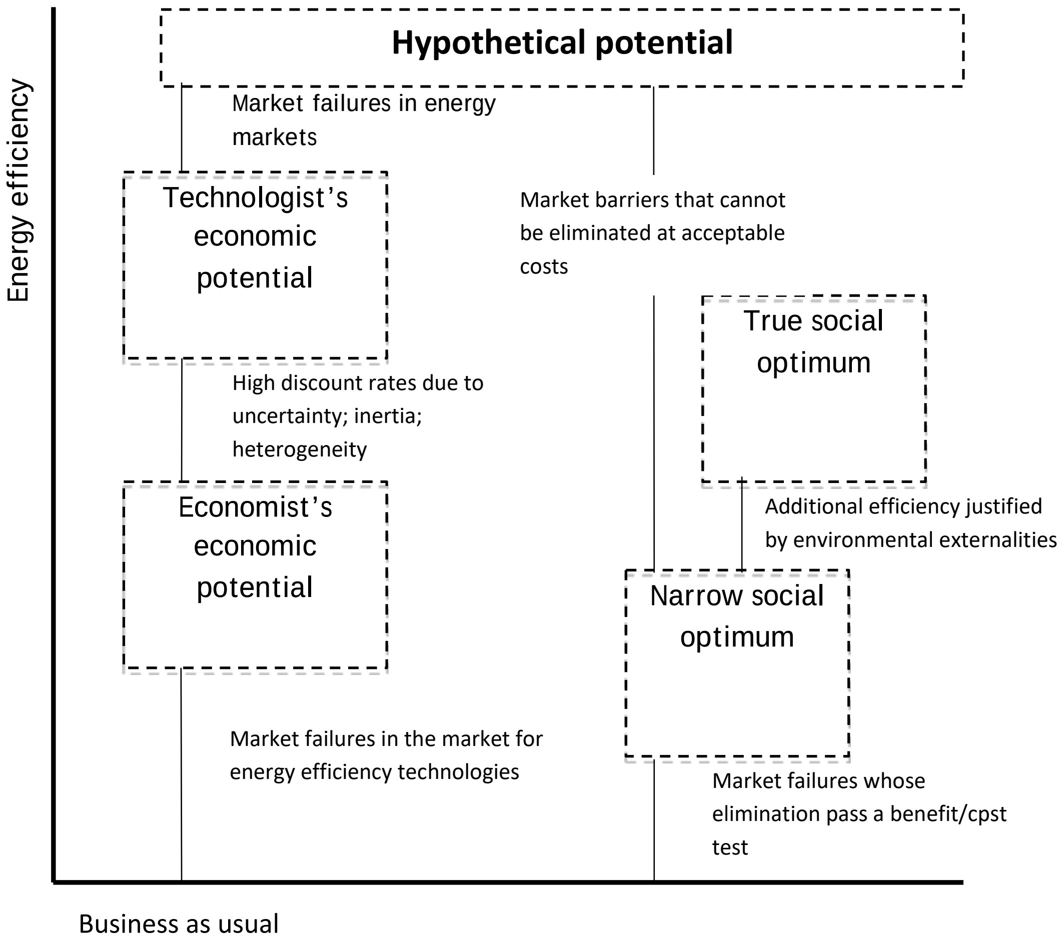

Figure 1. Different potentials for energy efficiency (revised from Jaffe & Stavins, 1994a).

Backlund et al. (2012b) argue that the technologist's economic potential sets the magnitude of the energy technology gap. Thus, only focusing on diffusion of more energy-efficient technologies and upgrading of equipment to best available technology (BAT) will not achieve the higher energy efficiency potential (the extended energy efficiency potential) which defines the *energy management gap*. In order to extend the potential for improved energy efficiency one has to remove not only barriers to the diffusion of energy-efficient technologies but also the barriers hindering energy management practices (Figure 2).

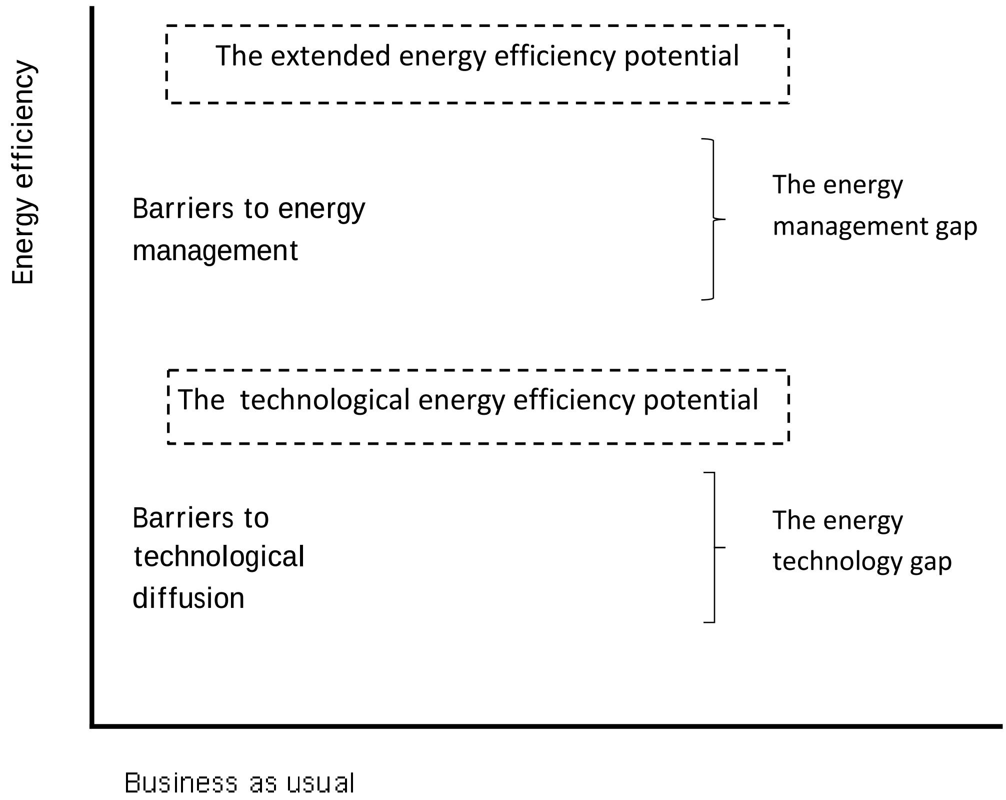

Figure 2. The extended energy efficiency gap (revised from Backlund et al., 2012b).

Energy management practices imply not only taking care of equipment but also continuous work in order to improve the overall energy efficiency level. This includes such main aspects as obtaining information about energy flows, defining the energy strategy, maintaining awareness among staff, and continuous improvement work (Abdelaziz et al., 2011; Caffal, 1995; Christoffersen et al., 2006; Gordic et al., 2010; Van Gorp, 2004; McKane et al., 2008; Worrell et al., 2003). Ottosson and Magnusson (2013) in their study of the Swedish pulp and paper industry mention increased staff knowledge of energy-related issues at industrial sites, as well as process innovation at the sites, and increased strategic focus on energy in the companies as benefits stemming from energy management. Since the focus has traditionally been on the diffusion of energy efficiency technologies, the level of diffusion of energy management practices has been shown to be quite low. For example, in the Danish case only 3-14% of the manufacturing companies with more than 19 employees perform energy management practices (mapping energy use, defining energy policy, quantifying goals, educating personal, etc.) (Christoffersen et al., 2006). In the Swedish case comprising energy-intensive industries (Thollander & Ottosson, 2010) the rate of energy management adoption was higher: 25-40% (for foundries and pulp and paper mills respectively). The studied parameters were pay-off criteria, long-term strategy, and allocation of energy costs. In another Swedish study Backlund et al. (2012a) showed that 75% of non-energy intensive and 30% of energy-intensive companies did not have a person working with energy issues, 50% of non-energy intensive and 33% of energy-intensive companies did not have an energy strategy, and 63% of non-energy intensive and 6% of energy-intensive companies did not allocate energy costs to the individual departments.

Backlund et al. (2012a) have tried to define the potential for improved energy efficiency in a study of energy-intensive and non-energy intensive companies. Non-energy intensive companies estimated the potential for improved energy efficiency from technology to be 20% and from energy management practices – 13%. For energy intensive industries, the energy efficiency potential from technology is 5% which is slightly lower than potential from energy managements practices which is 6%. It is worth noting that when considering both categories of companies together the technological and energy management potentials were estimated by the companies to be equal, or 6% (Backlund et al., 2012a).

3. Closing the energy efficiency gap by diffusion of energy-efficient technology

Improving energy efficiency by means of spreading energy-efficient technologies has as shown above historically been placed in focus. This is the basis for the EU's policy orientation, as an example. The measures mentioned in the EC's Action Plan for Energy Efficiency are, first, setting the energy performance requirements for different products, to improve generating capacity and to decrease transmission and distribution losses. Second, the action plan calls for international collaboration when it comes to such tradable goods as appliances. And third, it declares innovation and technology to be important aspects to achieve the set energy efficiency potential. It further promotes the Strategic Energy Technology Plan as an overview of "a coherent long-term energy technology" (EC, 2006).

It is stated in the Action Plan that in order to realize the potential for improved energy efficiency it is necessary to encourage the development of energy-efficient technologies and their uptake (EC, 2006). This can be done, for example, by means of such policies as VA, subventions, white certificates, certifications for promoting energy service markets (based on direct and indirect subsidies) that decrease the price of energy efficiency and consequently increase the demand for energy-efficient technologies (Backlund et al., 2012b). Thus, while there are many different policies to promote improved energy efficiency, the majority of these focus on the diffusion of new energy-efficient technologies. For example, awareness of improved energy efficiency can be raised by demonstrating new successful technologies, and international partnership can, in turn, be fostered by "bilateral and international trade and development policy, agreements, treaties and instruments (including dialogues) to promote the development and use of energy-efficient technologies and techniques" (EC, 2006).

In order to increase technologies' uptake on market, attention should be paid to the diffusion stages of energy efficiency technologies which generally represents an S-shaped curve (Jaffe & Stavins, 1994b). This implies that the diffusion is slow in the beginning due to lack of knowledge about a technology and its profitability, gaining speed after some time, and slowing down again due to saturation. This gradual diffusion can be explained by different market and non-market failures. For example, in the beginning of the technologies' diffusion process, governmental fossil fuel subsidies and high individual discount rates can slow down the process while obtaining information about technologies from the first movers accelerated further adoption. Jaffe & Stavins (1994b) provide a set of examples of governmental policies for particular market failures, for instance, policies such as information campaigns about a particular technology and product labeling to eliminate information barriers as well as governmental support for technological R&D (Jaffe & Stavins, 1994b). Figure 3 shows examples of how different factors can affect the adoption of technologies (Jaffe & Stavins, 1994b).

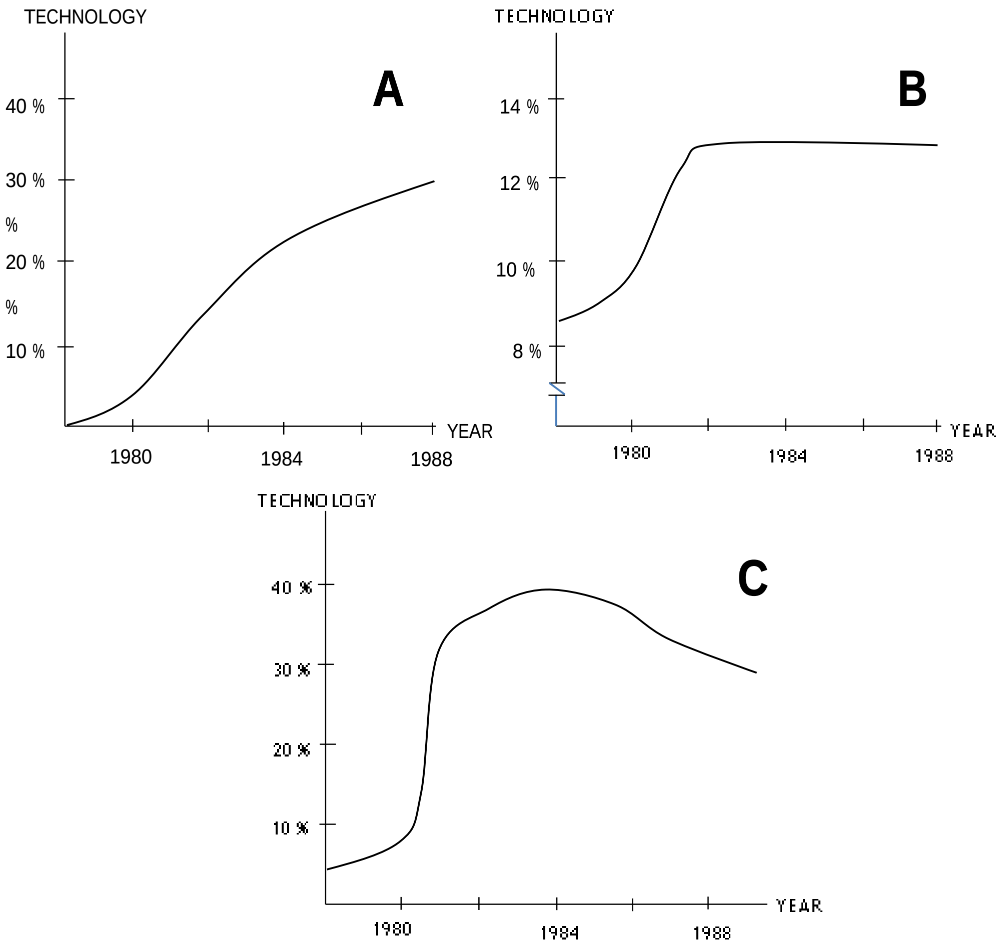

Figure 3. The effect of different factors on the diffusion of technologies for the U.S. households, y-axes represent diffusion of technology in % (revised from Jaffe & Stavins, 1994b).

A – The effect of improved energy efficiency on technological diffusion.
B – The effect of continually increasing subsidy on technological diffusion.
C – The effect of a one-time increase in regulatory stringency on technological diffusion.

The variations in the figure above show that improved technological diffusion also improves the level of energy efficiency. However, the effect of an investment subsidy for implementation shows an effect only in the first few years. Notably, Figure 3C shows the effect of a one-time change in an administrative policy (stricter regulation), and that this only has an effect on technology diffusion the first few years. After that, the effect of such a policy even decreases. The effect can be supported however if the subsidy is continually increased (Figure 3B). Thus, the energy paradox is discussed from the point of view of the distribution of energy efficiency technologies and the role of public policies in that.

4. Swedish energy-intensive industries

The Swedish industrial sector accounts for 144 TWh energy end-use (EEU) in 2011 (SEA, 2014). Biofuels and electricity dominate in the energy mix and fossil fuels comprise only 22% (Figure 4). According to the annual report of the Swedish Energy Agency, the use of oil increased insignificantly in 2010 after continuously decreasing. However, now there is a declining trend again due to the further substitution of biofuels (SEA, 2014).

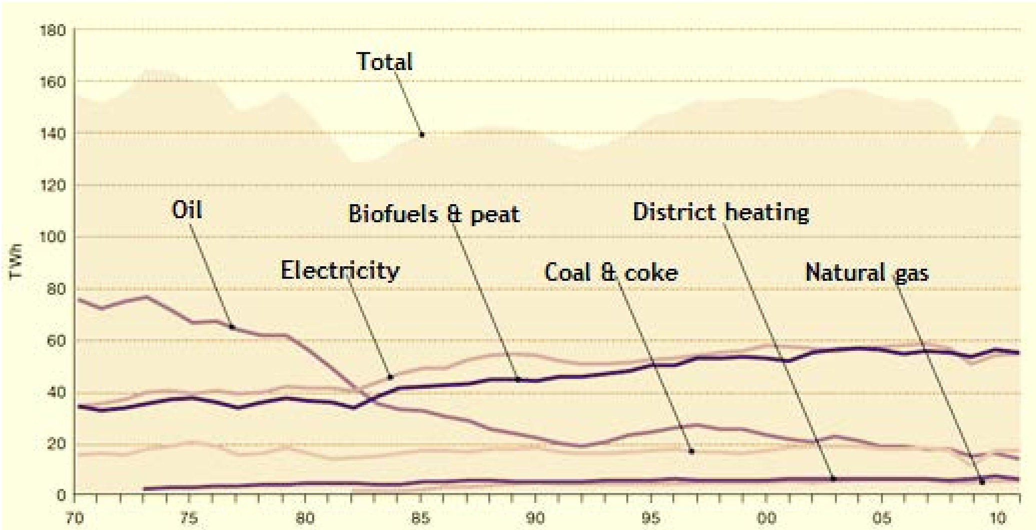

Figure 4. EEU in the industrial sector (revised from SEA, 2014).

Only 600 companies out of the total 59,000 (PWC, 2007) represent energy-intensive industries and thus 600 companies account for 77% of the EEU (SEA, 2014). These energy-intensive sectors are represented by the pulp and paper, iron and steel, chemical and wood products industries (Figure 5). A company is considered energy-intensive if their CO_2, energy and sulfur taxes are equal to or exceed 0.5% of the added value and if the costs of energy are equal to or exceed 3% of the production value (SFS, 2004).

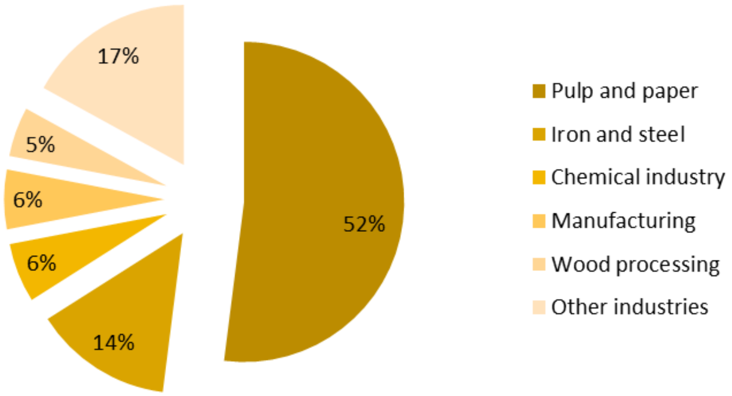

Figure 5. Industrial EEU by sector (revised from SEA, 2014).

Electricity is a major energy carrier for all of the abovementioned energy-intensive industries except for the wood products industry, which mainly uses biofuels (SEA, 2014).

5. Method

5.1. Description of the PFE

In order to quantify the potential for improved energy efficiency in the Swedish energy-intensive sector, the reported data from the PFE was used. The PFE is a policy measure for industrial EEU reduction in the form of a multi-year voluntary agreement (VA). The PFE was launched in 2005 providing the energy-intensive companies an exemption from the electricity tax (0.5 euro/MWh) provided that they introduce energy management systems (EnMS) and implement energy efficiency measures (EEM) at their sites, among other things. The requirements for the first two years of the program are to perform an energy audit in order to detect the measures for energy efficiency improvement as well as to introduce standardized EnMS (Swedish standard SS 627750, European standard EN 16001 or international standard ISO 50001). After that a company has to implement the measures with a payback time of less than three years (SEA, 2014). By participating in the program the companies also accept the requirement to introduce procedures for purchasing of energy-efficient equipment and procedures for energy planning (SEA, 2006). The main goal is to improve energy efficiency in the amount equal to the electricity tax that would have been paid otherwise during the program period. During the whole program period the companies should be working constantly with the EEM implementation, energy efficient procurement and planning which should be presented in a final report stating the total reduction of electrical consumption (SEA, 2005). The PFE was phased out in 2014.

5.2. The PFE database

Figure 6 presents the comparison between the companies which were eligible to participate in the PFE and the companies that actually applied for participation. The eligibility was determined by the energy intensity of the companies. It is obvious that the majority of participants has an electricity consumption of 200-1000 GWh/year. In total there were around one hundred participants.

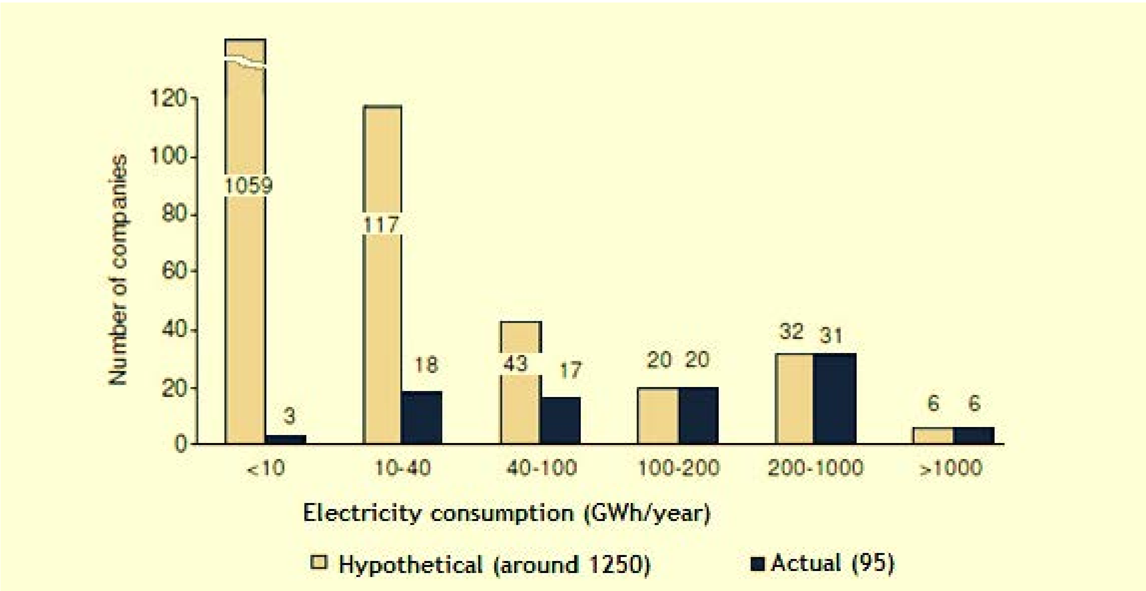

Figure 6. The companies eligible for participating in the PFE and actually participating (revised from Stenqvist & Nilsson, 2012)

The data was provided by the Swedish Energy Agency in the form of all the energy efficiency measures reported by the participants with their corresponding electricity savings in GWh/year, measures' payoff time, and the origin of the measures (how they were defined). The data correspond to the PFE's first period or in other words were collected through the companies' interim reports submitted after the second year and through the final reports. In total, the PFE's database consisted of 1,254 energy efficiency measures with corresponding electricity savings of 917 GWh/year. There were additional EEMs with electricity savings of 533 GWh/year reported by the Swedish Energy Agency separately for specific reasons and not included in the study.

The measures were placed by the Swedish Energy Agency into the categories depending on the system where the improved energy efficiency was found, for example, Lighting, Office equipment, Power-driven equipment, Indirect electrical efficiency, Motors, Vacuum system, etc. Apart from that the measures were categorized depending on what unit processes they belong to. This taxonomy was developed by Söderström (1996) in order to classify industrial energy use. The examples of unit processes are Lighting, Production processes, Pumping, Compressed air system, Ventilation.

Below the companies are presented according to the industrial sector they belong to (Figure 7). The industrial sectors are categorized according to the European Statistical classification system of economic activities NACE Rev. 2 (Eurostat, 2008). As can be seen, the majority of the companies belong to the pulp and paper sector followed by the chemical industry and wood products manufacturing.

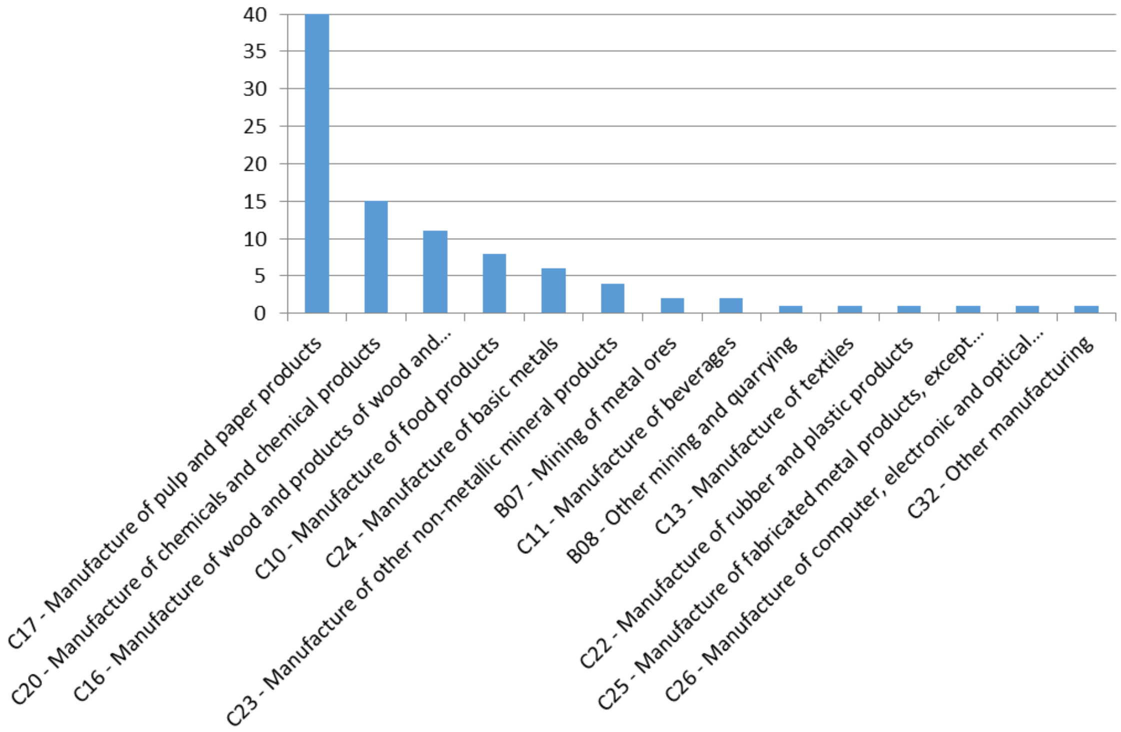

Figure 7. The number of the PFE's participants per industrial sector.

5.3. Categorization of the PFE measures

Further, all the measures were divided into the following categories: Investment in new technology, Adjustment of existing technology, Control systems, Behavioral changes, and Undefined measures. The categorization was inspired by Backlund & Thollander (2014), who estimated the energy management potential for small and medium-sized enterprises. The difference with this categorization is that control system measures were extracted into a separate category. The main idea of the categorization was to separate measures that involve technological changes from behavioral ones. Control systems thus is the transition category between technological and behavioral measures which requires involvement of staff.

All measures were individually assessed and during the assessment process many assumptions were made which are explained below.

Investment in new technology

- Various measures that require investments in the installation of new technologies.
- Such actions as "Refiner," “Pump” or other equipment are also categorized as "Energy efficient technologies" because they involve replacement of equipment or components to a more energy-efficient alternative.
- All lighting measures are assumed to belong to the category "Energy efficient technologies."

Adjustment of existing technology

- Various measures that require adjustment of existing technology.
- Measures involving removal of equipment are assumed to belong to the category “Adjustment of Existing Technology.”

Control systems

- Installation of control systems, runtime adjustment and automation measures are categorized as “Control systems” (need a separate category) and require personnel involvement and assessment, need to manually change or update automation.

Behavioral changes

- Optimization and operating measures are categorized as “Behavioral changes.” Process optimization measures (“Use of excess steam,” “Increased capacity,” “Improved condensate recovery” and “Improved heat recovery”) are categorized as “Behavioral changes” because it is clear that they involve staff and not only technology.
- Leakage detection and similar measures are categorized as “Behavioral changes.”
- Shutdown measures are assumed to belong to the category "Behavioral changes" (require introduction of new procedures and routines).
- If a measure comprises several actions, both technological and behavioral changes, it was given the highest level among them which is assumed to be behavioral. For example, a measure such as “Improved efficiency of compressed air system” is estimated to belong to the category “Behavioral changes” because it can include such sub-measures as installation of a new compressor with variable speed to introduce regular procedures of turning off the existing compressor and leakage control.
- Measures designated “controlling” can be defined as either technological or behavioral measures depending on whether they involve time or demand control. Time-control was categorized as “Behavioral changes” because it means change of procedures (switching the equipment on and off manually, for example). Demand-based adjustment was categorized as “Investment in new technology” because it comprises change in the motor speed which requires special equipment, a VSD or a gear.

Undefined measures

- A smaller amount of measures were not possible to categorize due to the unclear measure names (39 measures) and thus they were placed under the category “Undefined.” The same category also includes the measures which were not quantified in terms of the electricity savings. In total this category includes 174 measures.

6. Results

The evaluation of the program's first period (2005-2010) is based on the companies' interim reports containing savings from the planned EEM and the final reports also including estimated savings due to management and maintenance measures (Stenqvist & Nilsson, 2012). The total amount of EEM is around 1,250 resulting in 917 GWh/year electrical savings. Apart from these numbers, additionally 533 GWh/year are reported as electricity savings due to the energy efficiency procedures, project planning activities and measures categorized separately for specific reasons. Thus, a total of 1,447 GWh is to be saved as reported after the first period of the PFE. This number is referred to as the gross annual impact whereas the net annual impact of the PFE's first period is estimated to be 689-1,015 GWh (Stenqvist & Nilsson, 2012). This is due to such factors as free-rider effect (reporting of the EEM which have been implemented even without the PFE), spillover effect (extra savings not caused by participation) and double counting (effects from overlapping EEM counted twice). However, it is worth noting again that the categorization is based on the 1,254 measures with total annual savings of 917 GWh. All 1,254 EEMs are presented in Figure 8 according to the processes where the deployment of improved energy efficiency was achieved. Production processes showed the highest electricity efficiency figure followed by pumping, compressed air, and ventilation systems.

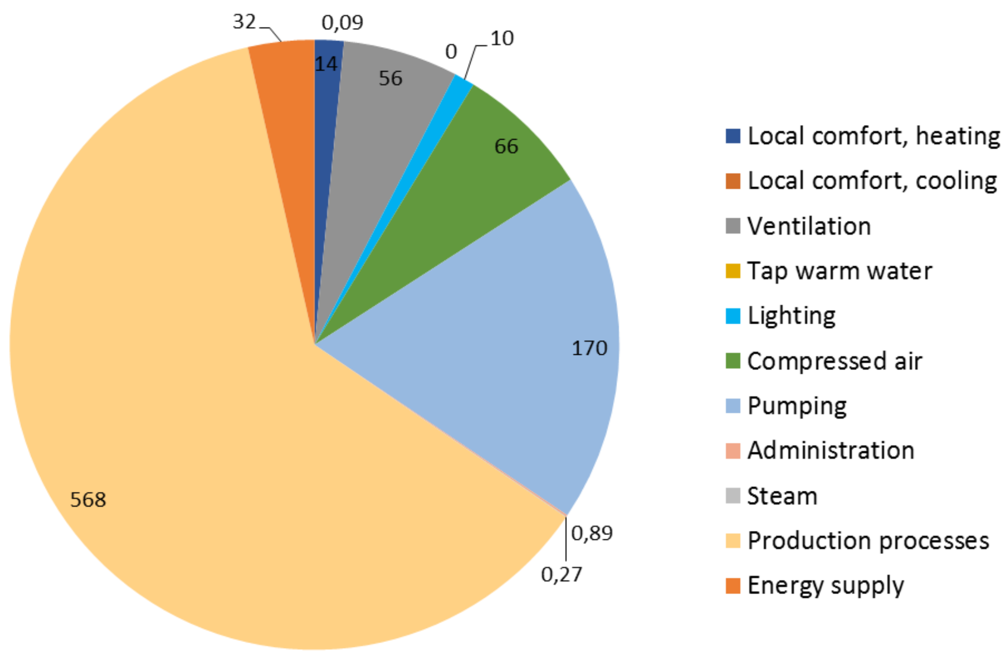

Figure 8. Improved electrical efficiency from the Swedish PFE according to processes, GWh/year (the total savings are 917 GWh/year).

After the categorization, the following results were obtained (Table 1). Thus, Investments in new technology represent 61% of all energy efficiency measures followed by Behavioral changes (29%). Control systems and Adjustment measures obtain only 7% and 2% respectively. The category of Undefined measures represents only 2%.

Table 1. The categorization of the PFE's energy efficiency measures.

Measure category	Number of measures	Electricity savings (GWh/year)
Investment in new technology	782	555
Adjustment of existing technology	30	22
Control systems	87	61
Behavioral changes	238	262
Other/undefined measures	117	17

Figures 9 and 10 show what kinds of measures were proposed for the particular unit processes and the size of the efficiency improvements they resulted in. Production processes are presented separately because they have improvement figures and number of measures and values for some other processes become too small to present on the same plot. As shown in Figure 9, the highest electricity savings for the category of measures "Investments in new technology" are found for pumping unit process followed by ventilation and compressed air systems. High savings for the category "Behavioral changes" are found for compressed air and pumping systems as well as the category of energy supply. However, the relation between the amount of electricity savings and the number of measures is of more importance. In other words, the number of energy efficiency measures and the magnitude of electricity savings related to them is not always the same. The category "Investment in new technology" has the highest number of proposed measures in comparison with other categories for almost every particular process. However, if one compares the relation between the electricity savings and the number of measures it will be much higher for the category "Behavioral changes" than for the category "Investment in new technology".

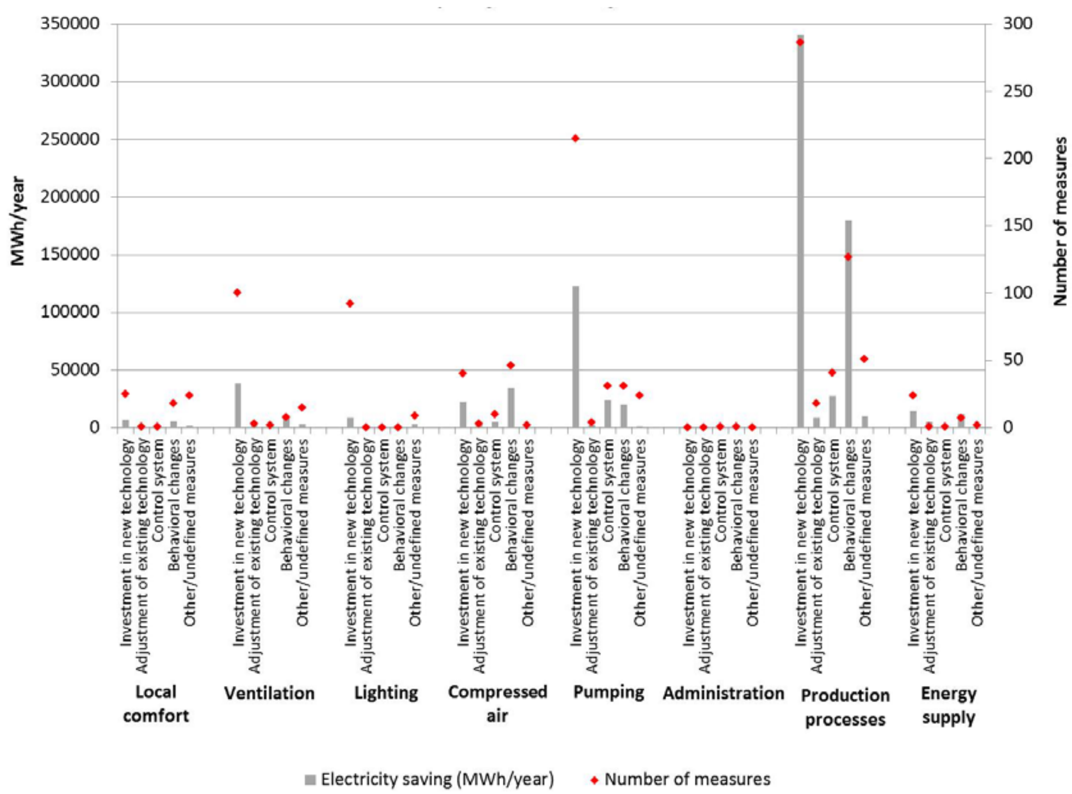

Figure 9. Electricity savings and number of measures for different unit processes (except production processes).

If only the measures proposed for the production processes are considered, the majority of improvements can be achieved by investment in new technologies, although electricity efficiency improvements due to behavioral changes show a rather big share as well (Figure 10). For the production processes too the relation between the electricity savings and the number of measures is higher for the category “Behavioral changes”.

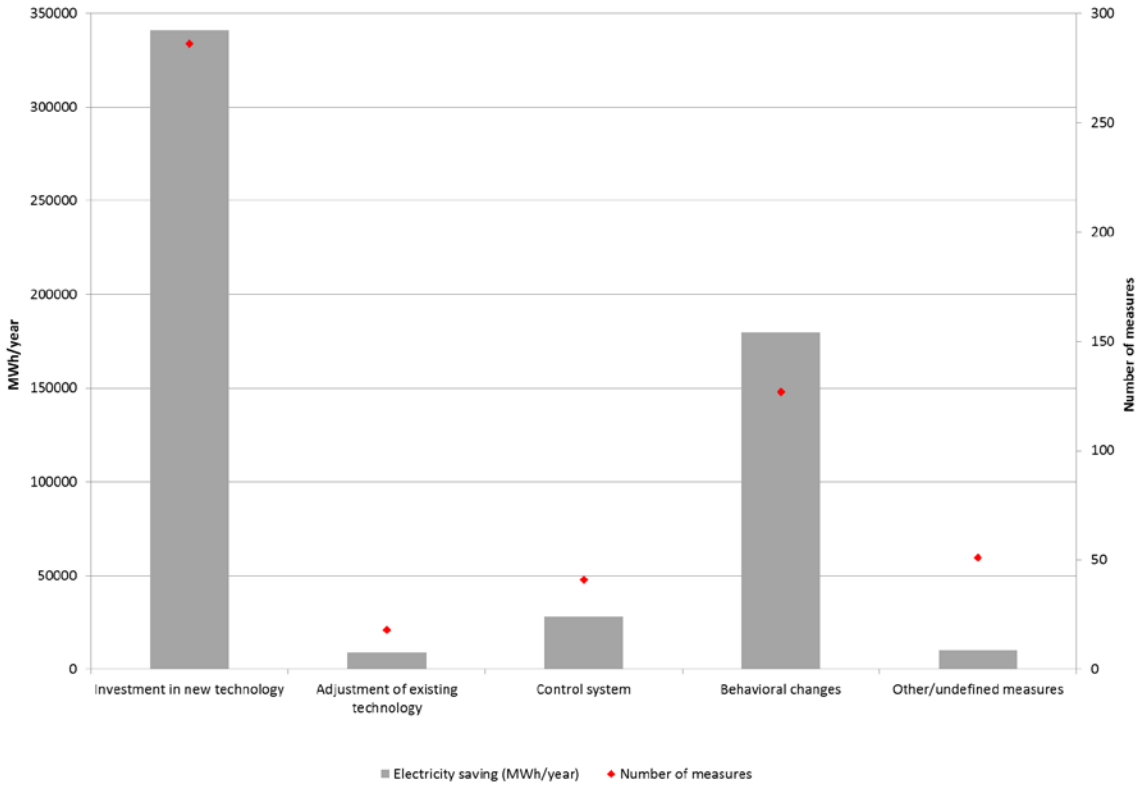

Figure 10. Electricity savings and number of measures for production processes only.

An interesting trend can be observed if the specific savings for a particular measure category are viewed, or in other words electricity efficiency improvements per number of measures proposed (Figure 11). While the efficiency improvements for the first three categories lie in the same range, the efficiency improvements due to the behavioral changes are higher for a single measure.

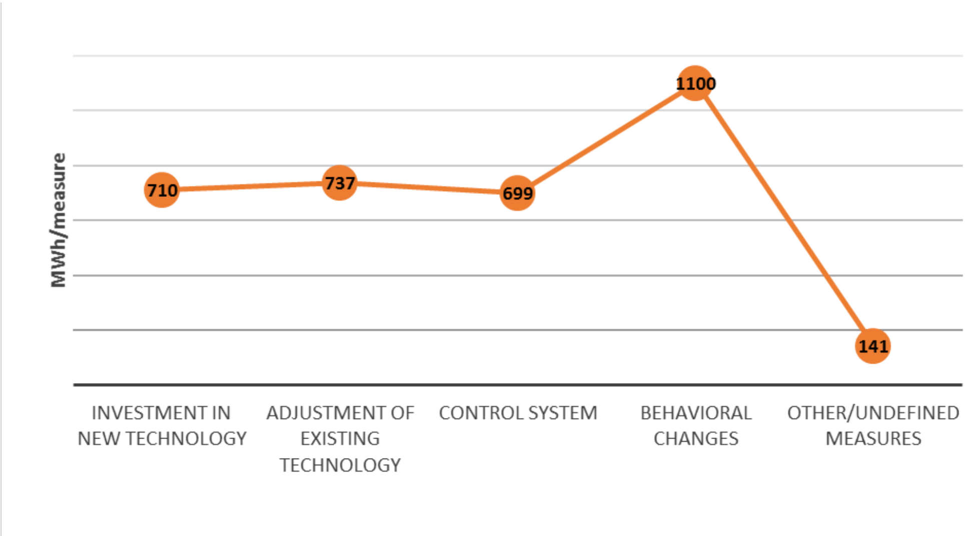

Figure 11. Specific electricity savings for different measure categories (MWh/measure).

In Figure 12 the share of the saving potentials for different categories of measures for various unit processes are shown.

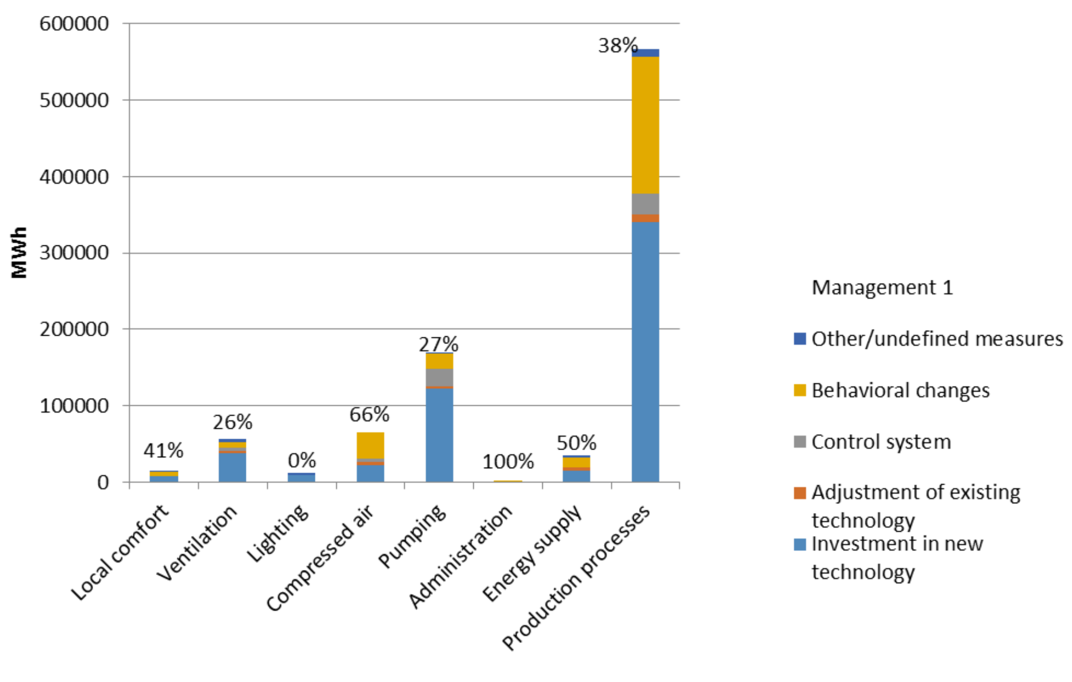

Figure 12. Energy efficiency measure categorization for various unit processes (% values show %of behavioral measures presented by Adjustment measures, Control systems and Behavioral changes).

Since the number of measures related to production processes significantly exceeds the number of measures related to other processes, the other processes are presented separately in Figure 13 below. The percent values above the bars are the share of the sum of the two categories: Control systems and Behavioral changes. It was decided to merge these two categories as mentioned above, as Control Systems is a transition category between behavioral and technological measures. Thus, one can see that behavioral measures represent the majority of measures for the compressed air system because a lot of measures for this process category represent leakage identification, compressor's heat recovery, reducing of the pressure, etc. The share of behavioral changes for the production processes is 37% and in this case the measures can include changing the production procedure, optimization, reducing amount of unplanned stops, reducing the flows, etc. All the measures for lighting are presented by technological changes.

On the similar Figures 13 and 14 below, the percent values for the behavioral changes are slightly higher. This is because for these figures, the behavioral changes were categorized to be presented by the sum of three categories of measures: Behavioral changes, Control systems and Adjustment of existing technology. This reasoning originates from the viewpoint that since adjustment measures often require involvement of the staff they can also be assigned to behavioral measures.

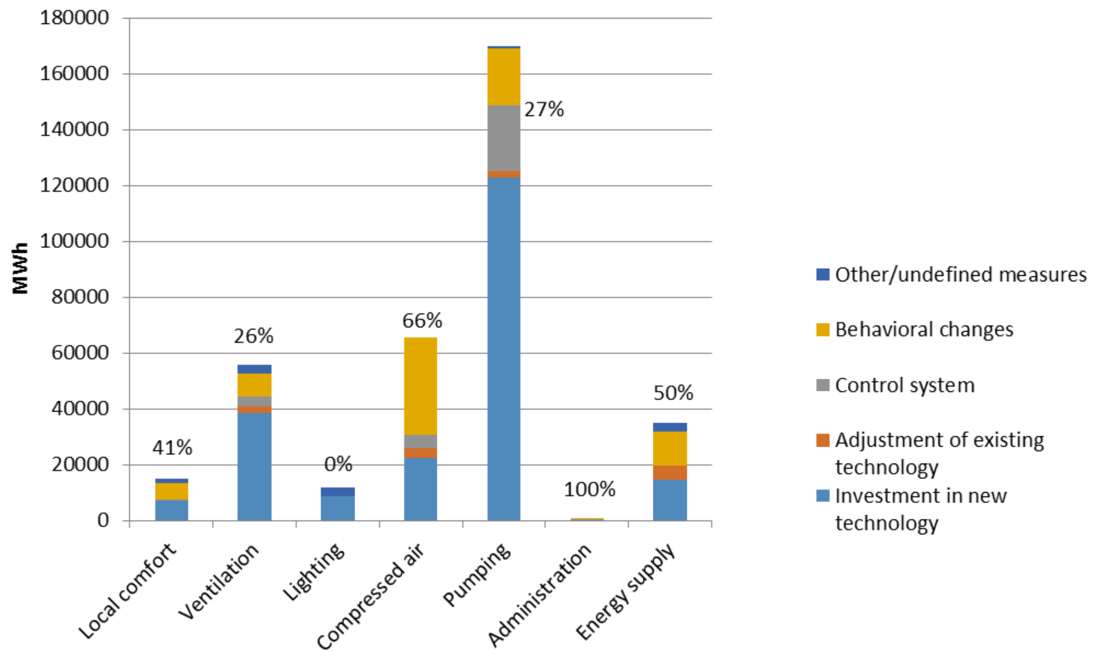

Figure 13. Energy efficiency measure categorization for various unit processes excluding production processes (% of behavioral measures is presented by Control systems and Behavioral changes).

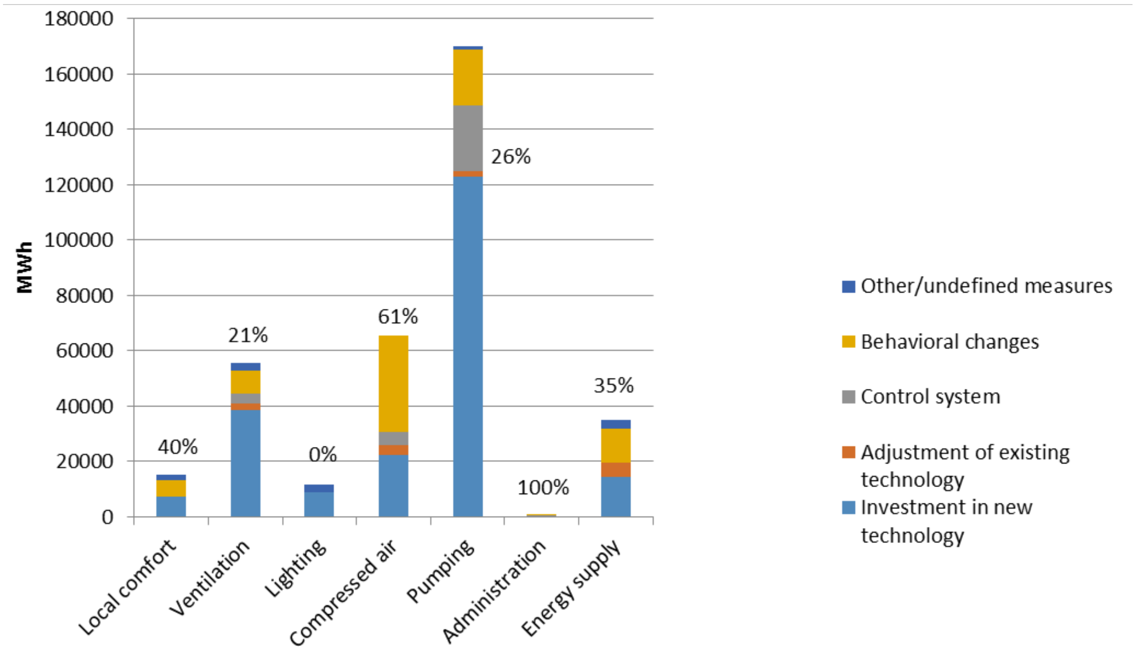

Figure 14. Energy efficiency measure categorization for various unit processes (% of behavioral measures is presented by Adjustment of existing technology, Control systems, and Behavioral changes).

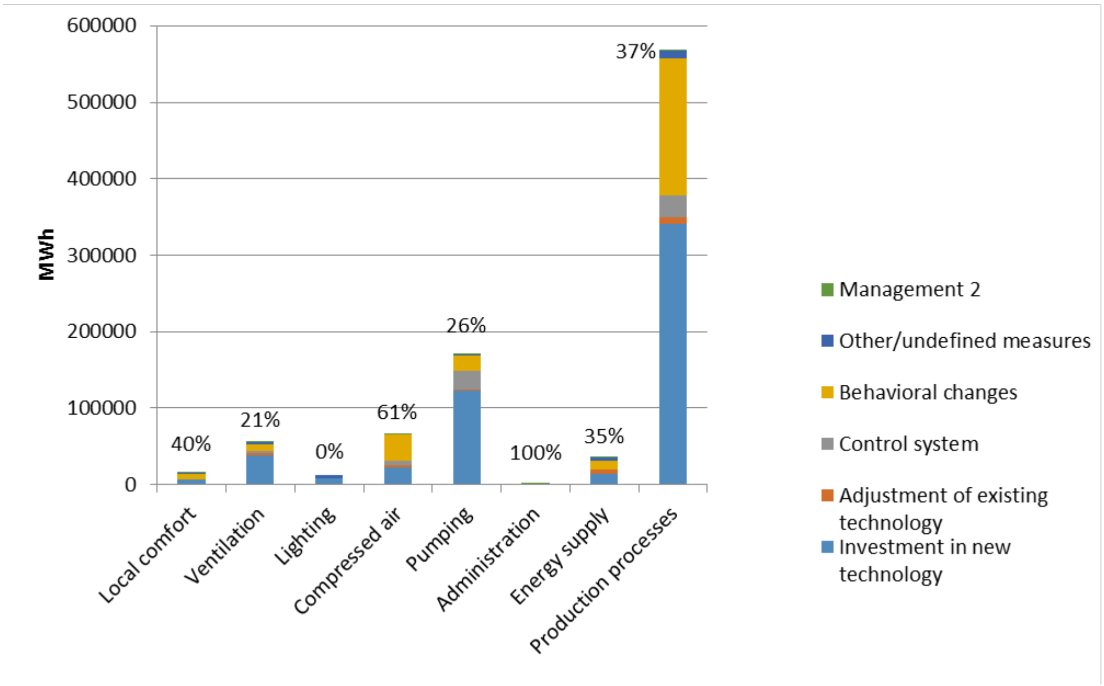

Figure 15. Energy efficiency measure categorization for various unit processes excluding production processes (% of behavioral measures is presented by Adjustment of existing technology, Control systems, and Behavioral changes).

The next figure (Figure 16) shows the origin of the measures.

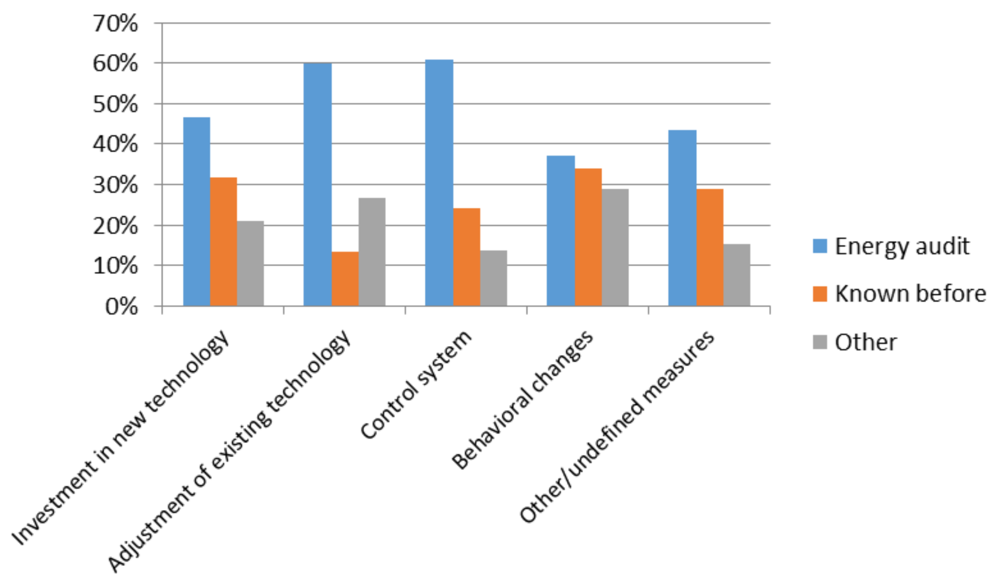

Figure 16. The origin of the proposed measures according to their categories.

Apparently, the energy audit triggers investments in new technology as well as adjustments of existing technology and control systems, but shows considerably lower impact for behavioral measures. This is naturally the case as an energy auditor is primarily a technical expert providing guidance on improvements based on one or a few site visits. This finding thus shows the importance of energy management practices where behavioral measures are also dealt with. As can be seen in Figure 14, these measures also have the shortest payback times.

The average payback time for Investments in new technology is 3.1 years, however the range is very big; from several months to several decades for such measures as replacement of a steering device for a pulp and paper plant or changing of washing line. The payback time for the category Adjustment in new technology is 2.4 years, for Control systems – 1.9 years and for Behavioral changes – 1.4 years.

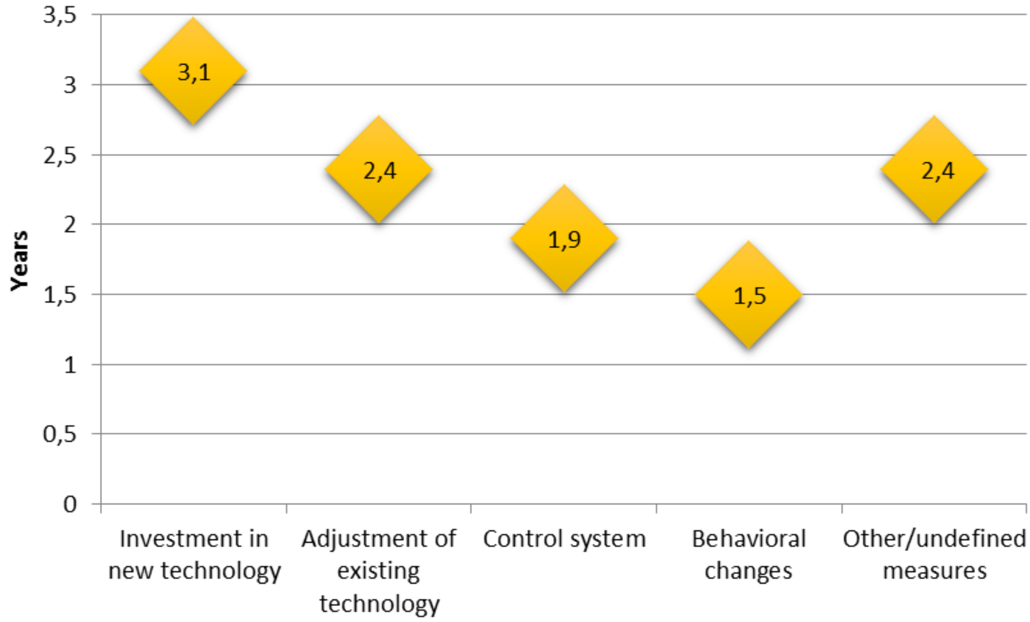

Figure 17. Payback time for different measures categories.

7. Discussion

In the current study an attempt has been to estimate the magnitude of the energy management gap. The difference from other attempts is that it is not based on theoretical assumptions but on real empirical results of the Swedish VA. Depending on how the energy management gap is defined its size differs. In this study, the extended energy efficiency gap was counted by the percentage of behavioral or management measures to energy efficiency. If the behavioral measures are considered to include two categories of measures (control systems and behavioral changes), the size of the energy management gap is 35% (322 GWh/year) and the size of the energy technology gap is in turn 63% (577 GWh/year). If adjustment of existing technology is added to the behavioral measures the magnitude increases to 38% (345 GWh/year) (see Figure 18).

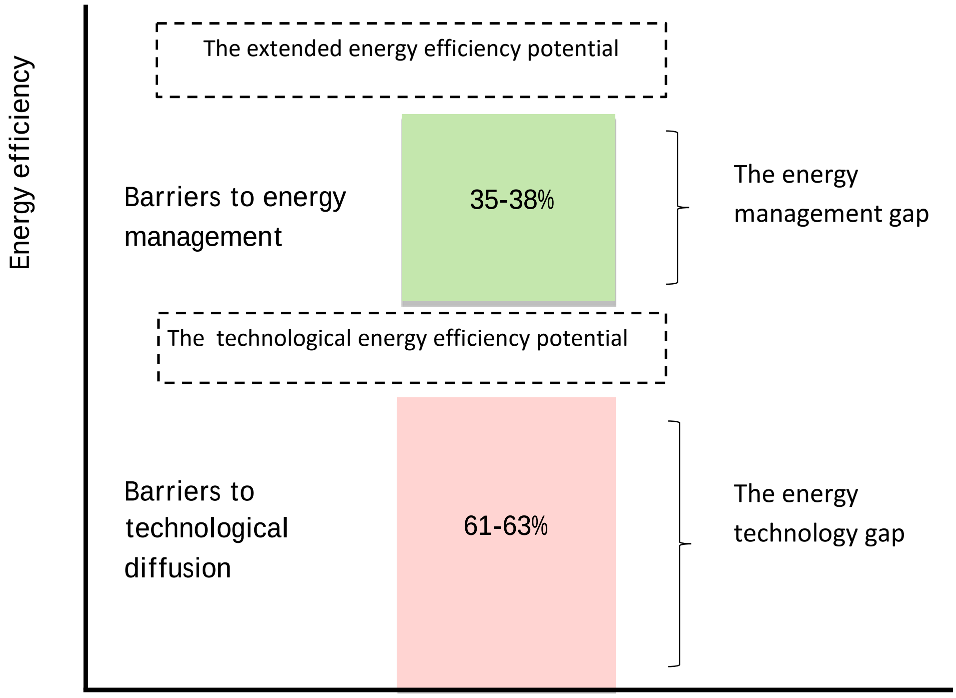

Figure 18. Quantification of the energy efficiency gap (categorization of the PFE database).

It is interesting to compare these results with the recent study (Backlund & Thollander, 2014) providing the indicative evidence from the field of the Swedish SMEs that participated in the Swedish Energy Audit Program (SEAP) on how large this extended potential is. The energy efficiency potential due to behavioral changes is estimated by the consultants performing energy audits to be only 1% (2.26 GWh out of 177 GWh) if the category Adjustment of existing technology is not added to the behavioral measures. If behavioral measures are counted together with this category the potential would increase to 28%. This significant difference can be explained by the fact that in the PFE the focus was not only on energy audit but also energy management. Also, recent research provides the firm's bottom-up view of this potential in the Swedish SMEs, and the Swedish steel industry. It is interesting to note that the companies' representatives estimated the potential for energy efficiency due to behavioral changes higher than the consultants (Backlund &

Thollander, 2014). It would be interesting to compare the results of this categorization with international studies as well. However, to the author's awareness, such studies categorizing technology and management measures have not previously been published, calling for further research in this area. It would also be interesting to compare the results of the categorization for various unit processes, e.g. ventilation, pumping, etc. with the international studies, and the outcome in other countries. However, even though numerous studies have been published on evaluation and reviewing of various policies, e.g. Price (2005), who reviewed 23 industrial voluntary agreement programs from 18 countries, and Rezessy and Bertoldi (2011), who reviewed EU voluntary agreement programs from 11 countries, these studies do not present in-depth findings on the implementation from various process categories. Moreover, if data did exist, comparisons would have been challenging as no uniform way of categorizing energy end-use measures resulting from industrial energy programs exists (Thollander et al., 2015).

These results could help to launch some changes in the orientation of the recent public policies aimed at promoting improved energy efficiency. For example, the EC and EED have a technologist's view on energy efficiency potential (Backlund et al., 2012b) and thus are striving for policies (such as VA, subventions, white certificates, certifications for promoting energy service markets) that can help overcome all the market barriers and not only market failures (EC, 2006; EC, 2012). Thus, the aim is to achieve not only the narrow social optimum but also the true one (as in Jaffe & Stavins, 1994). However, would this optimum be high enough to also close the extended energy gap? As mentioned before, the recent discussions in the energy efficiency field are built around how to overcome barriers hindering diffusion of technology with the help of public policies. Thus, the diffusion of energy-efficient technologies remains a key outlined means to improved industrial energy efficiency. The principal model for this originates from the neoclassical model where growth is achieved by technological development, and countries which are leading in the field of technological innovation also see economic growth. The technological diffusion model, exemplified by Jaffe and Stavins (1994), stipulates that technological innovation follows a diffusion pattern, which has several advantages. The model allows for policy-makers to launch supporting schemes for demonstration and early market movements, as the S-pattern, and thus diffusion is slow in the early phases of the market penetration of a new, more energy-efficient technology. Also, it allows for policy-makers to design and launch policies which directly promote certain types of technologies which prove more energy efficient than the former, for example energy labeling schemes and the European ESD. Yet another advantage is that the model actually provides a valid representation of how an economy can achieve an improved level of energy efficiency for some sectors, e.g. the building sector, where superior technologies are promoted and adopted for appliances. Within the EU, the model is shown to be the main model for understanding how improved energy efficiency can be achieved. "It is important to ensure that energy efficiency is taken into account and that new capacity reflects the best available technology (BAT)" (EC, 2011). EU is promoting the adoption of Best Available Technologies (BAT), and for a few sectors, BAT documents are created stating the most efficient technology level.

Up until today, few attempts have been made to complement this view, the most prominent reason being that, as stated above, it actually works. However, for the industrial sector in particular, the diffusion of technology model, which in relation to improved energy efficiency means diffusion of BATs, may sometimes prove difficult. First and foremost, industrial energy use is difficult to see as consisting of stand-alone technologies (appliances), where industry can go to the market and shop for a more energy-efficient appliance. Rather a majority of industrial energy use may in fact be viewed as consisting of processes. This means, as outlined by Westling (2000), that such are far more complex to procure, see Figure 19.

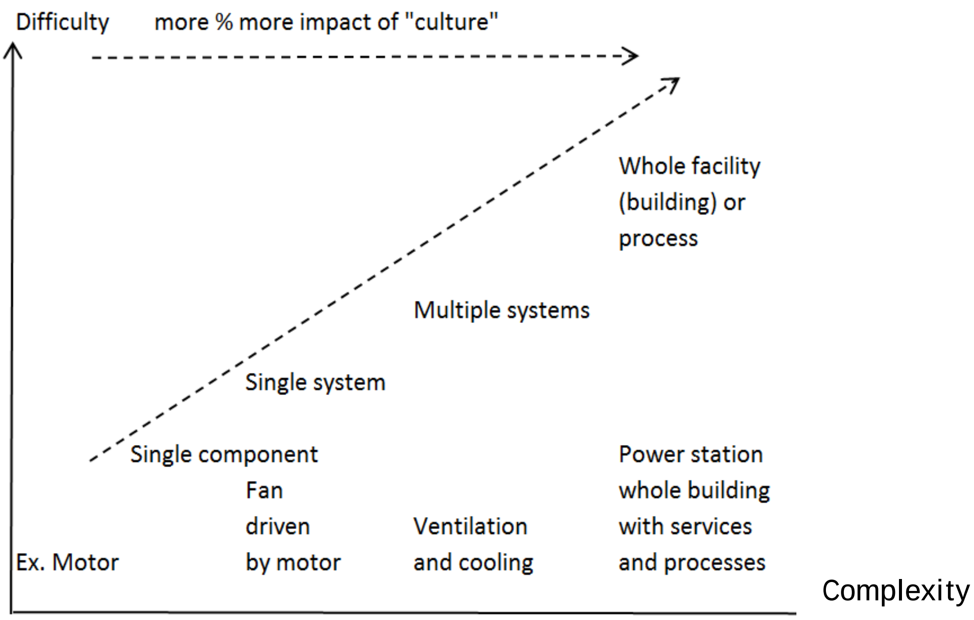

Figure 19: Complexity ladder of energy efficiency measures (revised from Westling, 2000).

Figure 19 illustrates that it is only in the lower parts of the complexity ladder that the diffusion of technology model may actually be valid. In the upper parts, consisting of systems or multiple systems, procurement is more difficult. However, as outlined by Waide and Brunner (2011) it is at the system level that higher levels of improvements may be found and thus, only focusing on single components, diffusion of energy-efficient technologies and upgrading of existing equipment will not help reach the extended energy efficiency potential. Backlund et al. (2012) stated, and this study has proven, that there is a large untapped energy efficiency potential within the management in existing technologies, which related to Westling (2000) is likely to be something that takes place in-house in a firm, on the higher levels of the complexity ladder, and thus outside the model for diffusion of technology. This, in turn, provides direct implications in the area of industrial energy policy decision-making. Policies, for example VA including energy management components, i.e., measures that are directed towards establishment of in-house energy efficiency activities, are an important complement, e.g. to direct investment subsidies or energy information programs such as energy audit programs, providing information on how to invest in more energy-efficient technology.

Relating our study to the concept of barriers, it should be noted that the emphasis on technology investments alone when studying improved energy efficiency should be complemented by studies on barriers for energy management practices as well, where e.g. hidden costs relating to Westling (2000) are likely to be higher as these tend to be more complex.

8. Conclusion

Shifting focus from only energy-efficient technologies to include diffusion of energy management practices can obviously extend the potential for improved energy efficiency. As was shown in this study, the energy management potential accounts for at least 35% of the total deployed energy efficiency potential. One should note though that this figure is much underestimated due to the fact that the PFE database used in this study for the energy efficiency measure categorization with the total electricity savings of 917 GWh/year does not include an additional 533 GWh/year reported independently. These electricity savings resulted from more energy-efficient procedures, project planning activities and measures categorized separately for specific reasons. The results of this study have proven that the untapped potential within the management in existing technologies for energy-intensive industries is rather big and leaves great room for improvement. This is also supported by the findings that the specific electricity potential (the amount of MWh electricity saved per one energy efficiency measure) is higher for behavioral measures than for technological ones (Figure 11). Moreover, this study has shown that energy efficiency measures related to behavioral changes have lower payback time (Figure 17).

This paper does not call for discarding the current deployment of industrial energy efficiency achieved by diffusion of technology, but rather contributes to an improved understanding of how the full energy efficiency potential can be reached by including the potential in energy management. This knowledge is useful for public policy-makers as well as industrial companies (managers and auditors). There is a need to work further with energy management practices which today lack the perspective of continuity. This can be achieved by means of development of new approaches (Paramonova et al., 2014) involving continuous work and learning. Notably, the concept of technology diffusion is rather passive from the managerial perspective in comparison with energy management practices which demand an active and participative crew, operator, or manager. In regard to this, energy management may thus be seen as an area which involves psychology and behavioral science. What indeed is important to point out is that energy management measures may be rather short-lived. Efficient routines are not emphasized within organizations, compared with technology implementation which remains, independent of the organization's ability or not to foster change towards improved energy efficiency. What this paper has proven is a real and existing area of improvement within energy-intensive industries deployable through management practices. From a policy perspective this strongly underlines the importance of energy management components in industrial energy policy design, apart from energy information programs, e.g. energy audit programs.

What underlines this even more is that the costs for the measures are lower than for all other categories. Industrial energy policy instruments including energy management components are normally found under the umbrella of VAs (Price, 2005). The focus of VAs thus should not be only on explicitly promoting technological progress by reducing asymmetric information barriers as stated in Blomberg et al. (2012). Furthermore, energy management practices could also be adopted within administrative policies, e.g. the Japanese Energy Conservation Law (Kimura & Fuyuhiko, 2014). In either case, energy management components in future policies are a critical and much needed component in a country's goal of improved industrial energy efficiency. One challenge in future research is to incorporate the extended energy management potential into existing theoretical foundations. This future research should also include studies on barriers for energy management, and in particular barriers such as hidden cost as these costs might be higher for some types of energy management practices.

If this is not achieved, future major emphasis will still lie in the area of technology diffusion. Thus, this paper has helped future researchers and theoreticians in actually proving that a real and tangible energy efficiency potential exists apart from technology adoption. This empirical finding hopefully takes us a small step further down the line of more efficient and sustainable industrial energy systems.

It should be noted that our findings relate to energy-intensive Swedish industries. Results from this study are generalizable to energy-intensive industries in other countries. However, it is less likely generalizable for small- and medium-sized and non-energy-intensive industries. This is further validated by a database of EEMs from Swedish policy programs including the one studied, where the majority of EEMs from Swedish industrial SMEs are from support processes, while the opposite holds true for the dataset from energy-intensive companies used in this study (Blomqvist & Thollander, 2015).

Further research is suggested in the area of barriers to energy management practices, and also in particular related hidden costs for such measures.

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References

Abdelaziz, E., Saidur, R., Mekhilef, S., (2011). A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews 15(1): 150-168.

Backlund, S., Broberg, S., Ottosson, M., Thollander, P., (2012a). Energy efficiency potentials and energy management practices in Swedish firms. ECEEE 2012 Industrial Summer Study.

Backlund, S., Thollander, P., Palm, J., Ottosson, M., (2012b). Extending the energy efficiency gap. Energy Policy 51: 392-396.

Backlund, S., Thollander, P. (2014). Estimations of energy efficiency management potential in small and medium sized firms. Energy Efficiency (in press).

Blomberg, J., Henriksson, E., Lundmark, R. (2012). Energy efficiency and policy in Swedish pulp and paper mills: a data envelopment analysis approach. Energy Policy 42: 569-579.

Blomqvist, E., Thollander, P. (2015). An Integrated Dataset of Energy Efficiency Measures. Accepted for publication in Energy Efficiency (Springer).

Brunke, J.-C., Johansson, M., Thollander, P. (2014). Empirical investigation of barriers and drivers to the adoption of energy conservation measures, energy management practices and energy services in the Swedish iron and steel industry. Journal of Cleaner Production 84: 509-525.

Caffal, C. (1995). Energy management in industry. Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). Analysis Series 17.

Christoffersen, L. B., Larsen, A., Togeby, M., (2006). Empirical analysis of energy management in Danish industry. Journal of Cleaner Production 14(5): 516-526.

DeCanio, S. J. (1998). The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 26(5): 441-454.

EC (2006). Communication From the Commission. Action Plan for Energy Efficiency: Realizing the Potential. European Commission. COM 545.

EC (2011). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy Efficiency Plan 2011. European Commission. COM (2011): 109.

EC (2012). Energy Efficiency Directive. European Commission, Directive 2012/27/EU.

EU (2009). Ecodesign Directive. Directive 2009/125/EC of the European parliament and of the council of 21 October 2009 establishing for the setting of ecodesign requirements for energy related products. Official Journal of the European Union.

Eurostat (2008). NACE Rev.2. Statistical classification of economic activities in the European Community. European Communities.

Fleiter, T., Fehrenbach, D., Worrell, E., Eichhammer, W. (2012). Energy efficiency in the German pulp and paper industry–A model-based assessment of saving potentials. Energy 40(1): 84-99.

Gordić, D., Babić, M., Jovičić, N., Šušteršič, V., Končalović, D., Jelić, D., (2010). Development of energy management system–Case study of Serbian car manufacturer. Energy Conversion and Management 51(12): 2783-2790.

Hirst, E., M. Brown (1990). Closing the efficiency gap: barriers to the efficient use of energy. Resources, Conservation and Recycling 3(4): 267-281.

IPCC (2014). Climate Change 2014. Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change. Fifth Assessment Report.

Jaffe, A. B., R. N. Stavins (1994a). The energy-efficiency gap What does it mean? Energy Policy 22(10): 804-810.

Jaffe, A. B., R. N. Stavins (1994b). The energy paradox and the diffusion of conservation technology. Resource and Energy Economics 16(2): 91-122.

Johnson, H. (2014). GHG Emissions and the Energy Efficiency Gap in Shipping. Chalmers Publication Library.

Kimura, O., Fuyuhiko, N. (2014). Does regulation of energy management systems work? A case study of the Energy Conservation Law in Japan. ECEEE Industrial Summer Study proceedings, pp. 647-657.

McKane, A., Scheihing, P., Williams, R. (2008). Certifying Industrial Energy Efficiency Performance: Aligning Management, Measurement, and Practice to Create Market Value. Lawrence Berkeley National Laboratory.

Nichols, A. (1994). Demand-side management Overcoming market barriers or obscuring real costs? Energy Policy 22 (10): 840-847.

Ostertag, K. (1999). Transaction costs of raising energy efficiency. (Paper presented at the 2007 IEA international Workshop on Technologies to Reduce Greenhouse gas Emissions: Engineering-Economic Analyses of Conserved Energy and Carbon). Download at: http://www.isi.fraunhofer.de/isi-wAssets/docs/x/de/publikationen/econserv.pdf [Accessed 2015-04-15]

Ottosson, M., Magnusson, T. (2013). Socio-technical regimes and heterogeneous capabilities: the Swedish pulp and paper industry's response to energy policies. Technology Analysis & Strategic Management 25(4): 355-368.

Paramonova, S., Ivner., J., Thollander., P. (2014). Outsourcing Industrial Energy Management: Industrial Energy Efficiency Networks Provided As an Energy Service. Outsourcing: Strategies, Challenges and Effects on Organizations: pp. 71-98. Nova Science Publishers, Inc.

Pihl, H. (2007). Ekonomi från början: en samhällsekonomisk introduktion. Studentlitteratur.

Price, L. (2005). Voluntary agreements for energy efficiency or GHG emissions reduction in industry: An assessment of programs around the world. Lawrence Berkeley National Laboratory.

PWC (2007). Incitamentsformer för ökade energieffektiva investeringar utanför energiintensiv industri [Types of incentives for increased energy efficiency investments outside the energy intensive industry]. Örhlings PricewaterhouseCoopers, Stockholm. [in Swedish].

Rezessy, S., Bertoldi, P. (2011). Voluntary agreements in the field of energy efficiency and emission reduction: Review and analysis of experiences in the European Union. Energy Policy 39(11): 7121-7129.

SEA (2005). Skattebefrielse på el – för effektiv energianvändning i industrin. Swedish Energy Agency, ET 2005:03/2005-01/2000. Stockholm. [in Swedish].

SEA (2006). Rutiner för inköp av elkrävande samt för projektering, ändring och renovering. Guide till PFE:s krav. Energimyndigheten, Stockholm. [in Swedish].

SEA (2014). Energy in Sweden 2013. Swedish Energy Agency ET 2013:29. [in Swedish].

SFS (2004). Lag (2004:1196) om program för energieffektivisering. SFS 2004:1196. Näringsdepartamentet. [in Swedish].

Sorrell, S., Scheich, J,. Scott, S., O'Malley, E., Trace, F., Boede, E., Ostertag, K., Radgen, P. (2000). Reducing Barriers to Energy Efficiency in Public and Private Organizations. Science and Technology Policy Research.

Sorrell, S., O´Malley, E., Schleich, J., Scott, S. (2004). The economics of energy efficiency: barriers to cost-effective investment, Edward Elgar Publishing.

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.

Söderström, M. (1996). Industrial Electricity Use Characterized by Unit Processes. A Tool for Analysis and Forecasting. Proc. UIE XIII Congress on Electricity Applications, Birmingham: 77-85.

Thollander, P., Ottosson, M. (2010). Energy management practices in Swedish energy-intensive industries. Journal of Cleaner Production 18(12): 1125-1133.

Thollander, P., Paramonova, S., Cornelis, E., Kimura, O., Trianni, A., Karlsson, M., Cagno, E., Morales, I., Jiménez Navarro, J.P., 2015. International study on energy end-use data among industrial SMEs and energy end-use efficiency improvement opportunities. Journal of Cleaner Production (In press).

Trianni, A., Cagno, E., De Donatis, A. (2014). "A framework to characterize energy efficiency measures." Applied Energy 118: 207-220.

Walde, P., Brunner, C. (2011). Energy-efficiency policy opportunities for electric motor-driven systems, OECD Publishing.

Van Gorp, J. C. (2004). Maximizing energy savings with enterprise energy management systems. Pulp and Paper Industry Technical Conference, 2004. Conference Record of the 2004 Annual, IEEE.

Westling, H. (2000). Final Management Report Annex III Co-Operative Procurement of Innovative Technologies for Demand Side Management. International Energy Agency Demand Side Management Programme, Paris.

Worrell, E., Laitner, J., Ruth, M., Finman, H., (2003). Productivity benefits of industrial energy efficiency measures. Energy 28(11): 1081-1098.