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Energy-efficient technologies and barriers to energy efficiency in manufacturing SMEs

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“God has shed His Grace, through a human face”

to Maria, Davide and Teresa

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1 Introduction

1.1 The relevance of the research topic

In the last 10 years the world is facing an impressive growth of primary energy demand, with an inversion of the role of non-OECD economies (mainly China and India) that, since 2008, have overcome the demand of the developed economies.

In particular the projections for 2035 provided by the most relevant international agencies [1] forecast the Chinese primary energy consumption to be almost double with respect to the American one.

Moreover, due to the heavy reliance on fossil fuels, the emissions of greenhouse gases (GHG, in particular of CO_2) in developing countries (usually called “coal economies”) have been foreseen to grow from 30 billion metric tons to even more than 40 billion metric tons: in this sense by 2028 studies [2] estimate China to overcome the emissions of United States, European Union and Japan. Therefore, energy has become a global concern on the public agenda.

In this respect several policies, and in particular the European Directive 2009/28-33 [3] aims at tackling these issues through, by year 2020, a reduction of 20% of the GHG emissions, increasing the share of primary energy produced through renewable energy sources to 20%, and reducing, with respect to the consumption of 1990, the energy consumption of 20%.

The efforts conducted on the three streams by European Countries are producing contradictory results: in particular, keeping the current trends, if the objectives of reducing GHG emissions and increase the share of renewables seem to be achievable, this is not true for the reduction of energy consumption. Indeed, with current trends, only 10% will be reached [4].Therefore, it is apparent the strategic role played by energy efficiency, that should be fostered at any level, in residential, industrial, commercial and transportation sectors.

A primary role for increasing energy efficiency can be played by industry, that is responsible of about 50% of the total energy delivered [1], and for which energy efficiency could not only represent a viable solution for reducing energy costs, rather than an opportunity to be really exploited since is “linked to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits” [5].

Focusing on the structure of the industrial sector, firstly, it can be observed that is largely composed (>99% in almost all countries) of Small and Medium Enterprises (then SMEs), that also cover a consistent portion of the domestic industrial consumption (in some cases, as from elaborations from the most recent estimations in Italy, more than 60% [6]); and, secondly, in industry, the non-energy intensive manufacturing activities, as showed by recent estimates, cover about 40% of the industrial consumption [1].

Moreover, an interesting study recently conducted by the Observatory of European SMEs (led by the European Commission) [7] has reported that “the overall picture is surprisingly unfavorable: close to two thirds of SMEs operating in the EU do not even have simple rules or devices for energy saving (63%). Less than three in 10 SMEs (29%) have instituted some measures for preserving energy and resources at their enterprise. Only 4% of EU SMEs have a comprehensive system in place for energy efficiency”.

As a consequence, in order to promote the most effective and successful policies to enhance industrial energy efficiency, it is crucial on one side to understand the critical areas for energy efficiency within SMEs, identifying and characterizing the enhancement opportunities – in terms both of technologies but also practices -, on the other side to understand the obstacles to the adoption of such technologies, i.e. the barriers.

Therefore, in the dissertation two main objectives have been defined and addressed:

RO.1: to develop a methodology able to measure the operational energy efficiency level and analyze the energy efficiency Best Available Technologies and Practices (BAT/Ps) in manufacturing SMEs.

RO.2: to develop a new taxonomy for the identification and evaluation of the barriers that limit the implementation of energy efficiency interventions in the industrial sector.

1.2 Structure of the dissertation

To properly address the RO.1, Chapter 2 and 3 will be respectively devoted to the development of a new methodology for energy assessment and the identification and characterization of the most effective energy-efficient technologies for manufacturing SMEs. Chapter 4, 5 and 6 have been devoted to the RO.2, with an identification, classification and evaluation of the barriers through a novel taxonomy specifically developed. In chapter 7 I will draw the summary conclusions of my dissertation.

The introduction of Chapter 2 (Section 2.1) will be devoted to understand the critical issues for energy efficiency in SMEs and the possible solutions, showing how an energy assessment could not only be merely seen as an audit, rather as a means to promote the technological transfer of the BAT/Ps towards SMEs, and describing the characteristics of existing audit methodologies. Stemming from the point above, the introduction is concluded with the definition of the characteristics of an effective energy assessment methodology within SMEs, in order to really promote the technological transfer of BAT/Ps. In Section 2.2 I detail the features of the new assessment methodology. On one side an indicator, Criticality Index, has been developed, able to consider the main criticalities, in terms of energy consumption, for each part of the enterprise's production system. On the other side, another indicator, Enhancement Index, has been developed, able to point out clearly the existing gap between the status quo of the enterprise with respect to the existing BAT/Ps, giving an estimation of the potential improvement. Merging the two indicators allows immediately to obtain a final indicator, Priority Index, encompassing all the preliminary technical and economic features of the most effective energy-efficient technologies to be suggested to the enterprise. In Section 2.3 I present the application of the methodology to validate it in several case studies, drawing in Section 2.4 the conclusions.

The effectiveness of the methodology presented in Chapter 2 is strictly related to the identification and characterization of the most effective energy-efficient technologies. Therefore, Chapter 3 has been devoted to analyze the BAT/Ps within SMEs in three main manufacturing sectors. Thus, after an introduction on the main issues of SMEs for energy efficiency (Section 3.1), in Section 3.2 I have presented how the comparison of Italian and Northern-American data about energy-efficient technologies within the industrial manufacturing sectors will be conducted. In Section 3.3 the comparison has been carried out, showing the correspondence of the BAT/Ps in terms of most diffused, highest energy saving and shortest return of the investment, putting in evidence commonalities and differences both for sector and firm's size. In Section 3.4, among the conclusions and further research issues, I have put in evidence that this first contribution in the research in which I have showed the correspondence of the characteristics and parameters of the BATP/s, open the research to a wider, more detailed and (statistical) significant analysis of the correspondence, within Western industrialized countries, of the energy efficiency practices.

Starting from the characterization of the BAT/Ps, it is apparent that some obstacles to the effective implementation exist, i.e. the barriers. Therefore, Chapter 4, 5 and 6 will be devoted to investigate this topic.

In this respect, Chapter 4 will present a preliminary investigation conducted in this topic. After a brief introduction on barriers to industrial energy efficiency (Section 4.1), Section 4.2 shows briefly that the debate on barriers in the literature is still open, since a unique classification of them is still lacking, the current taxonomies present several issues in classifying the barriers (in terms of overlaps and interactions among them), and also that SMEs are usually neglected in the empirical investigation of barriers. Therefore, Section 4.3 has tried to perform, starting from the characteristics of SMEs, a preliminary set of questions to be proposed to a sample of SMEs in Northern Italy, described in Section 4.4.Section 4.5 will present several interesting results of the barriers by firm's size, sector, and previous experience with respect to energy efficiency, showing the importance of avoiding bundling together SMEs when investigating the barriers to energy efficiency. Section 4.6 will be devoted to show a preliminary analysis of correlation among the barriers, showing further evidences of the possible existence of mechanisms and dynamics leading to barriers. In the conclusions of the chapter (Section 4.7), some importance further research issues on the topic to be addressed have been presented.

The preliminary investigation provided several suggestions for the development of a new holistic (in terms of both theory and practice) approach to barriers to energy efficiency, that is the object of Chapter 5. Indeed, after an introduction on the topic (Section 5.1), the literature review (Section 5.2) presents the current taxonomies to barriers to energy efficiency, arising several issues to be addressed that show the need to develop a new taxonomy (Section 5.3), in particular due to missing elements, overlaps and the so-called “implicit interactions”. Section 5.4 represents the core of the chapter, in which all the elements and features of the new taxonomy have been proposed and discussed, showing: the actors involved, the perspective of enterprises affected by the barriers, the effect of the barriers on the decision-making process and on the investments on energy-efficient technologies, and the existing relationships between the barriers. Section 5.5 contains the conclusions and the suggestions for validating the new taxonomy and for future research.

Starting from the taxonomy developed in Chapter 5, in Chapter 6 I present an empirical investigation of the new approach among SMEs. Therefore, after recalling in Section 6.1 and 6.2 respectively the importance of studying barriers for industrial energy efficiency and recalling the theoretical approach followed, in Section 6.3 I describe the methodology adopted to empirically investigate the barriers, in terms of how the study has been conducted and results collected. Section 6.4 will be devoted to the presentation and discussion of results, showing the existing differences between what enterprises perceive as barriers and what are the real ones, and their effects on the decision-making process. Section 6.4 contains also an investigation of the barriers with respect to several characteristics, some more usually related to energy efficiency (i.e. firm's size and energy expenditures), others related to the complexity of the enterprise (i.e. complexity of the production, demand variability, strength of the competitors). The results coming from those analyses represent the starting points for future research presented in Section 6.5.

As the reader may notice, some of the chapters of this dissertation are papers published or submitted in the last years. The consequence is that, in some cases, the background of the research may result to be repeated in more chapters. Nonetheless, for readers interested exclusively in part of my dissertation, it would be possible to address straightforwardly the interested section. For a reader interested in the whole dissertation, part of the introductive paragraphs can be easily skipped.

1.3 Bibliography of the Chapter

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2 Quick-E-Scan: a Methodology for the Energy Scan of SMEs

This chapter reports the content of the work published as:

Cagno, E, P Trucco, A Trianni, e G Sala. «Quick-E-scan: A methodology for the energy scan of SMEs.» Energy 35 (2010): 1916-1926.

The previous work that provided useful contributions on the topic is:

Cagno E., Sala G., Trianni A., Trucco P.. «A modular energy scan model for SMEs.» Proceedings of Energy Engineering, Economics and Policy (EEEP) 2009. Orlando, FL, USA, 2009.

This paper introduces the Quick-E-Scan methodology that has been developed to achieve the operational energy efficiency of small & medium enterprises (SMEs), characterized by being scarcely disposed to long energy audits and by a limited budget for energy management programs. On one side, through dividing the firm into functional units – either service (lighting, HVAC, etc.) or production units – the main consuming areas are identified and a criticality index is defined; conversely, an enhancement index highlights the gap of each unit towards the best available techniques (BATs) in energy management programs. Finally, a priority index, created with the junction of the two indexes, points out the most profitable areas in which energy saving measures should be implemented. The methodology, particularly quick and simple, has been successfully tested in 38 SMEs in Northern Italy.

2.1 Introduction

The global concern about energy is raising due to two main issues: on one side, the need to reduce the greenhouse gasses emissions – or, widely, reducing the environmental impact of the production and use of energy – and the need of a better use of the limited energy resources, for which the perception of scarcity made the previsions on future prices strongly affected by large uncertainties. The most promising solutions that seem to be viable are a widespread deployment of renewable energy sources (RES), and energy efficiency, that is, in some way, the best available renewable energy source.

Although proper RES are slowly finding a way through, there are still several barriers, mainly economic and cultural, that are limiting their full deployment. This is proven by the fact that, even considering favorable scenarios of policies that may strongly support and incentive RES, the share of non-Hydro RES in Electricity Generation will range between 10% (North America) and 23 % (OECD Europe) [1-2].

Thus the increase of energy efficiency will play a primary role to guarantee the objectives above expressed. The growing interest towards this topic is due to the strict connection of consumption and industrial costs, in particular when, as now, crisis have forced to better use the existing resources. Energy efficiency, that includes the reduction of the energy expenditures, but it is not limited to, can be pursued through a wise energy procurement (called “administrative energy efficiency”, e.g. reducing the specific price of a given source) but it would be much more effective – for the system as a whole – to directly reduce the consumption, with an increase of the so-called “operational energy efficiency”.

In recent times both Governments and policy makers have been strongly committed to reach a common environmental and energetic policy. Since now strong effort has been devoted to achieve the energy performance of buildings [3-8] and dwellings, but very few in the industrial sector [9], and mainly with high level analyses of national energy efficiency programs [see, for example, 12-14], although the industrial sector covers about 30% of the consumption (second after transportation) [2]. In particular, to be fully effective, Governments should take measures considering Small Medium Enterprises (SMEs), usually less efficient than Large Enterprises (LEs) and since – considering Europe but in some extent also North America – they represent more than 99% of the total number of industries and consume about 40% of the total for the sector. The attention towards SMEs is needed for several reasons:

1) a SME does not own an internal structure able to be focused on energy consumptions, and even it does not have the chance to. In SMEs it is quite diffused that the entrepreneur has to cover a number of different roles: operations, safety, administration, sales, marketing, planning, and he/she may also be employed within the factory. Briefly, energy is just one of the issues, there is not a specified focus on it;
2) consequently to point 1, the time devoted to energy efficiency activities is usually quite limited;
3) compared to LEs, SMEs have a limited access to the know-how of energy efficiency management and practices, easily represented by much more limited economic resources devoted to energy efficiency analyses and measures;

4) there is a strong financial barrier, identified in several studies [see, for example, 14,16]: usually pay-back-times (PBTs) of more than 2-3 years are considered, as prohibitive for SMEs, while generally LEs can afford investments for even more than 8-10 years;
5) need of matching immediately the problems emerged during an energy check-up with the respective solutions that may be implemented;
6) SMEs, just for their structure – small and medium – do present a variety of situations (in terms of technologies and processes adopted) much more extended with respect to LEs.

Considering the issues described above, it is possible to draw some considerations:

- ✓ point 1 will probably be unsolved, since SMEs' entrepreneurs will probably keep covering different roles within the firm, and there is still not a unique and clear solution to enhance their attitude towards the energy issue compared to other issues;
- ✓ SMEs prefer the technological transfer of Best Available Technologies/Practices (BAT/Ps) respect to full innovation measures, since BAT/Ps have been successfully (in terms of costs and benefits) implemented somewhere, thus with an accessible (also from an economical point-of-view) know-how. Furthermore, solely the implementation of BAT/Ps is able to guarantee the best level of energy efficiency available in the market;
- ✓ the implementation of BAT/Ps responds to most of the issues, except from point 4 and point 2, referred to the so-called "disturbance".

Moreover, it emerges the need of an energy scan methodology to evaluate the "operational" energy efficiency, since solely an energy scan is able to clearly identify the most critical points within a firm and define the energy saving opportunities [10-11]. The energy audit is composed by four main activities: initiating, preparing, executing and reporting.

More in general, the energy audit can be performed with different depths of analysis, according to the needs of the firm, easily referable to three categories: walk–through, mini–audit, and maxi–audit.

As a consequence, with a selection of the appropriate type of audit for the given production plant, it is possible to perform the best analysis with the available effort of both time and budget. Below a brief description of three types of audit is provided.

Walk–Through Audit: alternatively called simple audit, screening audit or preliminary audit, it is the simplest and quickest type of audit; it involves minimal interviews with site operating employees, a brief review of the facility bills and other operating data, and a walk-through of the facility to become aware of the possible areas of energy waste or inefficiency.

Mini–Audit: alternatively called single-purpose audit, it can be considered as an expansion of the walk-through audit described above, by collecting more detailed information on facility performances and for a more detailed evaluation of energy savings opportunities, included a financial analysis of the needed investments.

Maxi–Audit: it provides a dynamic and detailed energy project implementation plan for a given firm. This type of audit uses computer models to simulate buildings and equipment operations based on weather, equipment set points, hours of operation, etc.; one of its key elements is the energy balance, using an inventory of energy-using systems, assumptions of current operating conditions and calculations of energy use, then compared to the firm bill charges. Obviously, the effort in more accurate estimates of energy savings is paid by higher audit costs.

After this brief overview, it can be concluded that energy audits could be a good starting point that provides the guidelines for a more detailed analysis, but the actions suggested after the audit often depends on auditor's experience and knowledge. Moreover, a more detailed audit may provide excellent results, but the deep and long analysis of any energy stream into the production plants – with direct measures of energy consumption and frequent inspections – is not attractive for the firm's stakeholders, especially in the case of SMEs.

Nonetheless, considering SMEs, with the critical points described above, an energy scan methodology should have the following characteristics:

- ✓ it should need an analysis of the firm as quick as possible – usually a *walk-through audit* –, in order to reduce the "disturbance" due to the plant's energy audit;
- ✓ it should be very fast in suggesting the needed actions to work out the critical areas that have been identified in the energy audit;
- ✓ it should be able to *focus highly* the needed actions (e.g. it should suggest clearly to substitute some lamps within the lighting system with others of a more efficient type, not only to suggest to act in the lighting system);

- ✓ it should propose a list of actions that might be chosen, considering that energy does not represent the unique focus of the entrepreneur;
- ✓ the actions suggested should be exclusively BAT/Ps in order to guarantee the best level of energy efficiency effectively achievable;
- ✓ it should provide immediately a monetary estimation of savings and implementation costs, so that it should be easy to evaluate the economic burden and the financial exposure due to the full implementation of the actions;
- ✓ it should be able to modify and tune the suggested actions (in economic terms) according to some parameters that characterize the firm.

2.2 A new methodology for the energy assessment

The methodology proposed in this study has been entirely developed to increase the energy efficiency of firms, paying attention to the quick identification of the most profitable areas of improvement and selecting at the same time the needed actions – technological and/or organizational – to take advantage from the BAT/Ps for energy saving. Moreover, this new methodology aims at providing an important contribution on the development of assessment methods guidelines.

Entirely developed focusing on the SMEs' needs, the Quick-E-Scan aims at having the smallest impact on the plant's normal operations: in particular, it does not require the plant stop and it is totally "modular" in order to be adapted both to the variety of manufacturing firms and to the investigation level desired by the auditors. Nevertheless, those characteristics could extend the application of the methodology to LEsand beyond the manufacturing sector, although not analyzed in this study. The effectiveness of the methodology totally depends on the availability of a rich documentation on BATs, covering a large variety of intervention types in different industrial sectors.

The tool developed is, in the end, an energy audit assessment methodology that, starting from a walk-through audit, allows the auditors to get immediately familiar with the firm's characteristics, pointing out the most critical energy consumption areas - compared with BAT/Ps – and organize them on the potential energy savings. The result of this brief and focused audit is a consumption map with some "warning points" in which the firm has to focus its attention in order to raise its operational energy efficiency.

2.2.1 The Criticality Index

According to this new methodology, a given production plant can be divided into several Functional Units (FUs), homogeneous for different criteria (e.g. main energy resources used, management, technology, etc.), thus creating some “Service Units” (related to the production and distribution of different service systems, like compressed air, heating, air conditioning, etc., and shared by the whole production processes) and some “Production Units”, specifically addressed to the firm’s characteristics, i.e. production lines, etc. In the methodology it is possible to change the analysis detail and shape the analysis to match the characteristics of the firm: this modularity of the methodology has proven to be particularly important for SMEs, since they presents many differences between each other and difficulties to map the processes and the technologies adopted. Furthermore, a quick division of the production plant into FUs reduces the audit’s duration and consequently the “disturbance” of the energy efficiency analysis.

Once functional units are created, either Service or Production, they can be observed by different Energetic Vectors (i.e. electricity, gas consumption, etc.) and, through them, costs and environmental impact can be evaluated.

In detail, the expenditures related to the physical energy consumption can be either directly measured by a datalog or estimated through the rated load of the machines/services and experience of the plant’s operators. In this case, depending on the availability of the firm, more information will lead to a more focused estimation of energy expenditures and more punctual actions suggested.

Once expenditures have been estimated, the cost data shall be organized in a matrix like in Figure 1 divided into four main quadrants or sub-matrixes:

- I quadrant: considering that it takes into account the Service Units both in the rows and columns, it’s always a diagonal matrix;
- II quadrant: considering that service systems are usually well described by the energetic vectors (Service Units) it is generally a null matrix;
- III quadrant: this matrix is non-null if a Functional Unit has an own service system;
- IV quadrant: this matrix takes into account the existing relationship between the FUs and the five typical energetic vectors of manufacturing firms. As a matter of example, a lathe unit will have only an electricity resource consumption (for its

actuating systems) while a plastic production unit will have both a thermal and electricity consumption.

Criticality Index	Compressed Air	Lighting	Steam Generation	HVAC	Electric Appliances	Heat Electric Source	Heat Fuel Source	Oven	Chilling plant
Compressed Air									
Lighting			I				II		
Steam Generation									
HVAC									
UF Generic 1									
UF Generic 2			III				IV		
UF Generic 3									
UF Generic 4									
UF Generic 5									

Figure 1 Functional units and energetic vectors matrix relative to energy consumption

Once each FU total cost is calculated, each non-null value in the matrix can be weighted considering its contribution on the total cost and providing a normalized (on 10 basis) "score". In particular:

$$scoreCost_i = \frac{CT_i}{\sum_i^{\#\ cells} CT_i} \cdot 10 \qquad (1)$$

where:

- $scoreCost_i$ = score for energetic cost of the i-th cell;
- CT_i = energetic cost for the i-th cell.

At this level,both the deployment of the energy consumption and the cost deployment on the different Functional Units can also be observed: nevertheless, the data collection allows the auditors to double-check the consumption estimations provided by the operators and compare them to the bills paid by the firm.

In synthesis, the *scoreCost* index represents the division (normalized to 10) of the firm's energy expenditures respect to each FU and energetic vector: higher the value, higher the importance of a given FU and of a given vector.

Furthermore, operating in a very similar way, all the energetic vectors can be associated to the FUs, allowing the firm to consider the environmental impact - through either direct measurements or estimations - of the given energy resource, according to the existing Impact Assessment techniques [see for example, 18]. In particular, once the environmental impacts of each FU are considered, a score on 10 basis related to the environmental impact in the FUs – Energetic Vectors can be produced:

$$scoreEnv_i = \frac{EI_i}{\sum_i^{\#\ cells} EI_i} \cdot 10 \qquad (2)$$

where:

- $scoreEnv_i$ = score for environmental impact of the i-th cell;
- EI_i = environmental impact of the i-th cell.

As expressed before for the *scoreCost* index, the *scoreEnv* index represents the importance of a given FU or energetic vectors respect to the firm's emissions and waste. The *scoreEnv* index, developed within the present methodology, has been created in order to provide an analysis of the most critical areas for the environmental impact related to the energy consumption, an may result to be particularly attractive for firms interested in evaluating their production process for an environmental certification .

Finally, combining costs with environmental impact, a "Criticality Index" (then *CI*) can be defined: this index expresses the importance of a given unit considering both energy expenditures and environmental impact. The experience gained in the application of the methodology, testing it into different sized-firms, for a wide range of industrial districts, adopting different process technologies, has further suggested to slightly modify the *scoreCost* and the *scoreEnv* indexes, weighting them considering the firm's priorities and environmental strategy (e.g. pro-active, reactive, etc.). In conclusion:

$$\begin{cases} CI_i = (scoreCost_i \cdot W_C) + (scoreEnv_i \cdot W_E) \\ W_C + W_E = 1 \end{cases} \qquad (3)$$

where:

- CI_i = criticality index for the i-th cell;
- W_C = cost policy importance;
- W_E = environmental policy importance.

In synthesis, the methodology has created an index able to divide the energy expenditures into different FUs and energetic vectors, evaluating them considering their environmental impact, and providing, as result, a profile of the most critical areas of the firm for the energy consumption.

2.2.2 The Enhancement Index

On the other side, each FU can be characterized by an “Enhancement Index” (then *EnhI*) that expresses the management/technological gap of the FU compared to the BATs and the saving opportunities related to the gap reduction. In fact it is not sufficient to point out the highest energetic cost areas, since one area can present high energetic costs but very limited further enhancement opportunities, when the technologies and operational standards are the most advanced available in the market.

Thus, in this study a methodology able to point out the enhancement opportunities viable for each Functional Unit has been developed and tested: the gap analysis, already in use in other fields, can be here adapted and applied. As shown in Figure 2, the gap analysis is used here to examine the existing gap between practices and technologies adopted into the firms (as is) and the BAT/Ps, considered as a benchmark (to be), through the development and use of checklists helping the auditors to evaluate the state of the art of the firm and provide the suggestions for the needed actions to improve plant’s performance. As above said, the BAT/Ps, considered as a benchmark, have been considered in this study since they immediately point out the best level of energy efficiency achievable in each functional area.

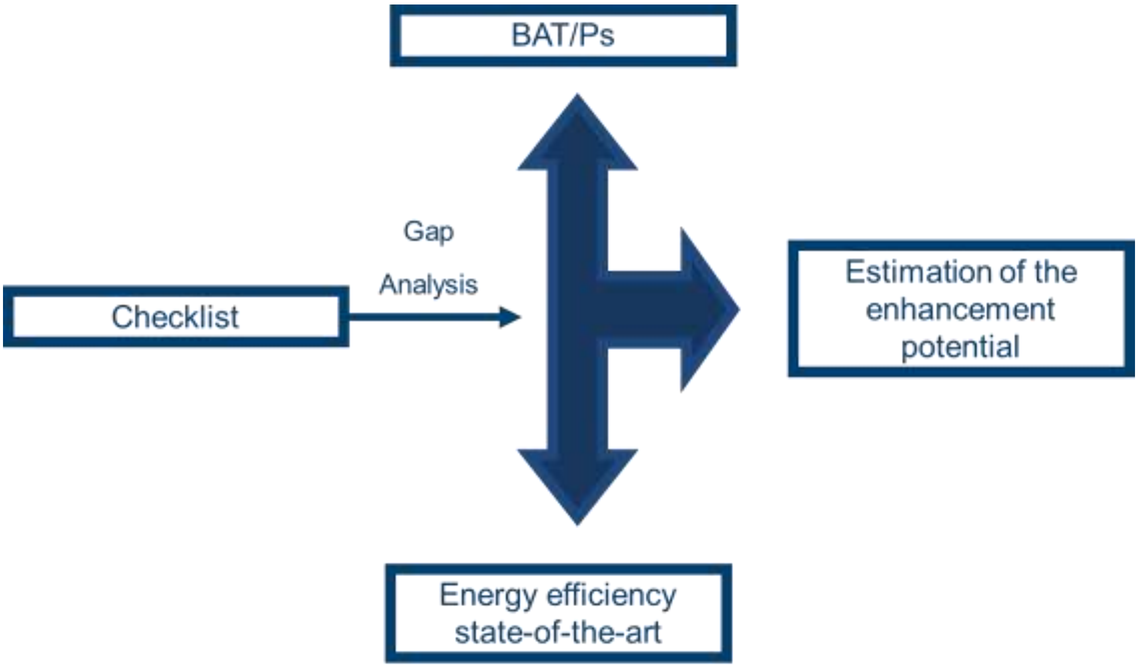

Figure 2Gap analysis use to determine the distance between the energy efficiency state-of-the art of a firm and the best available technologies and practices

In addition to the methodology for the identification of the enhancement opportunities, for this study an “ad hoc” checklist for each FU – either Service or Production – has been developed (and tested), putting in evidence the most widespread BATs and giving a score for their implementation level, so that each answer may quantitatively evaluate the existing gap between the Functional Unit and the BAT/Ps. Considering the wide differences between SMEs, in terms of technologies and production processes adopted, the “ad hoc” checklists proved to be quite helpful for the auditor to quickly identify the areas in which some energy efficiency actions should be taken and put in evidence exclusively the areas with a significant gap respect to the existing BAT/Ps. In more detail the checklists present two scores:

- ✓ a score related to each question; and subsequently
- ✓ a score related to each answer.

The two scores defined within the enhancement index are of paramount importance for the methodology, since they are able to immediately focus the attention of the auditor only on the most critical components within a FU and point out the effective application of BAT/Ps within each FU of the firm.

2.2.3 Definition of the scores

2.2.3.1 Score related to each question

As presented in the introduction, very much interest of the industrial world - and, in particular, of SMEs - has been paid to the monetary estimations of the savings related to the implementation of the energy efficiency actions.

In this study the score assigned to each question has been determined through an economic factor able to take into account the energetic savings related to the implementation of the energy efficiency action suggested: in fact, for each question expressed in the checklist developed for a given FU, an action can be defined, aiming at reducing the gap of the firm respect to the BAT/Ps.

The economic quantification of the savings coming from the implementation of energy efficiency action seems to be the lever for mitigating the risks associated with the first use of a technology within a firm, especially for SMEs, usually characterized by limited budgets devoted for the development of innovative and more energy efficient technologies.

The economic factor has been estimated following a three steps procedure:

STEP 1: estimation of the annual saving of each energy source due to the implementation of the action (i.e. estimation of kWh of electricity, Nm^3 of gas, kg of coal, etc.).

The annual energy saving associated to each question has been estimated referring to a large amount of case studies and public data source available, as the information published in the Industrial Assessment Centre database of the Department of Energy. The database published and frequently updated by the DOE includes more than fourteen thousand assessments and more than one hundred ten thousand recommendations from 1981 up to 2009, identified by a unique Assessment Recommendations Code (ARC): in the first dry-test of the methodology, the American data have been used and adapted to the European and Italian contexts, and compared with the punctual information coming from the experience and the estimations of the energy savings of the auditors. The two information substantially match, proving the hypothesis of the existence of the same BAT/Ps, at least in the West industrial world .

STEP2: quantification of the annual economic saving related to the implemented action, based on the costs of the supply contracts for each energy source (e.g. multiplying the kWh saved by the €/kWh).

STEP 3: evaluation of the profitability of implementing the recommendation related to the question, through the calculation the difference between the average annual saving and the annualized implementation cost . Since the profitability of the annual saving can be biased by isolated cases, it seemed wiser to allow the user (eventually with a comparison between the selected indicators) to choose the most appropriate indicator, e.g. considering also the median of the annual saving instead of the average annual saving and consequently avoiding possible outliers, as shown in Figure 3 and Table 1.

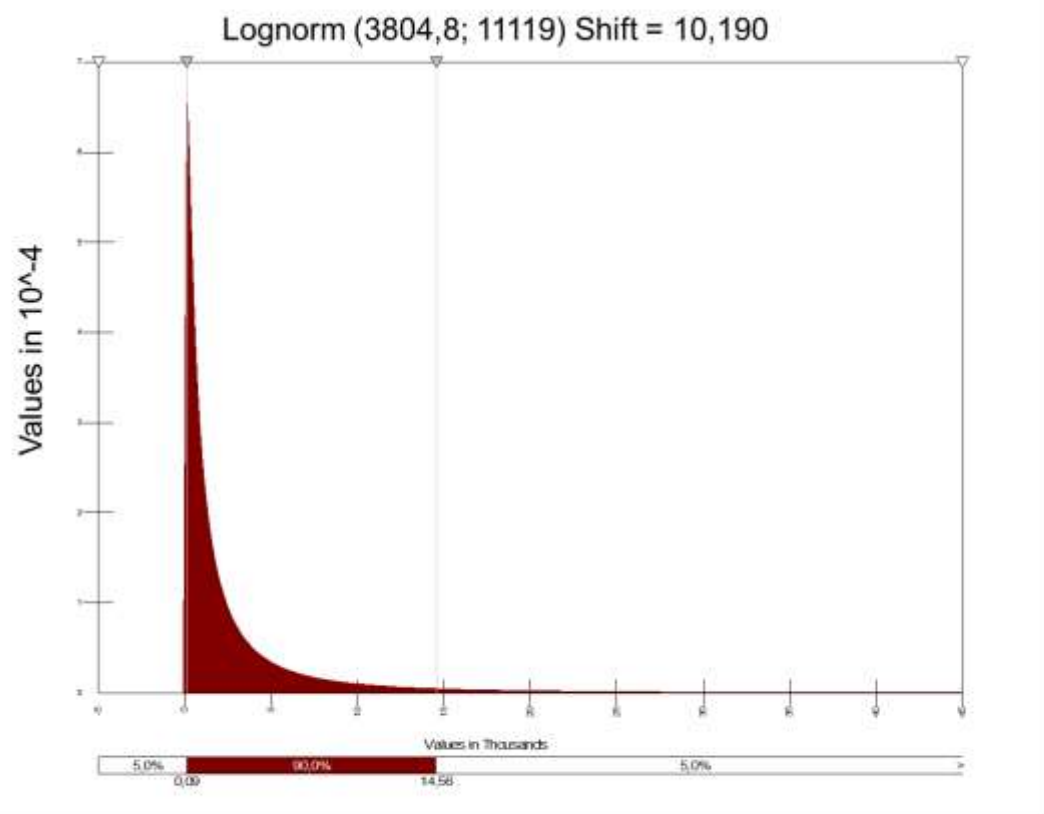

Figure 3 Distribution of the economic factor for the intervention ARC 2,7142: "Utilize higher energy efficiency lamps and/or ballasts".

Statistics for the intervention	Tot savings adj [€ 2009]	Imp cost adj [€2009]
Average	3,653.94	8,194.25
Median	1,269.96	2,121.80
Standard Deviation	8,888.51	21,139.93
Min	0	0
Max	198,566.75	1,030,503.19
5th Percentile	89.71	0
95th Percentile	14,422.53	35,930.94

Table 1Statistics for the intervention ARC 2,7142: "Utilize higher energy efficiency lamps and/or ballasts".

Finally the Economic factor takes the form:

$$EconI_i = \Delta saved_i \cdot p_i - ImpCost_i \quad (4)$$

where:

- $\Delta saved_i$ = amount of annual energy source saved due to the suggested action implementation;
- p_i = price of the energy source paid by the firm;
- $ImpCost_i$ = average (or median, or other indicator) annual implementation cost of the suggested action.

The monetary estimation of savings and implementation costs, has proved to be of particular interest for a SMEs' entrepreneur since it immediately relates the implementation of a given energy efficiency action(BAT/Ps) to the related economical burden and financial exposure.

It's worthy to be noticed that the reliability and robustness of the economic factor estimation obtained in 3-step methodology strongly depends on the quality of the data selected in STEP 1. Since the Quick-E-Scan approach is based on quantitative statistics of the estimation of the annual saving of each energy source due to the implementation of the action, it seemed of fundamental importance to select the most confident data to match the firm's characteristics. To do so, three filters have been established:

Age of the data: this filter aims at considering that, through the technological progress, the same action, implemented recently, could present lower cost than the same action implemented more in the past;

Standard Industrial Classification (SIC, now updated in the more recent NAICS, North American Industry Classification System): the effect of the implementation (both on energy savings and costs) of a given action could be quite different if the actions are applied in different industrial contexts;

Number of employees in the firm: energy savings and implementation costs of a given action could be strictly related to the firm's size.

In the first dry-test of the methodology, it has been observed that some of the existing filters needed to be removed, in order to guarantee a proper statistical significance of the information. It has been chosen – whereas necessary - to remove the filters with the following order:

- Age of the data;
- Standard Industrial Classification;
- Number of employees in the firm;

The order has been determined after a long simulation campaign, through the validation and the tuning of the methodology with test case studies: firstly, the oldest data proved to be less reliable respect to the existing energy efficiency technologies. Secondly, the test case studies found that the processes and the technologies adopted by a given firm were usually related to the product realized, (i.e. well represented by the main activity of the firm, the SIC), although they are partially in common between different sectors (e.g. lighting). And, finally, even with same technologies and process adopted to realize a given product, the simulations performed to test the methodology clearly underlined some existing differences in the estimation of the effects coming from the implementation of the same energy efficiency action between differently sized firms.

In Table 2 an example of the use of the three selected filters is presented, showing the importance of selecting the most fitting data in order to modify and tune the estimation of the effects – in terms of energy expenditures saved and implementation costs – of the suggested actions according to some parameters that characterize the firm: this is of fundamental importance for the success of the Quick-E-Scan methodology, since the industrial context in which SMEs operate is particularly diversified.

In the example provided in Table 2 it is possible to identify that, even with a very high number of interventions selected (minimum 3,514 interventions), there is a different estimation of the total energy savings and the total implementation costs (quantified and adjusted in € 2009), accordingly to the filters removed for the data selection. The example clearly shows the importance of selecting the most appropriate set of data respect to the firms' characteristics and the processes to be observed, in terms most recent data, industrial sector and number of employees.

Statistics for the intervention		Tot savings adj [€ 2009]	Imp cost adj [€ 2009]
Average	*all*	3,653.94	8,194.25
	>2000	5,368.67	13,224.23
	ISIC 25xx	3,264.03	7,086.95
	<100 employees	2,567.42	4,972.60
Median	*all*	1,269.96	2,121.80
	>2000	1,931.36	4,708.50
	ISIC 25xx	1,175.15	1,744.03
	<100 employees	935.40	1,404.22
Standard Deviation	*all*	8,888.51	21,139.93
	>2000	11,766.31	26,372.88
	ISIC 25xx	7,128.46	16,037.78
	<100 employees	6,245.88	18,463.84
Min	*all*	-	-
	>2000	-	-
	ISIC 25xx	-	-
	<100 employees	-	-
Max	*all*	198,566.75	1,030,503.19
	>2000	198,566.75	446,130.66
	ISIC 25xx	121,622.24	251,182.67
	<100 employees	142,871.68	1,030,503.19
5th Percentile	*all*	89.71	-
	>2000	151.54	-
	ISIC 25xx	74.27	11.46
	<100 employees	61.46	-
95th Percentile	*all*	14,422.53	35,930.94
	>2000	20,612.56	54,705.96
	ISIC 25xx	13,136.81	30,467.65
	<100 employees	9,758.84	19,033.61
sample	*all*	10,189	
	>2000	3,514	
	ISIC 25xx	1,709	
	<100 employees	4,104	

Table 2Statistics and sensitivity analysis for the intervention ARC 2,7142: "Utilize higher efficiency lamps and/or ballasts" according to some filters to be selected. The ISIC 25xx is the sector referring to the production of manufactured metal products.

2.2.3.2 Score related to each answer

The calculation of the score assigned to each answer (within a question), here called *RelSc*, follows a much simpler procedure: as it is generally done in models based on checklists, each question presents a limited set of possible answers to be chosen, and for each of them a numeric value representing the implementation level of BAT/Ps is provided. The score, depending on the question, is based through a Likert scale based on a fixed or variable steps, paying attention that the answer representing the full implementation of the BAT/Ps would have the null score: thus, the whole question would get the null score, according to the fact that the firm fulfills the gap towards the BAT/Ps and no recommended actions should be implemented. Close answers checklists have been chosen and proved to be sufficiently objective in the energy efficiency state-of-the-art analysis of the firm, avoiding the possible bias of the auditor during the plant's audit due to open answers; moreover, close checklists are much simpler to be filled in and can be easily verified, consequently reducing the disturbance of the audit (which is, as expressed above, one of the most critical issues for an energy assessment methodology particularly addressed to SMEs). In case of fixed steps scale, as in the example reported in Table 3, it is immediate to estimate the implementation of the given BAT/P related to a given question.

Score	**Question: "The percentage of use of high efficiency lamps and ballasts in the production plant is:"**
0	More than 75%
3.3	Between 50% and 75%
6.6	Between 25% and 50%
10	Less than 25%

Table 3Example of question based on a Likert fixed steps scale.

In case of variable steps scale, the intermediate values have been determined after a long simulation and tuning campaign that drove to the estimation of the savings coming from a partial implementation of a given BAT/P starting from data available in the database (related to the savings estimation coming from the full implementation of a given BAT/P),

2.2.3.3 Enhancement Index calculation

After the estimation of the scores related to each question and answer, a comprehensive score for a whole checklist can be straightforwardly determined:

$$GAP_{rel,i} = \sum_{k=1}^{N} \left(\frac{(RelSc_k \cdot EconI_k)}{\sum_{j=1}^{N} EconI_j} \right) \qquad (5)$$

Where:

- $GAP_{rel,i}$ = relative gap for the i-th Functional Unit;
- $RelSc_k$ = score for the k-th answer;
- $EconI_k$ = economic index for the k-th question.

This number represents the relative gap of a FU towards the BATs (0 = no gap; 10 = highest gap); once a full checklist score is available, it is necessary to set a index able to take into account the different importance of the checklists into a FU and obtain an absolute *EnhI* that can be used for the comparison among different FUs, as it has been already done for the *CI*:

$$EnhI_i = GAP_{rel,i} \cdot weightCL_i$$
$$weightCL_i = \frac{\sum_{j=1}^{N} EconI_j}{\sum_{k=1}^{N} \left(\sum_{j=1}^{N} EconI_j \right)} \qquad (6)$$

where:

- $weightCL_i$ = weight of the i-th checklist;
- $EnhI_j$ = Enhancement index for each questions, representing the benefits coming from the suggested action implementation;
- N= number of non – null questions.

2.2.4 The Priority Index

Combining the Criticality and the Enhancement Indexes, a "Priority Index" (then *PI*) can be obtained: this way the areas with the highest score - high energy consumption and significant gap respect to the BAT/Ps - will be the most effective for achieving energy and cost savings by the implementation of BATs:

$$PI_i = CI_i \cdot EnhI_i \qquad (7)$$

In case of FUs with very similar scores (economic evaluation) it could also be possible to include other qualitative considerations about the effects of the implementation of the suggested actions, such as quality of product, productivity, space use, worker's safety, etc. and perform a deeper analysis in order to choose the most critical FU.

2.2.5 Implementation sequence

The methodology presented in this study provides all the needed information about most profitable intervention areas, with the exception of the implementation sequence. At this stage it seems fundamental to divide the suggested actions into three categories, that represent the sequence for the implementation of the energy efficiency interventions to be applied:

I. Restoring operating parameters;
II. Service optimization;
III. Technical modifications, technological cycle modifications.

Restoring operating parameters. This category includes the easiest suggested actions able to achieve firm's performances without technological changes:

- Restoring standard parameters for the production (base standard);
- Personnel sensitization, information and training to minimize energy waste;
- Ordinary maintenance.

Optimizing operating parameters. Several cheap and useful interventions belong to this category, such as lowing the process temperature with the same product quality, shifting from corrective to predictive maintenance, etc., thus with limited changes in the existing production structure.

Technical/technological modifications: the third level surely requires the highest effort of the firm, like substitution of obsolete systems, changing the existing production technologies, etc., but usually those interventions are able to guarantee the highest energy savings.

2.3 Applications

The Quick-E-Scan methodology has been successfully tested in 38 firms in the Lecco's district (Italy), providing some indications about the energy saving opportunities of those firms.

The auditing process can be summarized in the five steps below:

1. "off-line" data collection (about 2 hours):
   a) General Information of the Firm: SIC, no. of employees, net invoiced, plant surface, office surface, importance of the environmental issue, etc.
   b) Electricity and other fuels bills;
   c) Description of the equipment of the firm, its power consumption (both in terms of electricity and other fuels): this part of the data collection is particularly critical for the whole success of the auditing process, according to the quality and accuracy of the estimates (e.g. percentage of use of peak power and load factor).
2. Definition of the analysis method (about 3 hours):
   a) Firm's description with information about the production process for the main products;
   b) Evaluation and focus of the main users of the firm, according to the SIC.
3. Plant's inspection and "on-line" data collection (about 3 hours):
   a) Inspection of production units;

b) Inspection of service units;

c) Collection of the different temperatures and pressures of the production process;

d) Checklist compilation according to the effective efficiency of the firm found during the plant's inspection;

4. Energy consumption data processing (about 3 hours):

   a) Calculation of the power equipment use (and service units' use) according to the estimates of the firm and the effective use assessed during the plant's inspection;

   b) Calculation of the load factor equipment' use (and service units' use) according to the estimates of the firm and the effective use assessed during the plant's inspection;

5. Quick-E-Scan methodology implementation and results analysis (about 5 hours)

   a) Calculation of the *CI* for each production and service unit, according to the energy consumption (costs) and the environmental impact;

   b) Calculation of the *EnhI* for each production and service unit, according to the efficiency level of the firm (gap from BAT/Ps obtained through the checklists);

   c) Calculation of the *PI* of each production and service unit;

   d) Implementation costs estimation and return of the investment analysis (according to the cost savings due to the intervention implementation);

   e) Report preparation with analyses and suggestions for the firm's management.

About one third of the sample (thirteen firms) is characterized by firms with less than 25 employees, twelve firms presents a number of employees within the range 25-50 and thirteen of them with more than 50 employees. The net invoiced of the firms (expressed in 2008 €) is quite vary (from 550,000 to 86 mln €), reflecting the variety of the firms in the sample (expressed both by the number of employees and the SIC): the standard deviation of the net invoiced - equal to 20,527mln€ - is larger than the average, equal to 15,641mln€. The calculated cost of electricity is mostly constant and fairly low (considering the Italian context), almost normally distributed with an average of 0.125 /kWh and standard deviation of 0.03: this result shows the same administrative energy efficiency of the sample.

Considering the operational energy efficiency of the firms, the average total Priority Index is equal to 6.92/10 but presents different behaviors according to the number of employees of the firms, as shown in Table 4: in particular, firms between 25 and 50 employees point out the highest total intervention priority value, equal to 8.89/10.

Intervention Priority (PI)	Average	<25	25<X<=50	>50
Level 1	0.36	0.31	0.55	0.23
Level 2	3.29	3.6	4.49	1.78
Level 3	3.27	3.53	3.85	2.42
Total	**6.92**	**7.44**	**8.89**	**4.43**

Table 4Intervention Priority (PI) considering the Number of Employees.

In more detail, considering the interventions for each level, the actions aimed at restoring the operating parameters (level 1) do not present a significant priority of intervention (values between 0.23 and 0.55, about 5.3% of the total *PI*), while the service optimization actions (level 2) count for about 47.5% of the total *PI*, with the exception of firms with 25-50 employees that present a value of 4.49 (around 50.5%). The level 3 actions – related to technical and technological cycle modifications – cover generally about half of the total *PI*, with an absolute value ranging from 2.09 (for firms with more than 50 employees) to 3.85 (25-50 employees).

In the following paragraphs a more detailed description of the characteristics of various firms will be provided, including an overview of the main suggested interventions (divided in the three categories reported in Section 2.2.5) to increase the energy efficiency according to the auditing process and the methodology described above.

2.3.1 Firm 1

The energy consumption of this firm is fairly relevant: the natural gas is consumed mostly within the HVAC system (80%) is about 180.000 m^3, and the total consumption of electricity accounts for about 2.73 mln kWh, mainly due to the printing process. In this firm the management show a fairly relevant interest in the environmental aspects respect to cost policies, with a weight respectively of 0.2 and 0.8. In Table 5the *CI* matrix for the firm is reported.

Criticality Index	Compressed Air	Lighting	Steam Generation System	HVAC	Motors	Oven	Cooling system	Total FU
Compressed air	1.13							1.13
Lighting		0.57						0.57
HVAC				2.78				2.78
Printing					3.23		0.24	3.47
Galvanization					1.97		0.08	2.05
Total VE	1.13	0.57	0	2.78	5.2	0	0.32	**10.00**

Table 5Criticality Index, firm 1.

During the auditing process, the firm reflected a good implementation of the BAT/Ps except from the HVAC system in which a significant lack of efficiency was observed, quantifiable in an *EnhI* of 2.27 on 4.71, as shown in Table 6.

Enhancement Index	Compressed Air	Lightin g	Steam Generation System	HVAC	Motors	Oven	Cooling system	Total FU
Compressed air	0.22							0.22
Lighting		0.38						0.38
HVAC				2.27				2.27
Printing					0.55		0.41	0.96
Galvanization					0.58		0.30	0.88
Total VE	0.22	0.38	0	2.27	1.13	0	0.71	**4.71**

Table 6Enhancement Index, firm 1.

Coupling the two indexes (*CI* and *EnhI*) the *PI* is straightforward: from the calculation, the HVAC system presents more than 60% of the benchmarking gap of the firm respect to the BAT/Ps (6.31 on total a *PI* of 9.82, as in Table 7) , and 60% of it can be considered as innovation gap, as resulted in Figure 4.

Priority Index	Compressed Air	Lighting	Steam Generation System	HVAC	Motors	Oven	Cooling system	Total FU
Compressed air	0.25							0.25
Lighting		0.22						0.22
HVAC				6.31				6.31
Printing					1.77		0.10	1.87
Galvanization					1.14		0.02	1.17
Total VE	0.25	0.22	0	6.31	2.92	0	0.12	9.82

Table 7Priority Index, firm 1.

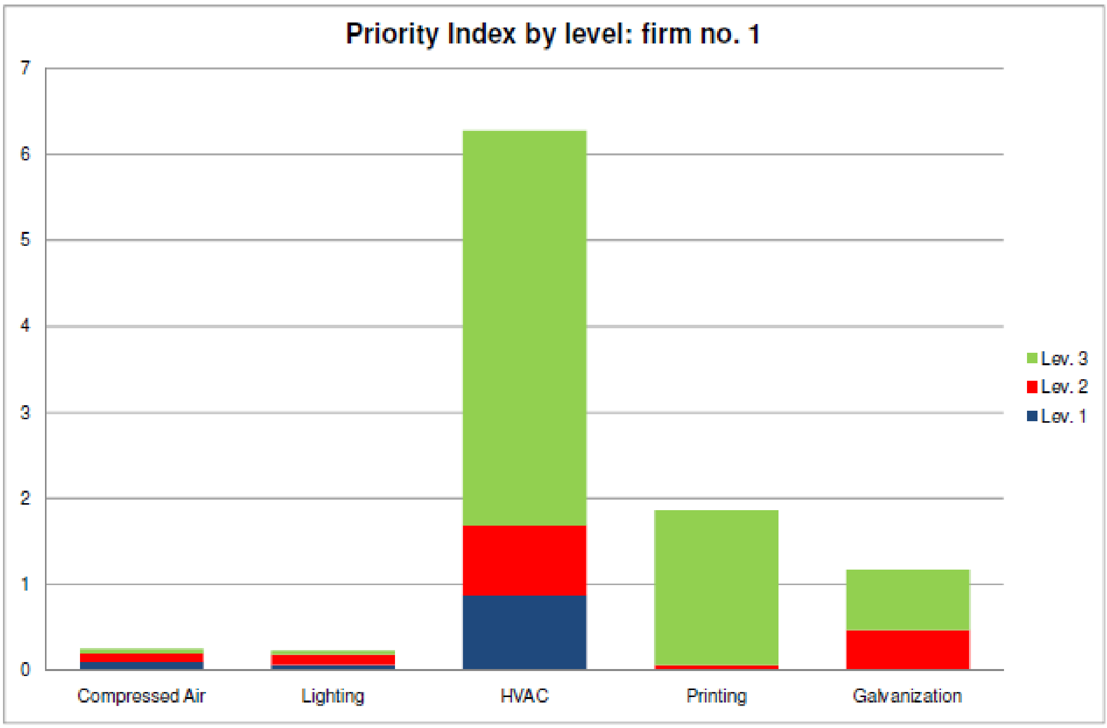

Figure 4 Priority Index by level, firm 1.

Thus, focusing on the HVAC plant, the main suggested actions to increase the energy efficiency of the plant are listed below:

- ✓ Air condition only space in use (ARC code 2.7222);
- ✓ Condition smallest space necessary (ARC code 2.7223);
- ✓ Use radiant heater for spot heating (ARC code 2.7231);
- ✓ Use heat from boiler blowdown to preheat boiler feed water (ARC code 2.1243).

It seems to be clear that just the last suggested action requires a relevant implementation cost, since a circuit for the preheating is needed. But, it is even possible to increase the energy efficiency of the firm with just the implementation of three actions (2.7222, 2.7223 and 2.7231) connected with of the optimization of operating parameters. This results proves that, to optimize the energy efficiency of the firm, an entrepreneur should fully implement the list of suggested actions, but something quite useful could be done even with a limited budget.

2.3.2 Firm 2

This firm is dedicated to the production of unsupported plastics film & sheet and showed a quite relevant implementation of the BAT/Ps. The annual consumption of both electricity (about 4.4 mln kWh) and other fuels (such as gas and diesel, respectively 95,000 $m^3$and 2,845 dm^3) can be considered relatively high compared to the direct costs of production, with a share of about 36%.

The FU of extrusion consumes around 70% of the total energetic cost of the whole firm; all other units (either production or service) do not cover more than 30%.

The Quick-E-Scan methodology allows to clearly separate the two effect of consumption (criticality) and gap from BAT/Ps (enhancement): thus, from the walk-through audit, even with such a high energy consumption (both electricity and other fuels), the extrusion unit emerged as quite competitive with the best available technologies according with the IAC database. In conclusion, considering a median value for the estimation of the economic factor within the enhancement index, the *PI*s of the extrusion unit was the highest, followed by the chilling unit (0.55 and 0.44 respectively), as shown in Table 8. This result points out one of the most important advantages of the Quick-E-Scan methodology, its modularity. In fact, even with a well-detailed energy audit conducted not dividing the firm into FUs, it would not have been possible to highlight the differences between the two FUs, from the point of view of energy efficiency.

Priority Index	**Compressed Air**	**Lighting**	**Steam Generation**	**HVAC**	**Electrical appliances**	**Heat Fuel Source**	**Oven**	**Chilling Plant**	**Total FU**
Compressed air	0.21								0.21
Steam Generation									0
Lighting		0.01							0.01
HVAC									0
Cutting					0.09				0.09
Extrusion					0.11	0.42			0.53
Chiller								0.45	0.45
Grain Machine					0.12				0.12
Total VE	0.21	0.01	0	0	0.32	0.42	0	0.45	**1.41**

Table 8Priority Index, firm 2, base case.

Considering then the extrusion unit, it has been pointed out a need of restoring (level 1) and innovative (level 3) actions while the chiller unit, even if it was well maintained and operated (level 1 and 2), was just obsolete (with a need of innovative actions, level 3), as shown in Figure 5. Since the Quick-E-Scan suggests actions related to the BAT/Ps, implementing the level 3 actions suggested, the best level of energy efficiency achievable is guaranteed to the entrepreneur.

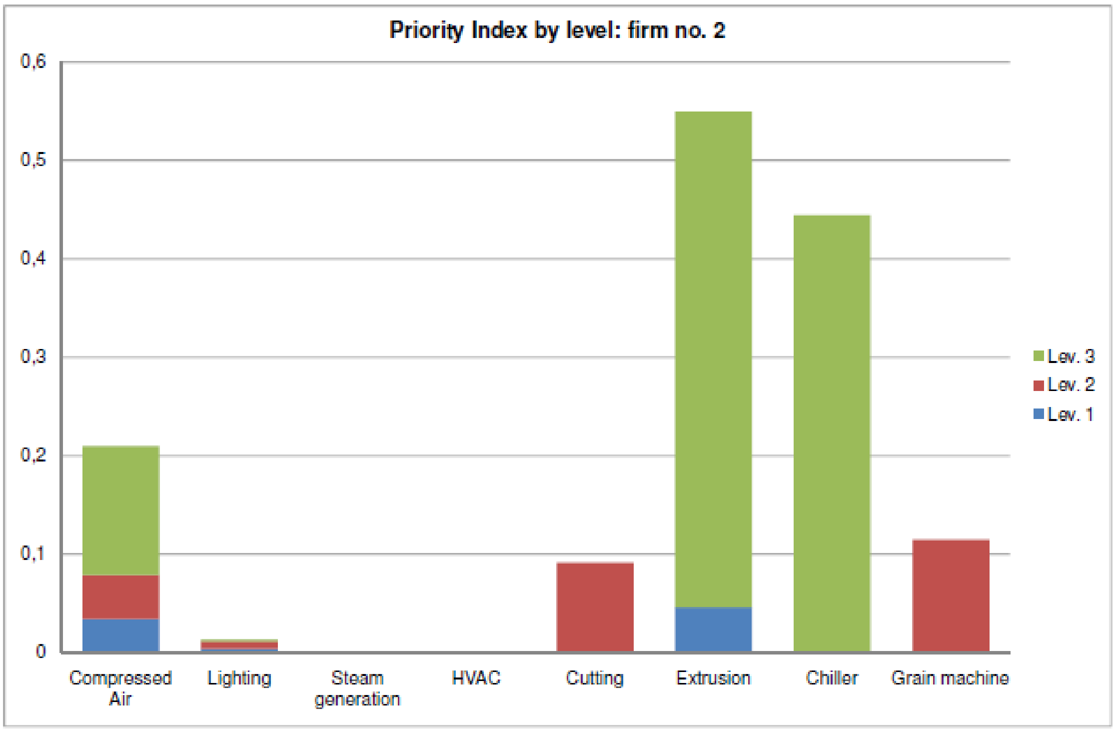

Figure 5 Priority Index by level, firm 2.

Briefly, the most effective interventions to be considered are related to the extrusion unit, and in particular are:

- ✓ Replace over-size motors and pumps with optimum size (ARC code 2.4131);
- ✓ Use most efficient type of electric motors (ARC code 2.4133);
- ✓ Increase Insulation Thickness (ARC code 2.2512).
- ✓ While, considering the chiller unit, the Quick-E-Scan methodology suggested to:
- ✓ Replace existing chiller with high efficiency model (ARC code 2.2622); or
- ✓ Use Cooling Tower or Economizer to Replace Chiller cooling (ARC code 2.2614).

For what concerns the chilling unit, the two actions suggested here are in alternative: they represent some options for the entrepreneur that he/she may follow according to other firm's needs (e.g., if space outside is not available, cooling towers do not seem to be applicable).

In this case study a sensitivity analysis has been conducted to understand the effect of a different estimation of the economic factor for the enhancement index. In fact, if the median value of the economic factor for the replacement of the existing chiller with high efficiency model (ARC code 2.2622) was 14,378 €, the average value for the same intervention was 29,955 €, whilst the average and median value for the replacement of over-size motors and pumps with optimum size (ARC code 2.4131) was substantially the same (about 18,000 €). This difference plays a very important role in the estimation of the enhancement index. In fact, as shown from the Table 9, the enhancement index of the chilling unit raises from 0.36 to 0.49, whilst the enhancement index of the extrusion unit slightly changes from 0.31 to 0.30.

Enhancement Index	**Base Case**	**Sensitivity Analysis**
Compressed air	0.47	0.45
Steam Generation	0.30	0.29
Lighting	0	0
HVAC	0	0
Cutting	0.16	0.15
Extrusion	0.31	0.30
Chiller	0.36	0.49
Grain Machine	0.16	0.15
Total VE	**1.75**	**1.84**

Table 9Enhancement Index, firm 2, comparison between base case and sensitivity analysis.

The effect of this change in the quantification of the enhancement index has effect also in the determination of the priority index for the functional units, where – as reported in Table 10 – , the chilling unit becomes the most critical FU for the firm, and, consequently, the replacement of the existing chiller with a higher efficiency model becomes the most urgent intervention to be evaluated.

Priority Index	**Base Case**	**Sensitivity Analysis**
Compressed air	0.21	0.21
Steam Generation	0.01	0.01
Lighting	0	0
HVAC	0	0
Cutting	0.09	0.09
Extrusion	0.55	0.53
Chiller	0.44	0.60
Grain Machine	0.11	0.11
Total VE	**1.42**	**1.56**

Table 10Priority Index, firm 2 comparison between base case and the sensitivity analysis.

2.4 Conclusions

The methodology described in this paper requires a quick analysis of the firm, thus reducing the disturbance and is able to quickly and in detail point out the most critical areas for the energy efficiency of a firm. These characteristics seem to be particularly suitable with SMEs, that are not well disposed to have long and detailed energy audits, need punctual information about actions needed but they are not able to deploy a well-structured energy management program and cannot afford a long financial exposure. Thus, starting from a punctual and scalable analysis of the energy consumption, it is possible to determine the most critical areas, i.e. the areas (service or production units) with the highest consumption within the firm. The modular structure of the methodology has shown to be particularly useful here, since it has proved to be able to immediately highlight the functional units that are relevant for the firm's energy consumption.

Secondly, an index related to the most needed actions within each area is calculated, in terms of gap towards the best available techniques/practices, since BAT/Ps assure the best level of energy efficiency effectively achievable. The enhancement index here created contains information about energy savings and implementation costs (modified according to the firm's characteristics) of the given action: this is of particular interest for SMEs, where energy is just one of the issues, the entrepreneur is quite sensible to the economic burden (and the financial exposure) related to the implementation of an action, and the same action could present different effects if applied in different contexts.

At the end, combining the two indexes a priority index tells the most profitable areas in which energy efficiency actions shall be implemented: the higher the index, higher the priority of intervention. It seems important to underline that a list of suggested actions is created, in order to present some investment opportunities according to the effective budget available.

The Quick-E-Scan methodology needs only 16 hours to be implemented in a SME, from the off-line data collection (general information about the firm) to the final report containing the recommendations for the firm's management. Thanks to its ease of use it has successfully tested in 38 SMEs of Lecco's district (Italy).

In conclusion, it seems remarkable to notice that:

- ✓ the estimation of the savings is based essentially on the comparison with the efficiency of a given FU towards the BAT/Ps: being a follower in the implementation of the BAT/Ps related to some areas is absolutely normal (usually firms are *followers* in some areas and *first movers* in others), and allows in any case to achieve the efficiency of the system. Furthermore, in case of SMEs, it is quite difficult to be followers in some areas and first mover in others since the budget for process innovation is usually limited: thus, it is more frequent to adopt efficient solutions applied elsewhere;

- ✓ the Quick-E-Scan methodology is based on the data availability of a database that collects the implementation of many actions: otherwise the statistical significance of the savings - and thus the results of applying the methodology - would be jeopardized;
- ✓ the *energy savings* have been obtained through the use of the IAC data based on US industries: the further and widespread application of the methodology will allow to have country-specific and industry-specific results that will be the new and more reliable references for the further implementation of the Quick-E-Scan methodology, since they would refer to a closer context;
- ✓ one of the biggest advantages of the methodology relies on its quickness (from offline data collection to results, 16 hours have been estimated) and, thanks to its ease of use, the small body of knowledge needed by an auditor to implement it.

The methodology has been successfully applied and evaluated in several SMEs, but the approach has been tested also in some LEs (the results have not been reported since they are not of interest for this specific study) proving to be modular and easily applied in every industrial context.

A widespread application of the Quick-E-Scan methodology will create a database with the most implemented actions throughout SMEs (with regards to some parameters like SIC or firms' size) within a given territory. The database would help the authorities to point out a limited list of actions that should be particularly boosted to achieve rapidly and largely the energy efficiency of the industrial sector of a given region.

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3 Analysis of the most effective energy efficiency opportunities in manufacturing primary metals, plastics and textiles small- and medium-sized enterprises.

This chapter reports the content of the work published as:

Cagno E., Trianni A., "Analysis of the most effective energy efficiency opportunities in manufacturing primary metals, plastics and textiles small- and medium-sized enterprises.", ASME Journal of Energy Resources Technology, 2012, (paper accepted).

The previous work that provided useful contributions on the topic is:

Cagno E., Trianni A., «Sustainable Development: analysis of the most effective energy efficiency interventions within four Italian manufacturing sectors.» Proceedings of the 16th Annual International Sustainable Development Research Conference. Hong Kong, China, 2010 (b).

Cagno E., Trianni A., «Sustainable development: evaluation of costs and benefits for the most effective energy efficiency interventions within the Italian industrial sector.» 4th International Conference on Energy Sustainability. Phoenix, AZ, USA: ASME, 2010 (c).

Governments are pursuing a variety of measures to reach common and more efficient environmental and energetic policies: nonetheless the effort has shown to be not sufficient, since the objectives stated in the EU Directive 2009/28/EC on energy efficiency seem quite distant to be reached. A greater attention has obviously been paid towards the industrial sector, which utilizes a major share of primary energy consumption: since now several actions have been taken to achieve the energy performance of buildings, but very few in the operations. Nonetheless, in order to be most effective, governments should focus their attention not only to energy-intensive Large Enterprises (LEs), but also on non-energy intensive Small & Medium Enterprises (SMEs), that represent the vast majority of the total number of industries, cover a consistent share of the energy consumption of a whole domestic industrial sector, and are usually less efficient than LEs. The paper aims to highlight the most effective Energy Savings Opportunities (ESOs) for reducing energy consumption in industrial operations that have been successfully implemented in a large number of SMEs case studies investigated in North America and Italy, showing a correspondence (in terms of savings and costs) between the two data bases. The paper analyzes the ESOs, characterized all by being Best Available Technologies and Practices (BAT/Ps), with a cross-analysis within three manufacturing sectors, i.e. primary metals, plastics and

textiles, and considering different sub-sizes among SMEs, in order to show commonalities and differences among the sample. The ESOs have been analyzed and ranked according to different criteria of importance, highlighting the most diffused, those having the highest energy savings, and those with the shortest pay-back time. The scope of the elaboration of these criteria is twofold: on one side, it allows to be closer to the entrepreneurial sensibility, guiding entrepreneurs in evaluating a possible investment in energy efficiency; on the other side, it provides important suggestions for a public local authority that, through financial support and/or other policies, aims at diffusing the adoption of BAT/Ps and increasing the sectors' energy efficiency and competitiveness.

3.1 Introduction

The global concern due to the increase of primary energy consumption and the emissions of green-house-gases (GHG) coming from the use of fossil fuels has driven the attention of public policy makers of most developed countries on energy efficiency. On one side, the global energy consumptions trends seem to reveal a very much worrying perspective. In particular, the pace of demand growth slackens progressively over the proportion period: in the period 2010-2015, it will grow by an average +2.5%, then the rate of growth will drop to +1.5% in 2015-2030. This strong growth is mainly due to non-OECD economies' growth [1]. On the other side, developing countries account for over three-quarters of the increase of global CO2 emissions between 2004 and 2030 [2], and those economies are expected to drive the significant growth of emissions since their heavy reliance on coal [1], showing that the phenomenon does not seem to end shortly.

Thus, it seems of fundamental importance to tackle those issues with the promotion and diffusion of energy efficiency, that is linked to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits, also considering the importance of reversing the existing trends towards the objectives of the so-called "20-20-20" (i.e., 20% reduction in GHG-emissions, a share of 20% of energy produced by renewable energies and 20% improvement in energy efficiency) by 2020, as stated by the most recent Directive published by the European Council, 2009/28/EC [3].

The objectives have become of strategic importance for many countries, in which very much attention has started to be devoted to the industrial sector, that, as from the most recent estimations, covers about 50% of the total energy delivered [4]. In this sense, energy efficiency within the industrial operations seems to represent a very important issue to be addressed, since, in many cases, energy expenditures are not just limited to (even) a consistent impact on pollutants' emissions (environmental issues), but may also cover a large share of the total production costs (economic issues), thus being quite critical for the whole sustainability of a firm.

The contributions in the literature on the identification of the most effective energy saving opportunities have been mainly addressed to the energy intensive sectors, e.g. iron & steel [5 - 9]; but, still very little importance has been yielded to the non-energy intensive manufacturing ones. Indeed, in those sectors, non-negligible in terms of energy consumption and number of employees, great opportunities for improving energy efficiency can be recognized, since the interest at the moment has been limited to the development of energy assessment methodologies [10], several industrially-oriented tools, and the development of specific and punctual technologies for a better use and management of energy. As a consequence, a clear analysis and highlighting of the best existing opportunities for enhancing energy efficiency is still lacking and needed.

Another interesting point for the research comes from the composition of the industrial sector, that – both in Europe, but, with slight differences, also in North-America – is almost exclusively made by non-energy intensive Small and Medium Enterprises (SMEs) – i.e. by myriad small consumers, each of them offering a small contribution to the total energy consumption –, and by few energy-intensive "large" consumers. Indeed, as from recent estimations in Italy [11], the industrial sector is largely composed (> 99%) by SMEs, that cover a consistent portion (more than 60%) of the domestic industrial consumption. Nonetheless, several analyses showed that energy efficiency since now has seemed to be hardly achieved within SMEs, that are usually less efficient than LEs, as showed by several studies [10]. In particular, in 2008 the Observatory of European SMEs (led by the European Commission) reported (Figure 1) that "the overall picture is surprisingly unfavorable: close to two thirds of SMEs operating in the EU do not even have simple rules or devices for energy saving (63%). Less than three out of 10 SMEs (29%) have instituted some measures for preserving energy and resources at their enterprise. Only 4% of EU SMEs have a comprehensive system in place for energy efficiency" [12].

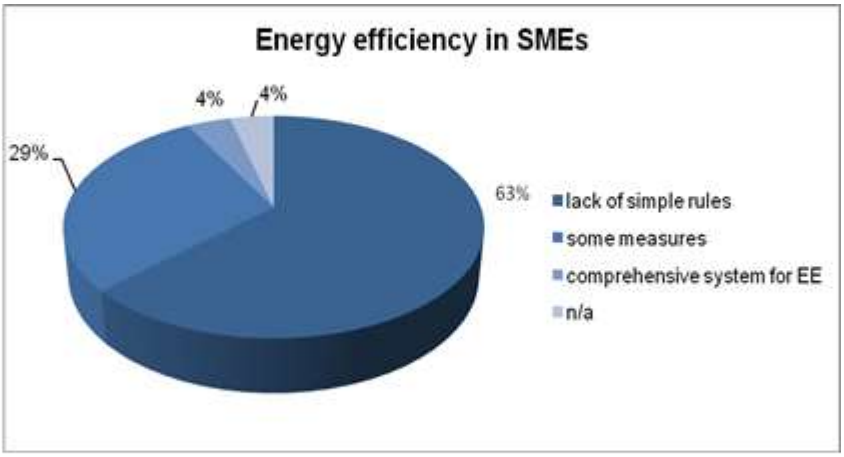


Figure 1Energy Efficiency in SMEs. Source: elaboration from European Commission report data [11].

One of the preferred means to increase energy efficiency among SMEs seems to be the technological transfer represented by the application of successful Best Available Technologies and Practices (then BAT/Ps), i.e. technologies and practices already developed and successfully applied in other enterprises. In particular, it is clear that, as emerged in other research [13], energy efficiency does not represent the unique issue to be faced by entrepreneurs, and in particular in SMEs, where the same person (i.e. usually the entrepreneur him/herself) is in charge of several activities, from production planning to sales and marketing. Moreover, quite often SMEs do not have a dedicated structure (with resources and personnel) focused on energy management and/or energy efficiency; therefore, the resources devoted to the research of inefficiencies (e. g. collecting and analyzing information) and opportunities result to be very limited. Furthermore, in SMEs, since entrepreneurs are quite often in charge of the investments with their own capital, the long pay-back-times (PBT) might represent a barrier to the increase of energy efficiency. In particular, this might happen for large investments in improving the existing equipment. Another problem that SMEs have to face is the so-called disturbance of energy audits, i.e. the possible disruption of the normal activities for the research of punctual inefficiencies and opportunities, with consequent hidden costs of the investments, thus reducing the hypothetical potential of the ESOs.

As we have showed the importance of improving energy efficiency among non-energy intensive enterprises and SMEs, the purpose of this study is to perform an analysis focused on the identification and further evaluation of BAT/Ps considering a cross-sector analysis of some important Italian industrial sectors. In particular, the research has been focused to enterprises located in Lombardy, one of the most industrialized and richest (and also most densely populated) regions in Europe, that is a first-mover with respect to industrial energy efficiency activities.

The results of the study will give an important contribution to the identification of the BAT/Ps that best fit SMEs according to their main characteristics (e.g., main activity and size). This represents an important innovation in the research since the identified BAT/Ps would provide a strong contribution in effectively increase the industrial energy efficiency. Indeed, BAT/Ps can be easily adopted by entrepreneurs – from both a technical and managerial viewpoint –, and supported – and funded – by policy-makers.

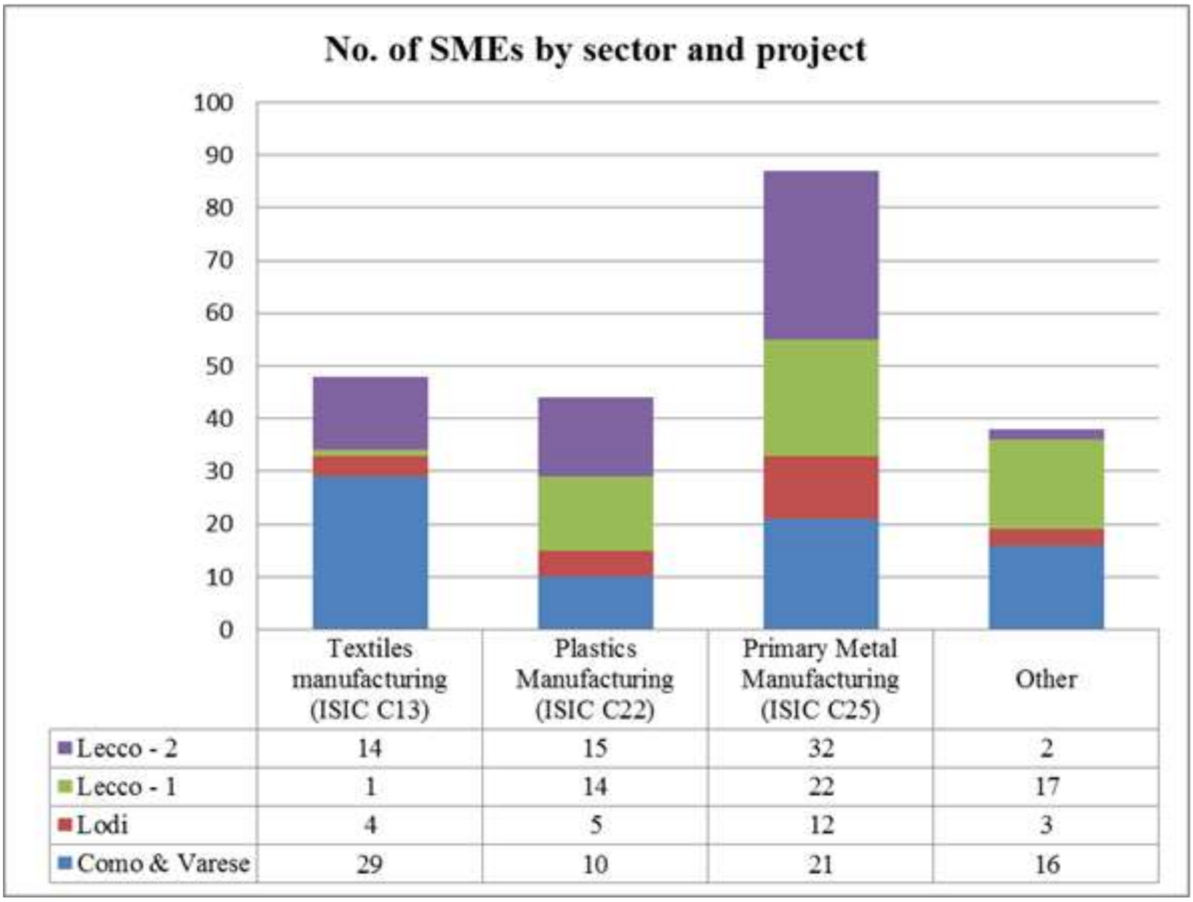
Furthermore, the paper will open the research putting in evidence similarities in energy efficiency issues among different countries (i.e., United States and Italy), thus representing a first contribution to the identification, development and promotion of common policies for industrial energy efficiency.

3.2 The research project

The research has been conducted within a series of projects developed by Politecnico di Milano, mostly supported by Lombardy Region and the Chambers of Commerce of different Lombardy provinces (Lecco, Lodi, Como and Varese), and the participation of some enterprises that have been selected among the most representative industrial sectors of the region.

The projects involved 217 manufacturing SMEs mainly distributed among the following three sectors, according to the International Standard Industrial Classification of All Economic Activities "ISIC rev.4" (Figure 2):

- 48 Textiles Manufacturing (ISIC C13) enterprises;
- 44 Plastics and Rubber Products Manufacturing (ISIC C22) enterprises;
- 87 Primary Metal Manufacturing (ISIC C25) enterprises.



	Textiles manufacturing (ISIC C13)	Plastics Manufacturing (ISIC C22)	Primary Metal Manufacturing (ISIC C25)	Other
Lecco - 2	14	15	32	2
Lecco - 1	1	14	22	17
Lodi	4	5	12	3
Como & Varese	29	10	21	16

Figure 2Population of the Italian database divided by sector and territory.

The sample is composed by non-energy intensive manufacturing SMEs (considering here non-energy intensive enterprises those enterprises whose energy expenditures do not exceed 2% of their turnover, as done in other research, e.g. [13-14]), belonging to sectors of particular importance for the Lombardy region, in terms of: number of enterprises, number of employees, Gross Domestic Product (GDP), total sector energy consumption, consumption by single firm, and for being strategic for the regional economy that strongly relies on them.

The activities within the projects lied firstly in performing energy assessments in the selected enterprises, in order to point out the areas with highest consumption, inefficiencies and opportunities of savings. Secondly, in proposing the firms a set of the most important ESOs – with a quantification of energy savings and implementation costs – that, according to their characteristics, would enhance their energy efficiency.

The projects brought three main results: firstly, they allowed to obtain a map for the industrial energy-efficiency state-of-the-art in some provinces among the Lombardy region, in particular considering the effective energy waste. Secondly, they allowed to highlight which ESOs might be of particular interest, if supported, for the industrial energy efficiency enhancement of the investigated provinces. Thirdly, through the execution of the energy assessments, it had been possible to create a database to characterize the most effective industrial ESOs, in terms of:

- ✓ Frequency of implementation: the most suggested ESOs in firms with same characteristics are able to easily convince entrepreneurs of the ESOs' effectiveness, since the risk, related to the implementation of a given ESO, is partially reduced;
- ✓ Estimated annual energy saving (expressed in tons of oil equivalent, then toe) and the implementation costs: the most saving ESOs are able to more consistently reduce the energy consumption and expenditures; and
- ✓ Payback time (expressed in years, or fractions of a year): the ESOs have to be evaluated also according to the financial capability of the firm; the shortest pay-back time ESOs are able to reduce the firm's energy consumption limiting its financial exposure. Moreover, this indicator is of particular interest also for policy makers, since it is related (in particular its inverse), to the effectiveness of the investment.

Actually, the Northern-Italian database is growing but still relatively small (of about 2,000 ESOs suggested), and does cover only a still important, but limited set of sectors: for these reasons the Italian database does not seem to represent a fully reliable source of data for projecting the evaluations on ESOs. Therefore, the data gathered during these projects have been compared with an American database created by the Industrial Assessment Centers (then IAC) within the United States Department of Energy [15]. The aim of the comparison was to verify the consistency – with respect to several firms' characteristics as sector (related to the technology and processes adopted) and firm's size – of the Italian database with respect to the IAC one, and to assess the reliability of the IAC database to make evaluations and estimations also within Italian enterprises.

The IAC database is much wider than the Italian one, consisting of more than 14,000 energy assessments and about 110,000 suggested ESOs (from year 1981 to 2009), covering almost all the industrial sectors, but with a significant share of ESOs suggested for the primary metal, plastics and textiles manufacturing sectors (with a share respectively of about 15.7%, 9.4% and 7.7%). The database contains a list of information for each ESOs suggested, including:

- a brief description according to an Assessment Recommendation Code (then ARC) uniquely identified by a number;

- an estimation of both the saving and the implementation cost (expressed in real United States Dollars, USD);
- the year of the assessment.

In this research we have cut the data of the IAC database selecting assessments conducted after year 2000, in order to use only the most recent information and to have a closer monetary estimation of savings and implementation costs.

With respect to the usual classification of SMEs enterprises [16], within a range of 10-250 employees, we have created here some further classes (Table I), since it has been verified a different behavior of Small Enterprises (SEs, 10-49 employees) with respect to Medium (MEs, 50-99 employees) and Medium-Large Enterprises (MLEs, 100-249 employees). Moreover, as showed for the management of some other enterprises' aspects in terms of organizational behavior [17], although still some differences exist (e.g. presence of an internal energy manager, real-time monitoring of the energy consumption, etc.), MLEs tend to behave, with respect to the energy efficiency management structures adopted internally, as LEs (>250 employees).

Dimension	*No. of employees*
Small (SEs)	10-49
Medium (MEs)	50-99
Medium-Large (MLEs)	100-249

Table 11Classification of the enterprises depending on the number of employees.

3.3 Analysis of the ESOs

Looking at the implemented ESOs in the three sectors (Table II), it is possible to see that the most implemented ESOs between the two data sets (the IAC and the Italian set, reported as "ITA") are the same and mostly in the same order. With respect to the Primary Metal manufacturing, a slight exception occurs for the Textiles manufacturing for the ARC 2.4221 ("Install compressor air intakes in coolest locations"). Taking again as reference the Primary Metal manufacturing sector, and considering the Plastics manufacturing sector (ISIC C22), similar considerations can be drawn. Indeed, the first three and the fifth ESOs are exactly the same and in the same order; the ESO ARC 2.2511 ("Insulate bare equipment"), fourth in the IAC rank, in the Italian rank appears in the sixth position, whilst in the Italian rank fourth position it is possible to find ARC 2.4111 ("Utilize energy-efficient belts and other improved mechanisms").

ARC code	Energy Saving Opportunity Description	*IAC rank*	*ITA rank*
ISIC C25 "Primary Metal Manufacturing"			
2.7142	Utilize higher efficiency lamps and/or ballasts	1	1
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	2	2
2.4221	Install compressor air intakes in coolest locations	3	3
2.4133	Use most efficient type of electric motors	4	4
2.4111	Utilize energy-efficient belts and other improved mechanisms	5	5
ISIC C13 "Textiles Manufacturing"			
2.7142	Utilize higher efficiency lamps and/or ballasts	1	1
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	2	2
2.4133	Use most efficient type of electric motors	3	4
2.4111	Utilize energy-efficient belts and other improved mechanisms	4	5
2.4221	Install compressor air intakes in coolest locations	5	3
ISIC C22 "Plastics Manufacturing"			
2.7142	Utilize higher efficiency lamps and/or ballasts	1	1
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	2	2
2.4221	Install compressor air intakes in coolest locations	3	3
2.2511	Insulate bare equipment	4	6
2.4133	Use most efficient type of electric motors	5	5

Table 2Comparison of ISIC C25 "Primary Metal Manufacturing", ISIC C13 "Textiles Manufacturing" and ISIC C22 "Plastics Manufacturing" between the IAC database and the available Italian data. Criterion of selection: most implemented ESOs.

When considering a combination of sector and number of employees, the suggested ESOs in the two data sets are mostly the same; moreover, also the parameters used to characterize the suggested ESOs (in particular, frequency of implementation, estimated energy saving and implementation cost) are mostly consistent.

In Table III one example has been reported considering the comparison of the parameters for the ARC 2.4236 ESO ("Eliminate leaks in inert gas and compressed air lines/ valves") for the combination "Primary Metal Manufacturing" and "50-99 employees". In this case, the median values of both data sets are almost identical, but a different dispersion has been observed, reasonably attributable to a wider sample. Indeed, the American data result to be more dispersed, with the Italian data ranging between the 25st - 73rd percentile for the energy savings and between the 28th – 75th percentile for the implementation costs of the American data.

Sample (no. of implementations)	296		32	
Statistics	IAC db values		ITA db values	
	Impl. Cost [USD 2009]	kWh saved	Impl. Cost [USD 2009]	kWh saved
Average	691.36	48,529.07	393.73	29,593.13
Minimum Value	5.24	1,116.82	185.27	12,577.00
1st quartile	161.41	12.252,64	243.33	19,921.50
Median	347.32	25,574.87	349.16	25,661.50
3rd quartile	780.51	58,598.00	554.48	40,196.75
Maximum value	9,000.00	842,133.89	752.80	57,662.00

Table 3Comparison of ARC 2.4236 "Eliminate leaks in inert gas and compressed air lines/ valves" between the IAC database and the available Italian data in the ISIC C25 "Primary metal Manufacturing" sector, 50-99 employees.

Moreover, similar considerations can be drawn for the other four ESOs suggested for the given combination "sector"/"number of employees" ISIC C25/50-99 employees, and in particular for:

I. ARC 2.7142 – Utilize higher efficiency lamps and/or ballasts;
II. ARC 2.4221 – Install compressor air intakes in coolest locations;
III. ARC 2.4133 – Use most efficient type of electric motors;
IV. ARC 2.4111 – Utilize energy-efficient belts and other improved mechanisms.

The correspondence can be also observed for the following combinations "sector"/"firm's size":

- Textiles Manufacturing (ISIC C13) - 100-249 employees;
- Plastics and Rubber Products Manufacturing (ISIC C22) - 50-99 employees;
- Primary Metals Manufacturing (ISIC C25) – 100-249 employees .

For the other combinations some similarities have been observed, but it had not been possible to draw any conclusion since the sample is, at this stage of the research, still limited.

In conclusion, since an overall consistency between the two data bases has been observed, the IAC database, much wider than the Italian, can be adopted to evaluate the energy efficiency ESOs suggested for the three sectors of interest, taking into consideration the parameters used for the evaluation of the ESOs depending on the size of the enterprises, as showed in Table I.

In order to understand the most important ESOs – with respect to the criteria of Highest frequency of implementation, Highest estimated annual energy saving, and Lowest pay-back time – , it has been necessary to create several clusters of analysis, each of them created by a combination of sector and firm's size, obtaining a 3x3 matrix (three sectors by three SMEs' sub-sizes). This allows each cluster to be more homogeneous, for type of activity, processes, sub-size, energy expenditures and technologies adopted, and thus to obtain more specific and reliable information. Moreover, clustering the database allows to put in evidence commonalities and differences among the three sectors and the three firms' sub-sizes, quite interesting for energy policy makers willing to identify and promote the most effective ESOs. Considering now each cluster, the first operation on the data, in order to limit the effect of possible outliers affecting the reliability of the results, was to eliminate the ESOs suggested less than 20 times. Secondly, the ESOs have been analyzed separately, in order to obtain the estimated parameters needed for the projections. In particular, a thorough statistical analysis of the database allowed to prove that, within each cluster, the values for energy savings and implementation costs are, as expected, non-normally distributed, as showed in the following example (ISIC C25, SE, ESO "Utilize high energy efficiency lamps and/or ballasts", Table IV and Figure 3). Indeed, it seems realistic to assume that, in many cases, the suggestions are conservative in terms of low energy savings, and just in few cases they estimate great savings.

Statistics for the ARC 2.7142 energy saving	*IAC db energy saving [kWh]*
Average	29,610.38
Standard deviation	57,972.95
Skewness	6.61
Minimum	271.00
Maximum	675,580.25
Median	12,530.22
1st quartile	5,051.13
3rd quartile	30,588.05
5th percentile	1,207.96
95th percentile	101,121.64

Table 4Statistics for the energy saving of the ARC 2.7142 ESO "Utilize higher efficiency lamps and/or ballasts".

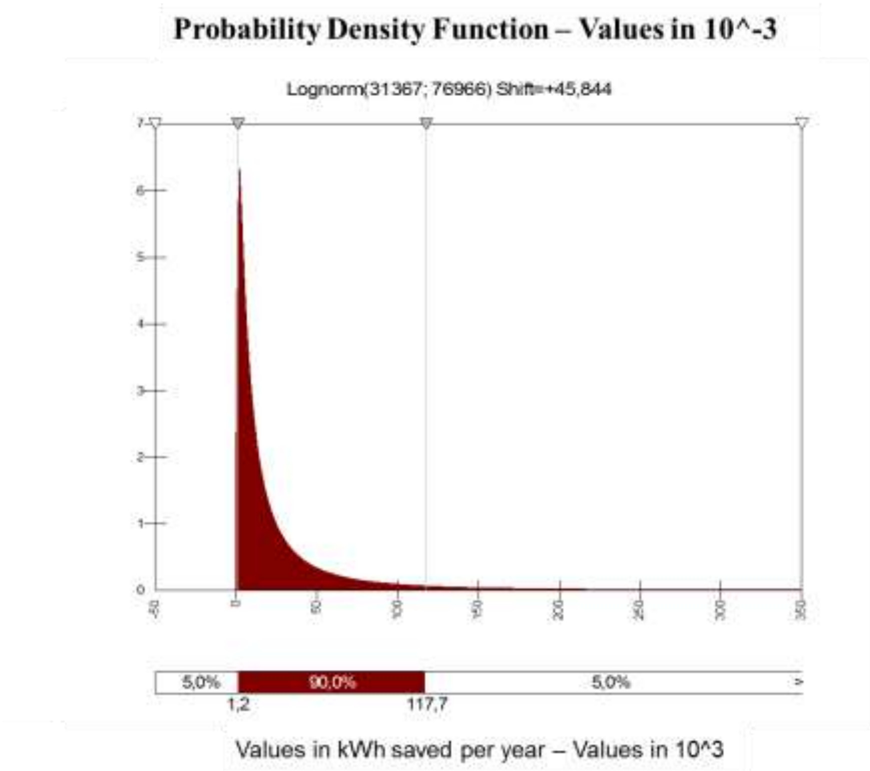


Figure 3Probability distribution of total energy savings [kWh/year] for the ARC 2.7142 ESO "Utilize higher efficiency lamps and/or ballasts".

Starting from the example reported, to better consider the very high skewness of the distribution (6.1) and the wide range of results (more than 675,000 kWh of range between the minimum and the maximum value), the median total energy saving, rather than the average, has been considered as representative of a given ESO. This statistics, indeed, allows to eliminate the tail-values providing more reliable estimations of the effective values of the two parameters. In addition to that, it should be observed that, considering the shape of the distribution, in this case the median value is conservative, since it is closer to the first quartile with respect to the third, thus avoiding over-estimations for energy savings.

Moreover, considering the energy savings, since the IAC database contains an estimation of the monetary amount of energy saved by fuel (expressed in real USD), in order to obtain a physical value of the energy savings transposable also to other contexts, all values should be converted in toe, and the following calculations have been made:

- adjustment to USD 2009, through the GDP Implicit Price Deflator;
- calculation of the kWh per year saved by each fuel source: the USD 2009 have been divided by the energy price of the given source saved (e.g. in case of

- electricity, through the Average Retail Price of Electricity to Ultimate Customers by End-Use Sector suggested by the US Department of Energy [18]);
- calculation of the toe saved, considering, e.g. in case of electricity, 1 kWh equal to 0.187x10-3 toe (as from [19]).

In the following section the results of sample analyses have been reported, with a discussion of the commonalities and differences found with other analyses conducted in this research, ranking the ESOs with respect to the criteria of the most implemented, the highest energy savings and the shortest pay-back time.

3.3.1 The most implemented ESOs

3.3.1.1 Primary Metal Manufacturing Sector (ISIC C25) – SEs (10-49 employees)

Firstly, considering exclusively the five most implemented ESOs (with the number of implementations ranging from a minimum of 88 to a maximum of 262) reported in Table V, it can be observed that the savings achievable are not negligible, with a total energy saving of 9.9 toe/year per enterprise, and with a very limited pay-back time (in all cases lower than three years).

Secondly, and quite interesting, it can be observed that besides ESOs requiring an innovation in the equipment (i.e. ARC 2.7142, ARC 2.4221 and ARC 2.4133), there are also ESOs aiming at restoring the original functionality of the system (ARC 2.4236) and at effectively optimizing the actual use of the resources (ARC 2.4231). These results are of particular interest, since they show that, in order to increase the energy efficiency of the primary metal manufacturing sector, it is quite important to devote adequate resources for a proper use of the existing systems, and optimize their performance, and not sufficient to exclusively realize huge investments in new machineries/equipment.

Thirdly, with a closer look to the ESOs, the IAC database suggests to pay particular attention to three areas:

Lighting system (ARC 2.7142);

Compressed air system (ARC 2.4236, ARC 2.4221 and ARC 2.4231); and

Motors (ARC 2.4133).

ARC code and Int. Description	No. impl.	Annual saving [toe/year]	Impl. Cost [USD 2009]	PBT [years]
2.7142 – Utilize higher efficiency lamps and/or ballasts	262	2.34	1,459.15	1.98
2.4236 – Eliminate leaks in inert gas and compressed air lines/valves	185	3.36	334.60	0.24
2.4221 – Install compressor air intakes in coolest locations	103	1.05	330.51	1.07
2.4133 – Use most efficient type of electric motors	102	1.36	1,326.83	2.81
2.4231 – Reduce the pressure of compressed air to the minimum required	88	1.79	19.91	0.02

Table 5Analysis of ISIC C25 "Primary Metal Manufacturing" – and SE (10-49 employees). Criterion of selection: most implemented ESOs.

In particular, the compressed air system seems to be the most profitable area, in terms of savings and payback time. In fact, summing up the annual energy savings of the ESOs referring to that area, it is possible to observe an energy saving of about 6.2 toe/year, and all by ESOs with a pay-back time even shorter than 18 months (the highest one occurs for ARC 2.4221, and is equal to 1.07 years).

Moreover, thanks to the matrix structure, it is possible to perform several analyses, e.g. comparing SEs with MEs and MLEs, and also comparing textiles and plastics with respect to the primary metal manufacturing sector.

3.3.1.2 Primary Metal Manufacturing Sector (ISIC C25) – Comparison among SE, MEs, and MLEs

For what concerns SEs vs. MEs and MLEs, since the sample is not homogeneous (due to a different number of energy assessment in the cells), an indicator called diffusion – calculated as the ratio of the number of suggestions of a given ESO on the total number of assessed firms within each cell –, that represents the share of enterprises in which, within each cell, the given ESO has been suggested. In the primary metal manufacturing sector it can be observed (Table VI) that the first five ESOs are almost the same and with a comparable diffusion coefficient within each cell, with shares ranging from around 24% to even more than 84%. This results are quite relevant since they put in clear evidence that, even for different sizes, SMEs share almost the same inefficiencies.

ARC code	Energy Saving Opportunity Description	Share
Small enterprises (10-49 employees), SEs		
2.7142	Utilize higher efficiency lamps and/or ballasts	80%
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	56%
2.4221	Install compressor air intakes in coolest locations	31%
2.4133	Use most efficient type of electric motors	31%
2.4231	Reduce the pressure of compressed air to the minimum required	27%
Medium enterprises (50-99 employees), MEs		
2.7142	Utilize higher efficiency lamps and/or ballasts	84%
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	51%
2.4221	Install compressor air intakes in coolest locations	36%
2.4133	Use most efficient type of electric motors	34%
2.4111	Utilize energy-efficient belts and other improved mechanisms	24%
Medium-Large enterprises (100-249 employees), MLEs		
2.7142	Utilize higher efficiency lamps and/or ballasts	72%
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	56%
2.4221	Install compressor air intakes in coolest locations	34%
2.4133	Use most efficient type of electric motors	30%
2.4231	Reduce the pressure of compressed air to the minimum required	24%

Table 6Analysis of ISIC C25 "Primary Metal Manufacturing" – a comparison between SEs, MEs and MLEs. Criterion of selection: most implemented ESOs

3.3.1.3 SEs – comparison among the three investigated sectors

Considering SEs, the results reported above are confirmed also in a pairwise comparison with the textiles and plastics sectors (Table VII): in particular, in the case of ISIC C22 (plastics) four ESOs are in common (respectively ARC 2.7142, 2.4236, 2.4133 and 2.4221), whilst the ARC 2.4231 is substituted by the ESO ARC 2.2511 "Insulate bare equipment". In the case of ISIC C13 (textiles) three ESOs are in common (respectively ARC 2.7142, 2.4236, 2.4133) whilst in the list it is possible to find the ARC 2.2511 "Insulate bare equipment" and ARC 2.4111 "Utilize energy-efficient belts and other improved mechanisms".

This analysis, showing the presence of inefficiencies in the practices for insulation among the textiles and plastics sectors, highlights the importance of the needed attention to be paid towards the use of heat in these sectors.

ARC code	Energy Saving Opportunity Description	Share
ISIC C22 "Plastics Manufacturing" / SEs		
2.7142	Utilize higher efficiency lamps and/or ballasts	80%
2.2511	Insulate bare equipment	56%
2.4133	Use most efficient type of electric motors	31%
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	31%
2.4221	Install compressor air intakes in coolest locations	27%
ISIC C13 "Textiles Manufacturing" / SEs		
2.7142	Utilize higher efficiency lamps and/or ballasts	87%
2.4133	Use most efficient type of electric motors	51%
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	47%
2.2511	Insulate bare equipment	44%
2.4111	Utilize energy-efficient belts and other improved mechanisms	36%

Table 7Analysis of ISIC C22 "Plastics Manufacturing", ISIC C13 "Textiles Manufacturing" – and SEs. Criterion of selection: most implemented ESOs.

Looking with more detail to the ESOs related to the compressed air system, it is possible to observe that the results are partially consistent, in terms of toe saved. Indeed, considering the best five ESOs, as calculated above, the energy consumption can be reduced of respectively 13.24 (ISIC C22) and 17.39 (ISIC C13) toe/year by enterprise, that should be compared to the 9.9 toe/year saved in the ISIC C25 sector. In these case, the slight increase in the toe saved can be due to the higher importance of energy in the plastics and textiles manufacturing processes with respect to the primary metal manufacturing ones.

In conclusion, the results for the most implemented ESOs in the three investigated sectors clearly show the importance of the general services in support of the production processes, quite often neglected since partially not directly involved in the production processes. This consideration, in the broad view of the 20% energy efficiency enhancement, seems to have a non-negligible impact on the effectiveness of the tools to-be provided by policy-makers to SMEs in terms of regulation, funding, and training activities aiming at increasing their industrial energy efficiency.

3.3.2 The ESOs with the highest energy saving

The research has investigated, for the three considered sectors, the ESOs with the highest annual energy saving, thus those singularly able to provide the highest contribution in reducing energy consumption and expenditures. Unfortunately, with a minimum threshold of 20 implementations, it is not possible to clearly identify single ESOs among the sectors. A reasonable explanation of this can be represented by the fact that the investigated sectors are, indeed, quite broad and many technologies and practices can be adopted within each of them. Therefore, in order to find a single ESO, it would be necessary to narrow the type of activities within each sector and focus separately on each of them: although the research has followed this path finding some similarities, it led to ESOs with such a low diffusion coefficient that the values of savings and costs might be completely distorted. As a consequence, the indications coming from those ESOs could be completely misleading, unreliable, and, thus, unacceptable.

Although it is not possible to point out single ESOs, it is considered still of interest to identify some “areas of interventions” that seem to lead to the highest energy savings. In particular, from a pairwise comparison of the three investigated sectors, the following areas have been identified:

- ✓ Thermal System (ARC 2.2xxx);
- ✓ Motor systems (ARC 2.4xxx);
- ✓ Building and Grounds (ARC 2.7xxx).

The results are quite important since the highlighted areas from 50% to even more than 70% of the ESOs for the given sectors, thus showing the importance, in order to achieve the highest savings, to specifically address those areas.

In particular, the research has found that, for what concerns the thermal system, the importance of this area is considerable for the primary metals manufacturing sector, whilst it is of less importance for the textiles and the plastics sectors: a reasonable explanation of this can be represented by the fact that heat represents the most important energetic vector in textiles and plastics production processes. As a consequence, to be competitive, an accurate monitoring of heat use – and also the performance of the equipment for which heat is required or produced – is extremely needed, and, as from the analyses’ results, already in place. Moreover, within the motor systems area, beside the well-known importance of motors (ARC 2.41xx), it can be found a considerable importance of the air compressed system (ARC 2.42xx), that is mostly in common by the three sectors. And, finally, in the building and grounds area it is possible to notice the highest importance occurs for the lighting system, with a set of ESOs that vary from restoring and cleaning the equipment, to significantly shifting to highest energy efficiency lamps and ballasts.

In order to evaluate the results with a higher confidence, a sensitivity analysis has been performed, following two paths: on one side the implementation threshold has been raised from 20 to 30 implementations; on the other side the implementation rate to 10%. In both cases, the results have been confirmed.

3.3.3 The ESOs with the shortest payback time

A further analysis has been conducted to highlight the ESOs with the shortest payback time (PBT), i.e. the ESOs with the lowest ratio of implementation costs on energy savings (expressed in monetary units). A note of caution here is appropriate: since the IAC database reports exclusively the direct implementation costs of the ESOs, it is not possible to point out the so-called “hidden costs”, usually attributable to organizational processes, especially in the operations management. Therefore, the presence of hidden costs could, partially, increase the real ratio costs/benefits of the ESOs.

In the following, a sample analysis considering MLEs has been reported. Considering exclusively the five shortest PBT ESOs, the analysis of the IAC database has suggested the following results, as reported in Figure 4):

- ✓ ARC 2.3131 – Reschedule plant operations or reduce load to avoid peaks;
- ✓ ARC 2.6218 – Turn off equipment when not in use;
- ✓ ARC 2.7124 – Make a practice of turning off the lights when not needed.

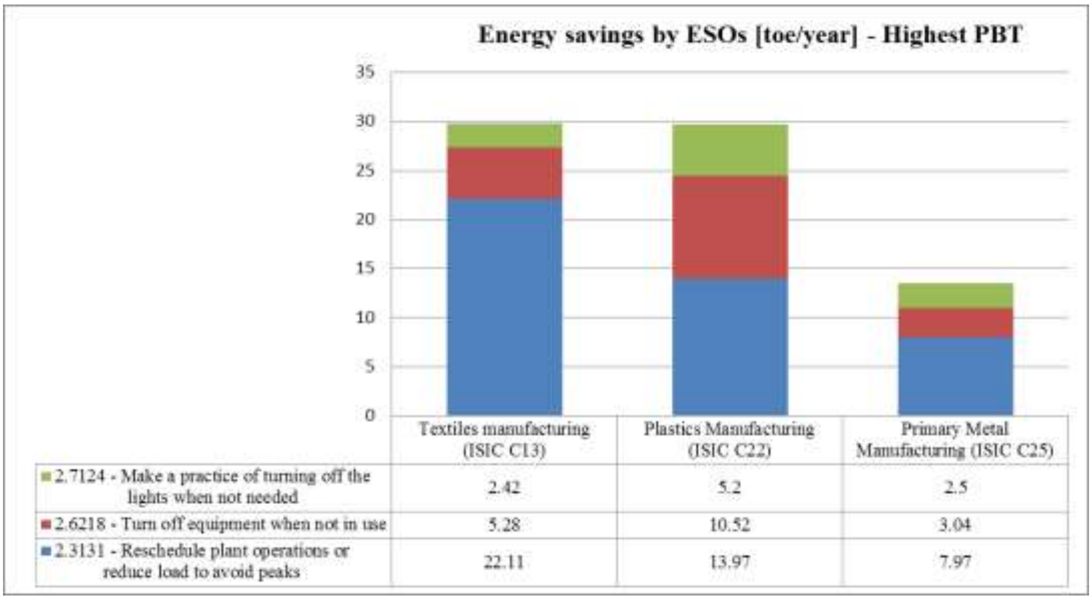


Figure 4Analysis of ISIC C13/C22/C25 - MLEs. Cross-sector analysis of ESOs on annual energy saving. ESOs ranked by shortest payback time.

This analysis has confirmed the importance of a wise and well-structured management of the plant’s operations, showing that the ESOs able to lead to immediate savings are strictly linked to having any equipment maintained and operated correctly: in fact, the ESOs listed above present with very high median energy savings (although with differences among the sectors) and an almost null median implementation costs. For this reason, the PBT of these ESOs can be considered null. Nonetheless, it seems wise to point out that, since those ESOs need an extensive involvement of the operators at the start, and also to make the people part of the process, some organizational costs for a real implementation should be expected.

Nonetheless, the presence of good practices represents a very much interesting result, since it broadens the concept of energy efficiency to the whole plant's operations, and not exclusively to the production processes: in fact, looking at ARC 2.3131 "Reschedule plant operations or reduce load to avoid peaks", even if this ESO cannot fully fall into the strictest concept of energy efficiency (i.e. producing the same output with less energy in input), nonetheless it can be recalled to the "operational energy efficiency" concept, as defined by Cagno et al. [10], since a proper scheduling of the operations allows to contract a lower peak load (in MWe) with the electricity distributor, thus lowering significantly one of the greatest energy fixed costs. This is of very much importance in countries, e.g. Italy, with very high energy prices.

Considering the whole list of ESOs, even if they present almost null direct implementation costs (but, again, some hidden costs should be assumed also here), the "good practices" suggested prove to be quite promising: for example, turning off the equipment when not in use (ARC 2.6218) has showed a reduction in the energy consumption ranging from 3.04 to even 10.52 toe/year.

3.4 Conclusions and further research

As from the most recent inputs of the European Commission on the need to increase of energy efficiency, and considering the structure of the industrial sector, the paper dealt with the identification and evaluation of the most effective ESOs that should be promoted and adopted to improve industrial energy efficiency within SMEs, for which energy does not usually seem to represent a major concern.

In order to be most effective in the promotion and adoption of the existing BAT/Ps, on one side SMEs' entrepreneurs have to be aware and fully convinced on the effectiveness of their decisions in investing resources to reduce their energy consumption, on the other side policy-makers need to know where to devote the necessary resources. Therefore, the research has presented three distinct perspectives for the analysis of the data regarding the ESOs: the most suggested, the highest saving, and the shortest pay-back-time ESOs.

To identify the most effective ESOs, the study has analyzed and compared different databases coming from Northern- Italy projects and the US Industrial Assessment Center database, that collects the implementation of many actions among US enterprises. A point-to-point analysis for the two datasets showed that, concerning the most implemented ESOs in the investigated sectors, are about the same. Secondly, the distribution of values of the characteristic parameters for the ESOs (in terms of energy savings and direct implementation costs) showed several similarities. And, thirdly, the values of energy savings and implementation costs are comparable. Therefore, the correspondence of the two datasets and the transferability of the information contained in the IAC database have been observed, thus enabling to use the IAC database to make projections in Italy.

Starting from this correspondence, the research has provided a deep insight into the ESOs for three important manufacturing sectors in Lombardy (textiles, plastics and primary metal manufacturing), trying to put in evidence the most effective ESOs according to the considered criteria.

A punctual analysis for the most suggested ESOs within SEs showed the importance of lighting and compressed air systems: this is in line with what expected, as those systems are usually neglected since they are not directly related to the firms' productivity, although they can consistently affect the production costs.

Moreover, considering the highest energy saving opportunities, although it is not possible to draw any conclusion on a single ESO for the three considered sectors and firm's size, due reasonably to the variety of processes and technologies that can be adopted, some interesting areas of ESOs have been identified. The found ESOs belong to three important areas for the firms, such as thermal systems, motor systems and lighting, with some differences among the sectors that broadly reflect the importance of some processes: e.g., thermal systems in textiles and plastics sectors seem to be quite well monitored due to the importance of heat in the production processes, thus being more efficient than thermal systems in the primary manufacturing sector.

Thirdly, a consistent contribution towards the energy efficiency enhancement could come from a widespread adoption of the practices for a wise and well-structured management of the plant's operations: in an cross-sector analysis among MLEs, the shortest pay-back ESOs require exclusively a minimum effort for their implementation (i.e. mainly information diffusion, since they are good practices), thus not needing a huge monetary investment nor any innovation in the existing production process.

The present study opens the research to the investigation of ESOs among other relevant sectors for the local North-Italian industrial structure, putting in evidence commonalities and differences with the findings here reported. Furthermore, the results represent the basis for the investigation of the most effective policies and the evaluation of the projections for the deployment of the ESO among the North-Italian manufacturing sector to reach the target requested by the European Union on the 20% reduction of energy consumption. Furthermore, a third research stream is represented by an investigation of the energy efficiency barriers among SMEs starting from a punctual analysis of each ESO, in terms of characteristics, variables of context, and existing energy efficiency policies.

3.5 Bibliography of the Chapter

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4 Dealing with barriers to energy efficiency and SMEs: some empirical evidences

This chapter reports the content of the work published as:

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The previous works that provided useful contributions on the topic are:

Cagno E., Trianni A., «Evaluation of the existing barriers for energy efficiency in Industrial operations: a study within the Italian Industrial Sector.» Proceedings of the 16th Annual International Sustainable Development Research Conference . Hong Kong, China, 2010 (d).

Trianni A., Cagno E.,. «An analysis of the energy efficiency barriers within the Italian SMEs manufacturing industry.» XVI summer school F. Turco. Abano Terme, 2011 (a).

Trianni A., Cagno E., «Energy Efficiency barriers in industrial operations: evidence from the Italian SMEs manufacturing industry.» 2011 Summer study on Energy Efficiency in Industry. Niagara Falls, NY, USA: American Council for an Energy-Efficient Economy (ACEEE), 2011 (b).

This paper aims at providing an identification and an analysis of the most relevant barriers to energy efficiency that limit a widespread implementation of the Best Available Technologies and Practices (BAT/Ps) through the investigation of 128 non-energy intensive manufacturing Small and Medium-sized Enterprises (SMEs) in Northern Italy. The study, starting from the existing literature, performs an investigation of the operational difficulties occurring when it has been decided to undertake the process of investing resources in energy-efficiency interventions. The most perceived barriers have been analyzed with respect to several important characteristics (among others, sector and firm's size). This examination shows also that very much attention should be paid to avoid bundling together SMEs of different sizes and sectors, since different behaviors with respect to the perception of the barriers can be observed. The analysis of the sample presents some interesting trends considering the perception of the barriers with respect to previous experience of the enterprises on energy efficiency. The paper also explores, through a preliminary analysis, the correlations among questions in order to understand the dynamics and the possible effects of a given barrier with respect to others. Several suggestions for future research in this important area have been provided.

4.1 Introduction

The manufacturing industry, according to the most recent estimates of the International Energy Agency [1], in 2008 accounts for about 79% of the global coal consumption, more than one third of the global gas consumption, and also uses 41.7% of all electricity produced. Moreover, a recent research has shown that the industrial sector uses “more energy globally than any other end-use sector, currently consuming about 50 percent of the world’s total delivered energy” [1]. Besides the recent “reduction in energy use during the recession, mainly as a result of substantial cutbacks in manufacturing that had more pronounced impact on total fuel consumption than did the marginal reductions in energy use in other sectors” [1], the increase of primary energy consumption and the emissions of green-house-gases coming from the use of fossil fuels have drawn the attention of public policy makers of most developed countries on industrial energy efficiency. In particular, within the European Union, the implementation of the so-called Directive “20-20-20” (i.e., 20% reduction in GHG-emissions, a share of 20% of energy produced by renewable energies and 20% improvement in energy efficiency) [2], will make the implementation of cost-effective energy efficiency measures within industry really of fundamental importance for firms’ competitiveness, and especially in countries like Italy, where the electricity price is almost double than other European countries [3]. In fact, considering the impact of the 20-20-20 Directive on the domestic industrial systems, the trend of consumption needs to be dramatically changed and new and more efficient measures need to be adopted, driving the industrial system to be more energy-competitive and thus, by the fact, with the result of exiting the market for the less-competitive companies.

Focusing on the structure of the industrial sector, firstly, it can be observed that is largely composed (>99% in almost all countries) of Small and Medium Enterprises (then SMEs), that also cover a consistent portion of the domestic industrial consumption (in some cases, as from elaborations from the most recent estimations in Italy, more than 60% [4]); and, secondly, industry is mainly devoted to non-energy intensive manufacturing activities, defining here non-energy intensive manufacturing industries as firms whose energy costs do not exceed 2% of their turnover, as assumed by other researches in this field [5].

As a consequence, in order to promote the most effective and successful policies to enhance industrial energy efficiency, it is crucial to fully understand what the difficulties are and where they are rooted within those (non-energy intensive manufacturing SMEs) types of firms. In particular, these difficulties put in evidence the existence of barriers with respect to energy efficiency, and thus a lot has still to be done in developing and putting together all the elements of the puzzle for understanding why energy efficiency measures are often not implemented, especially in SMEs. To do this, a research activity has been conducted involving, through several projects, many Northern-Italian SMEs, policy makers and local entrepreneurial associations.

4.2 Focusing the problem

A barrier for energy efficiency, as defined by Sorrell et al.[6], is “a postulated mechanism that inhibits investments in technologies that are both energy efficient and (at least apparently) economically efficient. Table 1 reports the approach adopted by Sorrell et al. – followed by Rohdin et al. [7] – through which a single barrier can be classified according to three main categories: economical, organizational and behavioral. But there are still some misalignments in the definition and classification of a barrier, as identified by Weber[8].

The barriers to industrial energy efficiency have been widely investigated since late 1980s. In particular, it is possible to notice that the research started from the evidence that, even with a very high potential for energy efficiency widely recognized, “[…] many investments in energy efficiency fail to be made despite their apparent profitability […]” [9]. In the first stages, many authors devoted their attention to a deep and rigorous investigation of the reasons behind the failure in the application of the Best Available Technologies / Practices (then BAT/Ps), aiming at providing a description of the existing barriers that limit the industrial energy efficiency. Hirst and Brown [10] provided a fundamental framework for evaluating market barriers to energy efficiency, pointing out the existence of the so-called “structural barriers” to energy efficiency, e.g. distortion in fuel prices, uncertainty about fuel prices, government fiscal and regulatory policies, codes and standards, and some “behavioral barriers” as the attitude towards energy efficiency, the perceived risk of energy-efficiency investments, information gaps (either in the content or in the form of information), and misplaced incentives to apply energy-efficient technologies and practices. Brown [11], based on the debate in the literature on market failures and market barriers, provided an up to date literature review of market failures, as misplaced incentives with the “principal-agent” problem, distortion in fiscal and regulatory policies, unpriced costs as externalities, unpriced public goods as energy, insufficient and incorrect information. The author also performed a literature of the market barriers to energy efficiency, highlighting three main barriers, the low priority of energy issues, the capital market barriers, and the incomplete markets for energy efficiency. Other authors, as Reddy [12] tried to identify and characterize the actors involved in the process of improving energy-efficiency, and described several barriers that affect them. In particular, Reddy described the energy consumers, with problems of ignorance or awareness, high initial costs, existence of other issues than energy costs, lack of support on investing in new energy-efficient technologies, and uncertainty about current and future energy prices. The author also provided an insight on the other actors of the energy-efficiency improvement process, such as end-use equipment manufacturers, end-use equipment providers, energy-carrier producers and distributors, local (or national) financial institutions, government (or country), and international multilateral and industrialized country funding (or aid) agencies. DeCanio provided an interesting contribution to the research, highlighting, among other barriers to energy efficiency, the importance of the bounded rationality behavior of investors, as a primary element inhibiting the adoption of energy-efficient technologies [9], expressed through the adoption of approximate criteria and routines to evaluate the profitability and benefits of technologies and practices. Moreover, DeCanio, in an empirical investigation on lighting upgrades underlined that, besides the importance of economic factors on the profitability of the investments, a large number of organizational and institutional factors also move paybacks, such as who is the equipment supplier and who provides the installation of the equipment [13]. Other contributions in the debate can be observed from several authors who tried to categorize, rather than describing the barriers: e.g. Weber [8] accomplished an interesting viewpoint, proposing a distinction of the barriers, as emerged from the up-to-date literature, into: (i) Institutional, (ii) Market (barriers and failures); (iii) Organizational, and (vi) Behavioral. For a comprehensive collection of the most important literature, it is remarkable a 2010 study performed by Sorrell et al. [14] for the United Nations Industrial Development Organization who have gathered and discussed a large number of recent and past studies on the barriers to energy efficiency, under the structure of the taxonomy provided by Sorrell et al. [6].

It is possible to see another path of the research moving towards the empirical evaluation of the identified barriers among different contexts, in terms of industrial sectors - with particular attention towards the energy-intensive sectors (in particular iron and steel), as done by Rohdin et al. [7] for the Swedish foundry industry, that took as reference for their evaluation the framework provided by Sorrell et al. [6], by Zhang and Wang [15] , who highlighted the barriers to energy saving technologies and productive efficiency in the Chinese iron and steel sector, or by Nagesha and Balachandra [16] that investigated two Indian small clusters of foundries and brick and tile. Nonetheless, other studies focused on different sectors - including manufacturing and non-manufacturing –, as those done by Sorrell et al. [6] analyzing the mechanical engineering sector in UK, Germany and Ireland, or Massoud et al. [17], who investigated drivers, barriers and incentives for energy efficiency within the food industry in Lebanon. To complete the picture of the studies, it is not possible to forget the broad analyses for countries, including also the proposal of policies for the industrial energy efficiency improvement. In particular it is worth to remark the study by Levine and al. [18], who linked market failures and government policy in the United States. It is also possible to find national studies performed in order to evaluate the barriers to industrial energy efficiency investments, as Sardianou in Greece [19], Reddy and Shresta [20] in India for electricity technologies, Painuly [21] in a comparison between India and China, or Schleich [22] who compared the barriers to energy efficiency across the German commercial and services sectors.

As briefly expressed in the introduction, even considering the wide literature of which a part has been reported above, few studies have been explicitly devoted to the evaluation of the barriers and effective policies in case of manufacturing SMEs [16,23]. At the moment, very little attention has been devoted in investigating barriers to energy efficiency putting in evidence commonalities and differences with respect to sectors, firms' size, and evaluating the possible relationships between barriers, the difference between the perception of the barriers with respect to the effective ones, in which phase of the investment process in new technologies they act, and also their dynamics of appearance within a firm.

Moreover, it should be pointed out that, even assuming the taxonomy provided by Sorrell et al. [6] as a main reference in theory of barriers, the taxonomy has analyzed the barriers from the point of view of theories in which the barriers might fall, i.e. economic, organizational and behavioral theories, but admitting that possible interactions among barriers might exist. Nonetheless, the scientific debate on the nature of the barriers is still open, since, according to Weber [8] "each barrier will have economic, behavioural and organizational aspects: the three groups form perspectives that highlight particular aspects of a complex situation". This means that, looking at the problems effectively affecting SMEs (here called "operational barriers"), it is apparent that the relationships among problems exist and they cannot be recalled uniquely to a single theoretical barrier: previous studies [5], in fact, testing the barriers with multiple case studies, have been forced, in order to consider the theoretical barriers, to refer exclusively the questions to a main barrier.

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

Table 12Classification of barriers to energy efficiency based on Sorrell et al. [6].

4.3 Barriers for SMEs

Focusing on SMEs, some barriers that are quite difficult to be investigated, or may cover some aspects of minor interest for those enterprises were excluded in the analysis. In particular, it is possible to see some barriers related to the complexity of the organization, as “Principal-Agent Relationship” and “Split Incentives”: in case of

SMEs, in fact it seems clear that almost all decisions, included the decisions on investing capital for an energy efficiency intervention, are made by a small board or even directly by the entrepreneurs themselves. Thus, those barriers, representing respectively some behavioral aspects related to the control on agents by the principal, or even possible divergent interests between who decides on energy efficiency and who invests, tend to fade in SMEs whereas quite often the entrepreneur his/herself controls directly the operations and especially makes both decisions and investments. Another barrier, i.e. "Moral Hazard", represents a dynamic related to the asymmetry of information with respect to the decisions on energy efficiency: since it implies the relationship between entrepreneurs and technologies/services providers, it is of quite difficulty to be thoroughly investigated with questions solely to the entrepreneur, and for this reason it has not been investigated in this study. In addition to that, the "Power" barrier has not been investigated in this study since, as expressed briefly in the introduction, the firms have been involved in small research projects aimed at increasing energy efficiency, thus proving to not consider energy efficiency and energy management as peripheral issues by the management.

Moreover, it should be pointed out that, as expressed in the previous section, several difficulties representing barriers for SMEs do not seem to be uniquely referable to a single barrier, as already put in evidence by Rohdin and Thollander [5], that, in their study, refer the questions to a "main theoretical barrier", implying, but not investigating, the possible existence of a "secondary" or "not primary" theoretical barrier related to the main one.

As a consequence, in this study, rather than directly asking the single theoretical barrier, some practical aspects (i.e. operational barriers) of the difficulties in choosing and adopting and energy-efficiency intervention have been investigated. Thus, a single question, reported in Table 2 with a "Y", can cover one or more of the theoretical barriers classified by Sorrell et al., and not all of them in the same depth, i.e. a given question can be related primarily to a given theoretical barrier, and secondarily to one or more other theoretical barriers. The results of this operation of re-structuring and rephrasing barriers into operational barriers, have been reported in Table 2.

	Questions	*Description*
Y1	Lack of time or other priorities (comparing energy efficiency efforts respect to production efforts)	Time for investing new energy efficiency opportunities, analyzing data and information is primarily an hidden cost to be considered. Furthermore, the efforts in devoting time for energy efficiency investigations do not lead to certain outcomes: thus, production efforts tend to have greater weighting, since they can lead to certain outcomes.
Y2	Lack of capital - either public or private - to be devoted to energy efficiency investments	Limited access to capital, either internal funds or borrowing, may prevent energy efficiency measures from being implemented
Y3	Lack of internal technical skills	Management and/or personnel may not be able to evaluate energy-efficiency opportunities, thus requiring some additional efforts (also in terms of economic resources) in order to make the needed evaluations. Furthermore, this lack partially explain the “rule of thumb” evaluations that are taken without the needed technical skills.
Y4	Difficulty in gathering external technical skills	Management can face the high additional costs related to gathering external skills, and they may also feel the difficulties in investing resources for not certain outcomes, thus tending to favour the status quo.
Y5	Poor information for decisions regarding energy efficiency	The information on energy efficiency can be perceived by investors as poor and lacking on some important details, thus preventing the investment on cost effective opportunities.
Y6	Lack of personnel awareness	Personnel might resist change primarily since it is committed to what it is doing, since it has established routines that are difficult to be modified. Moreover, it also may not have environmental values, therefore giving a lower priority to efficiency improvements.
Y7	Lack of managerial awareness	Management may not have environmental values, therefore giving a lower priority to energy efficiency improvements. Moreover, it might also resist change since it gives greater weight to certain outcomes (production) respect to uncertain outcomes (energy efficiency).
Y8	Low returns for energy efficiency investments (other priority for capital investments)	Low returns reflect the heterogeneity of energy-efficiency solutions, that might have low savings, or strong variances for savings, preventing them to be cost effective. Moreover, low returns reflect some additional technical or financial risk that might be not under control, thus preventing long time horizons investments.
Y9	Scarce information regarding energy efficiency opportunities and winning solutions	The information might be scarce, i.e. not specific, personalized, vivid, simple and available close in time to the relevant decision.

Table 2Operative questions respect to Theoretical Barriers as by Sorrell et al. [6].

Several more questions have been addressed to the interviewees: firstly, it has been decided to investigate whether the firms would more likely to incur in difficulties for implementing management interventions (DM), or technical interventions (DT) regarding energy efficiency. Secondly, it has been asked if in the recent past (3 years) they had adopted energy efficiency interventions, or conducted energy audits, in order to evaluate their previous experience to the energy efficiency topic and the possible relationships on the perception of the barriers.

4.4 Methodology of the study

The barriers to energy efficiency have been investigated through the involvement of 128 out of more than 200 firms participating in research projects that, through partially public-sponsored energy audits (i.e. energy audits mainly funded by the Regional Government and the local Chambers of Commerce), were interested in identifying, characterizing and evaluating the most important energy efficiency interventions, through the use of a specifically-developed methodology [24]. The SMEs – according to the definition provided by the European Commission in 2003 [25] – mainly belong to the most important sectors of the Lombardy Region in Italy (in terms of employees and energy consumption), as classified according to the International Standard Industrial Classification of All Economic Activities "ISIC rev.4", as reported in Table 3.

	Distribution by number of employees			
Manufacturing sectors	10-49 (SE)	50-99 (ME)	100-249 (MLE)	*total*
Textiles - C13	11	8	5	24
Wood - C16	3	2	2	7
Plastics - C22	14	5	4	23
Basic Metals - C24	11	8	0	19
Primary Metals - C25	18	5	4	27
Others	10	13	5	28
total	67	41	20	128

Table 3Classification of the firms involved in the projects (respect to ISIC rev.4 and number of employees).

As it can be argued from Table 3, the SMEs have been divided into 3 classes – Small Enterprises (SEs), Medium Enterprises (MEs) and Medium-Large Enterprises(MLEs) – since there is the possibility that, considering the organizational processes within SMEs, there might be a difference in their behavior, as observed in other issues, e.g. occupational health and safety management [26-28]. For this reason, in this study SEs refer to 10 to 49 employees, MEs from 50 to 99 employees, and MLEs from 100 up to 249 employees.

This operation of sub-sizing the sample allows to see that more than 70% of the sample (93 out of 128) belongs to four important manufacturing sectors, i.e. textiles, plastics, basic and primary metals, and about 85% of it (108 out of 128) is made of SMEs with less than 100 employees (SEs and MEs).

Before the energy audit, the auditor conducted a semi-structured interview to the person in charge of energy issues for the visited site. The interview aimed at allowing the auditor to have a full picture of the firm, including the firm's organization, a full description of the production process, and a brief description of the equipment, with the identification of the main equipment installed, the net electrical and thermal power installed for each machinery, etc. This discussion is considered of fundamental importance due to the explorative nature of the study, since, during the interview, it had been possible to understand the critical areas of the firm identified directly by the interviewee.

After the interview, in 128 cases, the auditor had the possibility to ask the respondent to fill out a short guided questionnaire in which he/she should provide his/her view about the existing difficulties in choosing and adopting an energy efficiency intervention, through the list of questions reported in the previous section. A Likert scale score from 1 to 4 has been assigned to each question in order to rank the results from the questionnaire: 1 point if the respondent considered the question to be "not important", 2 points for "scarcely important", 3 points for "important", and 4 points if "very important".

A note of caution is warranted in that the sample has not been randomly selected and its size is too small to be statistically representative. Nonetheless, due to the explorative nature of this study, it has been considered still of interest to investigate this sample of the total population of SMEs in order to get the first understandings, some of which might be further extended.

4.5 Results and discussion

4.5.1 Analysis of the whole sample

In Table 4 it is possible to see the rank of the barriers according to their overall average scores. As first results, two main problems have emerged:

the lack of capital (either public or private, i.e. Y2) is perceived as very critical, and reasonably reflects the status-quo of industries struck by the global financial crisis. In this sense, it sounds reasonable to think that the financial support of energy-efficiency investments by Governments and/or public administrations might represent the "activation energy" to enhance industrial energy efficiency;

the problem of information emerged, expressed both by the lack of data, as poor information that might support the energy efficiency decisions (Y5), and the form of the information on possible energy-efficiency interventions (Y9).

Rank (average score)		*Question*	*Comment*
1 (3.03)	Y2	Access to capital (lack of capital - public and/or private - to be devoted to energy efficiency investments)	42 out of 128 respondents considered the access to capital a very important barrier to energy efficiency.
2 (2.85)	Y9	Scarce information regarding energy efficiency opportunities and winning solutions	83 out of 128 considered the scarcity of information as, at least, important.
3 (2.77)	Y5	Poor information for the energy efficiency decisions	More than 70% of the respondents considered this barrier as important.
4 (2.70)	Y3	Lack of internal technical skills	65% of the respondents identified this as, at least, an important barrier that prevents the decisions regarding energy efficiency.
5 (2.61)	Y8	Other priorities for capital investments (low returns for energy efficiency investments)	In general, production-related investments proved to be more important than energy-efficiency investments (almost 60%).
6 (2.53)	Y1	Lack of time or other priorities (comparing energy efficiency efforts respect to production efforts)	18 interviewees perceived this as a very important barrier.
7 (2.35)	Y4	Difficulty of gathering external technical skills	50 out of 128 respondents consider this as an important barrier, although they participate in a project with external energy-efficiency experts.
8 (2.25)	Y6	Lack of personnel awareness	More than 60% of the interviewees consider this barriers as scarcely or not important.
9 (2.03)	Y7	Lack of managerial awareness	Only 6 respondents consider this as a very important barrier.
(2.59)	DT	Difficulty in implementing technical interventions	17 interviewees consider this as not an important difficulty.
(2.35)	DM	Difficulty in implementing management interventions	26 interviewees consider this as not an important difficulty.

Table 4Average score of the barriers with respect to the whole sample.

As a consequence, the respondents highlighted the difficulties both of making decisions on energy-efficiency interventions (i.e., if the intervention is “worthy to be implemented”), and “how to implement it” (expressed in terms of financial availability).

With respect to previous literature, the findings here reported seem to confirm the importance of lack of capital highlighted by other studies in the industrial sector [6,16], although conducted in other contexts (respectively LEs and energy-intensive industries). Nonetheless, only in Rohdin and Thollander [5] the information-related barriers has seemed to play such an important role as here.

Furthermore, a group of barriers just underneath the main ones described above can be observed: considering the low returns for energy efficiency investments (Y8), it seems reasonable to relate this barrier to uncertainty and risk, in the sense that greater uncertainties on the effective performance and risks might affect the profitability of an energy-efficiency investment, thus making production-related interventions more interesting for an investor with limited budget. This result seems to confirm what found in the few case-studies analysis performed by Rohdin et Thollander [5], in which risk and uncertainty appear as non-negligible barriers. Nonetheless, it seems reasonable to assume that a removal of the capital availability barrier might represent the driver for removing those barriers, since more capital would remove the problem of choosing between investing in energy-efficiency interventions or elsewhere (typically production-related investments).

Moreover, considering the lack of internal technical skills (Y3) and the lack of time (Y1), they together contribute to the “hidden cost” barrier. In fact, it seems reasonable to assume that less technical skills would lead to incurring more difficulties when selecting and gathering the needed information to make a choice about an energy efficiency intervention. Moreover, less technical skills would also lead to taking more time to perform a consumption analysis for the equipment, etc. The position of the hidden cost barrier in the ranking appears to be in conflict with previous studies, for which hidden costs represent the most important barrier [5-6,19]: an explanation for this misalignment might be found in the sample.

Likewise, considering the other barriers, it emerged that the difficulty of gathering external technical skills (Y4) and the awareness with respect to the energy-efficiency subject (Y6 & Y7) are not considered as important barriers: this result is not confirmed in a previous research, in fact for Nagesha and Balachandra [16] awareness represents the most important barrier, but in the present case it was expected since each firm had voluntarily joined the research projects in which external energy auditors and energy efficiency experts have been involved. Moreover, it sounds reasonable to assume that, at least partially, the investigated sample is familiar with the energy-efficiency subject, and this may explain the low scores in the “lack of awareness” barriers, underestimating the real perception of the barriers for the universe. Note that the SMEs involved in this study are sensitive, agile, and consequently do not seem to find many difficulties in making improvements within their plants, either in implementing technical (DT) or management (DM) interventions. But, again, this might underestimate the difficulties for the universe.

The considerations drawn above do exclusively reflect the average behavior of the interviewed SMEs: since the sample is not homogeneous for sectors and number of employees, it has been considered as of interest to perform several further analyses in order to evaluate what (if any) are the differences and commonalities among sectors and number of employees.

4.5.2 Analysis by firm's size

In Table 5, the results of the major barriers derived from the questionnaire have been reported, mainly putting in evidence some interesting trends, due to different firm's sizes.

	Number of employees		
Question and average score (by firm's size)	*15-49*	*50-99*	*100-249*
Y1 - Lack of time or other priorities (comparing energy efficiency efforts respect to production efforts)	2.60	2.67	1.94
Y2 - Access to capital (lack of capital - public and/or private - to be devoted to energy efficiency investments)	3.03	3.13	2.78
Y3 - Lack of internal technical skills	2.84	2.76	2.11
Y4 - Difficulty of gathering external technical skills	2.36	2.42	2.17
Y5 - Poor information for the energy efficiency decisions	2.77	2.79	2.72
Y6 - Lack of personnel awareness	2.14	2.13	2.89
Y7 - Lack of managerial awareness	1.98	2.00	2.24
Y8 - Other priorities for capital investments (low returns for energy efficiency investments)	2.63	2.53	2.72
Y9 - Scarce information regarding energy efficiency opportunities and winning solutions	2.90	2.89	2.61
Average score by firm's size	2.58	2.59	2.46
DM - Difficulty in implementing management interventions	2.26	2.37	2.61
DT - Difficulty in implementing technical interventions	2.28	2.89	2.94

Table 5Average score for the barriers derived from the questionnaire divided by firm's size.

This analysis allowed some effects to be appreciated. In particular, the lack of time (Y1) is considered in a different manner by MLEs with respect to SEs and MEs: this phenomenon can be explained by the fact that the greater the size, the more structured the firm's organization, the lower the perception of the barrier, thus leading to a "reverse" size effect. Indeed, a "larger structured" organization will have personnel devoted to the maintenance of the plant's equipment, to the research of "inefficiencies", and consequently to the identification of the energy efficiency opportunities. In some of the MLEs companies involved in this research, it has been found that the personnel involved in the energy-efficiency related issues had the possibility to participate in training courses, sharing information experiences, showing that although limited, a budget from the firm's top management had been devoted to energy-efficiency issues. Lack of time (Y1) in MLEs does not represent a major barrier with respect to SEs, where the person in charge of energy efficiency issues (usually the entrepreneur him/herself) has also the responsibility of managing the plant, managing clients and suppliers, marketing products, etc.

The reverse size effect can be also appreciated in the case of lack of internal skills (Y3) and, with lower evidence, for the scarce information regarding energy efficiency opportunities and winning solutions (Y9): SEs and MEs are usually led by one entrepreneur that might be very expert in the production process, but sometimes does not own the skills to identify and fully evaluate the energy inefficiencies that might occur in the whole plant's operations. Vice versa, MLEs usually have a team (or, at least one person) devoted to the maintenance of the equipment, as expressed above, thus developing the necessary experience to find, evaluate and propose effective solutions with respect to energy-efficiency issues.

For what concerns other trends, it is possible to notice a "direct" size effect (the larger the size, the larger the perception of the barrier) in the "lack of personnel awareness" barrier (Y6): in particular, it can be inferred that, as expressed in the 'Barriers for SMEs' section, the control on the "good practices" for managing the plant is stricter when the firm has very few employees. In this case in fact it has been observed that the person in charge of energy issues (usually directly the entrepreneur) has the opportunity of better controlling the energy-efficiency behavior of the personnel during the plant's operations. On the contrary, the management of MLEs is not able to maintain such control over the personnel, thus tending to blame the difficulty on energy efficiency to a lack of the personnel awareness.

This direct size effect can be appreciated also for the difficulties in implementing either management (DM) and technical solutions (DT). This might be explained by the fact that, in SEs, all decisions (and, thus, also those concerning energy efficiency) are often taken by one single person, the entrepreneur him/herself. For this reason, there is little difficulty in implementing either management (DM) in MLEs or technical interventions (DT) in MEs and MLEs. On the contrary, in a pairwise comparison of energy saving, knowledge, information etc., the larger the size, the more difficult will be to implement the decisions, as emerged during the interviews and suggested by the fact that, in both questions, the questions have a score of 2.61 and 2.94 – respectively for difficulty in implementing management (DM) and technical interventions (DT) – considerably higher than the average score of the same firm's size barriers, 2.46.

All questions have been tested through ANOVA in general terms, and a modified Tukey-Kramer test [29,30] to identify which levels of firm's size were significantly different (i.e. "**",significant, *p*-value <0.05, "*", almost significant, *p*-value<0.10). It can be argued from the p-values that there is a significant difference for the levels investigated in the following questions, as showed in Table 6:

- y1 – Lack of time or other priorities (comparing energy efficiency efforts with respect to production efforts);
- y3 – Lack of internal technical skills;
- y6 – Lack of personnel awareness;
- DT – Difficulty in implementing technical interventions.

	y1	y2	y3	y4	y5	y6	y7	y8	y9	DM	DT
Classes of size	0.029 **(a)	0.422	0.008 **(a)	0.545	0.966	0.002 **(b)	0.455	0.147	0.272	0.240	0.001 **(b)

Table 6 p-values for the relation 'classes of size' with respect to the investigated questions. Where

> **(a): lower average for Small & Medium enterprises respect to Medium-Large enterprises;**
>
> **(b): higher average for Small & Medium enterprises respect to Medium-Large enterprises**

4.5.3 Analysis by sector

Another analysis has been performed in order to show commonalities and differences (if any) with respect to the primary activity (i.e. the sector) of the interviewed enterprises. The results of the average scores for the questions have been reported in Table 7.

It is worth to be pointed out that the scores for the Textiles Manufacturing enterprises (ISIC C13 sector) are lower than the corresponding for the whole sample in all questions.

	Av. score	*Sectors* C13	C16	C22	C24	C25	Others
Y1 - Lack of time or other priorities (comparing energy efficiency efforts respect to production efforts)	2.53	1.95	2.83	2.59	2.83	2.58	2.62
Y2 - Access to capital (lack of capital - public and/or private - to be devoted to energy efficiency investments)	3.03	2.74	3.14	3.23	3.13	3.12	2.92
Y3 - Lack of internal technical skills	2.70	2.39	2.86	2.71	2.88	2.84	2.69
Y4 - Difficulty of gathering external technical skills	2.35	2.13	2.29	2.33	2.27	2.40	2.58
Y5 - Poor information for the energy efficiency decisions	2.77	2.39	2.86	3.24	2.67	2.64	2.88
Y6 - Lack of personnel awareness	2.25	2.05	2.33	2.29	2.00	2.36	2.42
Y7 - Lack of managerial awareness	2.03	1.82	2.33	2.20	1.60	2.17	2.12
Y8 - Other priorities for capital investments (low returns for energy efficiency investments)	2.61	2.05	3.43	2.62	2.53	2.68	2.81
Y9 - Scarce information regarding energy efficiency opportunities and winning solutions	2.85	2.68	3.29	3.00	2.59	2.83	2.96
DM - Difficulty in implementing management interventions	2.35	2.14	2.86	2.43	2.07	2.25	2.58
DT - Difficulty in implementing technical interventions	2.59	2.24	3.00	2.57	2.60	2.67	2.69

Table 7Average score for the barriers derived from the questionnaire divided by sector.

This is of particular interest, since represents the effect of a deep crisis in the last two decades that occurred at least in Italy within the textiles sector, mostly due to the growing competition of other countries, mainly belonging to emerging economies: as a consequence of this, a lot of industries have closed, changed their main business, or transferred their core activities in other countries. This, coupled with the fact that, in the Textiles sector, energy represents a critical issue with anon-negligible share of the total production costs, seems to represent the driving force for the “survived” companies to be more cost-competitive, thus being more (energy) efficient in the production process. In this sense, Textiles’ interviewees did not seem to feel very burdensome barriers, since, and this has been also inferred by the energy audits, they have already moved towards the BAT/Ps. In fact, testing, as done in the previous sub-section, the difference between “Textiles” and “non-Textiles” manufacturing SMEs (i.e. “**”,significant, *p*-value

<0.05, “*”, almost significant, *p*-value<0.10), the factor is at least almost significant in 8 out of 11 questions, as showed in Table 8.

	y1	y2	y3	y4	y5	y6	y7	y8	y9	DM	DT
Textiles	0.001 **	0.004 **	0.006 **	0.129	0.003 **	0.102	0.052 *	0.000 **	0.074 *	0.017 **	0.112

Table 8p-value for the comparison 'Textiles' with respect to 'non-Textiles' enterprises.

In order to analyze the possible differences among other sectors, an ANOVA with Tukey-Kramer comparison has been conducted with a reduced sample (i.e. removing textiles enterprises), but it does not allow to draw any other particular conclusion, since a statistical evidence on the questions has not emerged.

Considering Italy, it is possible to observe that the phenomenon that interested the textiles sector is now in place for the other sectors, highlighting the perception of lack of competitiveness of those sectors with respect to their efficiency, that might lead to the dramatic consequences already happened in the textiles sector. In particular, the growing competition of emerging economies, that necessarily present lower labor costs compared to Italian ones, is driving the attention of the interviewed SMEs towards energy-efficiency: indeed, although energy does not usually cover a consistent share of production costs for their sectors, energy efficiency seems to be one leading path for the their survival.

4.5.4 Analysis with respect to the previous experience in energy efficiency

It was considered as of interest to investigate a different perception of the barriers respect to some interesting characteristics of the firms, and in particular with respect to their previous experience on energy efficiency, measured as the previous adoption of energy-efficiency interventions and the execution of an energy audit, reported in Figure 1.

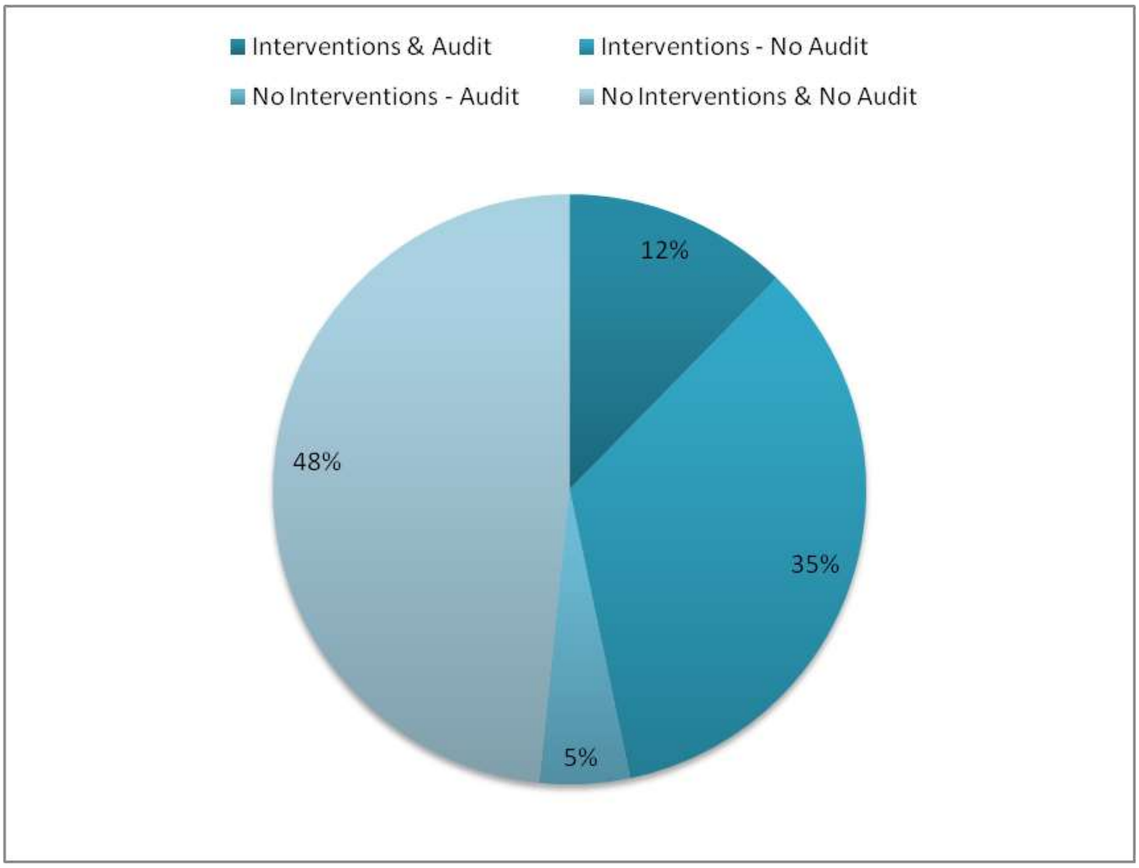

Figure 1Distribution of the sample with respect to the previous experience on energy efficiency.

For this reason, it has been decided to analyze the barriers with respect to their previous adoption of energy efficiency interventions, and, analogously, to analyze the barriers with respect to a previous experience in energy audits, as reported in Table 9.

	Have you adopted EE interventions in the recent past (3 years)?		Have you conducted energy audits in the recent past (3 years)?		Av. score
	yes	*no*	*yes*	*no*	
Y1 - Lack of time or other priorities (comparing energy efficiency efforts respect to production efforts)	2.37	2.63	2.10	2.58	2.53
Y2 - Access to capital (lack of capital - public and/or private - to be devoted to energy efficiency investments)	2.92	3.08	2.76	3.07	3.03
Y3 - Lack of internal technical skills	2.51	2.86	2.76	2.69	2.70
Y4 - Difficulty of gathering external technical skills	2.13	2.52	2.33	2.35	2.35
Y5 - Poor information for the energy efficiency decisions	2.49	3.00	2.62	2.80	2.77
Y6 - Lack of personnel awareness	2.14	2.34	2.05	2.29	2.25
Y7 - Lack of managerial awareness	1.90	2.11	1.86	2.06	2.03
Y8 - Other priorities for capital investments (low returns for energy efficiency investments)	2.47	2.71	2.43	2.65	2.61
Y9 - Scarce information regarding energy efficiency opportunities and winning solutions	2.62	3.05	2.57	2.90	2.85
Average score for the barriers	2.40	2.70	2.39	2.60	
DM - Difficulty in implementing management interventions	2.14	2.52	1.81	2.47	2.35
DT - Difficulty in implementing technical interventions	2.43	2.72	2.57	2.59	2.59

Table 9Analysis of the barriers with respect to adoption of energy efficiency interventions and experience in energy audits.

The previous adoption of energy-efficiency interventions seems to show a lower perception of the barriers by the respondents, expressed in every barrier. And the same, with the unique exception of the question “Y3 – lack of technical skills”, can be concluded also for those who have previously conducted an energy audit. Therefore, it can be argued that a previous experience in the “energy-efficiency” topic seems to be an important factor to mitigate the effect of the barriers. Nonetheless, it is not possible to draw any conclusion since a statistical evidence on the questions has not emerged testing the responses with ANOVA and Tukey-Kramer comparison (p-value <0.05).

4.6 Further evidences on the correlations among barriers

The aim of the correlation analysis is two-fold. Firstly, an investigation on the possible relationships among barriers is carried out, trying, although not of primarily scope for this study, to sketch possible dynamics between the perception of the barriers. Moreover, the relationships among the categories of the barriers (i.e. what they refer to) can provide useful hints for policy makers in order to enact effective policies and actions for promoting energy efficiency. To do that, the questions have been firstly classified according to several following categories:

Resources:	*Y1* - Lack of time or other priorities (comparing energy efficiency efforts with respect to production efforts);
	Y2 - Access to capital (lack of capital - public and/or private - to be devoted to energy efficiency investments)
	Y8 - Other priorities for capital investments (low returns for energy efficiency investments)
Skills:	*Y3* - Lack of internal technical skills
	Y4 - Difficulty of gathering external technical skills
Information:	*Y5* - Poor information for the energy efficiency decisions
	Y9 - Scarce information regarding energy efficiency opportunities and winning solutions
Awareness:	*Y6* - Lack of personnel awareness
	Y7 - Lack of managerial awareness
Difficulties:	*DM* - Difficulty in implementing management interventions
	DT - Difficulty in implementing technical interventions

Secondly, a correlation analysis of the responses has been performed, trying to put in evidence high correlations (with a correlation coefficient higher than or equal to 0.6) that might reflect common behaviors among the barriers. Whether not possible, it has been decided to analyze also relationships with at least a correlation coefficient equal to 0.5 .

4.6.1 Analysis of the whole sample

For what concerns the whole sample, all the questions present a correlation coefficient lower than 0.6; nonetheless, with a correlation coefficient of at least 0.5, it is possible to appreciate that the responses on questions “Y3 – Lack of technical skills”, “Y5 - Poor information for the energy efficiency decisions”, “Y6 – Lack of personnel awareness” and “DM – Difficulty in implementing management interventions” seem to be interrelated, as reported in Figure 2.

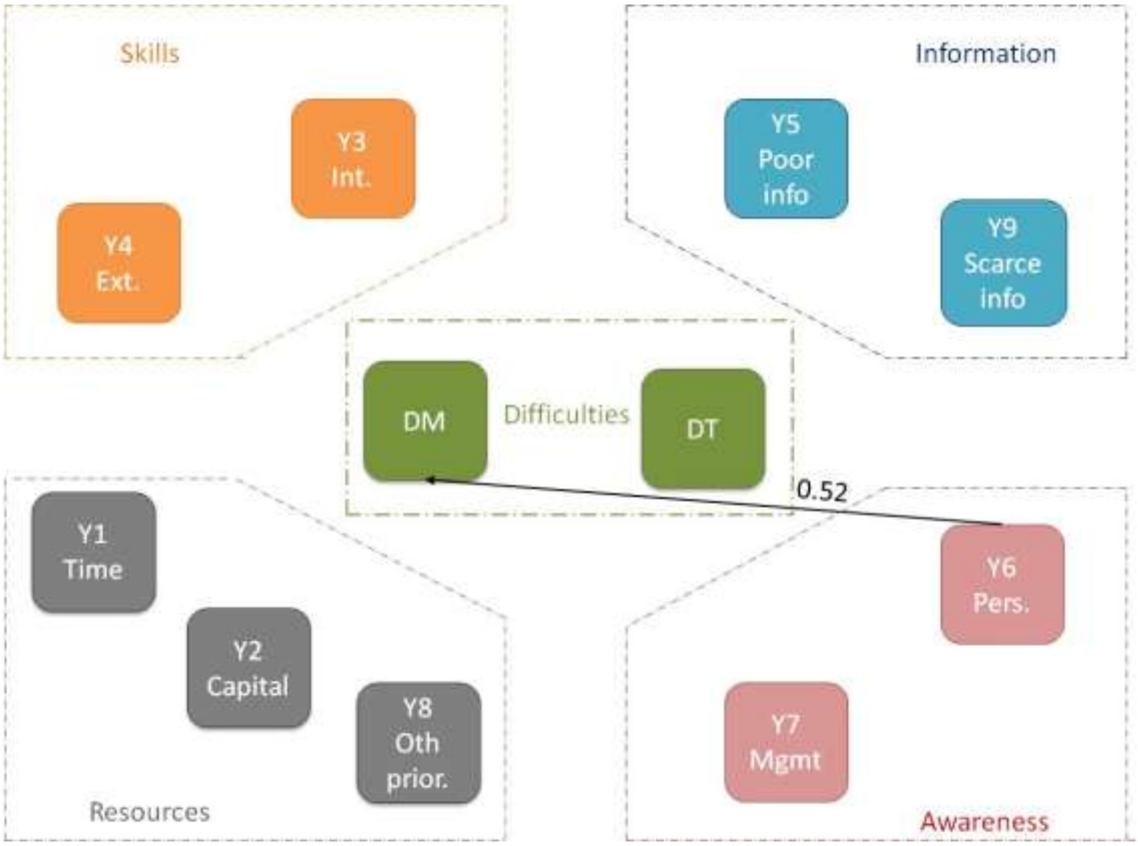

Figure 2Correlation coefficients for barriers and difficulties.

On one hand, it seems reasonable to assume that the relationship between Y3 and Y5 is a causal relationship: people without sufficient technical skills in evaluating energy efficiency solutions would perceive the available information as not sufficient to take decisions, thus showing the need for more information in order to take decisions (but it could be seen also in the positive sense, i.e. people with sufficient technical skills would perceive the information as sufficient). Therefore, this lack of skills and information seems to lead to difficulties in implementing energy efficiency interventions, and in particular management interventions.

On the other hand, it is reasonable to assume that the difficulties in implementing management interventions could be also explained by a low awareness to the energy efficiency topic by the personnel: especially for management interventions, the full collaboration of the personnel is of fundamental importance; moreover, a period to adapt to new routines is needed, and thus a low awareness can prevent the adoption of such interventions.

Starting from these findings on the whole sample investigated, some further analyses have been conducted to point out possible commonalities and differences with respect to the firm's size and the sector.

4.6.2 Analysis by firm's size

Since a separate analysis of the three sub-samples (SEs, MEs, MLEs) seems to highlight a different behavior of SEs with respect to MEs and MLEs on some questions, a comparison between SEs and "non-SEs" has been conducted, as reported in Figure 3.

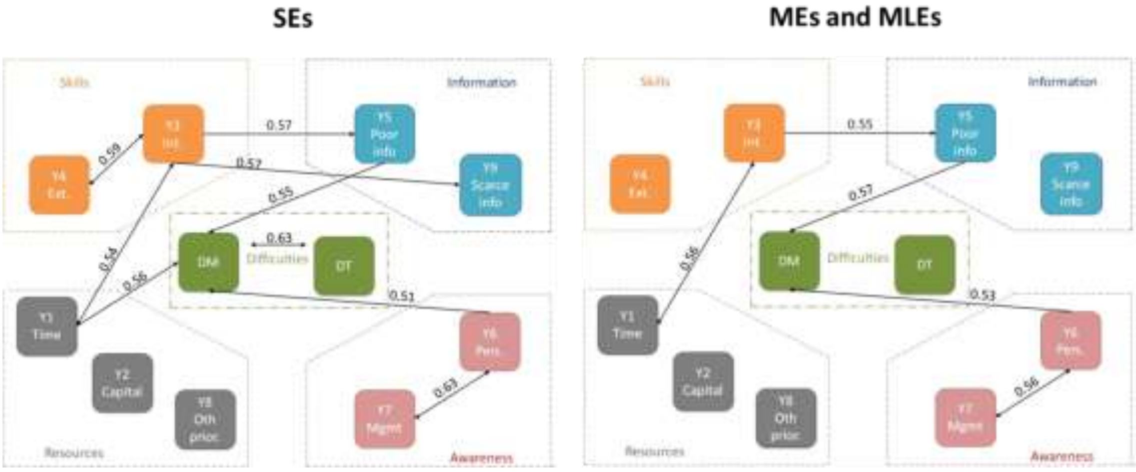

Figure 3Comparison of correlation coefficients in SEs and non-SEs.

In particular, it is possible to notice, in addition to the already mentioned relationships for the all sample – that can be observed for MEs and MLEs enterprises – the presence of several other correlations, especially for SEs.

More in detail, for SEs the perception of lack of technical skills is supported by the difficulty in gathering external skills, and has also a direct effect on the perception of the form of information: it seems clear that without the needed technical skills, the information would be perceived as incomplete and unclear, thus preventing from the adoption of the intervention.

Moreover, another interesting correlation could be observed between the difficulty in implementing either management (DM) or technical (DT) interventions: in particular, the stronger correlation (0.63) seems to reveal that, especially for SEs, difficulties in making energy efficiency are quite in common, i.e. enterprises that are proactive in making a technical intervention (i.e. do not feel strong difficulties in doing it) would perceive less difficulties also in implementing other types of interventions, e.g. related to operations management.

Furthermore, the correlation between the lack of time and poor information seems to be related again by a causal relationship, since, and this seems to be particularly evident for SEs, energy-efficiency decision makers (i.e. usually directly the entrepreneurs) do not have enough time to look for detailed information about energy efficiency solutions, thus perceiving the available information as lacking of some important details. Moreover, the lack of time could also represent the origin of the difficulties in implementing management interventions, since, as expressed above, those require long time to be implemented, in terms of both new practices to be spread and adopted and monitoring of the success of the intervention, thus preventing them from being applied in SEs where there is not usually devoted personnel.

4.6.3 Analysis by sector

Considering the strong differences in the average values of the barriers for the Textiles sector with respect to the non-Textiles sectors, an analysis has been performed for putting in evidence possible differences also from the viewpoint of correlations. It should be noticed that the Textile's subsample is quite limited (24 industries, as from Table 3) with respect to the non-Textile subsample (of 104 SMEs): therefore, it is reasonable to assume two different correlation coefficients (respectively 0.6 and 0.5) for a pairwise comparison that might take into account that the two samples are not equally populated.

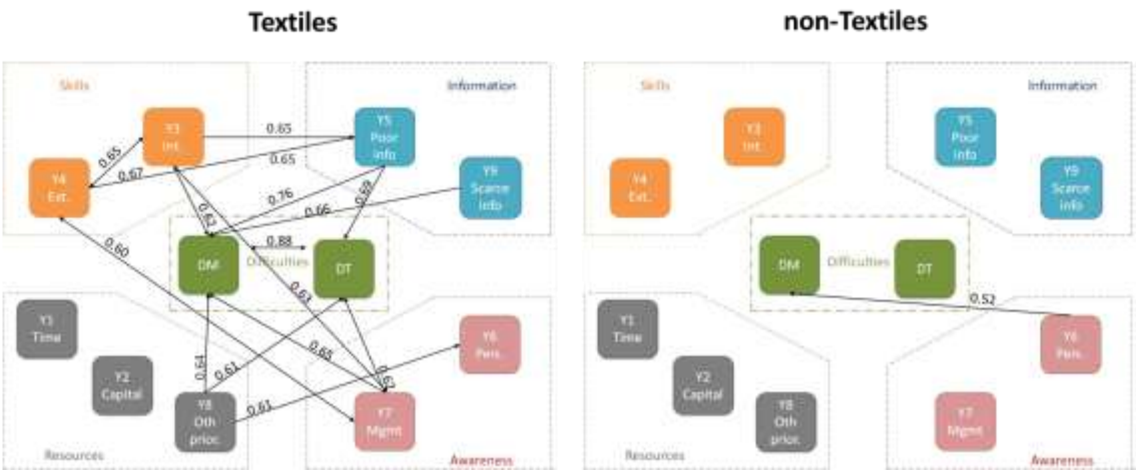

Figure 41Comparison of correlation coefficients in Textiles and non-Textiles enterprises.

As it can be inferred from Figure 4, the non-Textiles enterprises revealed very low correlation coefficients (only Y6 and DM have a correlation coefficient greater than 0.5), and also other correlation analyses on single sectors seem to confirm this conclusion, whilst in the Textiles sample a lot of questions seem to be correlated. Among the others, it is worth to notice the very strong correlation coefficient between question "DM – Difficulty in implementing management interventions" and question "DT – Difficulty in implementing technical interventions", equal to 0.88. This, coupled with the absolute values in the Textiles sector, (as from Table 7, respectively 2.14 and 2.24) seems to show the very low perception of difficulties in implementing energy efficiency interventions for this sector. Moreover, the links between Skills (Y3 and Y4), Information (Y5 and Y9) and Difficulties (DM and DT) , of which it is possible to have a hint for the whole sample, for the Textile enterprises seem to be even greater. In fact, in addition to the Y3-Y5 and Y5-DM correlations, the strong correlations between questions Y3 and Y5 and between questions Y5 and DT, with coefficients respectively of 0.67 and 0.69, seem to show that the perception of not having difficulties in gathering external skills allows to perceive the information as sufficient, thus reducing the difficulties in implementing energy efficiency interventions.

4.7 Conclusions

The paper dealt with an important issue in the research of the barriers to energy efficiency, i.e. to evaluate them in non-energy intensive SMEs, adding some interesting pieces to the puzzle.

First, the barriers have been investigated considering a set of questions that may cover one or more theoretical barriers expressed in the literature, that have been rephrased in order to investigate practical aspects of the difficulties when decision makers undertake the process of investing resources in energy-efficiency interventions. The major barriers that emerged in this study are represented by: access to capital; lack or imperfect information on cost-efficient energy-efficiency interventions; and the form of information. Moreover, it can be argued that the awareness of personnel and management does not really represent a barrier to the implementation of energy-efficiency interventions. As the nature of the sample investigated, that seems to be particularly aware with respect to energy-efficiency issues, this result has to be considered with caution, and within its limitation. Thus, it seems reasonable to assume that these findings are conservative and the effect of the awareness barriers has been underestimated.

In this study it has been decided to avoid investigating the barriers related to the organizational and decisional structure, considering that, in a sample represented by

SMEs, they tend to fade or assume less importance, since the organization of the firm is usually very simple and the decisions tend to fall within the normal responsibilities of one single decision maker (usually, the entrepreneur him/herself).

Second, and very important for the scientific research, it is necessary to avoid bundling together SEs, MEs and MLEs, when it is likely not correct: this is the case of several barriers investigated, such as *lack of time*, *lack of internal skills*, *lack of personnel awareness*, and *difficulty in implementing* either *management* or *technical interventions.* This is an important contribution to the literature, which, as now, has tended to consider those three different kinds of enterprises, with respect to the barriers to energy efficiency, as a whole.

In particular, it has been observed that MLEs suffer from the lack of time or lack of internal skills less than SMEs, due to a more structured organization, e.g. people usually in charge of activities for enhancing energy efficiency. Moreover, it can be argued that SEs and MEs have a more agile internal structure, that reduces the difficulties in implementing both management and technical energy efficiency interventions, and allows to more closely control the operations of the personnel, developing into it the awareness of the importance of an energy-efficient behavior.

Likewise, but this study represents one of the first contributions in the field, it has been observed a significant difference in the sample according to the sector: in fact, even if all the investigated SMEs can be considered as non-energy intensive, the Textiles sector (C13) presents a lower perception of all the barriers with respect to the other investigated sectors. This result has been supported by an ANOVA analysis of the responses, that showed a statistical difference (at 90% significance) for 8 out of 11 questions. These findings broadens the research on energy efficiency barriers to a deeper analysis of non-energy intensive enterprises, showing that it seems superficial to bundle them as a single group of enterprises.

Third, the analysis of the sample showed some interesting trends with respect to previous experience of the enterprises with respect to energy efficiency. It has been observed, although not supported by any statistical evidence, that the previous adoption of energy-efficiency interventions seems to show a lower perception of the barriers by the respondents, expressed in every barrier.

As a common observation to the three conclusions, it is considered as of fundamental importance to proceed with the methodology of investigation adopted in this study, since uniquely through an extensive campaign of research it would be possible to gather the necessary information and build the knowledge to make consistent conclusions on barriers to industrial energy efficiency, putting in evidence commonalities and differences among the enterprises, in order to promote the most effective policies to overcome the barriers.

Fourth, a preliminary analysis of correlations among questions that shows some links between several categories of barriers (information, skills and awareness) seems to confirm the results on the need of avoiding bundling SMEs on firm's size and sectors and opens the research to a deeper investigation of the barriers, in order to fully understand the dynamics and the possible effects of a given barrier with respect to others. In fact, it seems that only an effective comprehension of the effective barriers would lead to a formulation and adoption of punctual and effective energy policy instruments. At the moment, and with such a limited number of questions, it is not possible to fully evaluate the origin of a given barrier, nor to test the implications of a barrier on another. Again, enlarging the number of questions and the sample investigated seems the preferred means in order to obtain the needed information to provide consistent and statistically based conclusions. Moreover, an important contribution to this research could come from evaluating the existing differences between the perceived and the effective barriers, thus investigating, through a deeper analysis of firms' characteristics, the real weaknesses of SMEs with respect to energy efficiency.

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5 A novel approach to barriers to energy efficiency

This chapter reports the content of the work submitted as:

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A critical review of the literature highlighted the need for a new taxonomy en-compassing the most relevant barriers stemmed from previous studies, and accounting for interactions and independences of the barriers to avoid overlaps and implicit interactions. This paper provides a novel approach for barriers to the adoption of industrial energy-efficient technologies, coping with the issues risen by the review of the literature.

Moreover, we have developed a taxonomy adaptable to empirical research, able to evaluate the differences between perceived and real barriers, the effect of the barriers on decision-making processes, and the interactions among barriers. This represents an useful instrument both to enterprises and policy-makers to identify critical factors to improve industrial energy efficiency.

5.1 Introduction

The global concern for the primary energy consumption increase, the correlated increase of the GHG-emissions and the uncertainty on the effective available resources has made energy efficiency a priority on the policy agenda of most countries. In Europe, increasing energy efficiency has been broadly considered as the best method to obtain some of the most important objectives set by the European Commission in 2008 for what concerns the reduction (20%) of GHG-emissions and 20% reduction of energy consumption [1].

However, still many industries do not pursue this path, even if economically and environmentally attractive. This has been called “energy-efficiency gap” [2], and has been widely investigated in the literature [2-7]. Much of the research has focused on the industrial sector, that, as from recent estimates, has a share of about 50% of the world’s delivered energy consumption [8]. In the industrial sector the energy expenditures often are less than 5% of total production costs. Consequently, investments to improve energy efficiency are not fully appreciated, and often not perceived as strategic [9]. This is very typical for on one side for non-energy intensive enterprises, on the other side in particular for small and medium-sized enterprises, that often are a key part of national economies (e.g. for the number of enterprises, employment, etc.). A recent study by the Observatory of small and medium-sized enterprises [10] found that only 4% of those enterprises in the European Union have a comprehensive system to monitor and improve energy efficiency". While barriers exist, it is important to note that energy saving technologies and practices may also represent a strategic and competitive advantage through the development of new markets or new market opportunities, as shown by various authors [11-13]. On the basis of a comprehensive review of the literature on barriers and existing taxonomies for barriers to industrial energy efficiency improvement, we will propose a new taxonomy able to encompass the most relevant barriers stemmed from previous studies. Moreover, the novel approach accounts for interactions and independences of the barriers to avoid overlaps and implicit interactions. This enables to come to a taxonomy that can be used in empirical research and is able to evaluate the differences between perceived and real barriers, the effect of the barriers on decision-making processes, and the interactions among barriers. This represents an useful instrument both to enterprises and policy-makers to identify critical factors to improve industrial energy efficiency. A preliminary test has been carried out in some exploratory cases to validate the new taxonomy.

The paper is structured as follows: in Section 2 of this paper we critically evaluate existing literature. In Section 3 we analyze the needs for a new taxonomy, which, in Section 4, is proposed. Finally, we draw conclusions and highlight some further research issues in Section 5.

5.2 Literature Review

The existence of a gap between the profitable energy efficiency improvement potential, and those effectively implemented, is clear since early 1970s. Starting from the large literature on the topic, we have performed a review of the most relevant contributions in the literature that categorized the barriers to energy efficiency. Indeed, a comprehensive categorization of the barriers in taxonomies is necessary to obtain a complete picture of a complex problem, allowing to more effectively formulate policy responses to reduce the impact of barriers.

The first attempt to provide a systematic study of the problem has been performed by Blumstein et al. [14], that have defined and classified various types of social and institutional barriers to cost-effective energy conservation measures. According to Blumstein et al., six categories of barriers can be identified, although not all barriers can be easily classified to belong to a single category:

(i) *Misplaced Incentives*: the economic benefits of energy conservation do not always accrue to the person who is trying to conserve;
(ii) *Lack of Information:* the efficient working of the market depends on the parties to transactions having adequate information;
(iii) *Regulation :*if a cost-effective measure conflicts with existing codes or standards, its implementation will be difficult or impossible;
(iv) *Market Structure:* even though a conservation measure or device is cost effective, it may not be on the market;
(v) *Financing:* energy conservation measures often require an initial investment; thus, the availability of capital may be necessary for some measures;
(vi) *Custom*: if a cost-effective conservation measure requires some alteration in the habits of the consumer – affecting the "this is the way we have always done it" – or seems contrary to some accepted value, it may be rejected.

Another classification of barriers related to energy efficiency can be found in the Third Assessment report by the Intergovernmental Panel for Climate Change (IPCC) [15] that performed an extensive insight in the existing literature for the barriers to greenhouse gas (GHG) emissions, providing a useful instrument to address the issue from a policy-makers' perspective. In this study, the IPCC has put in evidence the sector and technology-specific barriers and opportunities and categorizing the barriers to eight sources, as follows: (i) *Technological Innovation*, (ii) *Prices,* (iii) *Financing*, (iv) *Trade and Environment*, (v) *Market Structure and Functioning,* (vi) *Institutional Frameworks*, (vii) *Information Provision*, and (viii) *Social, Cultural, and Behavioural Norms and Aspirations*.

Always starting from a policy makers perspective, it is remarkable the contribution of Painuly and Reddy [16] that addressed barriers to electricity conservation measures, both on the supply side as well as the demand side. The authors have divided the barriers into: (i) *Technical*, (ii) *Institutional*, (iii) *Financial*, (iv) *Managerial*, (v) *Costs*, and (vi) *Information*.

An important contribution can be found in the study performed by de Almeida et al. [17], based on a study carried out for the European Union (EU) with respect to practical issues that should be addressed by policy-makers in coping with barriers. The study provides an insight on energy-efficient motor technologies, trying to categorize the barriers according to five elements: (i) *Awareness of the options*, (ii) *Technical options*, (iii) *Economic barriers*; (iv) *Internal conflicts*, and (v) *Market structure*.

It is worth citing Weber, who, in very concise viewpoint but with smart hints for further research [18], proposes a distinction of the barriers into: (i) *Institutional*, (ii) *Market* (barriers and failures); (iii) *Organizational*, and (vi) *Behavioral*.

5.2.1 The Sorrell et al. taxonomy

A crucial development is the study of energy efficiency barriers by Sorrell et al. [19] with a more recent discussion [20] that, taking important elements from Jaffe and Stavins [2] and Golove and Eto [21], proposes a new categorization of barriers, built on the theoretical background of the barrier, i.e. economic, behavioral, organizational (see Table 1). This study is currently a key reference in the literature on barriers [22-26].

Perspective	Examples	Actors	Theories
Economic	Imperfect information, asymmetric information, hidden costs, risks.	Individuals and organizations considered as rational and aiming at maximizing profits.	Neo-classic economy
Behavioral	Incapability to process information, form of information, inertia.	Individuals with bounded rationality, with non-economic behavior and/or under various social influences.	Transaction costs economy, psychology, decisional theories.
Organizational	Lack of power and/or influence by people in charge of energy management; lack of organizational culture leads to ignore energy issues	Organizations are considered as social systems influenced by objectives, routines and structures with different power.	Organizational theories.

Table 1Different perspectives of energy efficiency barriers according to Sorrell et al. [19].

Starting from the economic perspective, a vast literature basis since the 1970s (for a collection of old studies, see e.g. Krieg [27]) addressed the topic of energy efficiency, with the identification, according to neo-classical theories, of the so-called *market barriers* to the adoption of energy efficient technologies. In the context of energy efficiency, market barriers refer to any market-related factor that inhibits energy efficiency improvements [15,28]. It is possible to summarize the market barriers to three main groups: when energy costs are not a major concern, when they are low relative to costs of many other goods and services, and thirdly, when the investment of energy-efficient technologies is inhibited by barriers in capital markets.

It is worth noticing that critiques on earlier attempts to categorize barriers [29-30], helped to more clearly distinguish *market failures* with respect to market barriers. In particular, according to the neo-classical theories, market failures occur when more requirements for an efficient attribution of the resources are violated [2,6,31]:

- a complete set of markets with well-defined property rights exist such that buyers and sellers can exchange assets freely;
- consumers and producers behave competitively by maximizing benefits and minimizing costs;
- market prices are known by all consumers and firms; and
- transaction costs are zero.

Sorrell et al. [19] have adopted this perspective and clearly distinguished non-market and market failures, as presented in Section 2.1.1. Moreover, an important point addressed in the study by Sorrell et al. is the inclusion in the taxonomy of the two non-economic perspectives , i.e. the behavioural and the organizational ones, which will be addressed respectively in Section 2.1.2 and 2.1.3.

5.2.2 The economic perspective

5.2.2.1 The non-market failure barriers

Heterogeneity: the argument is straightforward [2,21]. Although a technology may be cost-effective on average for a class of users taken in aggregate, the class itself consists of a distribution of consumers: some could economically purchase additional efficiency, while others will find the new level of efficiency not cost-effective [32].

Hidden Costs: according to Nichols [33], engineering-economic studies fail to account for either the reduction in benefits associated with energy efficient technologies or the additional costs associated with them. Therefore, the studies overestimate efficiency potential. Nichols identified three broad categories of hidden costs: (i) general *overhead* costs of energy management, (ii) costs *specific* to a technology investment, and (iii) *loss of benefits* associated with an efficient technology.

Access to Capital: many consumers have access to capital only at costs well above the average rate of return on capital in the economy. Hirst and Brown [34] identified and highlighted the difficulty to obtain capital to finance interventions, and several conclusions are confirmed by a recent United Nations Environment Programme (UNEP) study [35]. Further evidence of the Access to Capital barrier can be found in several recent studies [23,36-42]. This might be particularly critical for low income households but also for small and medium-sized enterprises, as noticed by several authors [11, 43-45]. Golove and Eto [21] have argued that this barrier can be better understood as an information problem, since there is a cost entailed in investigating the credit worthiness of small firms and individuals.

Risk: according to Sorrell et al., both high discount rates for energy efficiency and the rejection of particular energy efficient technologies may represent a rational response to risk. The study distinguishes three broad categories, as follows: (i) *External* Risk, (ii) *Business* Risk, and (iii) *Technical* Risk. The authors point out a relevant issue that will result of particular importance for the further discussion: "risk may be difficult to evaluate objectively and while *perceptions* of risk may inhibit investment, this does not mean that those perceptions are rational". As example, the uncertainty about energy prices, especially in the short term, seems to be an important barrier, as stressed by Velthuijsen [46] that often leads to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate [15], thus inhibiting the investment.

5.2.2.2 The market failure

Imperfect Information: the insufficient information about the energy performance of different technologies lead consumers to make sub-optimal decisions based on provisional and uncertain information, and consequently to underinvest in energy efficiency [2,28]. Moreover, as Hewett and IPCC note [47,15], the problem is likely to be more serious when the product or service is purchased infrequently – as the case of large investment in new and more energy efficient technologies – , the rate of technology change is rapid relative to the interval between purchases, and it is often difficult to quantify the energy savings that resulted from its installation, since usage patterns may have changed.

A special form of imperfect information exists, when parties to a transaction have access to different levels of information, therefore creating the so-called *asymmetric information* barrier, that lead to the three following barriers: split incentives, adverse selection and principal-agent relationships.

Split Incentives: this barrier, related to the appropriation of the benefits coming from energy-efficient technologies, has been recognized for many years and it clearly of major importance [14]. For example, individual departments in an organization may not be accountable for their energy use and therefore have no incentive to improve efficiency. Or, as DeCanio [48] notes, quite often managers remain in their post for relatively short periods of time, thus having no incentive to initiate investments that have a longer pay-back period. Therefore, *split* or *misplaced incentives* are able to inhibit investment [6].

Adverse Selection: as Hewett [47] notes, credence goods such as energy-efficient technologies or services are particularly vulnerable to adverse selection, since, in many cases, it is difficult for consumers to ascertain the quality and the effectiveness prior to purchase [5]. As a consequence, in the industrial world, purchasers might tend to buy technologies according to visible aspects such as price, and be reluctant to pay the price premium for high efficiency products.

Principal-Agent Relationships: this barrier might be found in the energy service market and within organizations. To ensure interests are met, the principal may strictly monitor the agent, and/or create an appropriate incentive structure. This barrier has been thoroughly investigated for the adoption of energy-efficient measures: for example, DeCanio [49] observed that firms use very stringent payback criteria which are significantly greater than firm's cost of capital. For further evidence, see, e.g., [21,28,50-53].

But, one of the greatest benefits of the study performed by Sorrell et al. is the inclusion of other non-economics perspectives in the taxonomy, i.e. the behavioural and the organizational theory ones – according to "the wide range of empirical research that has demonstrated that assumptions of economic rationality on the part of energy users are fundamentally flawed [19,54].

5.2.3 The behavioural perspective

5.2.3.1 Bounded Rationality

The authors note that, as a consequence of *bounded rationality* introduced by Simon [56], firstly individuals and companies will tend to make satisfactory decisions rather than searching for optimum decisions. Secondly, constraints on time, attention, resources and the ability to process information, lead to optimizing analyses being replaced by imprecise routines and rules of thumb.

With the expression of Bounded Rationality it sounds more clear that decisions are not taken as established by economics, rather decision-makers are bounded to many limitations in attention and resources, being able to elaborate only a limited set of information. This phenomenon has not been considered in the traditional economic models: nonetheless, it might be important for the energy service market, characterized by presenting complex and considerable information costs, with the consequence that, e.g., the attention is almost exclusively devoted to the core production activities, ignoring or neglecting considered a peripheral issue, as energy management

Sorrell et al. underline that, differently from what suggested by Eyre [56], they do not consider it as a market failure, rather than a departure from the logic of economic rationality, as suggested by Sanstad and Howarth [51], and quote several empirical studies of energy decisions supporting the hypothesis of bounded rationality (see, e.g., de Almeida[57]), showing how, e.g. payback rules and capital budgeting may represent different types of routines.

5.2.3.2 The human dimension

ignored, should be specific, personalized, vivid, clear, simple, close in time to the relevant decision, before the investment in a new energy efficient technology, and, as suggested by Seligman [58], "feedback should be given on the beneficial consequences of previous energy decisions if subsequent efficiency measures are to be encouraged".

Credibility and Trust: in addition to the characteristics expressed above, as Stern [59] notes, it is important for a successful diffusion of energy efficient technologies that the information source has credibility. Although the Form of Information, Credibility and Trust refer to distinct aspects of information, Sorrell et al. combine them, since in empirical research these could not always be distinguished.

Inertia: based on the study by Hewett [47], this barrier is considered as the combined effect of treating differently gains from losses, giving greater weighting to certain outcomes with respect to those that are uncertain, and minimizing the regret. All three factors may cause individuals and organizations to favor the status quo. As an example, suppliers might deliver what they think consumers want, but in markets characterized by a high degree of Inertia or risk aversion on the part of suppliers, there may be latent demand for higher levels of energy efficiency than readily available in the market [15].

Values: taking the inspiration outside the industrial world [19], this barrier represents a concrete improvement in the research, since it clearly shows that economic considerations provide only one element of a decision. Therefore, values represent a relevant explanatory variable to explain the efficiency gap.

5.2.3.3 The organization theory perspective

If we look at enterprises as systems with relationships and conflicts among individuals and departments with different cultures influencing decision-making, it is important to note that the organization of the firm might represent a barrier for the adoption of energy-efficient technologies.

Power: since there might be diverging interests within the firm, it seems clear that possible conflicts for the use of limited resources may arise. As expressed by Morgan [60], Power represents the medium through which conflicts of interest get resolved, thus influences “who gets what, when and how”. As the responsibility for energy issues is usually assigned to engineering or maintenance departments (and, some cases for small and medium-sized enterprises, the two may coincide), it is possible that the top management consider energy issues as peripheral, thus avoiding to devote power, funds and management support. Therefore, energy efficiency opportunities, although considered as technically and economically viable, may be missed.

Culture: adopting the view of Hatch [61], “culture is broadly defined as the mix of knowledge, ideology, values, norms, laws and day-to-day rituals that characterize a social group”. Therefore, culture represents a relevant variable in explaining the failure to adopt energy efficient technologies.

5.3 The need for a new taxonomy

5.3.1 Issues arising from the literature review

5.3.1.1 Missing elements

Looking at the taxonomy of Sorrell et al., we can observe that several barriers have not been included or explicitly addressed. With more detail:

- from the point of view of the market barriers, we can observe the *distortion in energy resources prices* [34]. This is a quite important aspect for energy efficiency, since the price that consumers pay does not fully reflect the externalities cost for energy. Indeed, all the environmental and social costs associated with fuel production, consumption, transmission and use, are not considered;
- stemming from some considerations on market barriers addressed by Hirst and Brown [34], Jaffe and Stavins [2], and Brown [6], the *low diffusion of technologies* should be considered as a barrier, because it implies that the

technologies are not actually fully available, as well as the training and the expertise to manage them. Therefore, it represents a barrier that should be explicitly addressed;

- another barrier that has not been considered, but emerged in an empirical study by Trianni and Cagno [11] is the difficult *access to external competences*. Usually – but not correctly – is included in the hidden costs barrier, since it is a market problem of energy efficiency that has its roots outside the company, and thus should be distinguished;
- as proposed by Howarth and Andersson [4], *high initial costs* should be considered as a separate barrier, since they reflect an aspect that it is not possible to be completely referred to hidden costs and capital availability barriers;
- the *distortion in fiscal and regulatory policy* represents another barrier to energy-efficient technologies [6,34]. This has been proven in empirical studies, e.g. performed by Alderfer et al. [62] for the installation of distributed generation, by Koomey [63] for commercial buildings, for small-industry clusters [64] and Kranz and Worrell for CHP depreciation [65];
- the *perception of being already efficient* represents an important behavioural barrier towards the adoption of energy-efficient technologies. This has emerged in Vine et al.[66] from a research on promoting energy-efficient technologies and practices in California;
- as underlined by DeCanio [48]the l*ow priority of energy issues* might represent another organizational barrier that should be explicitly addressed. As expressed by Hirst and Brown [34], several factors draw firms to consider energy issues as of minor concern, discouraging investments in energy conservation. This includes a possible fall in energy prices, as the one occurred during the 1980s [29]. In addition to that, another factor is the small incidence of energy costs on total production costs: as a consequence, it is easy for enterprises to ignore them, as summarized by Brown [6] and, with further empirical evidences, by a recent study of the International Energy Agency [28];
- *technology-related* barriers can represent, in some cases, a really important issue for the deployment of energy-efficient technologies. This has been

highlighted by the study of de Almeida et al. [17], which empirically proved the existence of the barrier "technical characteristics may not be applicable";

- finally, other studies(as highlighted by Shipley and Elliott [67]) have identified some barriers, i.e. the *lack of expertise and competences to identify the inefficiencies and the opportunities and to implement energy efficiency measures*. These barriers have also been empirically investigated among small and medium-sized enterprises in two recent studies by Thollander et al. [68] and Trianni and Cagno [11].

5.3.1.2 Overlaps

The disaggregation of the barriers according to the theoretical models enables to collect and analyse different approaches (e.g. economical, behavioral, and organizational), providing different perspectives to analyse the barriers. Nonetheless, this approach may result in partial overlap of barriers, since the proposed barriers represent, quite often, elements in which implicit interactions exist. For example, transaction cost economics combines neo-classical ideas with behavioural theories (e.g. bounded rationality) and derives an explanatory theory for the existence and structure of organizations [69].

Heterogeneity: although the argument is straightforward – i.e. some users could economically purchase additional efficiency, while others will find the new level of efficiency not cost effective – this might the effect of different barriers that cannot be combined. For example, technological risks for one plant are may be greater than for another, thus depending on the specific situation. The same can be observed for Hidden Costs, that might be quite specific for a firm and thus limiting the economic performance of an intervention. Moreover, an intervention might not be worth being implemented since different enterprises adopt different parameters to evaluate economic performance. When Principal-Agent Relationships occur, higher hurdle rates can be established, thus reducing the economic efficiency of several considered measures. For these reasons, Heterogeneity of the technology is recognized as a barrier to energy efficiency, but it does include many different issues that should be investigated separately.

Imperfect Information: Sorrell et al. define this as a barrier, but it could be more appropriate to see this market failure as a set of barriers, comprehensive of all the problems related to the information flow [6,15,34,51]. Therefore, on one side we can see overlaps with Hidden Costs, by means of the transaction costs for gathering, analyzing and applying the interventions [21]. On the other side, imperfect information encompasses the market failure asymmetric information, that leads to Adverse Selection, Moral Hazard and Split Incentives.

Incomplete Markets for Energy Efficiency: as clearly expressed by Blumstein et al. [14], “even though a conservation measure or device is cost-effective, it may not be on the market”. Despite the fact, as expressed by Jaffe and Stavins[2] that the diffusion of economically superior technologies is typically gradual, it is possible that, as suggested by Golove and Eto [21], certain powerful firms may be able to inhibit the introduction by competitors of energy-efficient, cost-effective producers.

Bounded Rationality: Adverse Selection is the result of Bounded Rationality in a context in which the decision-maker does not know the benefits of the opportunities. In case of lack of information the choice will be made on the most evident characteristics. Nonetheless, Bounded Rationality leading to the adoption of imperfect evaluation criteria might be used also in principal-agent relationship dynamics, where the criteria of judging the investments are affected by approximations (maybe due to lack of time or competences). In this case it is clear that the Bounded Rationality barrier, which in Sorrell et al. is considered as behavioural, overlaps with barriers belonging to Power, which is an organizational barrier.

5.3.1.3 Implicit interactions

Sorrell et al., in their model, admit the possible existence of interactions between the barriers. These represent the possible relationships (e.g. causal, combined effect, etc.) between one barrier - or a set of barriers - with another barrier - or another set of barriers -, i.e. the former could modify the latter in different ways. Therefore, several problems arise when identifying and developing policies and measures to address those barriers. We would prefer to call them as “implicit interactions”, because the definition of barriers themselves implies those interactions. It can be seen that this concept differs from the overlap one, since in this case the barriers are distinct, but there is a link between them.

Looking at the taxonomy by Sorrell et al., some implicit interactions can be highlighted:

- Lack of Time, attention and competences to understand the information represent barriers strictly related to the adoption of approximate criteria for evaluating energy efficiency investments, that by Sorrell et al. are combined in the Bounded-Rationality barrier;

- Principal-Agent Relationship represents a dynamic in which two separate barriers act simultaneously: i.e. the lack of instruments to control operators and opportunistic agent-behavior. The combined action of the two barriers might result in the use of higher rates of return.

- Access to Capital represents the barrier that looks at the economic and financial availability – in terms of both borrowed capital and internal funds – of the enterprise with respect to the capital devoted for investments in energy efficiency opportunities. This is modified by the concurrent effect of two separate barriers: on one side, the priorities, that are strictly related to the behavior of decision-makers (their sensibility to energy efficiency, etc.); on the other side, the effective total available capital, that is rather an economic barrier.

5.4 A novel taxonomy for energy efficiency

5.4.1 Designing a new taxonomy

The literature review demonstrated that several issues still need to be addressed. First of all, a taxonomy for energy efficiency that encompasses all the previous contributions needs to be developed, since at the moment existing taxonomies tend to cover a wide range of barriers, but not all of them. In that respect, in order to clearly identify the barriers, all the barriers within the taxonomy should be clearly distinguished, thus avoiding any possible overlap or implicit interaction. Therefore, on one side, the elements of the taxonomy should be reduced at the minimum terms in order to analyze the possible interactions among independent barriers. On the other side, this implies to perform the classification of the barriers according to the actors affected by the barriers for the energy-efficient purchase and operation decisions.

Moreover, in order to be a really useful tool for enterprises and policy-makers in understanding the barriers to industrial energy efficiency, the taxonomy needs to be developed and shaped to be easily used in an empirical investigation. Within the empirical investigation, another crucial point for the effectiveness of policies to improve energy efficiency is represented by the ability to clearly distinguish the perceived and the real barriers. Indeed, without a clear distinction between perceived and real barriers, a policy for industrial energy efficiency may result to be abruptly ineffective.

5.4.2 Description of the barriers

The taxonomy has been developed to encompass the relevant barriers observed in the literature. The taxonomy will separate the barriers assigning them to the actors involved.

In order to classify the barriers with respect to the actors which, besides the single enterprise, are involved in the energy-related purchases and operational decisions, we have followed the approach provided by Hirst and Brown [34] (see Figure 1). In that, it is possible to note that an enterprise operates within a given market that includes other actors (i.e. designers/manufacturers, technology suppliers, energy suppliers, capital suppliers). Therefore, there are barriers that inhibit the shift from the *status quo* to the *status of energy efficiency improved* that arise within this market, and not only within the single enterprise. Nonetheless, the enterprise and the actors within the market are subject to some regulations and influences given by governments and politics. For this reason, governments and politics should not be considered within the given market. Indeed, government and politics might affect the diffusion of technologies and/or energy suppliers imposing standards or particular policies to regulate the market, to modify the price and/or the availability of services/products, and also can influence a single firm through, e.g., tax policies.

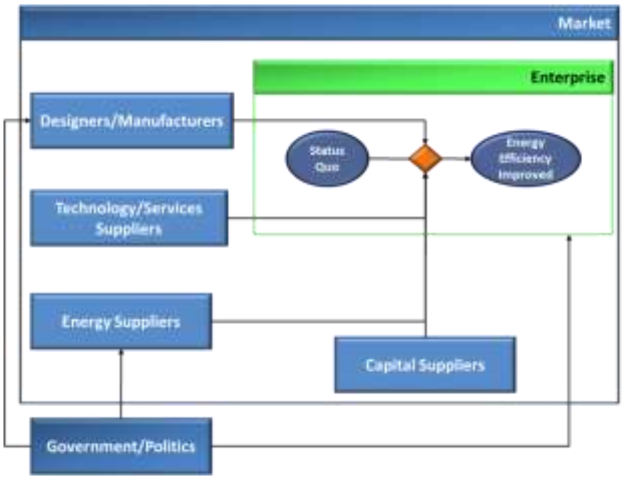

Figure 1Actors affected by the barriers for the energy-efficient purchase and operation decisions.

The barriers have been reduced to lowest independent denominator, reaching a high level of detail, presenting elements that might occur autonomously. This prevents from overlapping or implicit interactions, as found in the literature. Therefore, slightly modifying definition given by Sorrell et al., "a barrier is a postulated mechanism that inhibits investment in technologies that are both energy efficient and (apparently) economically efficient", *without the necessity that one or more other barriers occur*.

Below we provide the description of the barriers according to the actor to which the barrier is addressed: in this sense, of course, several repetitions of the barriers will occur, but, from the viewpoint of empirical investigation, it would be easier to underline the responsibilities and the causes for a non-adoption of an energy-efficient technology. The results of the new taxonomy are presented in Table 2.

Origin	Actor/Area	Barriers
External	Market	Energy prices distortion
		Low diffusion of technologies
		Low diffusion of information
		Market risks
		Difficulty in Gathering External Skills
	Government/Politics	Lack of proper regulation
		Distortion in fiscal policies
	Technology/Services Suppliers	Lack of interest in energy efficiency
		Technology Suppliers not updated
		Scarce communication skills
	Designers and Manufacturers	Technical Characteristics not adequate
		High initial costs
	Energy Suppliers	Scarce communication skills
		Distortion in energy policies
		Lack of interest in energy efficiency
	Capital Suppliers	Cost for investing capital availability
		Difficulty in identifying the quality of the investments
Internal	Economic	Low capital availability
		Hidden costs
		Intervention-related risks
	Behavioral	Lack of interest in energy-efficiency interventions
		Other priorities
		Inertia
		Imperfect evaluation criteria
		Lack of sharing the objectives
	Organisational	Low status of energy efficiency
		Divergent interests
		Complex decision chain
		Lack of time
		Lack of internal control
	Barriers related to competences	Identifying the inefficiencies
		Implementing the interventions
	Awareness	Lack of awareness or Ignorance

Table 2The new taxonomy, with a clear distinction of the origin (external, or internal, with respect to the firm), and the actors affected by the barriers.

5.4.2.1 The external (respect to the firm) barriers

5.4.2.1.1 Market

Energy Prices Distortion: as proposed by Hirst and Brown [34], energy prices do not take into account the externalities related to energy consumption.

Low Diffusion of Technologies: following the approach of Golove and Eto [21], the high energy-efficiency technologies quite often suffer from low diffusion, due to the innovative character of these technologies.

Low Diffusion of Information: this barrier refers to the time needed to refine and spread the information on energy-efficient technologies, as defined by Jaffe and Stavins [70].

Market Risks: as suggested by Hirst and Brown [34], uncertainties regarding future energy prices might represent a barrier to investments.

Difficulty in gathering external skills: the prices and/or availability of consultants might represent a barrier in the supply of existing energy-efficient technologies, as suggested by Trianni and Cagno [11].

5.4.2.1.2 Government/Politics

Lack of Proper Regulation: as proposed in the study performed by Wiel and McMahon [71], the lack of standards or classes (e.g. through clear labeling) for the energy efficiency performance might represent a barrier to select the most effective energy-efficient technologies.

Distortion in Fiscal Policies: Hirst and Brown [34] suggest this barrier, that includes all the issues related to a distorted fiscal policy that might inhibit the investments in energy efficiency.

5.4.2.1.3 Technology/services suppliers

Lack of Interest in Energy Efficiency: Reddy [72] has shown that technology suppliers may get higher returns in commercializing lower energy-efficiency technologies.

Technology/Services Suppliers not up to date: as Hirst and Brown suggest [34], if "*companies that manufacture, distribute and service energy-efficient products provide only limited training to keep their employees abreast of the latest technologies*", their customers will not be sufficiently and adequately informed, thus possibly selecting inefficient or even obsolete technologies.

Scarce Communication Skills: as shown by Hirst and Brown [34], if suppliers are not able to communicate the effective performance of energy-efficient technologies, those might be disregarded.

5.4.2.1.4 Designers and Manufacturers

Technical Characteristics not Adequate: as suggested by de Almeida et al. [39], the technology characteristics of energy-efficient technologies might be very particular, and thus difficult deploy in the market.

High Initial Costs: as proposed by Howarth and Andersson [4] and emerged in a study on barriers to efficient electricity technologies by Reddy and Shrestha [73], high initial costs for adopting new energy-efficient technologies represent an important barrier. This barrier might reflect the high design and manufacturing costs for delivering to the market an up-to-date energy-efficient technology: in this regard, we can assume that this barrier, although perceived by a firm when purchasing a technology, is due to a barrier in design and manufacturing.

5.4.2.1.5 Energy suppliers

Scarce Communication Skills: as reported by Sorrell et al. [19] different options in energy contracts might be presented in a unclear and not-vivid form, thus resulting to be unattractive for the customers.

Energy Prices Distortion: the energy prices do not fully reflect the costs afforded by producers in the different hours of a day, as suggested by Hirst and Brown [34] and Brown [6]; moreover, the energy prices might not incentive the adoption of energy-efficient technologies, since, as supported by a vast empirical experience, the higher the use, the lower the rate of energy price.

Lack of Interest in Energy Efficiency: as proposed by Reddy and Shrestha [73], the reduction of energy costs by firms imply lower returns for energy suppliers. Thus energy suppliers might be not interested to propose energy-efficient solutions to their clients.

5.4.2.1.6 Capital Suppliers

Costs to investigate debt carrying capability: as shown by Berry [74] and Schleich [75], and extensively analyzed by IPCC [15], the high transaction costs to evaluate debt carrying capability and to service a large number of small and medium-sized projects –

typical for energy-efficient technologies –, might be considerable, thus discouraging investors from financing energy efficiency investments.

Difficulty to Identify the Quality of Investments: as suggested by IPCC [15], capital suppliers might incur difficulties to evaluate the investments for which they provide capital; thus, they might tend to grant capital only to well-known solutions, and thus preventing innovative energy-efficient technologies to be deployed.

5.4.3 The internal (within the firm) barriers

Several barriers are originated within the firm. Every function within the production system (see Figure 2) is characterized by its competences and behavior concerning energy. The simpler the organization system, more functions will be represented by a single decision-maker.

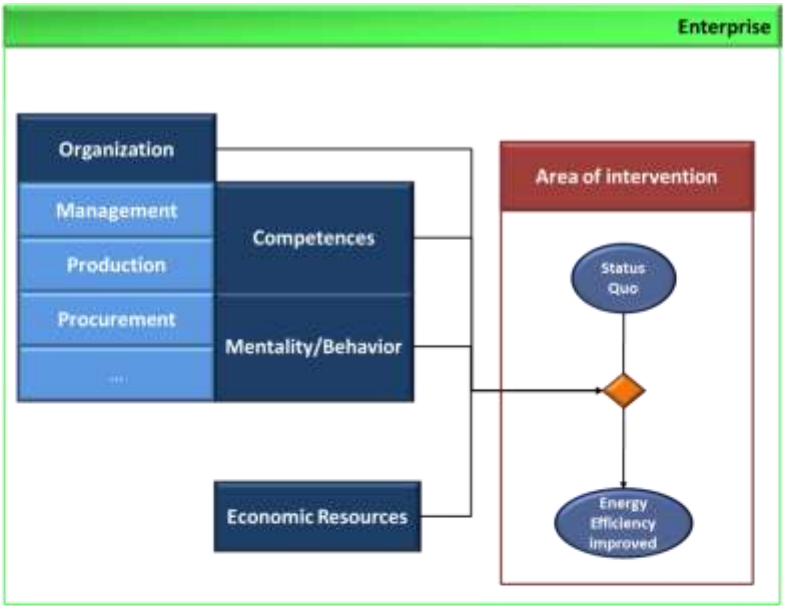

Figure 2The functions, within the firm, involved in the energy-efficiency decision-making process.

To investigate the barriers within the firm, we decided to follow the approach provided by Sorrell et al., thus analyzing the barriers by category. This is of fundamental importance for the taxonomy, since, if the barriers within the firm would be analyzed as the external ones, i.e. according to the involved actors, as done in Section 4.2.10 – two major problems would appear. The first is that each barrier related to the behavior of the people involved in a function should be repeated for each function within the enterprise, thus increasing the number of barriers at the lowest level of the taxonomy. The second is that, considering the unique mix of functions and features that characterize the single enterprise in terms of specific organizational structures, it hardly seems feasible to develop such a flexible taxonomy able to encompass all the possible combinations.

5.4.3.1.1 Economic Barriers

In this section we present the barriers related to the economic evaluation of an energy-efficiency investment.

Low capital availability: as emerged by several empirical studies [11,23-24,36], even with a great awareness on the benefits of energy-efficient technologies, and considerable commitment of management and personnel to energy, the firm does not have sufficient own capital to invest in energy-efficient technologies.

Hidden costs: those costs might differ significantly from the estimate in investment analyses: within this category all the transaction costs to obtain information on energy-efficient technologies, training personnel, fall. A further classification within this category can be provided: e.g. Hidden Costs can be distinguished according to the project stage in which they occur.

Pre-intervention Hidden Costs includes the research of energy inefficiencies and opportunities to increase energy efficiency [75]. In addition to the expenditures for energy audits, as underlined by Jaffe and Stavins [2], the costs to perform a preliminary evaluation of the investment and the costs to investigate the debt carrying capability should be included.

Focusing on the costs *during* the implementation of the investment, the introduction of new technologies may require the interruption of normal operations, thus incurring into disruption costs, as evidenced by Sorrell et al.[19], that, although “quite often neglected in the evaluation of the investments, are real. In this sense, investors may take a rational decision not to invest in the light of this additional costs”. Moreover, to this category we should not forget all the costs related to the modification of the production system (e.g. layout of the equipment) that is needed in order to install the new energy-efficient technology.

Considering the *post-intervention* Hidden Costs, as empirically studied by Rohdin and Thollander [23], it is possible that the costs to train personnel on the proper use of the new technology, developing new procedures for maintenance, adapting to the modified production system may represent a barrier to invest in energy-efficient technologies.

Intervention-related risks: as suggested by Jaffe and Stavins [2], some uncertainties and risks occur when implementing the energy efficiency interventions. As evidenced by Ross [44] and Sanstad et al.[76], the discount rates for future costs and benefits exceed consistently the conventional rule of thumb rates chosen for investments, i.e. either the rate of return available on investments with comparable risk or the rate at which the purchase is financed.

Interventions not sufficiently profitable: as proven by a vast empirical evidence, some enterprises often rationally discard investments with a rate of return lower than their internal rate of return. This can be particularly critical and thus represent a barrier for those energy-efficient technologies that require a significant change in the production system.

5.4.3.1.2 Behavioral barriers

In this section we present the barriers related to the behavior of operators and decision-makers within the firm.

Lack of Interest in Energy Efficiency: this barrier includes several elements, each of those contributing to the perception that energy issues are not sufficiently interesting:

- energy costs do not have sufficient weight with respect to the firm's production costs [6];
- the firm perceives itself as already efficient [77];

Other Priorities: this is a barrier particularly critical for small and medium-sized enterprises, since quite often the decision-makers might be focused exclusively on core business activities. Therefore, they tend to evaluate exclusively the interventions with considerable impact on the main production system activities, thus disregarding energy efficiency, as emerged in empirical research (see., e.g.,[23-24, 11]).

Inertia: as Sorrell at al. pointed out, this barriers represents the resistance to change, and, the more the change is radical, the higher will be. It can result in preferring interventions with quick and low investments and returns, thus very slightly modifying the production system.

Imperfect Evaluation Criteria: the decision-makers might not have the proper knowledge or criteria to evaluate investments. In particular the decision-maker might adopt approximate criteria or routines, as suggested by DeCanio [48,78], that do not allow her/him to thoroughly evaluate the effective performance of the interventions. In other cases the decision-maker might adopt criteria for the evaluation (as pay-back period, or rate of return of the investment) without any relationship with the uncertainty associated to the different alternatives to be evaluated.

Lack of Sharing the Objectives: as reported by DeCanio [48], some misalignments between the behavior of personnel and energy management objectives might occur.

Lack of Sharing the Objectives: as reported by DeCanio [46], some misalignments between the behavior of personnel and energy management objectives might occur.

5.4.3.1.3 Organizational Barriers

The organizational barriers arise from the interaction of different functions within a firm or organization in improving energy efficiency.

Low Status of Energy Efficiency: as shown by Sorrell at al. [19], the functions devoted to energy management do not have sufficient power to act effectively to improve energy efficiency.

Split Incentives: as suggested by Jaffe and Stavins [2] and reported by several other researches, the decision-maker of the investment might not gain the benefits from improving energy efficiency. This might occur at managerial level, at responsible of purchases, and production manager.

Complex Decision Chain: as proposed by Sorrell et al. [19], and also considered in the study of Benhaddadi and Olivier, [41], if the decision process involves several functions, it might occur difficulties to transfer information.

Lack of Time: as reported by Nagesha [79], the decision-maker does not have enough time to consider energy efficiency opportunities.

Lack of Internal Control: without adequate control systems, the agents might not implement energy efficiency practices. This phenomenon has been investigated in the study by Sorrell et al.[19], thus leading to the adoption of higher return rates for energy-efficient technologies.

5.4.3.1.4 Barriers related to competences

It is apparent that, in order to implement energy efficiency interventions, specific competences have to be available within the organization. Indeed, those barriers can be particularly critical for small and medium-sized enterprises, in which the personnel might be trained for operating the equipment but without sufficient knowledge to analyze inefficiencies, opportunities, and to implement the needed actions, as emerged from an empirical study on non-energy manufacturing small and medium-sized enterprises [11].

Identifying the Inefficiencies: this barrier might occur when, even with a great awareness of the energy issues, and conscious of the benefits of energy-efficient technologies, specific competences on methods and tools for identifying the energy waste are lacking.

Identifying the Opportunities: similarly for the barrier Identifying the Inefficiencies, this barrier represents the difficulty of identifying quickly and punctually the opportunities to improve energy efficiency.

Implementing the Interventions: this barrier shows the difficulty to implement practices and interventions for energy efficiency, without the support of external consultants or personnel.

5.4.3.1.5 Awareness

This barrier aims at pointing out the ignorance, on the energy efficiency topic, of decision makers.

Lack of Awareness (or *Ignorance*)*:* as reported by de Almeida et al. [39], the Lack of Awareness represents a status – not a behavior (already reported as a behavioral barrier in Section 4.2.2.2) – of the decision-makers, in which they simply ignore the possible benefits coming from the implementation of energy efficiency opportunities.

5.4.4 A taxonomy for empirical investigation

In order to adapt the novel taxonomy to the empirical investigation, we have slightly modified some internal barriers reported in Section 4.1.2 and have looked at the effect of the external barriers (reported in Section 4.1.10) on the firm, as reported in Table 3.In particular, we have decided to add two more categories, generally called Technology-related barriers and Information barriers.

		EXTERNAL BARRIERS																
		MARKET					GOVERNMENT/ POLITICS		TECHNOLOGY SUPPLIERS			DESIGNERS AND MANUFACTURERS		ENERGY SUPPLIERS			CAPITAL SUPPLIERS	
		ENERGY PRICES DISTORTION	LOW DIFFUSION OF TECHNOLOGIES	LOW DIFFUSION OF INFORMATION	MARKET RISKS	DIFFICULTY IN GATHERING EXTERNAL SKILLS	LACK OF PROPER REGULATION	DISTORTION IN FISCAL POLICIES	LACK OF INTEREST IN ENERGY EFFICIENCY	TECHNOLOGY SUPPLIERS NOT UPDATED	SCARCE COMMUNICATION SKILLS	TECHNICAL CHARACTERISTICS NOT ADEQUATE	HIGH INITIAL COSTS	SCARCE COMMUNICATION SKILLS	DISTORTION IN ENERGY POLICIES	LACK OF INTEREST IN ENERGY EFFICIENCY	COST FOR INVESTING CAPITAL AVAILABILITY	DIFFICULTY IN IDENTIFYING THE QUALITY OF THE INVESTMENTS
TECHNOLOGY-RELATED BARRIERS	TECHNOLOGIES NOT ADEQUATE											■						
	TECHNOLOGIES NOT AVAILABLE		■						■									
INFORMATION BARRIERS	LACK OF INFORMATION ON COSTS AND BENEFITS			■			■			■								
	UNCLEAR INFORMATION BY TECHNOLOGY SUPPLIERS						■				■							
	TRUSTWORTHINESS OF THE INFORMATION SOURCE								■		■							
	INFORMATION ISSUES ON ENERGY CONTRACTS													■		■		
ECONOMIC	*LOW CAPITAL AVAILABILITY*																■	■
	INVESTMENT COSTS												■					
	HIDDEN COSTS																	
	INTERVENTION-RELATED RISKS																	
	EXTERNAL RISKS				■													
	INTERVENTIONS NOT SUFFICIENYLY PROFITABLE																	
BEHAVIORAL	LACK OF INTEREST IN ENERGY-EFFICIENCY INTERVENTIONS	■					■	■							■			
	OTHER PRIORITIES																	
	INERTIA																	
	IMPERFECT EVALUATION CRITERIA																	
	LACK OF SHARING THE OBJECTIVES																	
ORGANISATIONAL	LOW STATUS OF ENERGY EFFICIENCY																	
	DIVERGENT INTERESTS																	
	COMPLEX DECISION CHAIN																	
	LACK OF TIME																	
	LACK OF INTERNAL CONTROL																	
BARRIERS RELATED TO COMPETENCES	IDENTIFYING THE INEFFICIENCIES																	
	IDENTIFYING THE OPPORTUNITIES																	
	IMPLEMENTING THE INTERVENTIONS																	
	DIFFICULTY IN GATHERING EXTERNAL COMPETENCES					■												
AWARENESS	LACK OF AWARENESS OR IGNORANCE																	

Table 3The proposed taxonomy modified for empirical investigation. The black cells highlight that the barriers of the "external barriers" columns will be investigated through the correspondent elements of the "barrier for empirical investigation" column. In italics we have reported the barriers that have been added to the taxonomy for empirical investigation.

5.4.4.1 Technology-related barriers

As described by Nagesha [79], considering two separate barriers, i.e. the Low Diffusion of Technologies (described in Section 4.1.1.1) and the Lack of Interest by Technology Suppliers(described in Section 4.1.1.3) in promoting and diffusing energy-efficient technologies, we can see that the effect of these barriers on the firm is exactly the same. Indeed, the firm perceives the energy-efficient Technologies as not Available, as it cannot recognize whether the unavailability of a given technology is due to the Low Diffusion of Technologies or to Lack of Interest by Technology Suppliers.

5.4.4.2 Information barriers

This category has been created in order to gather all the elements, external to the firm, related to the flow of information on energy-efficient technologies.

In particular, for a practical investigation on a firm, it is possible to find:

Lack of Information on Costs and Benefits: in this barrier the effects of several external barriers could be appreciated. In particular: the Low Information Diffusion (see Section 4.1.1.1), the Lack of Proper Regulation, in terms of classes of energy-efficiency performance of the technologies (see Section 4.1.1.2), and the Technology Suppliers not Updated on the new energy-efficient solutions (see Section 4.1.1.3).

Unclear Information by Technology Suppliers: this barrier might depend on the Lack of Communication Skills by technology suppliers (expressed in Section 4.1.1.3); moreover, the Lack of Proper Regulation, in terms of classes of performance for energy efficiency (described in Section 4.1.1.2) might inhibit a clear comprehension of the information.

Trustworthiness of the Information Source: as expressed in Section 4.1.1.3, this barrier might occur when technology suppliers have Scarce Communication Skills for promoting energy efficiency technologies or due to a Lack of Interest in providing clear and detailed information to their clients.

Information Issues on Energy Contracts: as described in Section 4.1.1.5, this barrier refers on the Scarce Communication Skills by energy suppliers in communicating the information, and/or a Lack of Interest in providing clear and detailed information to their clients.

5.4.4.3 Modifications of the internal barriers

For what concerns the barriers within the firm, the structure of the taxonomy presents some slight modifications, reported in Table 3:

1. in the economic barriers described in Section 4.1.2.1, the Investment Costs and the External Risks should be added;
2. the Low Capital Availability (Section 4.1.2.1) encompasses all the barriers referable to capital suppliers (Section 4.1.1.6);
3. the Difficulty of Gathering External Competences (expressed in Section 4.1.1.1) has to be added to the barriers related to competences (Section 4.1.2.4);

It is interesting to note that the external barriers reflect on the economic, the information and technology-related barriers, thus representing the impact of the external context on the firm. This is not true for the organizational or the behavioral internal barriers, that could even be independent from the external context. An exception occurs for the barrier Lack of Interest for Energy Efficiency (described in Section 4.1.2.2). Since it reflects how the firm pays attention on energy efficiency issues, this barrier will be strongly affected by the external context: the Energy Prices Distortion (Section 4.1.1.1), the Lack Proper Regulation, in terms of minimum standards for energy efficiency, the Distortion of Fiscal Policies (Section 4.1.1.2), and a Distortion in Energy Policies (Section 4.1.1.5) will deeply affect the interest of the firm with respect to energy efficiency issues.

In order to validate the capabilities of the new taxonomy, a preliminary test has been carried out in some exploratory cases represented by six industrial Italian manufacturing enterprises for different sectors, number of employees, annual turnover, energy expenditures, and different experience with the energy efficiency topic (i.e. having conducted energy audit or having implemented interventions specifically for increasing energy efficiency). In Table 4 we report the main characteristics of the enterprises used as exploratory cases to preliminary validate the new taxonomy.

The investigation on the exploratory cases has provided good results, since in all cases we did not found any operational issue that could not be referred to a barrier.

Enterprise	Sector	Employees (#)	Turnover (k€/y)	Energy Expenditures/ Turnover (%)	Have you adopted EE interventions in the recent past (3 years)? (Y/N)	Have you conducted energy audits in the recent past (3 years)? (Y/N)
1	Primary Metals	47	6,987	1.2%	Y	N
2	Textiles	92	16,740	9.3%	Y	Y
3	Plastics	129	13,807	1.9%	N	N
4	Primary Metals	203	37,284	7.1%	Y	N
5	Basic Metals	36	16,013	5.0%	N	N
6	Textiles	286	43,435	3.3%	N	Y

Table 4Main characteristics of the enterprises used as exploratory cases to preliminary validate the new taxonomy.

5.4.5 The importance of the real and perceived values of barriers for energy efficiency

It is apparent that every barrier is associated with the perception of the decision-maker and the value that he/she attributes to this perception.

For example, when proposing the same energy-efficient technology to two different firms – but being sure that it perfectly fits in both cases, therefore with the same real value of the barrier Technical Characteristics not Adequate – it might happen that in one case the decision-maker decides to not invest in it since he/she perceives it as not fitting to the firm's characteristics, whilst in the other case he/she decides to adopt it. The different behavior of the two decision-makers cannot depend on the real value barrier, rather on a different perception of the barrier.

Moreover, considering the same technology, it is apparent that High Investment costs might represent a barrier for one decision-maker and not for another decision-maker: this implies the existence of other barriers that affect the investment to improve energy efficiency.

The interpretation scheme (Figure 3) provides, focusing on a given barrier, a picture of the real and perceived values of the barrier. They jointly contribute (the former indirectly, through the latter; the latter directly) in creating the effect of the barrier on the firm's decisions.

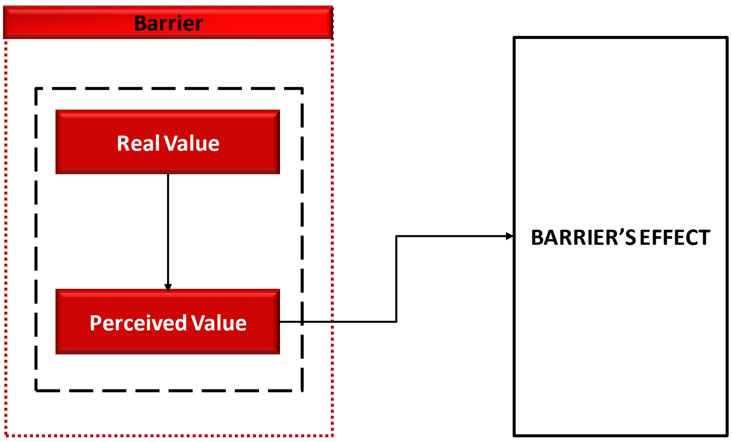

Figure 3The real and perceived values of a barrier and their indirect and direct effects.

In Figure 4 we report two examples of the effect of the barriers emerged in the exploratory cases. In one of the two Textiles enterprises visited, considering the barrier Technical Characteristics not Adequate, the perceived (value of the) barrier is higher than what accepted by the firm, so that, even if the real barrier is lower, the firm will not implement the investment in the energy-efficient technology. In the case of the Plastics enterprise, for the Imperfect Evaluation Criteria, the combination of the perceived and real barrier is acceptable by the firm, thus undertaking the investment. From the examples it is apparent that in the first case, if for other (than energy efficiency) purposes the investment is undertaken, the enterprise will experience a lower (than expected) effort to reach the status of energy efficiency improved from the status quo. As a consequence, if the investment would not be undertaken, a relevant opportunity of savings would be missed. Conversely, in the second case, since the decision would be made on the perceived value of the barrier, the enterprise would experience a greater (than expected) effort to reach the status of energy efficiency improved from the status quo. As a consequence, it would be needed to add further resources to overcome the real barriers: if the latter would not be available, the enterprise would not improve energy efficiency and the investment already undertaken would go wasted.

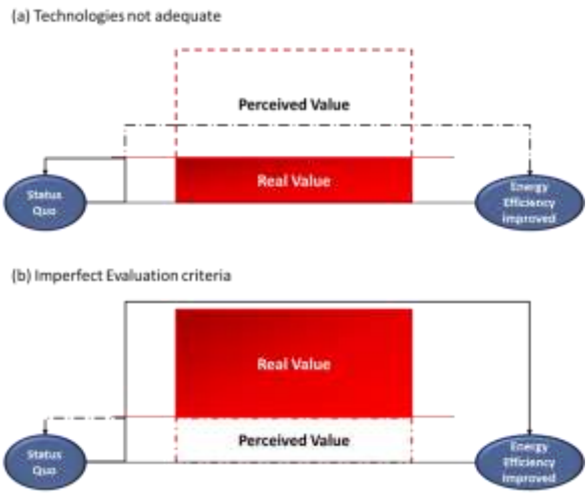

Figure 4Two possible results of how the combination of the real and perceived values of a barrier can affect the energy-efficiency improvement process.

Therefore, it is of fundamental importance to assess, for each barrier, the perceived and real values. Nonetheless, as expressed in Section 4.3, the enterprise will exclusively refer the perception of the external barriers. Thus, it would be possible, investigating exclusively an enterprise, to obtain the real values of the barriers that are originated internally.

In Table 5 we report the classification of the barriers according to the origin (internal/external). It is worth noting that some barriers as Intervention-related Risks and Intervention not Sufficiently Profitable consider problems that might arise within or outside the firm. As a consequence, they may have both an internal and an external origin. For example, as emerged from the exploratory analysis in one of the Primary Metal manufacturing enterprises, the barrier Intervention not Sufficiently Profitable was related, on one side, to the price of the technology to be adopted (external), on the other side to the rate of return of the investment (internal).

BARRIERS FOR EMPIRICAL INVESTIGATION		(a) **Origin:** *Internal (I) or External (E)*	(b) **Decision-making step**	**Spectrum of influence of the barriers**	
				(c) *To any invesment*	(d) *To energy efficiency: General (D) or Intervention-dependent (D)*
TECHNOLOGY-RELATED BARRIERS	TECHNOLOGIES NOT ADEQUATE	E	1, 3		D
	TECHNOLOGIES NOT AVAILABLE	E	1, 3		D
INFORMATION BARRIERS	LACK OF INFORMATION ON COSTS AND BENEFITS	E	2		D
	INFORMATION NOT CLEAR BY TECHNOLOGY SUPPLIERS	E	2		D
	TRUSTWORTHINESS OF THE INFORMATION SOURCE	E	2		D
	INFORMATION ISSUES ON ENERGY CONTRACTS	E	2		D
ECONOMIC	*LOW CAPITAL AVAILABILITY*	I	1,2,3	l	G
	INVESTMENT COSTS	E	3		D
	HIDDEN COSTS	I / E	2.3		D
	INTERVENTION-RELATED RISKS	I / E	3		D
	EXTERNAL RISKS	E	1		G
	INTERVENTION NOT SUFFICIENTLY PROFITABLE	I / E	3		D
BEHAVIORAL	LACK OF INTEREST IN ENERGY-EFFICIENCY INTERVENTION	I	1		G
	OTHER PRIORITIES	I	1		G
	INERTIA	I	1	l	G
	IMPERFECT EVALUATION CRITERIA	I	3	l	G
	LACK OF SHARING THE OBJECTIVES	I	3		G
ORGANISATIONAL	LOW STATUS OF ENERGY EFFICIENCY	I	2.3		G
	DIVERGENT INTERESTS	I	1		G
	COMPLEX DECISION CHAIN	I	2.3		G
	LACK OF TIME	I	1.3	l	G
	LACK OF INTERNAL CONTROL	I	3		G
BARRIERS RELATED TO COMPETENCES	IDENTIFYING THE INEFFICIENCIES	I	1.2		G / D
	IDENTIFYING THE OPPORTUNITIES	I	1.2		G / D
	IMPLEMENTING THE INTERVENTIONS	I	3		G / D
	DIFFICULTY IN GATHERING EXTERNAL COMPETENCES	E	2		G / D
AWARENESS	LACK OF AWARENESS OR IGNORANCE	I	1		G / D

Table 5Table of synthesis of the taxonomy proposed for empirical investigation highlighting the characteristics of the barriers investigated.

(a) The barrier may have its origin within the firm (Internal, I), or outside the firm (External, E);
(b) The barrier affects the Action “Generation of Interest” (1), the Action “Research of inefficiencies and opportunities” (2), or the Action “Investment analysis and intervention implementation” (3). One barrier can affect multiple actions.
(c) The barrier may affect any investment of the firm, i.e. not only those specific for the energy-efficiency improvement.
(d) The barrier, affecting exclusively energy efficiency, can be quantified in general (thus not depending on which action to be considered, G), or its value can vary according to a specific investment to be considered (intervention-dependent, D). One barrier can be both general and intervention-dependent

5.4.6 Effects of the barriers on the decision-making process

The literature on energy-efficiency decision-making is huge, and a review of it goes beyond the scope of this article: nonetheless, it is important to underline that some studies have been devoted to develop models to examine a firm's decision to implement a recommendation, thus analyzing which variables influence a firm's decision to adopt energy-efficient technologies (see, e.g., [80-81]). Another interesting study is represented by Tonn and Martin [82] that have addressed, through a follow-up survey of 42 companies, the decision-making stages to adopt energy efficiency measures, identifying seven stages: (1) No energy saving decision-making, (2) Initial efforts, (3) Energy Efficiency Program Implementation, (4) Energy efficiency Program direct effect, (5) Routinization of Energy Efficiency Program, (6) Inculturization of Energy Efficiency Program, and (7) Steady State. This approach has been considered but modified by a recent study of Hasanbeigi et al. [83] that have developed a conceptual framework for evaluating energy efficiency in the Thai industry. In particular, Hasanbeigi et al. distinguish three important actions: (1) Awareness, (2) Motivation, and (3) Action. We apply the same definition for our analysis of the barriers on the decision-making process, showing how barriers might inhibit the change from the first stage, i.e. status quo of energy efficiency, to the last one, which is the energy-efficient technology implemented within the firm.

We have synthesized the effect of the barriers on the decision-making process in Figure 5and Table 5, also considering the useful contributions provided by the preliminary investigation in the exploratory cases to refine the scheme. For clarity, since the interpretation scheme appears to be quite complex, we have decided to report the action of a barrier only if it is able to independently inhibit the achievement of a stage, whilst it is not reported if it acts combined with other barriers. For example, the effect of the Inertia barrier is reported exclusively for the first stage. In fact, Inertia is supposed to hinder by itself the generation of the interest to invest in energy-efficient technologies. We do not report the effect of Inertia in other stages. As example, Inertia might act concurrently with the Lack of Time to prevent reaching the knowledge of inefficiencies and opportunities.

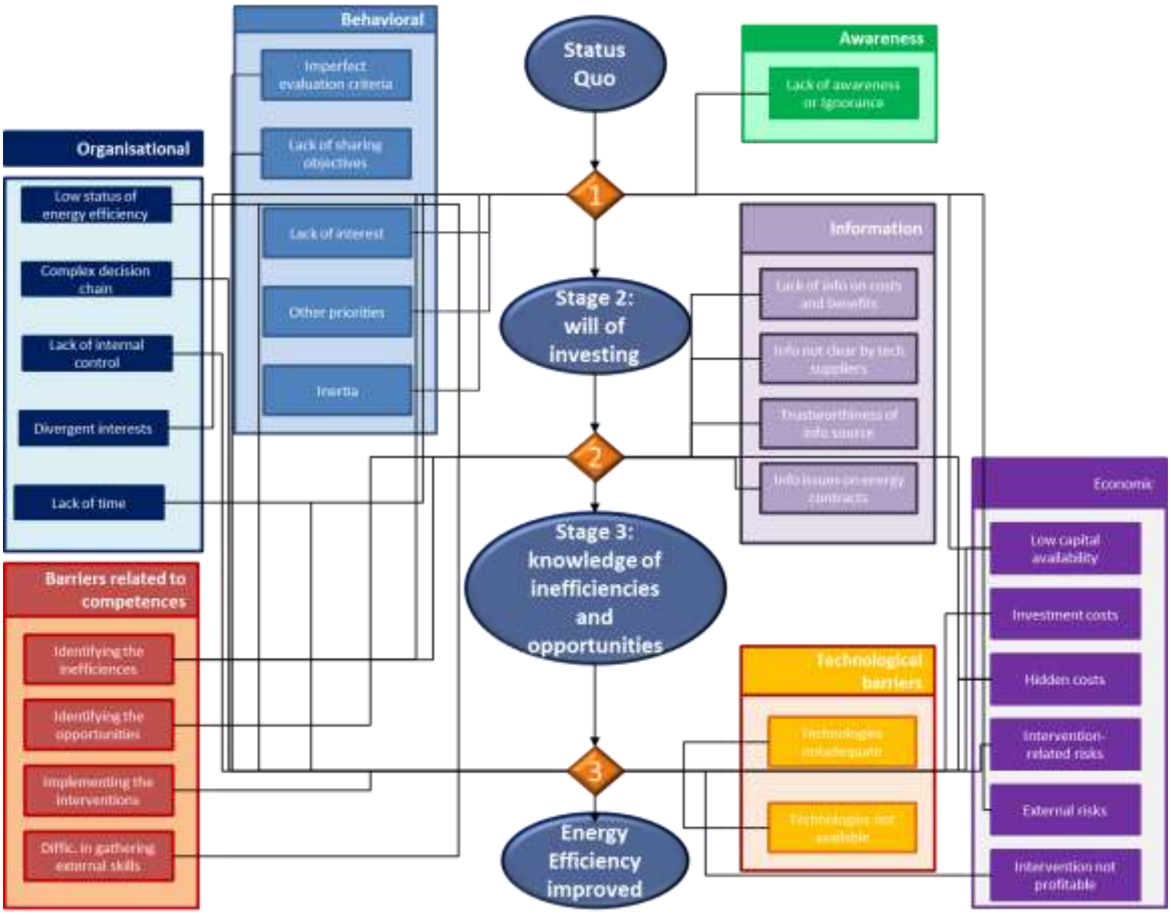

Figure 5The decision-making process and the barriers that can affect its actions, maybe inhibiting the change from one stage to another.

Stage 1: Status quo. It is the energy-efficiency status in which we can find the firm. It is rare that energy efficiency cannot be improved in any area.

Action 1: Generation of interest. This stage represents the generation of the awareness that energy expenditures can be reduced. This awareness arises the interest for energy efficiency, that represents the first step in the decision-making process.

Barriers to the generation of interest affect the generation of interest towards energy efficiency. In particular it is possible to find: (1) Low Capital Availability; (2) Lack of Time; (3) Risks; (4) Divergent Interests; (5) Inertia; (6) Other Priorities; (7) Low priority of Energy Efficiency; (8) Difficulty in Identifying the Inefficiencies.

Stage 2: Willingness to invest. The decision-maker is willing to invest resources in order to reduce the firm's energy consumption. It is reasonable to assume that a firm that stops at this step is aware of the importance of energy efficiency, but simply does not know how to do.

Action 2: Research of inefficiencies and opportunities. Once the firm is aware it is necessary to find the most critical areas with respect to energy efficiency.

Barriers to the knowledge of inefficiencies and opportunities. In order to be effective, a thorough knowledge of inefficiencies and solutions is needed. Several barriers tend to inhibit this knowledge, as: (1) Low Capital Availability; (2) Lack of Time; (3) Pre-intervention Costs; (4) Low Status of Energy Efficiency; (5) Complex Decision Chain; (6) Difficulty in Gathering External Competences; (7) Lack of Competences in Identifying the Inefficiencies; (8) Lack of Competences in Identifying the opportunities; (9) Information barriers.

Stage 3: Knowledge of inefficiencies and opportunities. In this state the decision-maker has the knowledge of the critical areas in which it would be necessary to act and the interventions needed. A firm that stops at this step is aware of its gap for energy management and of several opportunities for improving its energy efficiency, but does not consider the interventions as applicable or convenient.

Action 3: Investment Analysis and intervention implementation. Once interventions, benefits and costs are known, the decision-maker has to evaluate whether the investment is adequate and if it this profitable, according to its evaluation parameters.

Barriers to the implementation of the intervention: (1) Low Capital Availability; (2) Lack of Time; (3) Imperfect Evaluation Criteria; (4) Low Status of Energy Efficiency; (5) Complex Decision Chain; (6) Technologies not Adequate; (7) Technologies not Available; (8) Lack of Control; (9) Lack of Sharing the Objectives; (10) Lack of Competences in Implementing the Interventions.

Stage 4: Intervention implemented, energy efficiency improved. If the investment analysis and the implementation of the intervention have been properly conducted, the firm will save on energy (costs). It is worth pointing out that the satisfaction for the success of the process is of fundamental importance for considering future interventions, and, thus, for the future energy performance of the firm.

5.4.7 Spectrum of influence of the barriers

Since now the barriers have been categorized according to their origin and their influence with respect to the decision-making process, but there is another important characteristic to be pointed out for the empirical investigation and in order to analyze the possible interactions among the barriers. The spectrum of influence of the barriers is able to underline how general or, conversely, how specific, the effect of the barrier is on the firm's decisions. Becoming more specific with respect to energy-efficient technologies, we can distinguish between three different levels:

I. Barriers to investments: those barriers are not specifically related to energy efficiency, but generally consume the necessary resources for any investment and intervention;
II. Barriers to energy efficiency: those barriers represent a hurdle for any investment in energy-efficient technologies. Thus, they can be investigated regardless of the specific intervention to be considered;
III. Intervention-related barriers to energy efficiency: those barriers, whose values strictly depend on the specific energy-efficient technology to be considered, can be investigated exclusively considering a specific investment.

For example, for the first level, the Low Capital Availability, Inertia, Imperfect Evaluation Criteria and Lack of Time do not necessary refer exclusively to energy efficiency, but rather can be considered as general barriers to investments. For what concerns the second level, the barrier Complex Decision Chain represents a general barrier for energy efficiency investments, thus not depending on a specific intervention. It is now clear the difference with the third level: Hidden Costs can be investigated in their real values exclusively considering a specific investment in an energy-efficient technology, as emerged, e.g., in one of the Primary Metal manufacturing enterprises investigated.

This further characteristic allows to draw a wider picture of the barriers to energy efficiency, as reported in Table5.

5.4.8 Analysis of the interactions among barriers

The common simultaneous presence of several barriers in the same firm rises the attention in investigating the possible relationships among them, and trying to understand the possible effects on the firm. We identified, and preliminary tested through the six exploratory cases, three types of interactions: (1) causal relationship, (2) composite effect, and (3) hidden effect.

5.4.8.1 Causal relationship between barriers

The causal relationship between a barrier (A) and a barrier (B) exists when an increase of (B) is due to (A). This means that either (A) can generate (B), or just modify (B) (in case (B) already exists). The effect of the causal relationship might be delayed, i.e. the effect on (B) (creation or increase) might appear not simultaneously with (A). This implies that, as from the definition of barrier given in Section 4.2, once barrier (B) exists, it can stand autonomously even if barrier (A) decreases, or even disappears.

In Figure 6 we show the causal relationship (continuous lines; real and perceived) between two barriers, (A) and (B). We also put in evidence (dotted line) how this generates an effect on the value of the perceived barrier (B) (that influences the decision-making process).

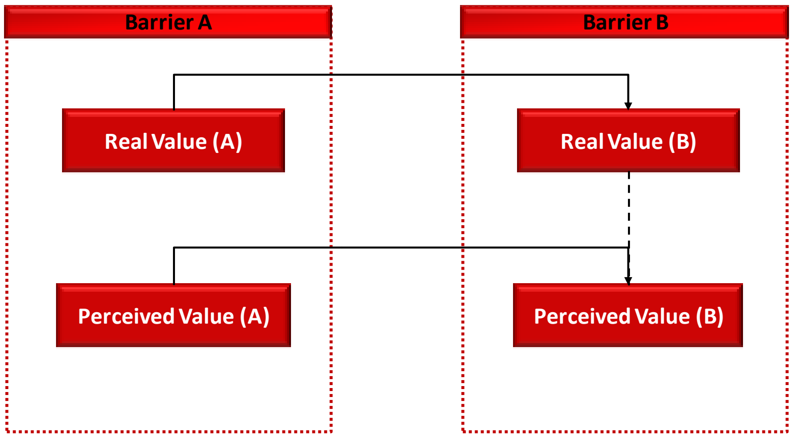

Figure 6The causal relationship between a barrier A and a barrier B.

In Figure 7 we report the complete scheme of causal relationships between the barriers, also considering the useful contributions emerged during the preliminary test performed in the exploratory cases.

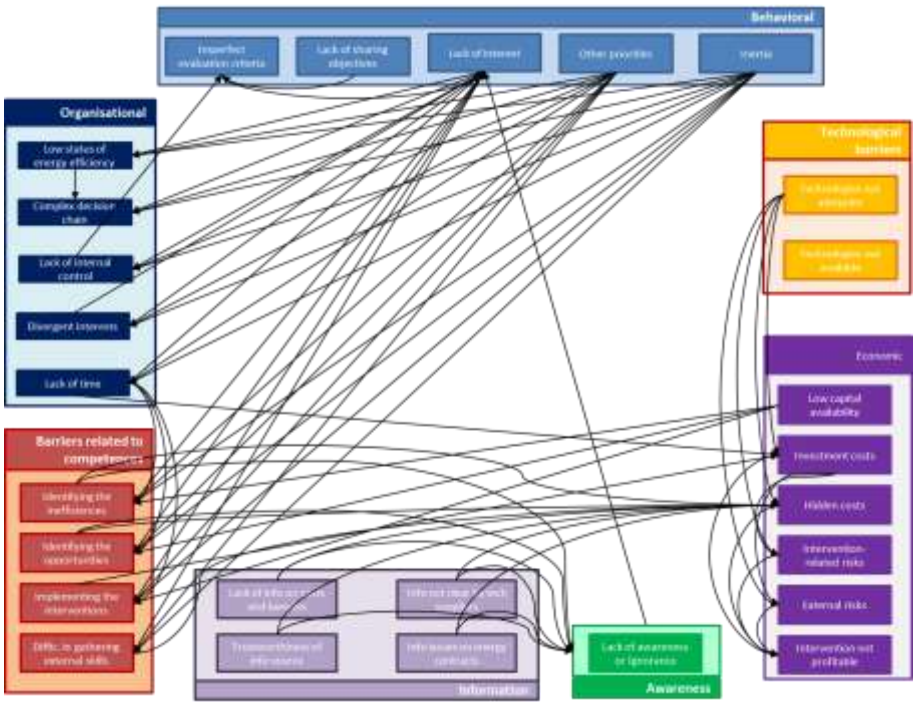

Figure 7Identification of the causal relationships between the barriers of the new taxonomy.

More in detail, we have expressed several links between behavioral and competences-related barriers: the presence of barriers such as Lack of Interest, Other Priorities and Inertia inhibits the development of the necessary competences for the identification of inefficiencies and opportunities, strengthening the ignorance on energy issues. Moreover, Ignorance of the potential benefits would consolidate a Lack of Interest on energy issues, thus creating a vicious circle among Ignorance and Lack of Interest on energy efficiency. In addition to that, it is important to point out that the Lack of Interest on energy efficiency might have a considerable influence on the Imperfect Evaluation Criteria adopted in evaluating the investments, e.g. adopting criteria unable to taking into account the life cycle costs of the equipment, with a further effect of the Inertia barrier, for which the criteria, even approximated or incorrect, are usually kept.

Figure 7 depicts various relationships between behavioral and organizational barriers, since, e.g. in the case of Lack of Interest, it can be found at all firm's levels, and may lead to Divergent Interests, since the firm is not able to address correctly the benefits due to energy-efficiency improvements to the decision-makers from which the investment depends.

With respect to organizational barriers, the Lack of tools for internal Control on the energy efficiency decision-makers by the firm's management, and the possible Lack of Sharing the strategic firm's Objectives, might be the origin of adopting restrictive economic criteria on the energy-efficiency investments: this dynamic, known as Principal-Agent Relationship and Moral Hazard, has been widely investigated in the literature, as summarized by Sorrell et al. [19-20]. Moreover, the Low Status of Energy Efficiency might be the origin of the Complex Decision Chain barrier, thus making the decision-making process on energy-efficiency investments long and complicated.

Considering competences, the Lack of Competences in Identifying both Inefficiencies and Opportunities might cause the Lack of Awareness on the real opportunities offered by the energy-efficiency market. Furthermore, it seems reasonable to assume that those lack of competences, due to a possible lack of resources (e.g., in terms of time and capital), might incur in increases of Hidden Costs (usually before the investments) for evaluating the opportunities and investment costs.

Finally, considering the economic barriers, we can see that High Investment Costs and Hidden Costs, and also Intervention-related Risks, play an important role in generating the Intervention not Profitable barrier, even if the energy efficiency performance of the intervention is proven to be, on average, positive [84]. Indeed, the characteristics of energy-efficient technologies might correspond partially to the firm's needs, thus generating costs and risks not acceptable by the firm.

5.4.8.2 Composite effect

The composite effect of the barriers occurs when several barriers operate simultaneously inhibiting energy efficiency, i.e. if combined with others, a barrier is able to inhibit the implementation of the intervention, but not acting by itself. The composite effect between barriers (A), (B) and (C) exists when the value of another barrier (Z) is influenced by the existence of (A), (B), and (C), as shown in Figure 8. In particular, with the continuous lines we report the composite effect between the barriers, (A), (B) and (C) on the value of (Z). We also put in evidence (dotted lines) that the barrier (Z) generates a back effect on both the perceived and real value of barrier (A), (B), and (C).

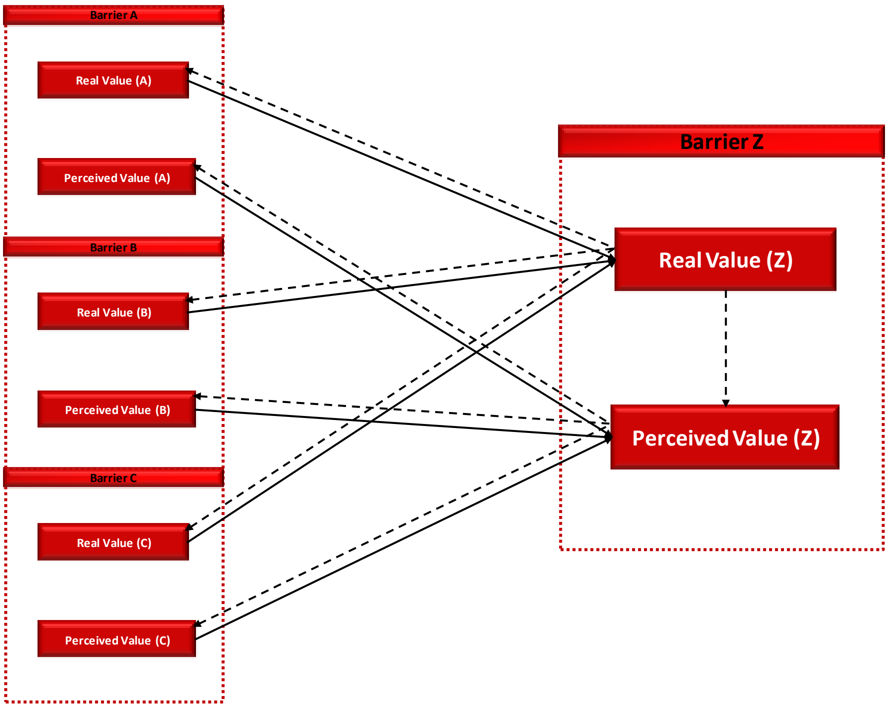

Figure 8The composite effect of three barriers A, B, and C on a barrier Z.

For example, we consider a case in which Hidden Costs, High Initial Costs and Resources for Higher Priorities Investments alone could not inhibit by themselves an investment in an energy-efficient technology. Nonetheless, as reported in Figure 9, the composite effect of those barriers could make Low Capital Availability a barrier. Indeed, the Hidden Costs, High Initial Costs and Resources for Higher Priorities Investments barriers influence the value of the Low Capital Availability barrier. At this point, it is also clear that the Low Capital Availability has an effect on the perceived and real value of

Hidden Costs, High Initial Costs barriers and also affecting the resources for higher priority investments.

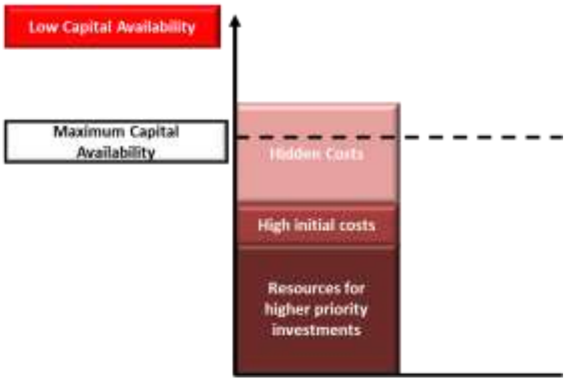

Figure 9The composite effect of three economic barriers on the Low Capital Availability of the enterprise.

As expressed in Section 4.6.1, Hidden Costs might be caused by other barriers, that thus operate indirectly on the Low Capital Availability barrier. As an example, if the information on the energy-efficient intervention is difficult to collect and requiring more resources, this will increase the hidden costs of the investment.

Analogously, as also emerged during the exploratory cases, we can detect several barriers having a composite effect with the Lack of Time, and particularly those reducing the time needed for taking a decision on the investment or enlarging the decision-making process, i.e. Information issues, Complex Decision Chain, Lack of Competences in Identifying both Inefficiencies and Opportunities, and Other Priorities.

Inertia expresses the resistance to change and/or the resistance to perform large investment in the firm, and represents a behavior that tends to increase the effect of several barriers. As a behavior against risk, Inertia appears each time the firm has to face a barrier that requires a strong initiative to be overcome, such as: Market or Intervention-related Risks, Trustworthiness of the Information, Technologies not Adequate, and Ignorance. Inertia, as a behavior limiting large investments, has a composite effect with the Complex Decision Chain barrier and the economic barriers related to the energy-efficiency investment, i.e. Investment and Hidden Costs, and Low Capital Availability.

But, we can see the composite effect of barrier also at different decisional levels. Indeed, taking medium and large enterprises as example, even if the reduction of energy consumption might represent a concern for the firm's management, nonetheless achieving the energy savings depend on the actions of lower levels. In addition to that, the Lack of Control can make the practices proposed by decision-makers as not adopted by the operator and might operate with the barrier Lack of Sharing Objectives. We can note that the interaction here is not of causal relationship, since the Lack of Control does not generate the Lack of Sharing Objectives. In fact, a more control does not make the firm's objectives as shared. Rather, quite often a tough supervision on the operators might have the opposite effect on their sensibility. When taking at example intermediate decisional functions, the Lack of Control barrier operates with the Divergent Interests barrier: e.g. the procurement functions might not be interested in adopting energy-efficient technologies since they would not gain direct benefits. Moreover, in conclusion, it should be added here that this type of interaction works also in the opposite direction: indeed, it seems reasonable to assume that a firm in which the objectives would be widely shared, the lack of control barrier would probably result as less important.

5.4.8.3 Hidden effect

The hidden effect of the barriers occurs when the firm is not aware of an existing barrier (A), but rather has the perception of having another barrier (B): the presence of the barrier (A) influences the perception of barrier (B), therefore the firm will tend to confuse (A) with (B), as showed in Figure 10. As a consequence, addressing (B) would be abruptly ineffective, since the real barrier is (A).

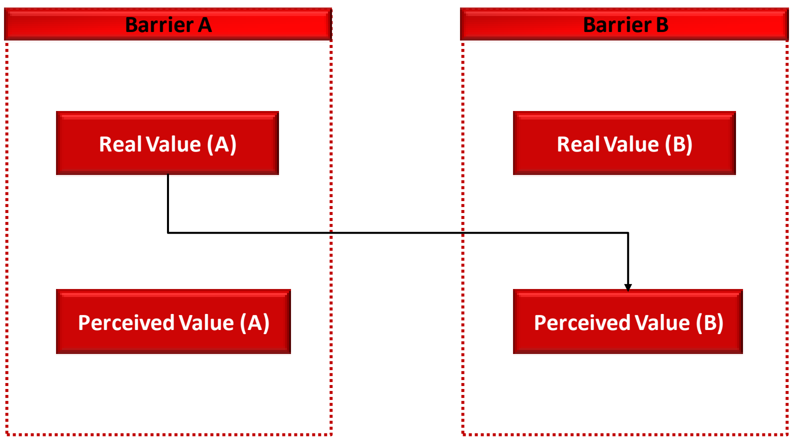

Figure 10The hidden effect of a barrier A on a barrier B.

As an example emerged from the exploratory cases, the Basic Metal manufacturing enterprise incorrectly considered an energy-efficient technology as not adequate, due to a lack of knowledge on the most recent available technologies: the perception of

Technology not Adequate here represents a Lack of Competences in Identifying the Opportunities.

Moreover, enterprises often acquire the knowledge of the opportunities proposed by the energy-efficiency market through the research of information and the collaboration with external consultants. Due to that, it might be possible to have a distorted perception of the real performance, identifying as critical barriers aspects that are not. It might be possible to consider a technology as not adequate, or overestimating costs and risks due to not clear or trustworthy information. In this case there is an hidden effect of Information issues and Lack of Interest for energy-efficiency on the incorrect perception of the Lack of Competences Identifying the Opportunities.

Analogously, it is possible to see the hidden effect of several barriers behind the perception of the barrier Interventions not Sufficiently Profitable. As an example, it is quite often diffused that energy efficiency technologies are not considered as sufficiently profitable due to Imperfect Evaluation Criteria, or due to a Lack of Interest and Inertia that lead to inaccurate analyses to evaluate them, or due to an underestimation of the real and wide benefits coming from the implementation of the energy-efficient technologies.

5.5 Conclusions and Further research

The problem of the energy efficiency gap in the industrial sector is present and quite relevant. Therefore, a deep comprehension of the obstacles to energy efficiency, i.e. the barriers, and their mechanisms and dynamics play an important role both for enterprises and for future energy policies to be really effective. Starting from the available literature on this topic, three main issues still need to be fully addressed.

Firstly, the existing taxonomies on barriers seem to not encompass all the elements already pointed out in the literature. Therefore, a novel approach has been proposed that aims at encompassing all the relevant contributions in this topic. The new taxonomy has been tested in a preliminary investigation of several enterprises – belonging to different industrial activities, and firm’s size – , where we do not have found any other barrier not considered. Although these preliminary results seem to be sound, further research needs to be carried out, in particular analyzing more specifically the taxonomy by sectors, technologies adopted, and firm’s size, etc., since we think that some characteristics of the taxonomy seem to be more specific with respect to these factors. In particular, the firm’s size seems to deeply impact on the organizational barriers.

The second issue arisen from the analysis of the literature is the presence of overlaps between the theoretical barriers, causing an incorrect and misleading classification of the barriers. This is even more relevant for the effective capability of the existing taxonomies from an operational perspective – i.e., when empirically investigating from the perspective of enterprises the theoretical taxonomies – , obtaining, as a result, a disguised comprehension of the barriers. The new proposed taxonomy has tried to reduce the barriers to the minimum independent terms: although further investigation needs to be performed, the preliminary test brought a positive result, with low correlations between the barriers.

The third issue are the implicit interactions between the barriers, that, without being fully and thoroughly analyzed, would not allow a correct comprehension of the mechanisms and dynamics of the barriers. The problem, already simplified through the reduction of the overlaps, has led to the identification of some existing relationships between the barriers, i.e. causal relationship, composite effect and hidden effect. To do this, a fundamental step was needed, i.e. a clear distinction between the real and perceived values of the barriers. Indeed, the perceived value drives the decisions on investments, whilst the real one is the barrier that the enterprise, by the fact, has to overcome, when undertaking an action for increasing its energy efficiency. In this respect, we have performed a preliminary identification of the primary effect of the barriers on the decision-making process steps. Moreover, we have tried to obtain an operative taxonomy, i.e. a taxonomy able to be effectively investigated and provide the viewpoint of enterprises. This has implied to perform a distinction between barriers originated outside or within the firm, and to understand the extent of the influence of a single barrier. Starting from the literature, all these features have been firstly tested through a preliminary investigation, also bringing several real examples. Nonetheless, future research is needed, in order to counter prove and get more evidences according to different firms' characteristics (e.g. sector, size, etc.), since, e.g., we would expect that the decision-making process for smaller enterprises would be more lean and simplified.

In a broader view, the empirical investigation will put in relation the barriers with several important characteristics that, since now, the literature has not addressed, such as: the behavior of the firm with respect to its competitors, the behavior with respect to its innovation processes, etc.. Indeed, these factors seem to represent, along with other drivers that at the moment the research is still investigating, and for which the first contributions are coming in the most recent years [23-24, 42, 83], key-elements for promoting effective energy efficiency policies in the industrial sector.

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6 Empirical Investigation of Energy Efficiency Barriers in Italian manufacturing SMEs

This chapter reports the content of the work submitted as:

Trianni A., Cagno E., Worrell E., Pugliese G., 6 Empirical Investigation of Energy Efficiency Barriers in Italian manufacturing SMEs", Renewable and Sustainable Energy reviews, 2012 (paper submitted).

The paper identifies and evaluates the barriers to industrial energy efficiency through the investigation of 48 manufacturing Small and Medium-sized Enterprises (SMEs) in Northern Italy. The study, starting from the existing literature, adopts an innovative taxonomy, which points out the need, when performing an empirical investigation within enterprises, of making a clear distinction between the perceived and real values of the barriers, and to evaluate their effect on the decision-making process. The most perceived and real barriers have been investigated with respect to several important characteristics of enterprises: firm's size, energy expenditures, complexity of the production, demand variability and strength of competitors.

The results of the study point out an important suggestion both for enterprises and policy-makers: despite the perception that economic and information barriers are the major obstacles to the adoption of energy-efficient technologies and behavioural barriers do not affects enterprises very much, the most relevant real barriers are the lack of interest in energy efficiency and the existence of other priorities, thus downgrading energy efficiency to a marginal aspect of the operations by decision-makers.

For what concerns the effect of the barriers on the decision-making process, the perceived difficulties do not take place exclusively in the last action, i.e. the analysis of the investment to be undertaken and the intervention implementation, but, with comparable importance, also in the generation of interest and knowledge of the opportunities.

This examination puts also in evidence that, when analyzing barriers to energy efficiency, it seems not fully appropriate to bundle together SMEs, since relevant differences can be appreciated both for perceived and real barriers. The analysis of the enterprises with respect to the other considered factors presents an interesting trend:

although several differences occur when looking to the perceived barriers, the real barriers seems to be lower with high or very high complexity of the production, high variability of the demand and strong competitors. The trend represents a really interesting and challenging issue for future research, since it might imply the existence of other factors (not only in terms of external pressures, but also within the firm) moving enterprises towards energy-efficient technologies.

6.1 Introduction

Despite the strong effort of energy policies in Europe, the target of reducing the energy consumption of 20% by year 2020 seems hardly to be achieved. Indeed, recent estimate revealed that, with current trends, only 10% of the reduction will be obtained, on one side showing the still existence of barriers towards the diffusion of energy-efficient technologies, on the other side moving the European Commission towards a new set of measures for increasing energy efficiency [1].

A major role in the game is played by the industrial sector, that, according to the most recent estimates [2], covers more than 50% of the total energy delivered. In this sense, obtaining a reduction of energy consumption in this sector should be seen as strategic by policy-makers for achieving the energy efficiency targets.

Within the industrial sector, according to a recent study by the European Commission [3], when looking at Small and Medium-sized Enterprises (SMEs), “the picture is surprisingly unfavorable: close to two thirds of SMEs operating in the EU do not even have simple rules or devices for energy saving (63%). Less than three out of 10 SMEs (29%) have instituted some measures for preserving energy and resources at their enterprise. Only 4% of EU SMEs have a comprehensive system in place for energy efficiency”.

Nonetheless, considering the domestic industrial structure, SMEs are strategic since they represent the large majority of the enterprises, cover a major share of the domestic industrial consumption, and, as emerged in other studies, are quite inefficient [4-7]. One reason for the low adoption of energy-efficient technologies within SMEs is represented by the lack of proper means to address their barriers towards energy efficiency.

In fact, at the moment we can find very few contributions in the literature addressing the barriers to energy efficiency in industrial SMEs. Therefore, understanding the barriers to energy efficiency seems to be really important to propose – by policy makers – the most effective means to overcome them. In order to do this, it is apparent the relevance of having an holistic approach to barriers to industrial energy efficiency, i.e. having a taxonomy able to understand and classify the wide spectrum of issues enterprises have to deal with when coping with investments in energy-efficiency technologies.

In the literature it is possible to find a large number of contributions, providing different perspectives on the taxonomies on barriers to industrial energy efficiency, and showing that the debate is still open [8-14]. Nonetheless, since now most of the studies tend to look at the barriers more from a theoretical viewpoint, rather than from an empirical one, i.e. by the enterprises' perspective.

A recent study by Cagno et al. [15] has proposed an innovative taxonomy encompassing the major contributions in the previous literature, but, at the same time, providing useful insights for empirically investigating the barriers to industrial energy efficiency. Indeed, the new taxonomy aims at contributing to fulfill the need of having a tool – in terms of theories and practices – useful both for enterprises and policy makers in order to clearly point out where the difficulties are rooted. In this study we adopt their approach investigating the new taxonomy in several manufacturing SMEs located in Northern Italy.

The structure of the paper is as follows: in Section 2 we describe the theoretical framework that represents the starting point for this research. This section will perform a brief review of the characteristics of the taxonomy adopted, pointing out the issues emerging for the application in SMEs and considering the transferability of the taxonomy to SMEs. In Section 3 we describe the methodology adopted to empirically investigate the barriers, in terms of how the study has been conducted and results collected. Section 4 and Section 5 will be devoted respectively to the presentation and discussion of results from the analyses and conclusions with further research.

6.2 Theoretical approach

Cagno et al. [15] propose a taxonomy in which the barriers are classified according to the responsible author in which they are originated, as reported in Table 1.

Origin	Actor/Area	Barriers
External	Market	Energy prices distortion
		Low diffusion of technologies
		Low diffusion of information
		Market risks
		Difficulty in Gathering External Skills
	Government/Politics	Lack of proper regulation
		Distortion in fiscal policies
	Technology/Services Suppliers	Lack of interest in energy efficiency
		Technology Suppliers not updated
		Scarce communication skills
	Designers and Manufacturers	Technical Characteristics not adequate
		High initial costs
	Energy Suppliers	Scarce communication skills
		Distortion in energy policies
		Lack of interest in energy efficiency
	Capital Suppliers	Cost for investing capital availability
		Difficulty in identifying the quality of the investments
Internal	Economic	Low capital availability
		Hidden costs
		Intervention-related risks
	Behavioral	Lack of interest in energy-efficiency interventions
		Other priorities
		Inertia
		Imperfect evaluation criteria
		Lack of sharing the objectives
	Organisational	Low status of energy efficiency
		Divergent interests
		Complex decision chain
		Lack of time
		Lack of internal control
	Barriers related to competences	Identifying the inefficiencies
		Implementing the interventions
	Awareness	Lack of awareness or Ignorance

Table 1 The taxonomy adopted in this study, with a clear distinction of the origin (external, or internal, with respect to the firm), and the actors affected by the barriers [15].

Nonetheless, taking into consideration the need to empirically investigate the barriers among enterprises, they have developed a taxonomy for field investigation, as reported in Table 2, in which they point out the origin of the barrier, that, with respect to the enterprise, might be either internal or external. This feature is particularly important since it shows that, through an investigation in a single enterprise it will be possible to obtain exclusively the perception of the external barriers, not necessarily the real external barriers. Indeed, it is apparent that the enterprise is not able to evaluate the real value of the external barriers, e.g. is not able to evaluate the value of the Lack of Interest for Energy Efficiency for technology suppliers, but rather the enterprise will provide how this barrier reflects on itself, i.e. the perception that energy-efficient technologies are not available.

Moreover, another important feature of the taxonomy is the capability to evaluate the barriers on the decision-making process of the enterprise, attributing each of them to one or more actions of the process, respectively the Generation of Interest (Action 1), Knowledge of inefficiencies and opportunities (Action 2), Investment Analysis and Intervention Implementation (Action 3).

A third quite important feature of the proposed taxonomy is the classification of the barriers dividing them with respect to their action on the enterprise (the so-called *spectrum of influence* on the enterprise), i.e. affecting any investment, only energy efficiency investments, or even depending on the specific investment in energy efficiency to be considered. This classification allows to understand that some barriers vary according to the considered technology: as a consequence, it will not be possible to obtain a real value, limiting the research to obtaining a general perception of those barriers.

Nonetheless, when considering SMEs, previous studies have pointed out that the structure of those enterprises, quite different from large enterprises (LEs), also affect empirical investigation. Indeed, in the case of SMEs the organizational structure is very simple, and quite often the decision belong exclusively to one person, i.e. the entrepreneur him/herself. Therefore, with the exception of Lack of Time, barriers like Divergent Interests between who decides on energy efficiency and who invests, Complex Decision Chain, Lack of Internal Control or even Low Status of Energy Efficiency tend to fade, since the entrepreneur has a direct control on the operations, and makes both decisions and investments.

BARRIERS FOR EMPIRICAL INVESTIGATION		(a) **Origin:** *Internal (I) or External (E)*	(b) **Decision-making step**	**Spectrum of influence of the barriers**	
				(c) *To any invesment*	(d) *To energy efficiency: General (D) or Intervention-dependent (D)*
TECHNOLOGY-RELATED BARRIERS	TECHNOLOGIES NOT ADEQUATE	E	1, 3		D
	TECHNOLOGIES NOT AVAILABLE	E	1, 3		D
INFORMATION BARRIERS	LACK OF INFORMATION ON COSTS AND BENEFITS	E	2		D
	INFORMATION NOT CLEAR BY TECHNOLOGY SUPPLIERS	E	2		D
	TRUSTWORTHINESS OF THE INFORMATION SOURCE	E	2		D
	INFORMATION ISSUES ON ENERGY CONTRACTS	E	2		D
ECONOMIC	*LOW CAPITAL AVAILABILITY*	I	1,2,3	l	G
	INVESTMENT COSTS	E	3		D
	HIDDEN COSTS	I / E	2.3		D
	INTERVENTION-RELATED RISKS	I / E	3		D
	EXTERNAL RISKS	E	1		G
	INTERVENTION NOT SUFFICIENTLY PROFITABLE	I / E	3		D
BEHAVIORAL	LACK OF INTEREST IN ENERGY-EFFICIENCY INTERVENTIONS	I	1		G
	OTHER PRIORITIES	I	1		G
	INERTIA	I	1	l	G
	IMPERFECT EVALUATION CRITERIA	I	3	l	G
	LACK OF SHARING THE OBJECTIVES	I	3		G
ORGANISATIONAL	LOW STATUS OF ENERGY EFFICIENCY	I	2.3		G
	DIVERGENT INTERESTS	I	1		G
	COMPLEX DECISION CHAIN	I	2.3		G
	LACK OF TIME	I	1.3	l	G
	LACK OF INTERNAL CONTROL	I	3		G
BARRIERS RELATED TO COMPETENCES	IDENTIFYING THE INEFFICIENCIES	I	1.2		G / D
	IDENTIFYING THE OPPORTUNITIES	I	1.2		G / D
	IMPLEMENTING THE INTERVENTIONS	I	3		G / D
	DIFFICULTY IN GATHERING EXTERNAL COMPETENCES	E	2		G / D
AWARENESS	LACK OF AWARENESS OR IGNORANCE	I	1		G / D

Table 2Table of synthesis of the taxonomy adopted for empirical investigation highlighting the characteristics of the barriers investigated. Source: Cagno et al. [15].

(a) The barrier may have its origin within the firm (Internal, I), or outside the firm (External, E);
(b) The barrier affects the Action “Generation of Interest” (1), the Action “Research of inefficiencies and opportunities” (2), or the Action “Investment analysis and intervention implementation” (3). One barrier can affect multiple actions.
(c) The barrier may affect any investment of the firm, i.e. not only those specific for the energy-efficiency improvement.
(d) The barrier, affecting exclusively energy efficiency, can be quantified in general (thus not depending on which action to be considered, G), or its value can vary according to a specific investment to be considered (intervention-dependent, D). One barrier can be both general and intervention-dependent

6.3 Methodology

The explorative nature of the study and the multiple sites investigated drove this study to be carried out as case-studies using semi-structured interviews and questionnaires. The 48 SMEs investigated (according to the definition provided by the European Commission [16]), located in the Lombardy Region[1], one of the most industrialized in Europe, had all f66666666666666666666666666666666666666656participated in a project carried out in 2010 and contributed voluntarily to this research.

A single case-study has been structured as follows: in the first part, the respondents – all of them responsible for energy issues at their site – provided some useful details about their firm's characteristics, describing generally their firm, their production, and their view about the type of market in which they operate and their position within that market. In the second part, the respondents have been asked to fill out a guided questionnaire covering various aspects of the energy efficiency topic, starting from providing detailed data about their firm's size, production, turnover, energy expenditures, and delving into barriers to and practices when coping with energy efficiency investments.

The investigation aimed at obtaining the perceived (Y_i') and the real (Y_i) – where available – values of the barriers (B_i), since they together contribute in determining the full picture of the barriers. The perceived values can be obtained asking directly some feelings and evaluations to the interviewees through one or a combination of several questions. The real values can be obtained through gathering several data (D_i) about practices and behaviors on the energy-efficient technologies investment processes. It is apparent that gathering the real values, since they do not refer to feelings, judgments or opinions by the respondents, could not be so straightforward, requiring, for a single barrier investigated, several data and/or information objectively registered.

In the following sections we will present separately how the perceived and real values of the barriers have been asked.

6.3.1 Perceived Barriers: detailed analysis of the questions

Measuring the perception of a given barrier could be quite difficult, since the respondent might be in the position of answering about his or her opinion or behavior

[1]The Lombardy Region has almost 10 million inhabitants and is located at northern Italy, 800 thousand enterprises and 1.2 million employees in the manufacturing activities. The Gross Product for the region is 296 billion euros, representing about 25% of the total Gross National Product, and being +29% and +37% higher of respectively the National and EU-25 per capita gross product. [17].

with respect to the topic. Therefore it has been decided to formulate the questions in the form of sentences to which agree or disagree, and, in order to rank the responses, to adopt a Likert scale score from 1 ("I completely disagree with the sentence") to 4 ("I completely agree with the sentence").

Looking at the values of the perceived barriers, as expressed above, it is quite often possible to obtain them through direct questions, e.g. for measuring the perceived value of the inertia barrier, asking how much the respondent agrees with the sentence: "It would be wise not to change the actual state of the production system".

Nonetheless, it is possible to have many aspects that should be composed and fall under the hat of the same barrier: therefore, the value of the barrier will depend on a combination of the responses to several questions.

This is the case of the Hidden Costs barrier (Y3.3'), that takes into account all the costs *pre*, *during*, or *post* the intervention. The *pre-intervention* hidden costs encompasses the research of energy inefficiencies and opportunities for increasing energy efficiency (Q3.3.1). The hidden costs *during* the implementation of the investment considers the disruption costs, and all the costs related to the modification of the production system (e.g. layout of the equipment) that is needed in order to install the new energy-efficient technology (Q3.3.2). Considering the *post-intervention* hidden costs, they include the costs for training the personnel on the proper use of the new technology, developing new procedures for maintenance, adapting them to the modified production system (Q3.3.4). As a consequence, the Hidden Costs perceived barrier will be felt as a big issue if just one of the three will be considered as a significant barrier (1):

$$Y3.2' = \max(Q3.3.1; Q3.3.2; Q3.3.3) \qquad (1)$$

Analogously for the perceived value of the Intervention not Sufficiently Profitable barrier: the firm might not decide to implement an energy-efficient intervention since it considers either that they have a high pay-back time (Q3.6.1) or, independently, with a too low economic return (Q3.6.2). Therefore, the perceived value of the barrier Intervention not Sufficiently Profitable (Y3.6') will be high if just one of them will be felt as a big issue (2):

$$Y3.6' = \max(Q3.6.1; Q3.6.2) \qquad (2)$$

Moreover, for the perceived value of the Lack of Interest in Energy-Efficiency Interventions barrier (Y4.1'): the firm might be not interested (3) either because it considers itself as already efficient (Q4.1.1), or, independently, if it considers its energy expenditures as so low that it does not worth to make an investment in order to reduce them (Q4.1.2).

$$Y4.1' = \max(Q4.1.1; Q4.1.2) \qquad (3)$$

Another perceived value that needs to be obtained through a combination of several pieces, is represented by the "Low Status of Energy Efficiency barrier (Y5.1'), it is necessary to take into account the perception of being already efficient, the too high payback, and also the other priorities the firm might have (Q4.2), Therefore (4):

$$Y5.1' = \max(Q4.1.1; Q4.1.2; Q4.2) \qquad (4)$$

6.3.2 Real Barriers: detailed analysis of the questions

The process of gathering the needed information for evaluating the real barriers is not as straightforward as done for the perceived barriers, due to the limitations already described in Section 2. In detail, it has been necessary to ask for data and more general information related to the given issue, in order to build the picture of the entity of the real barriers.

6.3.2.1 Low Capital Availability:

The Low Capital Availability barrier can be measured as the distance between the capital needed by the enterprise and the effective economic availability of the enterprise to perform investments in energy-efficient technologies. Therefore, it is possible to propose an index represented by the ratio of the capital required by the enterprise to perform investments in energy efficient on the budget effectively devoted to that scope in the last 5 years. The authors acknowledge that, in some cases, the request of resources could be influenced by the budget effectively available. Nonetheless, the authors, in the empirical investigation, have verified that the values provided by the respondents would not be influenced by the budget. Adopting a Likert scale from 1 to 4 to evaluate this parameter, the threshold values proposed are 1, 1.2 and 1.5. Of course, the first threshold is related to the existence of the barrier: in fact, if the ratio is lower than 1, the capital needed for investments is lower than the devoted budget, therefore the barrier does not exist. The other thresholds have been proposed by the authors starting from their previous experience in similar enterprises.

6.3.2.2 Lack of Interest:

An enterprise might not be interested in energy-efficient technologies for mainly two reasons: on one side, since the consumption is not relevant; on the other, because the enterprise is already (energy-)efficient. The evaluation of the effective energy efficiency status of the enterprise could not be obtained without a thorough energy audit. Indeed, given the enormous variety of technologies and processes adopted, characterizing the output in terms of energy (e.g. energy consumed by unit of product) does not seem to be fully applicable and reliable to SMEs. Therefore, the importance of energy expenditures, expressed as the ratio between the energy expenditures and the total costs of the production, is the sole indicator that was possible to be proposed and obtained. The three values for the thresholds proposed are 1%, 3% and 5%. The discussion on indicators of energy intensity is huge and beyond the scope of this study (see, e.g. Ramirez et al. [18]). Starting from the recent indications provided by the US Department of Energy [19] and Rohdin and Thollander [4], and combined with the finding of a study by Ramirez et al. [18], it is possible to assume the value of 3% as the discriminant between energy intensive and non-energy intensive enterprises.

6.3.2.3 Other priorities:

This barrier could be measured as the relative importance of investments in energy efficiency. Therefore, it is possible to propose an index represented by the ratio between the capital specifically invested by the firm for investments in energy-efficient technologies, and the total amount of the capital for investments performed by the enterprise in the last five years. More in detail, from the latter it would be wise to subtract the amount of capital devoted for investments considered as strictly needed for the business continuity, and therefore do not represent an option for the decision-maker. It is clear to the authors that this index could not embrace all the possible possibilities given by real cases: nonetheless, looking at the enterprises by experience, as first approximation, this index is the first indicator of the priorities. The three proposed values on a Likert scale are 0%, 5% and 10%. As done before, the first one traces the existence of the barrier, whilst the others have been proposed thanks to the experience of the authors.

6.3.2.4 Inertia

The Inertia barrier encompasses two different behaviors of the decision-maker: on one side, the resistance to change, on the other side, the resistance to risk.

For what concerns the resistance to change, it has been proposed to measure the number of changes the enterprise has adopted in the last five years, expressed in terms of product portfolio and technological processes. The indicators required are, respectively, the length of the average life-cycle of products, and the average life-cycle of processes (or modifications of production processes), with thresholds of 1, 2 and 5 years. For the type of enterprises considered, the value of 1 reflects a continuous change in the portfolio, 2 years seems to represent a reasonable threshold for measuring both changes in products and processes, whilst 5 years is considered as a very stable process (and is equal to the timespan observed). An average of the two indicators has been obtained as representative of the resistance to change.

By considering the resistance to risk, the indicator proposed is the maximum PBT. Indeed, this parameter expresses the caution with which the enterprises tends to protect itself from future uncertainties. In particular, the shorter the PBT, the more risk resistant the enterprise would be considered. Another option of indicator is represented by the risk-premium, i.e. the minimum amount of money to take into account the uncertainty of an investment. The higher this indicator, the more risk resistant the enterprise. Nonetheless, adopting a risk-premium was not so common: it the few cases in which it has been possible to obtain both parameters, we have observed that they proved to be strictly correlated, therefore providing the same indication about the resistance to risk of the enterprise. The three threshold values fixed are 1, 2 and 5 years. In particular, if maximum PBT is lower than one year, it means that the enterprise tends to consider investments uniquely referable to a given fiscal year. When the maximum PBT exceeds 5 years, the enterprise behaves with long decisional horizons/ planning; usually 2 years represents a common practice for evaluating the maximum return, in years, of an investment.

Having both a measure of the resistance to change and risk, it is possible to obtain a n estimation of the inertia barrier. There is no reason to assume that one of the two components of inertia, either resistance to change or resistance to risk, could have a greater importance on the barrier. Therefore, the authors propose to give the same weight to the two elements.

6.3.2.5 Imperfect evaluation criteria:

This barrier occurs when the decision-makers does not have the proper knowledge or criteria to evaluate the investments in energy-efficient technologies. On one side, the criteria are approximated or downgraded to routines. On the other side, the risks associated to different investments are not taken into account, e.g. in the pay-back time period or the rate of return, when evaluating the alternatives.

We have proposed to measure the capability of the respondents to take into account the risk associated to the investment in the evaluation of the profitability, with respect to the entity and the priority of the investment in a scale from 1 ("not able to take into account") to 4 ("always taking risk into account").

For what concerns the adoption of approximated criteria, the operating costs of the technologies are not usually considered as driver for the decision. Therefore, in the same scale, we have asked how frequently they make decisions basing their evaluations on a life-cycle cost perspective.

Since there is no reasonable explanation to provide more importance on one aspect with respect to the other on the barrier Imperfect Evaluation Criteria, it has been proposed to adopt the same weight.

6.3.2.6 Identifying the inefficiencies

This barrier represents the lack of knowledge of the enterprise about the needed competences to identify the inefficiencies in their production system. Therefore, in the interview, the respondents have been asked about the existence of specific equipment for measuring the energy consumption, the existence of tables to evaluate the trend of consumption of the equipment, and the presence of personnel able to develop a detailed map of the energy consumption. Therefore, basing on these responses, we have developed an indicator able to quantify their capability of identifying the inefficiencies, and measured with a Likert scale from 1 to 4.

6.3.2.7 Identifying the opportunities

Analogously to want done in Section 3.2.6, we have asked the respondents their capabilities about the existing opportunities for increasing energy efficiency, building an indicator to measure this barrier. In particular, we have used two discriminants factors to evaluate the lack of competences on the opportunities. On one side, we have asked the respondents to report, at least by areas – i.e. within each ancillary system, e.g. compressed air system, etc. – which are the Best Available Technologies. On the other side, we have asked the knowledge of the values of energy consumption, investment costs and operating costs for performing a benchmark analysis about the equipment in place and the existing opportunities. Therefore, basing on these responses, we have developed an indicator able to quantify their capability of identifying the opportunities, and measured with a Likert scale from 1 to 4.

6.3.2.8 *Implementing the interventions*

This barrier occurs when the enterprise is not able to perform an intervention for energy-efficiency without an external support. For a matter of simplicity, we have divided the interventions into three broad categories:

- Specific energy-efficiency interventions on the production technology.
- Light Modifications to equipment having a moderate influence on the production and/or on the ancillary systems;
- Interventions of restoring and/or optimizing the operative conditions of the equipment;

The evaluation of this barrier has been obtained as a weighted average of how frequently, in the last five years – with respect to the total number of interventions performed by category – the enterprise has been able to perform the intervention, without an external support, always with a Likert scale from 1 to 4.

6.4 Results and discussion

6.4.1 Whole sample

The analysis has been devoted to obtain the values of the perceived barriers for the whole investigated sample (Table 3): in this case the major barrier is represented by the Investment Costs for the energy-efficient technologies. This conclusion is perfectly in line with other studies [4,6-7,20-22], but was also expected. Indeed, the results reasonably reflect the status-quo of industries struck by the global financial crisis. As a consequence, enterprises have such a dramatic perception of their situation, often without even capital to pay off their suppliers, that seem to be paralyzed, and blame energy-efficient technologies to be too expensive.

Nevertheless, too high Investments Costs come along with other economic issues to be addressed: the presence of barriers as Hidden Costs and Technologies not Sufficiently Profitable expresses the two faces of the same coin, since they represent, on one side, higher costs than expected, on the other, not sufficient returns. Moreover, the Low Capital Availability can be found within the first positions, with an average score of 2.65 and 6th in the rank.

Rank	Range	Value	Perceived Barrier
1	>3	3.04	Investment costs
2	≅3	2.98	Information issues on energy contracts
3	≅3	2.90	Hidden costs
4	≅3	2.88	Intervention not sufficiently profitable
5	>2.5	2.73	Difficulty in gathering external skills
6	>2.5	2.65	Low capital availability
7	>2.5	2.63	Technologies not adequate
8	>2.5	2.58	Technologies not available
9	>2.5	2.56	Information not clear by technology providers
10	>2.5	2.52	Lack of Time
11	>2.5	2.52	Implementing the interventions
12	≅2.5	2.42	Lack of information on costs and benefits
13	>2	2.35	Intervention-related risks
14	>2	2.21	Identifying the opportunities
15	>2	2.17	Lack of interest in energy-efficiency interventions
16	>2	2.13	Other priorities
17	>2	2.08	Imperfect evaluation criteria
18	≅2	2.00	External risks
19	≅2	2.00	Trustworthiness of the information source
20	<2	1.88	Identifying the inefficiencies
21	<2	1.71	Inertia

Table 3Evaluation and ranking of the perceived barriers for the total investigated sample.

Moreover, with high values (close to 3), we can find that costs, although representing the major issue, are not alone. Indeed, it is possible to find the Information issues, represented by being in one of the first positions obtained by the barrier Information Issues on Energy Contracts (2^{nd} in the rank), but also with contributions due to the Information not Clear by Technologies providers (9^{th}), and the Lack of information on Costs and Benefits (12^{th}). Considering the literature, although the issues on energy contracts have not explicitly pointed out by previous empirical studies, information issues emerged as a primary barrier only in the findings of Rohdin and Thollander [4] and Trianni and Cagno [7].

Furthermore, just underneath the primary, we can find a group of barriers with a score greater or almost equal to 2.5, reflecting on one side the issues of technologies, perceived neither adequate nor available, on the other, but lower, the issues on competences (expressed by the barriers Difficulty in Gathering External Skills and Difficulty in Implementing the Interventions). We can interpret these findings as follows: SMEs perceive to be forced to adopt not customized solutions, but rather technologies usually specifically developed for larger customers, and find many difficulties in adopting external consultants able to support them in implementing the interventions.

Likewise, behind the group of barriers between 2 and 2.5, we have an interesting finding: the behavioural barriers are ranked (with the exception of lack of time) in the lowest positions (ranked below the 15th position), with scores close to or lower than 2. Indeed, the interviewed sample perceives itself as quite proactive with respect to energy efficiency.

For what concerns the effect of the barriers on the decision-making process, the analysis has revealed an almost equal importance of the three actions – Generation of Interest, Knowledge of the Opportunities and Investment Analysis and Intervention Implementation, with average scores respectively of 2.30, 2.48 and 2.67 –, with a slight greater importance of the third action. Therefore, the importance for the first decision-making action, i.e. Generation of Interest, represents an interesting result for policy-makers, since it might point out the need, beside a financial support of the energy-efficient technology, of adequate actions for increasing the interest of enterprises towards this topic.

In order to see a possible common trend between the perception of the barriers, we have performed a correlation analysis. The results of this analysis (Table 4) highlight that, with respect to the previous studies, the taxonomy adopted here gains a competitive edge. Indeed, reducing them to the lowest common denominator is proven by the usually very low correlation coefficients. As an example, the barrier Technologies not Adequate (Y1.1’) and Interventions not Sufficiently Profitable (Y3.6’), considering the most complete taxonomy provided by Sorrell et al. taken since now as reference [13], fall both into the Heterogeneity barrier. Instead, the two barriers present a very low correlation coefficient (only 0.08), showing that the perception of the barriers might be related to issues that are independent, and thus it could be wise to separate them. In few cases, the presence of fairly detectable correlations(with coefficients just a bit higher than 0.6) could be considered as proving the existence of possible dynamics within barriers, as suggested by Cagno et al. [15]. As an example, it is realistic to assume that enterprises that have and perceive few competences on identifying the inefficiencies, will present similar perceptions also for identifying the opportunities (r= 0.62) and implementing the interventions (0.61). Likewise, it is also interesting to note the correlation coefficient of this barriers with the barrier Lack of Time. In fact, it seems reasonable to assume that, people with scarce competence, would suffer much more from not having enough time to devote to the research of inefficiencies, opportunities, and to implement the interventions. As one interviewed said: “Well, I barely know what to do, and I do not even have time to do *these* things!”.

		Y1.1' TECHNOLOGIES NOT ADEQUATE	Y1.2' TECHNOLOGIES NOT AVAILABLE	Y2.1' LACK OF INFORMATION ON COSTS AND BENEFITS	Y2.2' INFORMATION NOT CLEAR BY TECHNOLOGY SUPPLIERS	Y2.3' TRUSTWORTHINESS OF THE INFORMATION SOURCE	Y2.4' INFORMATION ISSUES ON ENERGY CONTRACTS	Y3.1' LOW CAPITAL AVAILABILITY	Y3.2' INVESTMENT COSTS	Y3.3' HIDDEN COSTS	Y3.4' INTERVENTION-RELATED RISKS	Y3.5' EXTERNAL RISKS	Y3.6' INTERVENTION NOT SUFFICIENTLY PROFITABLE	Y4.1' LACK OF INTEREST IN ENERGY-EFFICIENCY INTERVENTIONS	Y4.2' OTHER PRIORITIES	Y4.3' INERTIA	Y4.4' IMPERFECT EVALUATION CRITERIA	Y5.4' LACK OF TIME	Y6.1' IDENTIFYING THE INEFFICIENCIES	Y6.2' IDENTIFYING THE OPPORTUNITIES	Y6.3' IMPLEMENTING THE INTERVENTIONS	Y6.4' DIFFICULTY IN GATHERING EXTERNAL COMPETENCES
Y1.1'	TECHNOLOGIES NOT ADEQUATE	-	0.02	0.00	0.02	-0.12	0.27	-0.17	-0.16	-0.07	0.11	-0.24	0.08	-0.04	0.15	0.16	-0.14	-0.05	-0.07	0.10	0.12	0.25
Y1.2'	TECHNOLOGIES NOT AVAILABLE		-	-0.20	-0.16	-0.02	-0.32	0.15	-0.10	-0.10	-0.02	0.34	0.13	0.01	0.17	0.00	-0.21	-0.06	-0.15	-0.19	-0.26	-0.23
Y2.1'	LACK OF INFORMATION ON COSTS AND			-	0.54	0.59	0.17	0.19	0.43	0.35	0.34	0.03	0.21	0.10	0.09	0.29	-0.25	0.39	0.27	0.58	0.49	0.48
Y2.2'	INFORMATION NOT CLEAR BY TECHNOLOGY				-	0.52	0.32	0.36	0.38	0.39	0.29	0.06	0.28	0.07	0.15	0.15	0.02	0.35	0.51	0.61	0.49	0.28
Y2.3'	TRUSTWORTHINESS OF THE INFORMATION					-	0.10	0.28	0.31	0.33	0.24	0.25	0.27	0.12	0.17	0.41	-0.10	0.39	0.34	0.56	0.47	0.56
Y2.4'	INFORMATION ISSUES ON ENERGY						-	-0.13	0.10	0.26	0.15	-0.34	0.22	0.01	0.03	-0.32	0.11	0.15	0.14	0.23	0.24	0.33
Y3.1'	LOW CAPITAL AVAILABILITY							-	0.58	0.12	0.00	0.36	0.15	-0.08	0.45	0.06	0.05	0.32	0.39	0.30	0.18	0.11
Y3.2'	INVESTMENT COSTS								-	0.19	0.19	0.18	0.06	-0.01	0.15	0.03	-0.04	0.30	0.49	0.36	0.37	0.23
Y3.3'	HIDDEN COSTS									-	0.36	0.08	0.19	0.23	0.06	0.10	-0.05	0.22	0.33	0.20	0.14	0.26
Y3.4'	INTERVENTION-RELATED RISKS										-	0.12	0.45	0.20	-0.08	0.24	-0.20	0.05	0.05	0.02	0.01	0.12
Y3.5'	EXTERNAL RISKS											-	-0.07	-0.06	0.25	0.13	0.05	-	-0.07	-0.06	-	-0.25
Y3.6'	INTERVENTION NOT SUFFICIENTLY												-	0.16	0.33	0.18	-0.33	0.30	0.23	0.14	0.16	0.01
Y4.1'	LACK OF INTEREST IN ENERGY-EFFICIENCY													-	0.19	0.25	-0.28	0.05	0.10	-0.05	-0.03	0.04
Y4.2'	OTHER PRIORITIES														-	0.16	-0.17	0.41	0.27	0.23	0.21	-0.01
Y4.3'	INERTIA															-	-0.12	0.04	0.08	0.03	0.10	0.25
Y4.4'	IMPERFECT EVALUATION CRITERIA																-	-0.07	0.09	-0.07	-0.03	0.00
Y5.4'	LACK OF TIME																	-	0.63	0.57	0.57	0.47
Y6.1'	IDENTIFYING THE INEFFICIENCIES																		-	0.62	0.61	0.36
Y6.2'	IDENTIFYING THE OPPORTUNITIES																			-	0.83	0.45
Y6.3'	IMPLEMENTING THE INTERVENTIONS																				-	0.42
Y6.4'	DIFFICULTY IN GATHERING EXTERNAL																					-

Table 4Correlation analysis for the perceived barriers in the total sample investigated.

Nonetheless, the analysis has been devoted also to investigate the values of the real barriers Table 5, pointing out possible differences, where available, with the perceived values.

Rank	Range	Value	Barrier
1	>3	3.29	Lack of Interest in Energy Efficiency Interventions
2	>3	3.13	Other Priorities
3	>2.5	2.57	Low Capital Availability
4	>2.5	2.54	Identifying the Inefficiencies
5	>2.5	2.52	Implementing the Interventions
6	>2	2.41	Imperfect Evaluation Criteria
7	>2	2.13	Inertia
8	<2	1.27	Identifying the Opportunities

Table 5Evaluation and ranking of the real barriers for the total sample investigated.

The picture, reported in Figure 1, is absolutely interesting: firstly, enterprises have an almost “perfect” picture of their difficulties in obtaining the capital for energy efficiency investments (average difference between perceived and real of 0.08) and of implementing the interventions (in this case, both perceived and real values are equal to 2.52). Nonetheless, they have serious problems of interest and priorities when considering energy efficiency interventions (average difference respectively of 1.12 and 1.00 more than the perceived value). Therefore, enterprises *think* to be interested and to consider properly (as a primary issue) energy efficiency, but not in reality. This is proven by the fact that resources and capital devoted for investments in energy efficiency are marginal with respect to other issues. In addition to that, higher values for the inertia and imperfect evaluation criteria barriers (average difference of 0.42 and 0.32) show that enterprises, although declare to be proactive and to adopt correct criteria to consider energy efficiency investments, they are reluctant to change, and to risk.

Another distorted perception can be found for the Identifying the Opportunities: barrier: from the results (average perceived value 0.94 greater than the real one), it seems that enterprises think that energy-efficient technologies should be something particularly “special”, therefore they have a perception of this barrier higher than the real value.

Moreover, the correlation analysis between the real barriers investigated did not show any significant link, with coefficients never greater than 0.35.

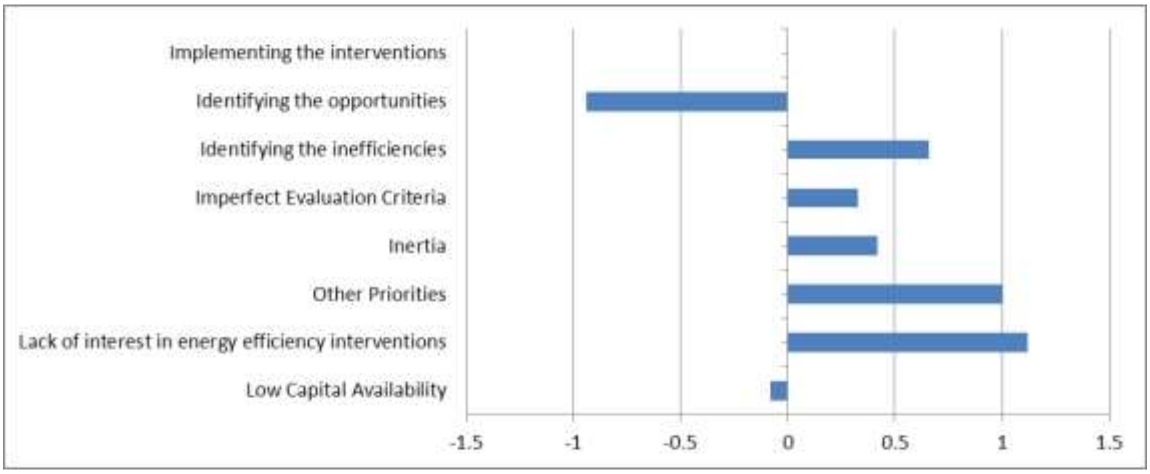

Figure 1Total sample – Evaluation of the difference between the perceived and real values of the investigated barriers.

In conclusion, we can say that, taking into consideration all the set of barriers investigated (interest, priorities, inertia, criteria, etc.), energy efficiency *effectively* results to be downgraded to a marginal aspect by the management of the firm. The findings seem to show a possible a possible path for reducing these barriers: in order to increase the priority of investments in energy-efficient technologies, it sounds apparent that more attention should be provided in clearly pointing out the benefits (direct and indirect) coming from the adoption of those technologies, as the approach followed by Worrell et al. [23].

In the following, we have tried to analyze the perceived and real value for clusters of data, putting in evidence possible commonalities and differences for the following factors:

- ✓ Firm's size;
- ✓ Energy expenditures;
- ✓ Complexity of the production;
- ✓ Variability of the demand;
- ✓ Strength of competitors.

If the first two are the most traditional factors to evaluate barriers to energy efficiency, due to their direct link with the energy use, we have performed a preliminary evaluation of the other three since are linked to factors related to the complexity of the context in which the enterprise operate [24]. In particular, the complexity of the production represents a view of the internal complexity, the variability of the demand the complexity with respect to the clients, and the third the complexity with respect to the clients.

In particular, due to the limited number of responses, it is not possible to perform a proper statistical analysis: nonetheless, we have pointed out the differences between the subsamples whether the average differ respectively at least of 20% (**) or 15% (*) from the average for the whole sample.

6.4.2 Firm's size

SMEs are usually bundled together, when it is likely not appropriate, as shown in previous research [7,25]. Therefore, starting from this consideration, in this study we adopt the classification within SMEs proposed by the European Commission [16], that combines the number of employees and the annual turnover (expressed in million €), creating a further class within medium-size enterprises, as follows:

- Small Enterprises (SEs), from 10 to 49 employees and an annual turnover up to 10 million €;
- Medium Enterprises (MEs), from 50 to 99 employees and an annual turnover up to 20 million €;
- Medium-Large enterprises (MLEs), from 100 to 250 employees and an annual turnover up to 50 million €.

In order to analyze the typical characteristics of smaller enterprises, following the results obtained by Trianni and Cagno [7] and Cagno and Micheli [25], we focus on SEs and MEs. Dividing as above the investigated sample is composed by 32 SEs ad 16 MEs. From an analysis of the perceived barriers (Table 6), we can appreciate several differences.

Perceived Barriers	Average	Questionnaire (32 SEs-16MEs)	
	Total	Δ= SEs-MEs	Significance[1]
Technologies not adequate	2.63	0.37	
Technologies not available	2.58	-0.34	
Lack of information on costs and benefits	2.42	-0.41	*
Information not clear by technology suppliers	2.56	-0.38	
Trustworthiness of the information source	2.00	-0.19	
Information issues on energy contracts	2.98	0.16	
Low capital availability	2.65	-0.16	
Investment costs	3.04	-0.13	
Hidden costs	2.90	-0.16	
Intervention-related risks	2.35	-0.03	
External risks	2.00	-0.19	
Intervention not sufficiently profitable	2.88	-0.47	*
Lack of interest in energy efficiency interventions	2.17	0.53	**
Other priorities	2.13	0.09	
Inertia	1.71	0.13	
Imperfect evaluation criteria	2.08	-0.16	
Lack of time	2.52	-0.25	
Identifying the inefficiencies	1.88	-0.19	
Identifying the opportunities	2.21	-0.16	
Implementing the interventions	2.52	-0.16	
Difficulty in gathering external competences	2.73	0.06	
Real Barriers	Average		
	Total	Δ= SEs-MEs	Significance[1]
Low capital availability	2.57	0.48	*
Lack of interest in energy efficiency interventions	3.29	0.31	
Other priorities	3.13	-0.03	
Inertia	2.13	-0.09	
Imperfect evaluation criteria	2.41	0.38	*
Identifying the inefficiencies	2.54	-0.13	
Identifying the opportunities	1.27	0.03	
Implementing the interventions	2.52	-0.53	**

Table 6Evaluation of perceived and real barriers by firm's size.

1 – The column reports the level of significance of the comparison.

**** - the average delta between the sub-samples (SEs vs MEs) is 20% greater than the average value for the response.**

*** - the average delta between the sub-samples (SEs vs MEs) is 15% greater than the average value for the response.**

Firstly, considering the barrier Lack of Interest in Energy Efficiency Interventions, the perceived value is obtained considering the maximum of two effects: on one side asking if the enterprise thinks that energy consumption cannot be reduced significantly since there are not areas with high inefficiencies; on the other side, the lack of interest asking if the energy costs are so marginal that it does not worth to invest in energy efficiency.

By looking with further detail to the differences in the responses for the two questions, the greatest difference between SEs and MEs occurs for the perception of having very low energy costs. Indeed, if MEs do not consider energy costs as marginal, SEs do it, whilst considering the perception of being already efficient, both of subsamples disagree. This result was partially expected since the enterprises voluntarily participated in the study on energy efficiency, thus showing a tendency of not perceiving themselves as already efficient. As a conclusion, the difference in the lack of interest between SEs and MEs is explained by a different perception of the importance of their energy costs.

Secondly, the barrier Intervention not Sufficiently Profitable, again, is obtained considering the maximum of two effects: on one side asking if the investment in energy-efficient technologies present too high PBT; on the other side, asking if they have too low returns. From a separate analysis of the two questions, firstly it is possible to see that in both questions the highest values occur for MEs. Moreover, the largest difference between SEs and MEs is for the too high PBT (score of 3.13 for MEs, 2.83 for SEs). In this case, it is reasonable to assume that MEs might have a wider portfolio of investments, therefore having access to investments with higher rate of returns, thus tending to downgrade investments in energy-efficient technologies.

Thirdly, considering the barrier Lack of Information on Costs and Benefits, MEs perceive this barrier more than SEs. In this case it is possible that SEs might have a close and direct contact with the information source. Therefore, also considering that the trustworthiness in SEs is perceived as a less important barrier than in MEs, SEs tend to trust to their information source, thus perceiving the available information as sufficient.

Moreover, although with an average difference not larger than 15% of the average value, it seems remarkable to note that SEs seem to have a greater perception than MEs for the barriers related to the technologies, either not available or not adequate, with a difference respectively of 0.37 and 0.34. This result looks reasonable, due to the very large variety of processes and technologies that are typical of SEs. Indeed, as emerged in one interviews, a respondent said: "*I know they have it, but it does not fully work for us*".

For what concerns the decision-making process, we cannot appreciate any particular difference, with exception of a small, still diffused, lower perception of the barriers for SEs with respect to MEs in all the three actions.

The analysis of correlations shows that a different behavior of SEs with respect to MEs can be observed: in particular, we have observed higher correlation coefficients between the information barriers and the barriers related to competences. This, also considering the results presented above, can be interpreted as follows: a very strong and direct contact with the information source, with a clearer form of the information about the technologies (in terms of costs and benefits, etc.), could release (at least, partially) the perception of barriers related to the competences, since it enables the information about energy-efficient technologies to be closer to the sensibility of entrepreneurs.

Instead, for what concerns MEs, we can see closer links between the information and the economic barriers, also with those related to risks (both intervention-related risks or external risks), thus showing that a perception of a not sufficient or unclear information could be connected to greater perceived uncertainties that might represent economic barriers to investments in energy-efficient technologies.

When considering the real barriers, the picture is surprisingly clear: firstly, SEs have, effectively, greater difficulties in affording the investments in energy-efficient technologies, as showed by the Low Capital Availability barrier (respectively of 2.73 for SEs, 2.24 for MEs). As emerged in previous studies [9], small business enterprises face strong difficulties in accessing to the credit system. This might be due also to the fact that banks, credit institutions, etc. do not have programmes specifically addressed for SEs. Therefore, when a SE requires capital for investing in energy-efficient technologies, greater difficulties for evaluating the investment (and the affordability by the firm) arise. This barrier clearly points out a problem of developing a credit system able to support enterprises when approaching investments in energy efficiency, thus financing effective available (also from an economical viewpoint) technologies.

Secondly, in SEs it is quite hard to have well-based systems for evaluating the investments. Therefore, the “rule of thumb” approach, pointed out by the Imperfect Evaluation Criteria, is more diffused (respectively of 2.53 for SEs, 2.16 for MEs). In this respect, it seems interesting to clearly show the performance of energy-efficient technologies, putting in evidence not only investment costs, but rather the duration and the life-cycle costs of the technologies.

Thirdly, MEs suffer from the implementation of the interventions more than SEs (respectively of 2.34 for SEs, 2.88 for MEs). This might be due to the fact that SEs are simpler and leaner, therefore in MEs the impact of the intervention on the existing functions is greater, in terms of time (and costs) of the production disruption, organizing the operations, etc.

6.4.3 Effects of other important factors on the results

6.4.3.1 Energy expenditures

We have performed a separate analysis for the factor “energy expenditures”, since, it is widely assumed as an important factor that should drive the attention of enterprises towards energy efficiency. Indeed, creating two classes (annual energy expenditures below or greater than 500 thousands € per year), we can appreciate, as reported in Table 7, that enterprises with higher energy costs generally have a higher perception of the barriers than those with low energy costs. In particular, the difference between the two samples is 15% of the average in the cases of barriers Technologies not Available, Information not clear by Technology Suppliers, and Intervention-related Risks.

Moreover, although not as evident as for the barriers listed above, large differences exist for the barriers Interventions not sufficiently profitable and Difficulty in Implementing the Interventions.

Nonetheless, taking a look to the values of the real barriers, an interesting trend emerged: with slight exceptions, the factor “energy expenditures” has an impact similar to the firm’s size. This, although expected – the greater the size, the greater the energy expenditures –, nonetheless points out the distorting effect played by the “energy expenditures” factor on the perceived barriers. Indeed, the role of high energy expenditures can be seen here as a multiplier of the perception of the barrier, adding worries that, in reality, do not seem to exist.

The conclusions have been confirmed by the correlation analysis of the perceived barriers in the two sub-samples: the results are quite in line with the analysis by firm’s size.

Perceived Barriers	*Average*	*Questionnaire (39 <500,000 €/year – 9 >500,000 €/year)*	
	Total	*Δ= Low-High*	*Significance*[1]
Technologies not adequate	2.63	0.08	
Technologies not available	2.58	-0.53	**
Lack of information on costs and benefits	2.42	-0.31	
Information not clear by technology suppliers	2.56	-0.54	**
Trustworthiness of the information source	2.00	-0.27	
Information issues on energy contracts	2.98	-0.16	
Low capital availability	2.65	0.11	
Investment costs	3.04	0.19	
Hidden costs	2.90	-0.26	
Intervention-related risks	2.35	-0.38	
External risks	2.00	-0.14	
Intervention not sufficiently profitable	2.88	-0.43	*
Lack of interest in energy efficiency interventions	2.17	-0.21	
Other priorities	2.13	-0.12	
Inertia	1.71	-0.22	
Imperfect evaluation criteria	2.08	-0.03	
Lack of time	2.52	0.23	
Identifying the inefficiencies	1.88	-0.02	
Identifying the opportunities	2.21	0.12	
Implementing the interventions	2.52	0.37	
Difficulty in gathering external competences	2.73	-0.06	
Real Barriers	*Average*		
	Total	*Δ= Low-High*	*Significance*[1]
Low capital availability	2.57	0.13	
Lack of interest in energy efficiency interventions	3.29	0.72	
Other priorities	3.13	0.02	
Inertia	2.13	-0.18	
Imperfect evaluation criteria	2.41	0.23	
Identifying the inefficiencies	2.54	0.26	
Identifying the opportunities	1.27	0.06	
Implementing the interventions	2.52	-0.59	**

Table 7Evaluation of perceived and real barriers by energy expenditures.

1 – The column reports the level of significance of the comparison.

**** - the average delta between the sub-samples (Low Energy Expenditures vs Higher Energy Expenditures) is 20% greater than the average value for the response.**

*** - the average delta between the sub-samples (Low Energy Expenditures vs Higher Energy Expenditures) is 15% greater than the average value for the response.**

6.4.3.2 Complexity of the production

We aimed at evaluating the possible effect of the complexity of the production on barriers to industrial energy efficiency. The factor has been obtained as a combination of variety of the production and production volumes, and two sub-sizes – low versus high and very high – have been created.

Considering the perceived barriers, as reported in Table 8, and taking as reference the previous analysis by firm's size, we can see that, in addition to the barriers already emerged, in general enterprises that consider their production as not complex tend to perceive the barriers as more critical compared with other enterprises. This is particularly evident for the barriers Technologies not Available and Other Priorities.

For the same reason, enterprises with low complexity present greater difficulties than those with very high complexity in the first stage of the decision-making process, i.e. the Generation of Interest for energy efficiency. In addition to that, the correlation analysis has shown that enterprises with low complexity present an interesting trend, tending to relate (through higher correlation coefficients) information barriers to barriers to competences. The results on this factor point out the possible existence of other factors able to relate the complexity of the production to the proactivity of enterprises with respect to energy issues.

When looking at the real barriers, indeed, enterprises that consider their production as not complex, suffer from the barriers of identifying inefficiencies and opportunities more than others. This might be due to the fact that, with a greater complexity of the production, greater attention should be given to the processes, therefore increasing the knowledge on the effective performance of the existing equipment, and on the possible solutions to reduce the consumptions.

Perceived Barriers	*Average*	*Questionnaire (24 Low – 24 High or very high)*	
	Total	*Δ= Low-High*	*Significance*[1]
Technologies not adequate	2.63	0.13	
Technologies not available	2.58	0.54	**
Lack of information on costs and benefits	2.42	0.17	
Information not clear by technology suppliers	2.56	0.38	
Trustworthiness of the information source	2.00	0.33	*
Information issues on energy contracts	2.98	-0.21	
Low capital availability	2.65	0.46	*
Investment costs	3.04	-	
Hidden costs	2.90	0.29	
Intervention-related risks	2.35	0.21	
External risks	2.00	0.17	
Intervention not sufficiently profitable	2.88	0.33	
Lack of interest in energy efficiency interventions	2.17	0.08	
Other priorities	2.13	0.50	**
Inertia	1.71	0.25	
Imperfect evaluation criteria	2.08	0.13	
Lack of time	2.52	0.54	
Identifying the inefficiencies	1.88	0.17	
Identifying the opportunities	2.21	0.38	
Implementing the interventions	2.52	0.33	
Difficulty in gathering external competences	2.73	-0.21	
Real Barriers	*Average*		
	Total	*Δ= Low-High*	*Significance*[1]
Low capital availability	2.57	0.18	
Lack of interest in energy efficiency interventions	3.29	-0.08	
Other priorities	3.13	0.10	
Inertia	2.13	-0.03	
Imperfect evaluation criteria	2.41	-0.23	
Identifying the inefficiencies	2.54	0.25	
Identifying the opportunities	1.27	0.29	*
Implementing the interventions	2.52	-0.13	

Table 8Evaluation of perceived and real barriers by Complexity of the production.

1 – The column reports the level of significance of the comparison.

**** - the average delta between the sub-samples (Low Complexity of the production vs High Complexity of the production) is 20% greater than the average value for the response.**

*** - the average delta between the sub-samples (Low Complexity of the production vs High Complexity of the production) is 15% greater than the average value for the response.**

6.4.3.3 Demand variability

In Table 9 we report the results of the analysis of the perceived and real barriers with respect to the demand variability of the enterprises, i.e. starting to evaluate the behavior on energy efficiency of enterprises used to change their production.

When looking the perceived barriers, we can observe that, with the exception of two cases, there are not quite relevant differences, even for the decision-making actions and the analysis of correlations. The perceived barriers with a deviation of more than 15% of the average value are Low Capital Availability and External Risks, that are greater for enterprises with low demand variability. The result seems to be realistic, since it is reasonable to assume that enterprises with higher demand are more used to face continuous changes, therefore having an attitude to look at the market and try to understand possible threats.

Nonetheless, even more interesting findings can be observed for the real barriers: in this case, enterprises with a low demand variability present almost everywhere greater barriers. This is particular evident in three cases, i.e. Lack of Interest in Energy Efficiency Interventions, Inertia, and Imperfect Evaluation Criteria. Taking into consideration that the sample is exclusively composed by SMEs, it seems interesting to note that those greater differences do not occur for economic barriers, rather for behavioural barriers. Within the limited representativeness of the investigated sample, it seems remarkable that the attention of policy-makers should be devoted to increase the interest towards energy efficiency, especially in very simple SMEs with low demand variability.

Perceived Barriers	*Average*	*Questionnaire (13 low – 35 high or very high)*	
	Total	*Δ= Low-High*	*Significance*[1]
Technologies not adequate	2.63	0.02	
Technologies not available	2.58	0.07	
Lack of information on costs and benefits	2.42	0.05	
Information not clear by technology suppliers	2.56	-0.05	
Trustworthiness of the information source	2.00	0.01	
Information issues on energy contracts	2.98	-0.11	
Low capital availability	2.65	0.52	*
Investment costs	3.04	0.17	
Hidden costs	2.90	0.01	
Intervention-related risks	2.35	-0.26	
External risks	2.00	0.37	*
Intervention not sufficiently profitable	2.88	-0.25	
Lack of interest in energy efficiency interventions	2.17	0.07	
Other priorities	2.13	0.20	
Inertia	1.71	-0.03	
Imperfect evaluation criteria	2.08	-0.03	
Lack of time	2.52	-0.09	
Identifying the inefficiencies	1.88	-0.13	
Identifying the opportunities	2.21	-0.10	
Implementing the interventions	2.52	-0.14	
Difficulty in gathering external competences	2.73	-0.03	
Real Barriers	*Average*		
	Total	*Δ= Low-High*	*Significance*[1]
Low capital availability	2.57	0.11	
Lack of interest in energy efficiency interventions	3.29	0.17	*
Other priorities	3.13	0.04	
Inertia	2.13	0.33	*
Imperfect evaluation criteria	2.41	0.38	*
Identifying the inefficiencies	2.54	-0.03	
Identifying the opportunities	1.27	0.04	*
Implementing the interventions	2.52	0.09	

Table 9Evaluation of perceived and real barriers by Demand variability.

1 – The column reports the level of significance of the comparison.

**** - the average delta between the sub-samples (Low Demand Variability vs High Demand Variability) is 20% greater than the average value for the response.**

*** - the average delta between the sub-samples (Low Demand Variability vs High Demand Variability) is 15% greater than the average value for the response.**

6.4.3.4 Strength of competitors

As reported in Table 10, we have analyzed the barriers in enterprises who have declared to work into a market with weak or strong competitors. The results on the perceived barriers do not show evident trends, with the exception of two barriers, i.e. Other Priorities and Imperfect Evaluation Criteria, and no clear evidences on the effect of barriers on the decision-making process can be appreciated.

In the first case, enterprises with high competitors have a higher perception of this barrier, reasonably worried of losing, due to the implementation of new technologies and consequent production disruption, their clients. In the second case, it is reasonable to assume that enterprises with low competitors could not be so familiar with proper or thorough investment analyses, therefore perceiving higher values of imperfect evaluation criteria.

By looking at the analysis of correlations, it seems worth mentioning the high coefficients (in some cases even greater than 0.7) between the barriers Lack of Information on Costs and Benefits, Information not Clear by Technology Suppliers, and Trustworthiness of the Information Source. This, coupled with the lower absolute values of the barriers (with respect to enterprises with strong competitors), means that enterprises with weak competitors hardly perceive the information issues as barriers.

For what concerns the real barriers, the analysis shows that the presence of strong competitors plays an important role. Therefore, enterprises working in a very competitive market present lower values of barriers like Imperfect Evaluation Criteria and Identifying the inefficiencies. This means that, thanks to the external pressures (competitors), some internal factors (within the firm) have moved the attention of enterprises towards energy-efficient technologies. Moreover, although not particularly evident, enterprises with strong competitors suffer more from the difficulties in implementing the interventions (although not “significant”), reasonably due to the fact that, with such a strong competition, they seem to fear a production disruption for implementing the energy-efficient technologies.

Perceived Barriers	*Average*	*Questionnaire (30 weak – 18 strong)*	
	Total	*Δ= Weak-Strong*	*Significance* [1]
Technologies not adequate	2.63	0.26	
Technologies not available	2.58	-0.03	
Lack of information on costs and benefits	2.42	-0.22	
Information not clear by technology suppliers	2.56	-0.34	
Trustworthiness of the information source	2.00	-0.09	
Information issues on energy contracts	2.98	0.14	
Low capital availability	2.65	-0.21	
Investment costs	3.04	-0.11	
Hidden costs	2.90	0.19	
Intervention-related risks	2.35	-0.14	
External risks	2.00	-0.27	
Intervention not sufficiently profitable	2.88	-0.29	
Lack of interest in energy efficiency interventions	2.17	0.18	
Other priorities	2.13	-0.42	*
Inertia	1.71	-0.11	
Imperfect evaluation criteria	2.08	0.40	*
Lack of time	2.52	-0.14	
Identifying the inefficiencies	1.88	-0.11	
Identifying the opportunities	2.21	-0.02	
Implementing the interventions	2.52	-0.14	
Difficulty in gathering external competences	2.73	0.19	
Real Barriers	*Average*		
	Total	*Δ= Weak-Strong*	*Significance* [1]
Low capital availability	2.57	-0.02	
Lack of interest in energy efficiency interventions	3.29	-0.04	
Other priorities	3.13	-0.13	
Inertia	2.13	-0.10	
Imperfect evaluation criteria	2.41	0.43	*
Identifying the inefficiencies	2.54	0.16	
Identifying the opportunities	1.27	0.26	**
Implementing the interventions	2.52	-0.23	

Table 10Evaluation of perceived and real barriers by Strength of competitors.

1 – The column reports the level of significance of the comparison.

**** - the average delta between the sub-samples (Low Strength of Competitors vs High Strength of Competitors) is 20% greater than the average value for the response.**

*** - the average delta between the sub-samples (Low Strength of Competitors vs High Strength of Competitors) is 15% greater than the average value for the response.**

6.5 Conclusions

The most recent inputs of the European Commission on the need to increase energy efficiency, renewed the interest towards the existence of the energy efficiency gap due to several barriers that inhibit the investments in technologies that are both energy efficient and (apparently) economically efficient. This is quite critical for SMEs, very few investigated by the literature, and for which quite often the adoption of even simple rules or devices for energy saving seems far from being reality.

Therefore, from both the perspectives of enterprises and policy-makers, the holistic approach (i.e. both theory and practice) to barriers to energy efficiency taken as reference in this study seems to be quite relevant. Nonetheless, the new taxonomy has been adapted accordingly to SMEs' characteristics, i.e. avoiding to consider the barriers related to the organizational and decisional structure. Indeed, in SMEs, those barriers tend to fade or assume less importance, since the organization of the firm is usually very simple and lean, and the decisions tend to be undertaken by one single decision-maker (usually, the entrepreneur him/herself).

With more detail, through the investigation of 48 manufacturing SMEs in the Lombardy region it has been possible to obtain a clearer picture of the perceived and real barrier to industrial energy efficiency, evaluating the importance of the perceived barriers on the decision-making process and their correlations. The analyses have been conducted according to different factors characterizing the investigated sample, as: firm's size, energy expenditures, complexity of the production, demand variability, and strength of the competitors. If the first two are the most traditional factors to evaluate barriers to energy efficiency, due to their direct link with the energy use, the study represents a first contribution in the literature, performing a preliminary evaluation of the other three factors, related to the complexity of the context in which the enterprise operate.

By considering the whole sample, the major perceived barriers that emerged in this study are represented by economic barriers (in terms of high Investment Costs, Hidden Costs and Intervention no -Sufficiently Profitable) and Information barriers (as Information Issues on Energy Contracts, Information not clear by Technology Suppliers and Lack of Information on Costs and Benefits). Moreover, it seems interesting to note that the behavioural barriers are ranked in the lowest positions, thus showing that the enterprises perceive themselves as pro-active with respect to the topic. For what concerns the analysis of the effects on the decision-making process, the result seems to show an almost equal importance of both the three actions – Generation of Interest, Knowledge of the Opportunities and Investment Analysis and Intervention Implementation, although with a greater value for the third action. This finding should be considered with particular attention by policy-makers, since they might reflect the need, for the enterprises, to increase the interest towards energy-efficient technologies.

The analysis of the real barriers allowed to draw an interesting picture: indeed, the enterprises have an almost perfect knowledge of their difficulties in obtaining the needed capital for financing the investments, but present much higher real barriers for the Lack of Interest and Other Priorities. Actually, they presume to be interested in energy efficiency, but they are not, downgrading energy efficiency to a marginal aspect of the operations. This result seems to be quite interesting for future research, since it points out the need to explore this misalignment between perceived and real barriers, in order to get a more detailed and precise picture of the barriers, that represents the basis for the promotion of future effective energy policies.

The differences between SEs and MEs in this study emerge for several perceived barriers, as the Lack of Interest for energy efficiency, Intervention not Sufficiently Profitable, and Lack of Information on Costs and Benefits. Considering the real barriers, SEs seem to suffer more than MEs from the Low Capital Availability and Imperfect Evaluation Criteria barriers, thus having greater difficulties in affording the investments in energy-efficient technologies and adopting more frequently rule of thumbs or routines to evaluate the investments. A greater difficulty suffered by MEs with respect to SEs is the implementation of the interventions, reasonably due to greater impact on the normal operations of the enterprises in terms of production disruption. Although with slight differences, the results are confirmed also in the analysis of the sample by classes of energy expenditures. In conclusion, as showed by the first contributions on this topic recently emerged in the literature, it seems necessary to avoid bundling together SEs, MEs and MLEs in a broad definition of SMEs for investigating energy efficiency, when it is likely not correct.

Interesting findings for the study come from the analysis of other factors, i.e. complexity of the production, demand variability and strength of competitors. Although with several differences for the perceived barriers and their effect on the decision-making process, the real barriers seems to be lower with high or very high complexity of the production, high variability of the demand and strong competitors. The trend represents a really interesting and challenging issue for future research, since it might imply the existence of other *distorting* factors (not only in terms of external pressures, but also within the firm) moving enterprises towards energy-efficient technologies.

Two interesting suggestions for future research can be drawn from this study: on one side, it seems interesting to extend the analysis of the barriers going deeper to study the behavior of enterprises with respect to several processes, i.e. combining energy efficiency and, e.g., innovation, entrepreneurship, etc.; on the other side, future research could investigate, as done by other research within large energy-intensive enterprises, direct and indirect benefits coming from the adoption of energy-efficient technologies within SMEs.

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7 Conclusions and further research

This dissertation aimed at investigating energy efficiency within SMEs by means of a comprehensive approach. SMEs are quite particular if compared to large enterprises, due not only to their variety of products, processes, technologies adopted, but also to their organization. Therefore, investigating energy efficiency among SMEs has needed particular attention to those specific characteristics. In the Introduction two main research objectives have been highlighted. In this chapter it is possible to provide an evaluation of each objective.

7.1 Research Objective no.1

RO1: to develop a methodology able to measure the operational energy efficiency level and analyze the energy efficiency Best Available Technologies and Practices (BAT/Ps) in manufacturing SMEs.

The need for a clear and punctual identification, characterization and evaluation of the BAT/Ps at the base for a methodology able to measure energy efficiency within SMEs has arisen from considering the characteristics of those enterprises.

In particular, SMEs do not own an internal structure able to be focused on energy consumptions. Rather, from the large number of energy assessments conducted, it is possible to confirm that in SMEs the entrepreneur is usually in charge of different activities, ranging from being responsible of the operations, of safety, administration, sales, marketing, planning, etc.. As a consequence, energy is just one of the issues, and the time devoted to energy efficiency activities is usually quite limited.

Moreover, compared to LEs, SMEs have a limited access to the know-how of energy efficiency management and practices, easily represented by much more limited economic resources devoted to energy efficiency analyses and measures.

In addition to that, from the empirical investigation it has been possible to confirm that usually pay-back-times (PBTs) of more than 2-3 years are considered as prohibitive for SMEs, while generally LEs can afford investments for even more than 8-10 years.

And, finally, SMEs, just for their structure – small and medium – do present a variety of situations (in terms of technologies and processes adopted) much more extended with respect to LEs.

As a consequence, SMEs prefer the technological transfer of Best Available Technologies/Practices (BAT/Ps) respect to full innovation measures, since BAT/Ps have been successfully (in terms of costs and benefits) implemented somewhere, thus with an accessible (also from an economic point-of-view) know-how. Furthermore, solely the implementation of BAT/Ps is able to guarantee the best level of energy efficiency effectively available in the market.

Considering these characteristics, the methodology proposed in this dissertation strongly relies on the identification and characterization of the BAT/Ps [1].

The identification of the BAT/Ps to be suggested to SMEs required a well-based statistical approach, thus a robust database of energy efficiency interventions able to guarantee the information provided. In this sense, a wide available database allowed on one side to characterize the BAT/Ps in terms of, e.g., area of intervention, energy savings by energy source, monetary savings, implementation costs, etc., on the other side to shape the parameters of the BAT/Ps on enterprises' characteristics (in terms of sector, firm's size, technology, etc.), in order to provide a more precise and reliable information.

Once the BAT/Ps have been characterized, it had been necessary to evaluate the effective implementation among enterprises. Thanks to a thorough analysis of the BAT/s, it was possible to identify, for each BAT/P, several levels of possible implementation. As a consequence, the development of checklists based on the identified BAT/Ps and their possible levels of implementation – with one checklist for each area of intervention –, allowed to determine what are the opportunities of energy saving in each area of the enterprise, thus quantifying the distance, from an energy efficiency perspective, of the enterprise from the best available solutions.

Once obtained a measure of the gap of the enterprise from energy efficiency, it was important to highlight the most relevant areas of consumption and intervention. Indeed, the distance on energy efficiency would not be important if the area, from the energy consumption viewpoint, would not be relevant. In this respect, the analysis of the BAT/Ps allowed to have a clearer picture of what might be the most critical areas of an enterprise (from the point of view of energy consumption, and, thus, for energy efficiency); moreover, thanks to the analysis of the energy flows within the enterprise, it has been possible to draw a map of the most interesting areas to be effectively investigated.

As a result of the combination of importance and opportunities for increasing energy efficiency, the developed methodology allowed to point out immediately the most profitable areas of intervention, providing not only the punctual identification of the opportunities of energy saving, but also a preliminary monetary estimation of savings and implementation costs.

The application of the methodology within several manufacturing SMEs has provided good results, since the outputs, although obtained with a walkthrough audit, are more similar to those coming from mini-audits.

Moreover, the effectiveness of the methodology can be observed from several perspectives. Firstly, the low time necessary to perform an energy audit, from gathering off-line data to the report publication, has been particularly appreciated both by enterprises and assessors, with an evident reduction of the disturbance on firm's activities. Secondly, related to the time, the costs for the audit seem to decrease: this represents a very important issue for SMEs, for which the costs of the energy audit, if compared to the needed investments, are not negligible.

Thirdly, the thorough analysis and strong reliance of proven BAT/Ps allowed to be reasonably confident that, with the proposed methodology, the best opportunities for energy savings within SMEs have been identified. With respect to this, having more detailed data to make projections and performing more punctual analysis seems the preferred means to evaluate how the information provided are precise.

Fourthly, basing the methodology on close checklists and on a stable theoretical approach, in which the BAT/Ps have been identified, classified and characterized from a large database of interventions, and the checklists generated on the base of the processes effectively in place in the enterprise, has allowed the results to be not heavily influenced or distorted by the expertise and skills of the assessor. This can be considered as a very important result, since it is able to guarantee the objectiveness of the results, whilst the current approaches strongly rely on the capabilities of the assessors.

Considering the enterprises in which the methodology has been tested, several of them have already implemented with success some of the proposed interventions (it is reasonable to expect to not have all of them implemented, since some interventions might not be coherent with other problems of the enterprises). Nonetheless, it is not possible here to draw any statistical conclusion, but the effective validation of the methodology, that represents a future issue to be addressed, will require a long time, and will be subject to several other variables (e.g. change in energy prices, change in the regulatory system, etc.).

Future research should be also devoted in comparing the proposed methodology with other available. Nonetheless, from what emerged from the energy assessments, and what said above, the Quick-E-Scan seems to be not heavily dependent on the expertise and skills of the auditors, whilst other walkthrough and mini- energy audit methodologies strongly rely on them, with results that would be hardly repeatable. As a consequence, the comparison would result quite difficult, requiring, as a precondition, the application of other methodologies by different assessors. The process has been preliminary followed with an existing energy audit methodology: nonetheless, a large sample in a large time should be needed for performing a reliable comparison.

In conclusion, the methodology developed seems to represent an effective means to promote the technological transfer of BAT/Ps to SMEs.

Nonetheless, the methodology could not be so effective without the identification and characterization of the BAT/Ps, to which I devoted a large part of my research activity [2].

In particular, thanks to several research projects, 217 energy audits within SMEs have been performed. The energy audits have been conducted by a group of energy efficiency experts – coming from different experience, i.e. some academics, some professionals – with an expertise of several years on the topic, able to cover all the energy efficiency issues both from an operational viewpoint – i.e. technological and organizational issues of production and ancillary systems, and even single technologies – , both from an administrative viewpoint, e.g. in terms of energy tariffs.

Thanks to the energy audits, it has been possible to create a database containing about 2,000 energy saving opportunities (ESOs). Each of them has been identified, described in terms of type of ESO (e.g. restoring, optimizing or innovating the equipment) and area of intervention, and characterized according to energy savings by energy source, monetary savings, implementation costs, and pay-back time of the intervention. Moreover, each ESO has been enriched by several information about the enterprise (type of activity according to the classification ISIC rev.4, firm’s size according to the European classification of SMEs, technologies addressed, processes addressed, etc.).

Even if the Italian database has seemed to be quite detailed, nonetheless due to its small size the issue of enlarging the data source, looking at the availability of other sources, arose.

Therefore, a comparison with a database of ESOs from the American industrial sector allowed to verify the statistical correspondence of the energy efficiency practices between United States and Italy, with respect to several criteria of analysis, such as diffusion, maximum savings achievable, and return of the investment. This result, beyond the preliminary purpose of the study, seems to represent the most interesting result, since, from an analysis of the ESOs for single factors, the characteristics and parameters of the ESOs seem to be quite similar. This result opens the research to a wider, more detailed and (statistical) significant analysis of the correspondence, within Western industrialized countries, of the energy efficiency practices. To do this, it seems important to perform two recommendations: on one side enlarging the factors considered and the detail of the analysis are needed; on the other side it should be taken into account that the variety and width of the sample might consistently affect the results.

When looking with higher detail to the specific ESOs emerged in the analyses for SMEs, it is possible to find several interventions that do not require innovation in the technologies: rather, in some cases, with almost null (direct) implementation costs and relevant savings, there are even “good practices” for managing the operations, thus proving the still existence of obstacles within SMEs to the adoption of the BAT/Ps. Moreover, a preliminary empirical analysis of the American database has showed that the highest energy saving suggested ESOs are not effectively those implemented. If, on one side, it is reasonable to hypothesize that there are some reasons for a lack of implementation of those ESOs, on the other it reasonably proves again the existence of barriers. As a consequence, a large part of the research has been devoted to the second research stream, aiming at studying in detail the barriers towards energy efficiency in SMEs.

7.2 Research Objective no.2

RO2: to develop a new taxonomy for the identification and evaluation of the barriers that limit the implementation of energy efficiency interventions in the industrial sector.

Considering the existing studies on barriers on energy efficiency, and in particular on taxonomies aiming at classifying them, through a detailed and thorough analysis of the literature, it has been possible to highlight three main issues that still needed to be addressed. Firstly, the existing taxonomies on barriers seemed to not encompass all the elements already pointed out in the literature. Secondly, in the taxonomies overlaps between the theoretical barriers can be found, causing an incorrect and misleading classification of the barriers. This is even more relevant for the effective capability of the existing taxonomies from an operational perspective – i.e., when empirically investigating the theoretical taxonomies – , obtaining, as a result, a disguised comprehension of the barriers. And, thirdly, the existence of implicit interactions between the barriers, that, without being fully and thoroughly analyzed, would not allow a correct comprehension of the mechanisms and dynamics of the barriers.

Moreover, very few studies had been explicitly devoted to investigate barriers to energy efficiency within SMEs.

Therefore, a preliminary investigation of the practical issues SMEs have to face when undertaking the process of investing resources in energy efficiency interventions has been performed [3], providing two main results.

Firstly, particular attention should be devoted when considering SMEs as homogeneous, when it is likely not correct. Indeed, for several barriers investigated, such as *lack of time*, *lack of internal skills*, *lack of personnel awareness*, and *difficulty in implementing* either *management* or *technical interventions*, it has been possible to observe different behaviors among sub-sizes. This is an important contribution to the literature, which, as now, has tended to consider those three different kinds of enterprises, with respect to the barriers to energy efficiency, as a whole.

In particular, it has been observed that MLEs suffer from the lack of time or lack of internal skills less than SMEs, due to a more structured organization, e.g. people usually in charge of activities for enhancing energy efficiency. Moreover, it can be argued that SEs and MEs have a more agile internal structure, that reduces the difficulties in implementing both management and technical energy efficiency interventions, and allows to more closely control the operations of the personnel, developing into it the awareness of the importance of an energy-efficient behavior. Likewise, but the study represents one of the first contributions in the field, it has been observed a significant difference in the sample according to the sector and previous experience of enterprises with respect to energy efficiency.

Secondly, thanks to an analysis of correlation of the barriers, it has been possible to appreciate not only the different results in terms of absolute values, but also different trends in the responses, implying the existence of different dynamics of the barriers. The latter seemed to represent an element particularly relevant for the research, since, thanks to a more detailed analysis of the effects, it could provide a clearer picture of how the decision-making process affects the viability of the investment.

The suggestions emerged from the preliminary investigation helped to refine how the issues emerged in the literature had to be addressed in a novel holistic (i.e. theory and practice) approach to barriers to energy efficiency [4].

Considering the first issue, i.e. that the existing taxonomies on barriers seemed to not encompass all the elements already pointed out in the literature, a novel approach has been proposed, that aims at encompassing all the relevant contributions in this topic.

In order to validate the completeness of the new approach, several preliminary case-studies and a larger investigation within SMEs have been conducted. Since all the barriers emerged in the case-studies and the large investigation have been referred to the elements of the taxonomy, it is possible to say, at least as preliminary result, that the objective has been achieved. Nonetheless, a future larger application of the taxonomy could provide the counter prove of the completeness of the new approach proposed.

The second issue arisen from the analysis of the literature is the presence of overlaps between the theoretical barriers, causing an incorrect and misleading classification of the barriers. This is even more relevant for the effective capability of the existing taxonomies from an operational perspective – i.e., when empirically investigating from enterprises' perspective the theoretical taxonomies – , obtaining, as a result, a disguised comprehension of the barriers. The new proposed taxonomy has tried to reduce the barriers to the minimum independent terms.

The validation of the second issue both through a preliminary test in few case studies and a larger investigation within SMEs brought positive results, with usually low correlations between the barriers. In this regard, I think that future research will be needed in validating the independence of the terms, but the objective seems to be achieved.

The third issue emerged in the literature is the existence of implicit interactions between the barriers, that, without being fully and thoroughly analyzed, would not allow a correct comprehension of the mechanisms and dynamics of the barriers. The problem, already simplified through the reduction of the overlaps, has led to the identification of some existing relationships between the barriers, i.e. causal relationship, composite effect and hidden effect.

To do this, the experience obtained through the preliminary investigation within enterprises allowed to formulate the need of a clear distinction between the real and perceived values of the barriers. Therefore, undertaking an investment in energy-efficient technologies might be completely affected by a distorted perception of the barriers.

Indeed, during the preliminary investigation, I have noticed that the enterprises took the decisions on investments based on the values of barriers they seemed to suffer from (perceived), but, by the fact, they suffered from other (real)barriers. As an example, although some enterprises blamed the lack of capital for not undertaking energy-efficient investments, it seemed apparent that, in general, they downgraded energy efficiency to a marginal aspect, they were not committed in reducing their energy consumption, and they did not even know how to do it.

Moreover, it seemed apparent that the enterprises did not had a clue about some important issues on energy efficiency, i.e. they could not report the real barriers affecting other actors involved in the energy efficiency market. Therefore, a taxonomy able to be effectively investigated and provide the viewpoint of enterprises could not avoid to perform a distinction between barriers originated outside or within the firm, and to understand the extent of the influence of a single barrier.

The validation of the taxonomy in the preliminary case-studies and the larger investigation within SMEs allowed to get confirmation of the existence of mechanisms and dynamics between the barriers. Nonetheless, future research in this field is needed, in order to counter prove the relationships hypothesized and get more evidences, since, e.g., the mechanisms of how a barrier has been originated could take a long time, with consequent appropriate timespan needed for observing the enterprise.

The suggestions coming from the preliminary investigation about the differences between perceived and real barriers have been confirmed by the study of the taxonomy adapted to be investigated within SMEs [5].

Indeed, by considering the whole sample the major perceived barriers are represented by economic barriers (in terms of high Investment Costs, Hidden Costs and Intervention no -Sufficiently Profitable) and Information barriers (as Information Issues on Energy Contracts, Information not clear by Technology Suppliers and Lack of

Information on Costs and Benefits). Moreover, the study allowed to appreciate that that the behavioural barriers are ranked in the lowest positions, thus showing that the enterprises perceive themselves as pro-active with respect to the topic.

Nonetheless, the analysis of the real barriers, where possible, allowed to draw an interesting picture: if on one side the enterprises had an almost perfect knowledge of their difficulties in obtaining the needed capital for financing the investments, they presented much higher real barriers for the Lack of Interest and Other Priorities. Actually, they presumed to be interested in energy efficiency, but they were not, downgrading energy efficiency to a marginal aspect of the operations.

Moreover, the need of avoiding bundling SMEs could be observed also here, both in terms of perceived and real barriers. Therefore, a future suggestion to policy-makers would be to look with attention to this difference when promoting future energy policies for overcoming the barriers to industrial energy efficiency.

Nonetheless, the empirical evidences on the new taxonomy are, at the moment, limited to the evaluation of the internal (with respect to the firm) and general (i.e. related to any investment) barriers to industrial energy efficiency within SMEs. Therefore, it is quite interesting to explore this misalignment between perceived and real barriers, in order to get a more detailed and precise picture of the barriers, since the full comprehension and analysis of the barriers represent a first step towards the development and deployment of effective policies to have a widespread adoption of the energy-efficient technologies and practices in the industry. Indeed, I would suggest to pursue the research in the following directions:

I. analyzing the barriers originated by other actors, i.e. technology providers and suppliers, energy suppliers, energy service contractors, etc.;
II. exploring the barriers that are intervention-dependent. To do that, a shift in the approach to the empirical investigation is also needed: it would be of fundamental importance to select one single intervention (or, a very limited category of interventions), trying to categorize it by the possible barriers, and evaluate them.

Another very interesting finding of the research comes from the preliminary analysis of several other factors related to the complexity of the enterprises, i.e. complexity of the production, demand variability and strength of competitors. In this respect, the presence of high or very high complexity of the production, high variability of the demand and strong competitors seems to have an effect of lowering the real barriers.

This result seems to be quite relevant for policy-makers, since it shows that there might be internal (with respect the firm) factors, and not just external forces or pressures, moving enterprises to overcome the barriers and thus adopting energy-efficient technologies, opening new research streams.

Firstly, further research should be performed to understand and evaluate the “specifically devoted” drivers to promote energy efficiency within the firm, thus bounding the benefits exclusively from an energy-saving perspective.

Secondly, it seems interesting and challenging to explore the possible connection between the processes of increasing energy efficiency and performing innovation, trying to grasp possible synergies between the two processes. In particular, the research could point out and evaluate the possible indirect benefits coming from the adoption of energy-efficient technologies, in terms of productivity, quality of products and processes, reliability and availability of the equipment and of the production system, etc., thus affecting the firm’s performance and competitiveness.

To do that, it is again of fundamental importance to select a limited set of the most effective energy-efficient technologies, trying to categorize them according to the possible indirect benefits and, through case studies and surveys, evaluate them.

In conclusion, it is apparent that a thorough comprehension and evaluation of the barriers on one side, and of the drivers on the other side, constitute, at the end, the two pillars for effective policies for a widespread adoption of energy-efficient technologies within SMEs.

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