Only non-energy benefits when adopting an EEM? Cases from industry

Enrico Cagno
Politecnico di Milano, Dept. Management, Economics and Industrial Engineering
20133 Milan
Italy

Andrea Trianni
Politecnico di Milano, Dept. Management, Economics and Industrial Engineering
20133 Milan
Italy

Davide Moschetta
Politecnico di Milano, Dept. Management, Economics and Industrial Engineering
20133 Milan
Italy

Keywords

non-energy benefits (NEBs), energy efficiency measures, case studies

Abstract

Considering the industry's contribution to energy and environmental issues, industrial energy efficiency is recognized as a fundamental step for increased sustainability. Energy efficiency in industry is achieved through the adoption of the so-called Energy Efficiency Measures (EEMs). Traditionally, it has been demonstrated how these interventions have both energy benefits, as the reduction of the energy consumption, and the so-called Non-Energy Benefits (NEBs) deriving from the adoption of a certain measure. In the existing literature, however, a considerable part of the scholars and of the practitioners just focus on the identification and definition of the positive benefits deriving from these measures after they have been completely adopted, thus neglecting to describe the full set of either positive and negative effects. Nevertheless, recently, the description of these effects has been accomplished exploiting different approaches. Thus, on the basis of previous literature studies and the emerging needs, that affect both the definition of the entire range of effects and the point of view adopted in their description, we have proposed a novel classification of the relevant items to be considered by an industrial decision-maker when deciding whether to adopt an EEM. Hence, by taking this perspective, we have investigated benefits and losses to ad-hoc selected industries where, through an interview, already adopted EEMs have been analysed. Finally, considerations and implications are drawn from the case studies and suggestion for further research are proposed, in order to improve the description of the EEMs in the industrial sector.

Introduction

World energy consumption is expected to increase by more than 50 % (EIA, 2014), mainly due to huge population growth and development of emerging economies. A lion's share in delivered energy consumption is played by the industrial sector, covering more than 50 %, followed by the transportation sector (about 30 %), with lower relevance of residential and commercial sectors. But, to the heavy reliance on fossil fuels, about two thirds of greenhouse gases emissions (GHG) can be attributed to energy generation and use. Here the relevance of the industrial sector is even larger, covering about 40 % of the emissions of CO_2, with worrying trends for developing countries (EIA, 2011). Thus, energy efficiency in all sectors, but especially within the industrial one, has raised to the top of energy policy-makers' agenda, thanks to its capability of reducing energy consumption and, hence, reducing the associated emissions of GHG. As authors note (Palm and Thollander, 2010), Energy Efficiency Measures (EEMs, including technologies and practices) should be promoted to reduce the existing energy efficiency gap.

In particular, recent research trends have observed that scholars and industry have so far paid little attention to increase the knowledge on how the existing barriers to the adoption of EEMs can be overcome (Cagno et al., 2013; Cagno and Trianni, 2013). More specifically, the discussion on the so-called Non-Energy Benefits (NEBs) should be clearly expanded offering both empirical evidence and proper modelling. Indeed, as Trianni et al. (2016) note, so far literature has not paid a large attention in fully describing the consequences (either positive or negative) deriving from the adoption of EEMs during its entire life, mainly limiting to the positive effects arisen when having adopted an EEM.

Nevertheless, it is clear in the day-by-day decisions that just looking at energy and NEBs does not seem to be coherent with the perspective of an industrial decision-maker. As energy efficiency is not the unique perspective (although maybe quite appealing), it is relevant to consider the broader set of implications in particular when implementing an EEM, also by considering possible synergies (positive or negative) with other activities. Moreover, when considering the use of an EEM, a decision-maker effectively looks what could be improved, but also could be worsening, as well as possible secondary effects (again, either positive or negative).

For this reason, as Heffner and Campbell (2011) pointed out and Trianni et al. (2016) recalled, a more thorough knowledge about the opportunities and the problems made available from an EEM could represent a value added for an industrial decision-maker, possibly modifying his/her judgement about the EEMs. A first step for an enhanced knowledge could be offered by a classification of the relevant items to be considered by an industrial decision-maker when deciding whether to adopt an EEM. We try to offer a contribution to address this research gap sketching the main set of impacts (either positive of negative) that could be expected when implementing and using an EEM. We have then conducted our exploratory investigation within Italian manufacturing companies, aiming at pointing out suggestions for industrial decision-makers about effective impacts (positive and negative) of EEMs, as well as collecting issues and recommendations for further research and improvement.

Sketching a novel framework to evaluate non-energy benefits and losses

Trianni et al. (2016) in their review have pointed out that the largest part of literature has so far offered an attempt in dealing with positive impacts (benefits) in the service phase of an EEM, therefore not fully addressing the set of impacts (either negative or positive) in the implementation and service phase. The review has been summarized in Figure 1 and in Appendix A. By implementation phase, the authors consider the time interval including the decommissioning of the existing non-efficient equipment, being followed by the installation, testing and the start-up of the efficient one (or, in case of practice, the time to effectively implement a new and more energy-efficient practice). The second phase, i.e. the service one, is the time window in which the EEM, after being put in place, is exploited and the energy savings should occur. Combining both the phases, the whole lifetime of the measure is obtained.

Based on such review, in the present study we present some key issues that are crucial for evaluating EEMs from an industrial decision-making perspective, summarized in Figure 2.

First of all, and new with respect to previous literature, the perspective of an industrial decision-maker, who has to thoroughly evaluate an EEM, should be taken. In fact, many studies have so far adopted the perspective of a company that supplies an EEM, thus showing a broad set of benefits coming after adopting a given EEM. Hence, by maintaining the perspective of an industrial decision-maker, we should remark that impacts should be considered taking into account both the implementation and the service phases characterizing an EEM. In particular, positive and negative impacts may deeply influence the perception of a decision maker about the sustainability of an EEM (thus including economic, environmental and societal pillars, as with triple bottom line perspective), since they include, among the other effects, production disruption and discomfort in production departments. In fact, a decision-maker is interested in an objective and detailed description of the possible benefits and, mostly, the losses perceived in an EEM implementation phase. But, particular attention should be also devoted in considering that some operating conditions may vary, thus changing the set of possible benefits during the service phase. Hence, a decision-maker

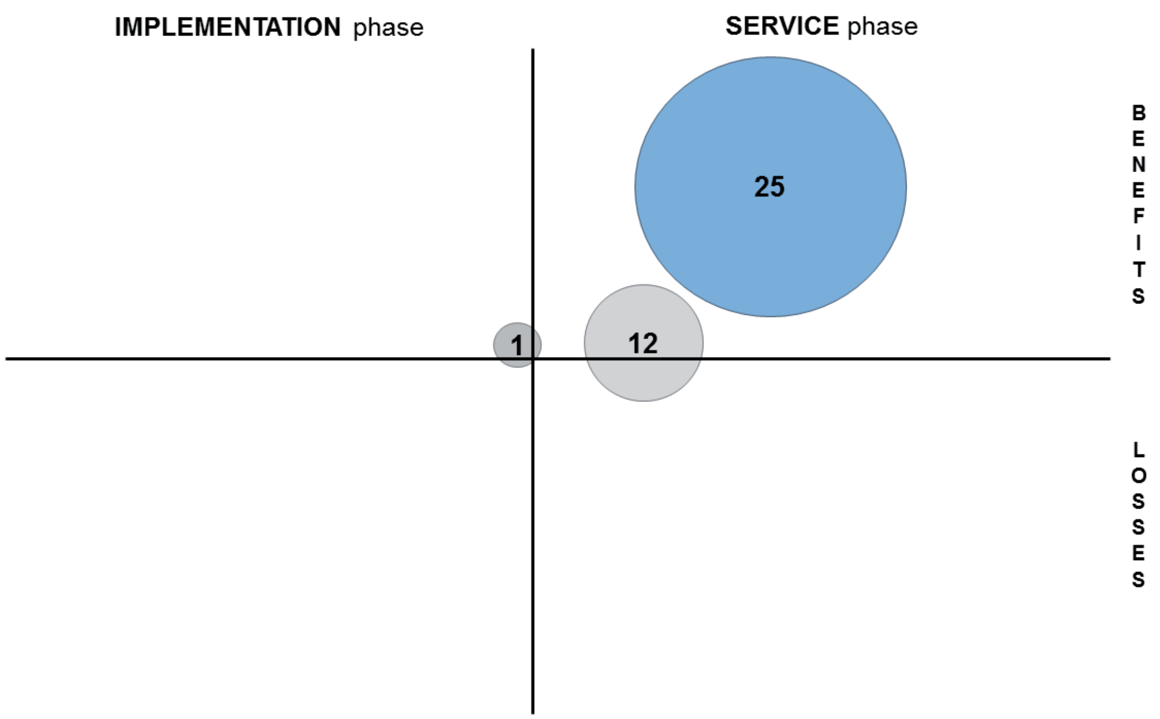

Figure 1. Focus of the existing literature studies on Non-Energy Benefits. Source: Trianni et al., 2016.

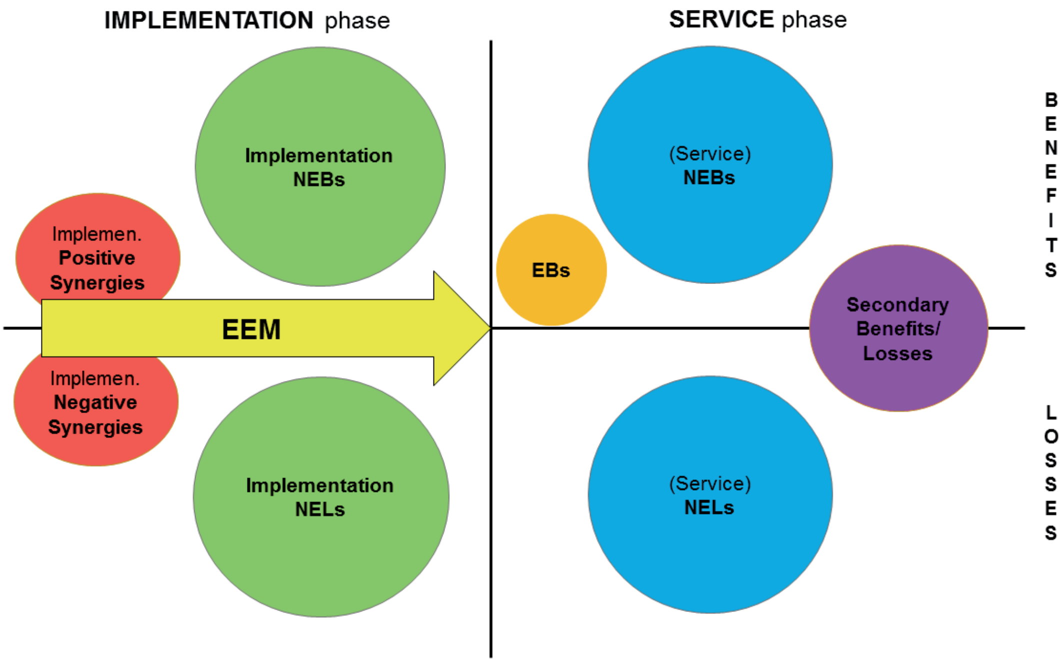

Figure 2. Broader set of impacts from adoption of an EEM: focus is given to both positive (benefits) or negative (losses) impacts, as well as in implementation and service phase.

may be quite interested in defining possible consequences of this specific phase on the surrounding environment (such as production disruption, noise or, e.g., stimulus for an area of a company to implement further modifications). In conclusion, attention should be paid to both the implementation and service phase of an EEM.

Additionally, in the wake of Skumatz and Gardner (2005), it is important to define whether the impact has a positive or negative effect on the organization; this leads to the definition of the positive impacts, identified as real Benefits, and negative effects for the enterprise, defined as Losses. For this reason, there is a clear distinction of the primary indirect service benefits into *Service Non-Energy Benefits* (*NEBs*), as pointed out by previous scholars (e.g., Worrell et al., 2003), and *Service Non-Energy Losses* (*NELs*). The first group accounts for all the positive effects that arise because of an EEM, while the second one includes all the impacts with negative consequences with respect to the perspective of the organization.

It is necessary to include the effects with positive or negative impact proper of the other phase of the life of a EEM, obtaining the *Implementation NEBs*, for the positive benefits with respect to the organization and, similarly, the *Implementation NELs*, which account for the negative impacts of the EEMs on the company. Furthermore, we have specifically set a focus on the *Secondary Benefits and Losses*, and pointed out to take into consideration the type of their impacts whenever available to make such considerations. Indeed, in the service phase, it is usually quite hard to forecast with detail this type of effect.

On the other hand, we have highlighted that some *Implementation synergies* (either positive or negative) may occur, and they should be carefully considered by an industrial decision-maker. Consequently, their distinction basing on the type of impact can be performed. For this reason, we have indicated with *Implementation positive synergies* those positive synergetic relationships arising in the implementation phase, while with *Implementation negative synergies* the negative secondary impacts emerged during the same phase.

Finally, those impacts strictly related to the variation of the energy flow and that normally are the easiest to be recognized are defined as *Energy Benefits* (*EBs*) (i.e. benefits directly related to the reduction of the energy consumed such as e.g., economic savings due to higher efficiency), thanks to their origin and, mostly, to the fact that they are direct impacts.

Empirical Evidence on evaluating benefits and losses with the novel classification

Due to the exploratory nature of the study, we have here adopted a case study approach. We have performed five interviews in manufacturing enterprises located in Northern Italy, which is a quite industrialized and wealthy industrial region. The investigation has been focused on enterprises with different characteristics: indeed, enterprises have been selected according to several manufacturing sectors and size. Additionally, the sampled enterprises present quite different relevance of energy issues, being them either energy-intensive or non-energy intensive. Furthermore, we aimed at evaluating the features of the proposed classification by dealing with enterprises with possible different pro-activity with respect to energy efficiency issues. Therefore, we have sampled enterprises with (and, in case, if mandatory) or without an internal energy manager. The main set of information regarding sampled enterprises is summarized in Table 1.

The selected companies belong to different range with respect to their size, ranging from 50 to about 700 employees, and are characterized by a turnover which varies from eleven millions of euro to approximately three hundred millions of euro per year, with different sectors of activity, here indicated through the corresponding ISIC rev. 4 code. Additionally, by

Table 1. Companies interviewed. We have marked with * the companies with a mandatory energy manager.

Company	No. of employees	Turnover	Sector	Energy Intensity	Internal Energy manager	Environmental Certifications
A	Medium	High	23.13 – glass production (C23)	High	Yes*	UNI EN ISO 14001:2004
B	High	High	31.09 – furniture production (C31)	High	No	None
C	Medium	High	23.99 – production of products with non-metallic minerals (C23)	Medium	Yes	UNI EN ISO 14001:2004
D	High	High	31.09 – furniture production (C31)	Medium	Yes*	UNI EN ISO 14001:2004
E	Small	Small	5.73 – tools production (C25)	Small	No	None

considering the energy intensity – here defined as the ratio between the energy expenditures and the turnover –, ranges from 0.80 % to values substantially higher than 3 %. Finally, part of the companies has an internal Energy Manager, both because of the law requirements (companies A and D) and because of a higher attention toward energy issues (company C); looking at the environmental certifications available, Table 1 reports the availability of the UNI EN ISO 14001:2004, which seems to be the only certification acquired that relates to environmental issues, despite one enterprise have all the requirements satisfied for the UNI CEI EN ISO 50001:2011 and is ready for acquiring the certification.

Findings were obtained through face-to-face interviews conducted with plant managers, company managers or other key people knowledgeable and responsible of decisions regarding the adoption of EEMs. Enterprises have been contacted by phone to verify their interest in taking part to the research and, in case of positive response, to set an appointment for a face-to-face interview as well as, whether possible, for a plant visit. The interview has been structured as follows: firstly, respondents have been asked to describe their company, reporting the most relevant information about their business characteristics such as size, turnover, annual energy expenditures. In this regard, interviewees have offered a detail regarding the production process, indicating the most critical phases and processes in place, as well as equipment.

Secondly, several information related to their attitude on investing in EEMs have been asked. In particular, we have asked them to describe some key features of EEMs recently considered for implementation (and, in case of a positive evaluation, effectively adopted). Thirdly, the interviewees, after a detailed presentation of the proposed classification, have been asked about energy and non-energy benefits and losses, discussing the detail about their EEMs. In this phase, interviewees have been asked to point out whether they had either a positive or negative impacts stemming from having implemented and put in service the EEM, as well as whether it was experienced during the implementation phase or the service phase of the considered EEM. Further, we have asked whether interviewees would be able to recognize such positioning of the impact without the presented classification, as well as suggestions for further improvement, if any.

Company A

This firm is a multinational corporation working in the manufacturing and sales of glass products. In the plant considered, one of the ten located in Italy, the company produces glass bottles mostly filled with water, wine and olive oil.

The company employs 22,000 operators worldwide, 1,450 in Italy and 150 in the plant considered. Thanks to the remarkable production volumes (about 400 tons/day of glass), the yearly turnover is approximately of €80,000,000. However, because of the relevant energy consumption, a large fraction of energy must be employed for process-related activities. In particular, two different sources, electric energy and natural gas, are used within the process. Though, because of the fluctuation of the volume produced, a trustful estimate of the energy intensity is not available, even if managers believe that the each of the aforementioned energy expenditures account for a considerable share of the turnover. Among the certifications acquired by the firm, the UNI EN ISO 14001:2004 is the only that relates with the protection of the environment where the firm is operating.

As per the current law, because of the actual energy consumption of the company, the internal energy manager is a compulsory figure in the company organization chart. However, because of the geographical distribution of the production sites and the relative tasks, the interview has been carried out with the support of an internal project manager, responsible for the maintenance and involved in the control quality.

Among the broader set of EEMs analysed during the interview, three have been pointed out as effectively applicable to the case, and therefore are considered as relevant with respect to the purpose of the present study, as summarized in Table 2.

The first consists in the *application of inverters coupled with the existing motors available in the cooling towers of the plant*. Such installations bring some benefits as of the inverters, such as the reduction of noise and of the energy consumption of about 10 % and, in addition, the improvement of the performance of the same cooling towers. This analysis can be considered quite interesting thanks to the impacts perceived, for three main reasons. Firstly, it was not expected that an inverter installed in the cooling tower motors would lead to an increased productivity and a better working environment, even if it has been recognized that when the tower motors are at full load,

Table 2. EEMs analysed with Company A with Energy and Non-Energy Benefits and Losses.

EEM	Description	Energy benefits	(Service) NEBs	(Service) NELs	Impl. NEBs	Impl. NELs
A.1	Inverters on cooling towers motor	N/A	Reduced maintenance costs; Reduced wear of the equipment; Reduced impact on the local community; Improved image in society; Improved process control; Reduced emissions of noise and vibrations; Reduced addiction to external conditions	N/A	N/A	N/A
A.2	Inverters on cooling fans	N/A	Improved productivity; Reduced addiction to external conditions; Reduced maintenance costs; Improved thermal comfort; Lower cooling requirements	N/A	N/A	N/A
A.3	Energy saving dryers connected to compressors	N/A	Recycling of the wasted heat available; Improved thermal comfort; Reduced wasted heat; Improved image in society; Lower cooling requirements	N/A	N/A	Variation of the layout
A.4	Install environmental control on compressors	N/A	Improved process control; Lower cooling requirements; Increased reliability of the equipment; Reduced emissions of noise and vibrations	N/A	Improved monitoring of the system state	N/A
A.5	Inverter and IE3 motor installation on vacuum pumps	N/A	Lower heating requirements; Reduced emissions of noise and vibrations; Reduced wasted heat; Improved process control	N/A	Improved monitoring of the system state	N/A
A.6	Recover wasted heat from furnace to heat production	N/A	Improved thermal comfort; Recycling of the wasted heat available; Improved image in society; Lower heating requirements; Reduced wasted heat	N/A	N/A	N/A

the aspiration inside the plant is noisy and may cause discomfort, reducing the performance of the operators. In addition, through the adoption of the novel classification interviewees noticed that the reduction of the vapour flowing out from the cooling tower reduces the impact in terms of heat released but it also has a psychological effect on the people living nearby the plant, which are less disturbed from the cooling system itself. This second aspect had not been recognized in the evaluation phase, since the company has never received complaints regarding its emissions (vapour, heat, water or waste), but this increased sense of safety of the local community is still perceived as an attempt toward sustainability.

Another interesting measure proposed consists in the *installation of an environmental control on the air compressors*. With this intervention, the load is continuously distributed among the available air compressors in order to reduce the energy consumption and increase their overall performance. In this case, the energy saved amounts at the 10 % of the previous consumption, and it allows for a better management of the air compressors, thus reasonably extending their lifetime. Thanks to the categories of impacts introduced, it has been possible to describe with a higher level of detail the consequences of the installation of a new and more efficient control over the plant, taking into account both the core process and the operations, but also considering operators' well-being. New with respect to the previous analysis conducted by the company in the decision-making phase, the impact of the EEM on the work environment emerged during the interview, especially for what concerns the emission of noise and vibrations. In addition, it is important to point out how an Implementation NEL has been recognized, denoting that this specific category was necessary to completely describe the impact of the measure on the production departments.

Finally, the *connection of energy saving dryers to the compressors* has been considered. Through this EEM, the dryers exploit the air warmed from the compressors during the cooling process of the equipment, instead of heating air specifically with this objective. The energy savings correspond to the total consumption of the dryers before the adoption, with a negligible electric consumption. What is different, in this case, is the existence of both Service NEBs as well as Implementation NEBs.

Company B

The firm employs 430 operators working on three shifts with a turnover of approximately €52,000,000 and the energy expenses are estimated to be approximately the 3.6 % of the turnover. The company produces furniture shutters basing on orders from customers, with a Just-In-Time methodology. The process begins with a Medium-density fibreboard (MDF) panel which is

Table 3. EEMs analysed with Company B with Energy and Non-Energy Benefits and Losses.

EEM	Description	Energy benefits	(Service) NEBs	(Service) NELs	Impl. NEBs	Impl. NELs
B.1	Installation of LED lamps in substitution of Neon lamps	N/A	Improved lighting conditions; Increased reliability of the equipment; Improved product control; Increased life of the equipment	Increased maintenance costs	N/A	N/A
B.2	Installation of solenoid valves to reduce pressure to the minimum	N/A	Reduced emissions of noise and vibrations; Increased reliability of the equipment; Reduced maintenance costs; Improved process control	N/A	N/A	N/A
B.3	Aspiration of machines with depression and external air	N/A	Lower heating requirements; Increased comfort for the operators; Reduced emissions of bad smells in the environment; Reduced wasted heat; Lower air treatment requirements	N/A	N/A	N/A
B.4	Installation of an inverter on the aspiration fan	N/A	Increased reliability of the equipment; Increased comfort for the operators; Reduced maintenance costs; Reduced emissions of noise and vibrations; Reduced emissions of bad smells and dust in the environment; Reduced wear of the equipment	N/A	N/A	N/A
B.5	Spray booths under Energy Saving Management	N/A	Lower heating requirements; Reduced impact on the local community; Increased comfort for the operators; Reduced wear of equipment	N/A	N/A	N/A
B.6	Unification of compressed air distribution system	N/A	Improved monitoring of the system state; Increased reliability of the equipment; Reduced addiction to external conditions; Improved process control	N/A	N/A	N/A
B.7	Connection in parallel of the compressors and improvement of the control	N/A	Increased reliability of the equipment; Improved process control; Reduced emissions of noise and vibrations; Reduced maintenance costs; Improved monitoring of the system state	N/A	N/A	N/A

cut, polished and varnished before the packaging phase and the expedition. Among the certifications acquired from the company, any interest has been shown for those that guarantee for the environmental protection, as the UNI EN ISO 14001:2004, since customers simply does not perceive as an added value for the enterprise this type of effort. Considering the energy expenses, it is possible to conclude that the energy manager is not required from the current regulation. Thus, the interview has been conducted with the general manager responsible for the administration of the company, i.e. the Industrial Decision Maker. The findings are summarized in Table 3.

For what concerns the measures analysed, an effectively case, applicable to the present study has been provided from the *installation of LED lamps in substitution of Neon lamps* (passing from old 2 × 58 W bulbs to 56 W new lamps), with further improvements in the lighting conditions and in the liveability of the production departments involved. In this situation, lights have not been substituted because of lighting conditions considered as poor, but because of the ending life of the previously installed equipment. This is the reason why the focus of the manager was on the maintenance required by the new equipment installed, considering it both as reduced maintenance activities and as higher replacement costs. However, it has been noticed how the improved lighting conditions allow increasing the mood of the workers and, consequently, to more easily identify the presence of defects on the final products, especially after the steps in the spray booths. In addition, this measure has offered the chance to confirm the need for different impact categories. In particular, the analysis accomplished focuses on the service phase and brings to the identification of different types of impacts, both positive and negative, justifying the definition of both Service NEBs and Service NELs.

Another relevant example with respect to the purpose of this study has been the *connection in parallel the installed compressors*, together with an improvement of their control. In particular, this intervention consists in a change in the way compressors are connected one with the others; indeed, they were previously connected exclusively to one department while, after the accomplishment of the EEM, their connection has become a parallel-type, stabilizing the requested load.

The interview revealed the attention towards the operating conditions of the compressors and the following maintenance, which seems to be a crucial aspect for the company's manager. Despite this consideration, however, the increased reliability achieved through this new parallel configuration has been noticed while explaining the reduction of the maintenance costs, demonstrated by a reduction of the maintenance tasks required by the operators. This finding seem to show that the evaluation previously accomplished by the company decision-makers were not enough precise to properly judge the potential of this EEMs for the company.

Company C

Company C produces waterproofing membranes composed both by synthetic materials, as flexible polyolefin (FPO) or Polyvinyl chloride (PVC), and bituminous materials, which have been the core process of the enterprise since it was founded. The company employs 110 operators on three shifts for five or seven days per week, depending on the production line considered. The turnover reaches €79,500,000 and the energy expenses are estimated to be about €1,500,000 (energy intensity of about 1.9 % and, thus, non-negligible).

With respect to the certifications acquired, the UNI EN ISO 14001:2004 is available in the company, proving a real attention towards the environmental issue. In addition, this interest is confirmed by the compliance with the thresholds imposed by the UNI CEI EN ISO 50001:2011, even if the company has not yet acquired the certification. By considering the energy consumption, an Internal Energy Manager is available and has taken part in the interview.

By looking at the EEMs studied with the collaboration of the enterprise that are also relevant for the purpose of the present study, three interventions are here reported (Table 4). The first is the *installation of inverter on the compressor* used for providing compressed air to the production departments. Apart from the interest for the maintenance of the installed equipment, the interview revealed the need for considering the whole life of the measure and, thus, the inclusion of the service phase and the implementation phase.

Another crucial example has been provided from the *substitution of the heat exchanger of the existing cogeneration system*. This EEM had as objective the substitution of a not correctly sized heat exchanger, in order to increase the share of energy recovered from the flue gases and transferring it to oil. This substitution has allowed to reduce the consumption of natural gas by approximately €80,000/year. The analysis of this EEM, which has been accomplished consequently to a wrong sizing of the cogeneration system heat exchanger, has brought to an improved image in society since the local community lives nearby the plant and perceives the different quantity of natural gas consumed. It has been noticed that, in addition, this improved image in society reflects into a lower presence of the local policymakers and governments, who control with lower frequency the emissions of the cogeneration plant thanks to the new intervention accomplished and the reduced gas consumption. This result was unexpected in the decision-making phase, since the intervention has been designed with the objective of reducing the gas expenses and has demonstrated to have a bigger impact, which has been structured through the classification and its discussion.

Finally, it is important the consideration of *the improvement of the thermal isolation* of valves for the bitumen distribution system. This EEM allowed for a reduction of the heat dissipations related to this particular system, with a particular attention for the valves, which are the most critique component of the system. This brings to a reduction of the quantity of fuel burned and, thus, of GHG emitted. The NEB that interests the most the manager, in this case, is the monitoring of the system. During the decision-making phase, indeed, the safety of the operators, the reduced wasted heat and the heating requirement had been foreseen, while the monitoring activity was supposed to end once the implementation phase was accomplished. However, the fact that the system is always under control allows for the detection of anomalies and the definition of corrective policies before these problems becomes serious issues. In addition to this, it is important to stress that the analysis of the service phase have brought to the definition of both positive and negative effects and thus, to the identification of service NEBs and service NELs; considering, on the other hand, the lifetime of the measure, what becomes clear is a further confirmation for the need of including the implementation phase during the analysis of the same EEM.

Company D

The company here proposed has two main lines of products: semi-finished elements for the furniture industry from Medium-density fibreboard (MDF) sheets (30 %–40 % of the turnover) and flat pack furniture (60 %–70 % of the turnover). The company employs 685 operators on two shifts with a turnover that is about €300,000,000, while the energy consumption includes 28 million kWh of electric energy and among 6 MW and 10 MW of heat provided to production department. Thus, considering the actual energy expenses, the energy intensity is slightly lower than the 3 %. Among the certifications acquired from the company, exclusively the UNI EN ISO 14001:2004 relates to the environmental protection with the aim of controlling the waste treatment and, in addition, the company has invested in the FSSC and in the PEFC, that guarantee for the quality and sustainability of raw materials and final products.

Thanks to the considerable energy consumption of the company, in relation to the current regulation, an internal energy manager exists and the same energy manager has collaborated during the interview. Considering the EEMs analysed within this enterprise (Table 5), the first interesting intervention presented is the *servers virtualization of the company*. The measure was aimed at reducing the number of servers available in the production and easing the communication with offices and managers. This communication includes information about performance, state of the equipment, level of production reached and the level of raw materials available. The measure reduced the number of servers through virtualization, with sensible advantages. In relation to the proposal about the categories of benefits, it is important to highlight how the introduction in the model of the negative impacts is required and, together with this aspect, it is important to consider the implementation phase, since an implementation NEL has been identified.

In addition, the *installation of inverters on air compressors* has been analysed. The measure here proposed aims at reducing the energy consumption related to compressors; this has demonstrated to be useful since the load on the compressors

Table 4. EEMs analysed with Company C with Energy and Non-Energy Benefits and Losses.

EEM	Description	Energy benefits	(Service) NEBs	(Service) NELs	Impl. NEBs	Impl. NELs
C.1	Installation of inverter on compressors	N/A	Reduced emissions of noise and vibrations; Improved process control; Reduced maintenance costs; Reduced wear of equipment/ Increased equipment life; Lower cooling requirements	N/A	Improved system monitoring	N/A
C.2	Installation of LED lamps instead of older lamps	N/A	Improved thermal comfort; Improved lighting conditions; Increased reliability of the equipment	Increased purchase of ancillary materials	N/A	N/A
C.3	Improvement of thermal insulation of the valves of bitumen distribution system	€100,000/year saved	Increased safety of the worker; Improved thermal comfort; Lower cooling requirements; Reduced wasted fuel	Higher heating requirements	Improved system monitoring	N/A
C.4	Change of the heat exchanger of the cogeneration system	€80,000/ year saved; Reduced emissions of pollutants	Reduced wasted fuel and heat; Improved image in society	N/A	Improved system monitoring	N/A

is not steady and, thus, the power absorbed could be sensibly reduced. Even in this case, it has been demonstrated the need to define both the phases here presented, since both implementation and service NEBs are available.

The same situation occurs for the *installation of inverter in the aspiration of the edging machines*. This measure consists in the installation of inverters on the aspiration on edging machines; this precise aspiration uses air taken from inside the production, which is filtered and expelled in the environment. Once the machines are operating with lower load, the dust emitted is reduced but the quantity of air used for this purpose remains the same. The intervention has been accomplished with the purpose or reducing the air expelled through the aspiration during lower operating levels, reducing the air treatment costs. The inclusion of both the implementation and the service phases helps to provide a proof of the completeness of the description provided in this way.

Company E

The company here proposed is a corporation that designs and construct moulds to be employed especially in the automotive sector. Consequently, each product is a unique part, totally tailored on the request of the customer. The firm employs 54 operators with a turnover of approximately €11,000,000, even if this value is characterized from a high fluctuation (+36 % with respect to the previous fiscal year). The total energy expenses are equivalent to the 0.9 % of the turnover, thus equivalent to about €100,000, required mostly for electric energy. The only certification acquired is the UNI EN ISO 9001:2008, which relates to the quality of the production and is strictly required from the customers, in order to maintain the whole customers' supply chain under a trusted quality system and, consequently, any particular effort towards the environmental protection has been accomplished by the management of the company. Because of the actual energy consumption, an internal energy manager is not required by current regulation and, thus, the interview has been conducted with one of the top manager of the company.

Among the measures analysed, one is considered to be more interesting than the others with respect to the purpose of the present study, i.e. the *installation of skylight on the roof to increase the use of daylight*. It is possible to say that the intervention has been accomplished mostly in order to improve the lighting conditions with the aim of improving the production supervision and control, which starts with a visual inspection after each working phase, even if a higher effort for the air conditioning is required. However, as happened in the previous measures considered, there are not exclusively benefits deriving from the measure itself. Moreover, in this specific case, the relative weight of other type of impacts, i.e. the service NELs, is considerably high.

Concluding remarks and further research

Combining all the interviewed above reported, what is obtained, exploiting a representation similar to the one used in Figure 2, is proposed in Figure 3.

From the study, it seems clear that Service NEBs are those impacts perceived by each of the firm. On the other hand, not all the other companies perceive the remaining categories of impacts defined within this classification, but all the primary impacts of both phases are considered and have been perceived during the analysis of the EEMs, while the energy benefits have been precisely evaluated just in one case.

Table 5. EEMs analysed with Company D with Energy and Non-Energy Benefits and Losses.

EEM	Description	Energy benefits	(Service) NEBs	(Service) NELs	Implementation NEBs	Implementation NELs
D.1	Improved thermal insulation of the buildings	N/A	Lower heating requirements; Lower cooling requirements; Improved thermal comfort; Improved productivity; Reduced air treatments requirements; Increased value of the estate	N/A	N/A	N/A
D.2	Servers virtualization of the company	N/A	Lower cooling requirements; Reduced maintenance costs; Improved monitoring of the system state	N/A	N/A	Variation of the layout
D.3	Installation of eco-save bulb and LED lamps instead of older/less efficient lamps	N/A	Improved thermal comfort; Improved lighting conditions; Improved product control; Reduced maintenance costs; Increased equipment life; Increased safety of the worker	N/A	N/A	N/A
D.4	Definition of a new control for the compressors	N/A	Lower cooling requirements; Reduced emissions of noise and vibrations; Reduced wear of equipment; Achievement of rebates or incentives; Reduced impact on the local community	N/A	Improved monitoring of the system state	N/A
D.5	Installation of \ inverters on the compressors	N/A	Lower cooling requirements; Reduced wear of equipment; Increased reliability of the equipment; Reduced maintenance costs; Reduced emissions of noise and vibrations (IO)	N/A	Improved monitoring of the system state	N/A
D.6	Installation of inverters on the motors used in production	N/A	Reduced wear of equipment; Improved process control; Increased reliability of the equipment; Reduced maintenance costs; Reduced emissions of noise and vibrations	N/A	N/A	N/A
D.7	Installation of high efficiency motors	N/A	Reduced maintenance costs; Reduced emissions of noise and vibrations; Improved thermal comfort; Improved productivity; Lower cooling requirements	N/A	N/A	N/A
D.8	Installation of inverter in the aspiration of the edging machines	N/A	Lower cooling requirements; Reduced emissions of noise and vibrations; Reduced air treatments requirements; Reduced impact on the local community	N/A	Improved monitoring of the system state	N/A
D.9	Optimization of the logistic of WIP and products	N/A	Reduced wasted fuels; Reduced labor costs; Avoided/delayed costs; Reduced emissions of pollutants and other gasses; Lower heating and/or cooling requirements	N/A	N/A	N/A
D.10	Power factor compensation after electric transfer room	N/A	Reduced wear of equipment; Reduced maintenance costs; Improved comfort of the operators; Increased reliability of the equipment	N/A	N/A	N/A

Table 6. EEMs analysed with Company E with Energy and Non-Energy Benefits and Losses.

EEM	Description	Energy benefits	(Service) NEBs	(Service) NELs	Implementation NEBs	Implementation NELs
E.1	Installation of skylight on the roof to increase the use of daylight	N/A	Reduced maintenance costs; Improved product control; Increased equipment life; Increased influence on customers; Improved lighting conditions	Higher cooling requirements (cold season); Higher heating requirements (warm season)	N/A	N/A
E.2	Heat recovery from the air generated form the compressors available	N/A	Lower heating requirements; Improved thermal comfort; Improved product quality; Improved process control	N/A	N/A	N/A
E.3	Installation of new compressors equipped with inverter	N/A	Reduced emissions of noise and vibrations; Reduced production costs; Improved process control; Reduced maintenance costs; Improved product quality	N/A	N/A	N/A

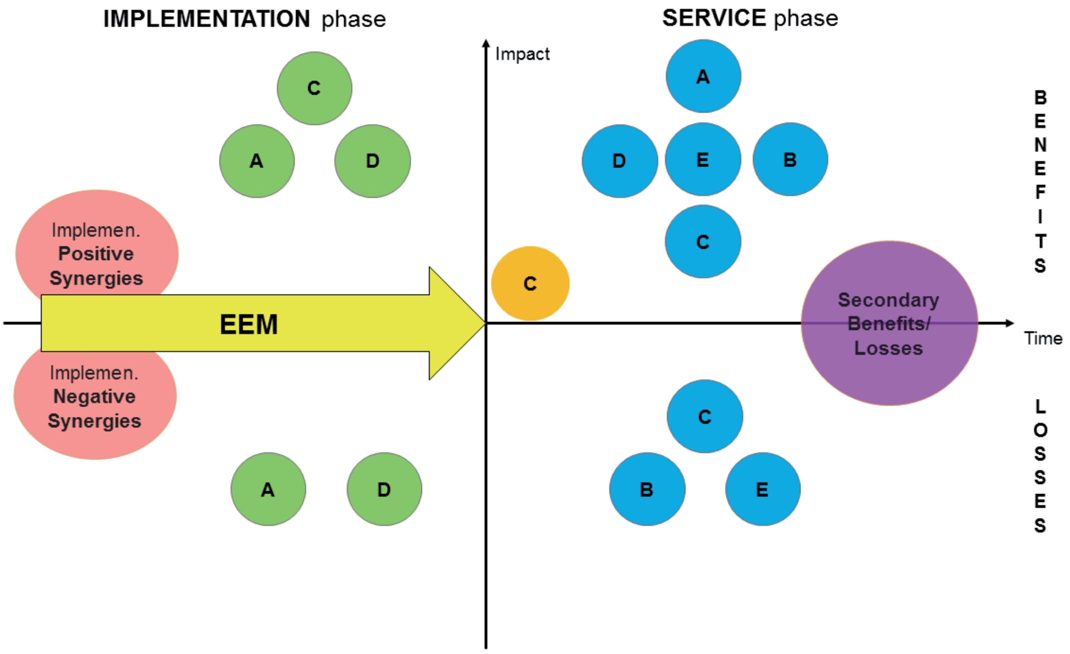

Figure 3. Synthetic results of the interview accomplished.

Basing on these considerations, it is possible to draw some conclusions about the classification and its utilization in the analysis of the EEMs. First, the definition of the two phases for the life of the EEM has been considered an interesting improvement in the evaluation of the measures, since the managers interviewed have confirmed that the previous approaches were overlooking the relevance of the time window assigned to the installation & implementation phase. In addition, a great relevance has been acquired by the clear definition of the negative impacts (perceived along the entire life of the EEM) and, thanks to the way they are analysed within the measure, it has been strongly appreciated the opportunity to accomplish a deeper analysis of the EEMs considered, with the discovery of new impacts, not even considered during the decision-making phase. In alternative, thanks to the new structure of the classification, it has been possible to re-define the nature of certain impacts that had been taken into account with a misleading nature and insufficient attention.

The present study has offered some useful insights for a new framework for the evaluation of the consequences deriving from the adoption of an EEM in an industrial plant. The main conclusion that can be gathered, as above mentioned, is the role played from the implementation phase, which strongly influences the final judgment concerning the EEM under evaluation. This does not mean that the Implementation phase is prevalent with respect to the Service phase, but rather that the Implementation – which is considered to include both the disposal of the non-efficient equipment, whether available, and the installation of the new one – has a strong a higher importance than that so far deserved. This is the reason why the enlargement of the focus with respect to the time axis was appreciated, also thanks to the feedbacks received from the managers interviewed.

The combination of this subdivision with the definition of the positive and negative impacts have brought to the definition of several categories of impacts. Thanks to the sampled case studies, such impacts have shown their suitability for an industrial decision-maker, who can improve the foresee regarding the behaviour of the EEM along its entire lifetime, improving the actions for maximizing the positive impacts in both phases (and, possibly, reducing the losses). As for example considering EEM #2 in Company D (see Table 2 for further detail), the perceived Implementation NEL is the Variation to the layout caused by the EEM; however, with a design accomplished in advance with respect to the implementation, it may also bring to an improvement in the working environment or in the process realized through the equipment installed.

As further research opportunities, a more thorough definition of the categories of the benefits and possible characteristics that these must have seems to be needed. This would be just a preliminary step towards a thorough framework describing the effects and suitable for a wider investigation. The definition of different characteristics regarding both the impacts and the way they are defined may enhance the analysis of the EEMs with respect to the Industrial Decision Maker perspective and, in addition, could be extended to the impacts perceived from the same decision maker, obtaining an exact description of the situation consequent to the adoption of the considered EEM.

These attributes and the characteristics could highlight different points of view and different perceptions existing in the same company at different levels but also could highlight different perception among companies with similar characteristics. This last aspect, in particular, could be interesting for the policy makers and the actors belonging at the Energy Efficiency Supply Chain, who could improve their performances knowing what companies effectively consider when evaluate the adoption of EEMs.

References

Cagno, E. & Trianni, A., 2013. Exploring Drivers for Energy Efficiency within Small- and Medium-sized Enterprises: First Evidences from Italian Manufacturing Enterprises. Applied Energy, 104, 276–285.

Cagno, E., Worrell, E., Trianni, A. & Pugliese, G., 2013. A novel approach for barriers to industrial energy efficiency. Renewable and Sustainable Energy Reviews, 19, 290–308.

[EIA], Energy Information Administration, 2011. International Energy Outlook 2011. U.S. Energy Information Administration Office of Integrated and International Energy Analysis U.S. Department of Energy, Washington, DC 20585, report no. DOE/EIA0484(2011), available at: http://www.eia.gov/ieo.

[EIA], Energy Information Administration, 2014. International Energy Outlook 2014. U.S. Energy Information Administration Office of Integrated and International Energy Analysis U.S. Department of Energy, Washington, DC 20585, report no. DOE/EIA0484(2014), available at: http://www.eia.gov/ieo.

Fleiter, T., Schleich, J. & Ravivanpong, P., 2012. Adoption of energy-efficiency measures in SMEs – An empirical analysis based on energy audit data from Germany. Energy Policy 51 (2012): 863–875.

Heffner, G. & Campbell, N., 2011. Evaluating the co-benefits of low-income energy-efficiency programmes. Workshop Report, OECD/IEA, Paris, available at: https://www.iea.org/publications/freepublications/publication/low_income_energy_efficiency.pdf.

Palm, J. & Thollander, P., 2010. An interdisciplinary perspective on industrial energy efficiency. Applied Energy, 87 (10), 3255–3261.

Skumatz, L. A. & Gardner, J., 2005. Methods and results for measuring non-energy benefits in the commercial and industrial sectors. Proceedings of ACEEE Summer Study on Energy Efficiency in Industry: Cutting the High Cost of Energy. West Point, New York, 163–176.

Trianni, A., Cagno, E., Moschetta, D., 2016. The need for a new approach in NEBs classification. Proceedings of the 2016 American Council for an Energy-Efficient Economy Summer Study on Energy Productivity. Sydney: ACEEE.

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

Appendix

Table A.1. Overview of literature contribution on Non-Energy Benefits for industrial energy efficiency measures.

Authors	Year	Type	Focus	Implementation/Service phase	Benefits/Losses
Benemnt and Skumatz	2007	Conference proceedings	Commercial and Industrial sector	Service phase	Benefits and Losses
Boyd and Pang	2000	Journal – Energy policy	Industrial sector	Service phase	Benefits
Bozorgi	2015	Journal – Energy Efficiency	Real estate	Service phase	Benefits and Losses
Bunse et al.	2011	Journal of Cleaner Production	Industrial sector	Service phase	Benefits
Cooremans	2011	Journal – Energy efficiency	Industrial sector	Service phase	Benefits
Elliott et al.	1997	Conference proceedings	Industrial sector	Service phase	Benefits
Finman and Laitner	2001	Conference proceedings	Industrial sector	Service phase	Benefits
Finster and Hernke	2014	Journal of Industrial Ecology	Industrial sector	Service phase	Benefits
Fleiter et al.	2012	Journal – Energy policy	Industrial sector and policy makers	Service phase	Benefits and Losses
Giannantoni	2009	Conference proceedings	Policy makers	Service phase	Benefits and Losses
Gillingham et al.	2004	Report	Policy makers	Service phase	Benefits
Hall and Roth	2004	Conference proceedings	Commercial and Industrial sector	Service phase	Benefits
Hall and Roth	2003	Report	Policy makers	Service phase	Benefits
Heffner and Campbell	2012	Report	Policy makers	Service phase	Benefits and Losses
IEA	2015	Report	Policy makers	Service phase	Benefits
IEA	2014	Report	Policy makers	Service phase	Benefits
Imbierowicz and Skumatz	2004	Conference proceedings	Policy makers	Service phase	Benefits and Losses
Laitner et al.	2001	Conference proceedings	Industrial sector	Service phase	Benefits
Lilly and Pearson	1999	Report	Industrial sector	Service phase	Benefits
Lung et al.	2005	Conference proceedings	Industrial sector	Service phase	Benefits
Worrell et al.	2002	Report	Industrial sector	Service phase	Benefits
Mills and Rosenfelds	1996	Journal – Energy	Industrial sector	Service phase	Benefits
Pearson and Skumatz	2002	Report	Commercial sector	Service phase	Benefits and Losses
Piette and Nordman	1996	Conference proceedings	Commercial and Industrial sector	Service phase/Implementation phase	Benefits and Losses
Pye and McKane	1999	Conference proceedings	Industrial sector	Service phase	Benefits
Pye and McKane	2000	Journal – Resources, Conservation and Recycling	Industrial sector	Service phase	Benefits
Ryan and Campbell	2012	Report	Policy makers	Service phase	Benefits and Losses
Skumatz and Gardner	1997	Report	Industrial sector	Service phase	Benefits and Losses
Skumatz and Dickerson	1998	Conference proceedings	Industrial sector	Service phase	Benefits
Skumatz and Gardner	2005	Conference proceedings	Commercial and Industrial sector	Service phase	Benefits and Losses
Skumatz et al.	2000	Conference proceedings	Residential sector	Service phase	Benefits
Smith-McClain et al.	2006	Conference proceedings	Residential and commercial sector	Service phase	Benefits and Losses
Trianni et al.	2014	Journal	Industrial sector	Service phase	Benefits and Losses
Trianni et al.	2016	Conference proceedings	Industrial sector	Service phase/Implementation phase	Benefits and Losses
Vine	2011	Report	Policy makers	Service phase	Benefits
Vine et al.	2000	Journal – Energy	Insurance, industrial sector, policy makers	Service phase	Benefits
Worrell et al.	2003	Journal – Energy	Industrial sector	Service phase	Benefits
Zhang et al.	2015	Journal – Applied Energy	Industrial sector	Service phase	Benefits
Zhang et al.	2014	Journal – Energy	Industrial sector	Service phase	Benefits