Evaluating the barriers to specific industrial energy efficiency measures: an exploratory study in small and medium-sized enterprises

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1. Introduction

The European Council (2012) recently revised its policies to boost energy efficiency by 20%, within the so-called "20-20-20 strategy", because only 10% would have been achieved according to current trends. This revision clearly shows that the energy efficiency issue has not been properly addressed by recent European energy policies. Much of the research efforts have so far concentrated on large energy-intensive industries, particularly process-specific sectors. Among others, Worrell (1995) discussed the impact of advanced technologies and energy efficiency in the iron and steel industry in China. Zhang and Wang (2008) discussed the growth in productive efficiency in the iron and steel sector due to several energy saving measures (such as pulverised coal injection technology and continuous casting technology) and the increase in the technique updating and transformation investments. Yuanyuan et al. (2010) investigated energy conservation and emissions reduction strategies in the foundry industry, highlighting and discussing the differences between China and other countries. Research has also devoted much attention to the cement industry. For example, Hasanbeigi et al. (2013) analysed the opportunities for energy efficiency improvements and CO_2 emissions reductions in China, similarly to the study by Worrell et al. (2000) in the United States. Madlool et al. (2011) reviewed and presented the energy use and energy saving measures by different cement firms. By looking at the pulp and paper industry, Kilponen et al. (2000) explored the

Abbreviations: EEM, energy efficiency measure; ESCO, energy service company; GDP, gross domestic product; HCE, high level of production complexity enterprise; HIE, high-innovative enterprise; HVAC, heating, ventilation and air conditioning; IAC, Industrial Assessment Center; ISIC, International Standard Industrial Classification of All Economic Activities; LCE, low level of production complexity enterprise; LIE, low-innovative enterprise; ME, medium-sized enterprise; SE, small-sized enterprise; SME, small and medium-sized enterprise.

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energy efficiency opportunities in a Finnish case study, while Thollander and Ottosson (2008) and Del Rio González (2005) analysed the factors influencing the adoption of clean technologies in the Swedish and Spanish pulp and paper industries, respectively. Fleiter et al. (2012a) recently assessed 17 process technologies to improve energy efficiency in the German pulp and paper industry. Finally, Oda et al. (2012) compared energy-efficient technologies by using cross-sectorial international analyses (power, steel, and cement industries).

The findings of such studies suggest that the most effective energy efficiency measures (EEMs) in energy-intensive sectors are highly process-specific. Nonetheless, it is difficult to identify specific EEMs to be promoted in very heterogeneous sectors, and even more when dealing with non-energy intensive industries. Such sectors cannot be neglected, as cover about 40% of world's total industrial energy consumption (EIA, 2011). Similarly, it is hard to abundantly apply process-specific EEMs in case of small and medium-sized enterprises (SMEs), which are quite numerous and have a very wide range of activities and an enormous variety of processes. Within the industrial sector, according to a study by the European Commission (2008), when looking at SMEs, "the picture is surprisingly unfavourable: close to two thirds of SMEs operating in the EU do not even have simple rules or devices for energy saving (63%, compared with 29.8% for larger enterprises, LEs). Less than three out of 10 SMEs (29%) have instituted some measures to preserve energy and resources at their enterprise. Only 4% of EU SMEs have a comprehensive system in place for energy efficiency", in contrast with a share of 18.9% for LEs. The Italian picture is even worse, where 74% of SMEs do not adopt energy saving measures. More recent findings from the UK show that 53% of the 4.8 million SMEs in the country have no methods in place to manage energy efficiency and that nearly one out of five (18%) do not know whether they had reduced their energy consumption over the past 12 months (RWE npower, 2013). Nonetheless, SMEs are crucial in terms of industrial energy consumption: for example, in Italy SMEs account for about 25 billion toe[1]/year, which is about 60% of the national industrial energy consumption (ISTAT, 2004). In addition, as a recent European investigation reports, SMEs, which account for 99.8% of all enterprises and employ more than two-thirds of the workers in the non-financial business economy – covering 20.8 million and about 87 million occupied persons, respectively –, have generated about 85% of new job opportunities in the last decade, i.e. about 1.1 million annually (EIM Business & Policy Research, 2011). Further, they are strategic for the future of the European industrial sector as a whole, having produced 58.2% of the EU value-added (about 3500 billion euros).

Hence, for both non-process-specific enterprises and SMEs, focus should be given to cross-cutting technologies[2] as they are the most diffused and most standardised (Shipley and Elliott, 2006). Furthermore, they comprise a consistent share of energy consumption. Among others, electric motor-driven systems account for about 70% of world's industrial electricity consumption, with an even higher proportion in Italy (IEA, 2011; Confindustria, 2011). Industrial lighting is the most diffused and covers about 5% of world's electricity consumption (IEA, 2006). Compressed air might reach 10% of industrial electricity consumption in the EU (Radgen and Blaustein, 2001), while HVAC systems (i.e. heating, ventilation, and air conditioning) represent 10–20% of final energy consumption in some industrial contexts (Perez-Lombard et al., 2011). Despite such relevance in terms of energy consumption, recent research has shown that the implementation rate of EEMs is still low (Bunse et al., 2011), often not exceeding 50% of the recommended actions (Anderson and Newell, 2004; Cagno and Trianni, 2012). Two main reasons seem to hinder higher adoption rates of EEMs: on the one side, generic energy policies do not account for the real EEM specificity to be fostered and the related barriers to be overcome. On the other side, we should acknowledge that an industrial manager must evaluate the investment in a focused EEM requiring a safe approach to the specific problems, as the investment necessarily influences not only energy issues, but also the whole firm operations and thus performance. Therefore, the distinction between which barriers hinder in general the adoption of EEMs from which specific barriers hinder a specific EEM should be made clear. An incomplete understanding of which specific barriers affect a particular EEM could prevent us from comprehending and distinguishing the "low-hanging fruit" in order to explain why enterprises do not actually implement the given measure (Shipley and Elliott, 2006). Additionally, policymakers could leverage on this enhanced understanding to support industrial managers in undertaking investment decisions more smoothly and consciously through, e.g. specific training, information, or subsidies, thus converting the "non-low-hanging fruit" into "low-hanging fruit".

Therefore, the analysis of the barriers hindering the adoption of EEMs should be deepened, so to provide the most useful suggestions for the development of the most appropriate energy efficiency policies and effective industrial practices. Specifically, we aim at gaining an understanding of how the values of different intervention-dependent barriers differ according to specific EEMs, especially with respect to their perceived average value at the company level or by technology area. To do so, we have performed an exploratory study among manufacturing SMEs analysing barriers to energy efficiency with respect to selected EEMs within particular cross-cutting technologies. From now on, the barriers should be understood as referring only to energy efficiency.

2. Barriers to industrial energy efficiency

Efficiency improvements such as the adoption of EEMs represent a key driver for increasing corporate sustainability (DeSimone and Popoff, 2000; Lozano, 2013), as they represent productivity improvements influencing both economic and ecological goals (Baumgartner and Zielowski, 2007). In order to make real progress in corporate sustainability as a whole, a holistic perspective should be encompassed (Linnenluecke et al., 2009). Hence, the study of barriers to EEM adoption may also be built upon studies of resistance to change in industrial corporate sustainability.

The literature has "recognized myriad barriers to change that affect different organizational levels" (Lozano, 2013; for a compendium of the barriers to change for corporate sustainability, please refer to Lozano, 2009). Some of these barriers are external, such as the lack of interest by consumers or investors (CEC, 2002) or lack of knowledge about the impacts on and from suppliers and customers (Rosner, 1995; DeSimone and Popoff, 2000). As Lozano (2013) pointed out, "companies have limited ability to overcome external barriers to change". Others are essentially within the organisation. In particular, internal barriers to change for corporate sustainability can be grouped according to several axes (Lozano, 2012, 2013). Barriers may affect individuals, groups, or even the whole organisation, present a different nature within the organisation (managerial, organisational, supportive, or historical), and reflect a different attitude (informational, emotional, systemic, behavioural).

[1] Ton of oil equivalent (toe) is defined as the equivalent amount of energy released by burning one tonne of crude oil. According to the International Energy Agency (IEA), a toe is defined as 41,868 MJ (IEA, 2010).

[2] Cross-cutting technologies are technologies not specific or related to a particular production and they are used by several different production systems within an industrial plant.

When considering studies on barriers to energy efficiency, we can find a substantial agreement both on the detailed barriers as well as in their categorisation. In addition to economic issues, EEM adoption is hampered by behavioural as well as organisational issues (Sorrell et al., 2004). For instance, some barriers such as the unwillingness to change affecting individuals – e.g. when "future disadvantages are accepted in favour of small, often irrational, present advantage" (Rosner, 1995) –, could be easily referred to energy efficiency (Sorrell et al., 2004). Organisational barriers to energy efficiency have been widely explored in the literature (DeCanio, 1993, 1998). Analogously, a key factor to improve sustainability is "understanding how the company's culture affects corporate responsibility performance" (Lyon, 2004), but the lack of an energy efficiency culture within companies is recognised and discussed as a relevant barrier to investments in energy efficiency (Sorrell et al., 2004). In addition, several authors have highlighted the relevance of information-related issues to the adoption of EEMs (e.g. Rohdin and Thollander, 2006).

In a recent work, Cagno et al. (2013) collected relevant contributions from an all-encompassing review of early works and presented a taxonomy for barriers to industrial energy efficiency. In particular, their taxonomy distinguishes between barriers based on their spectrum of influence – from general to specific EEMs – resulting in key points for the empirical investigation (Table 1). This spectrum of influence can highlight how general or specific the effect of the barrier is regarding firm decisions. Firstly, general barriers are not specifically related to energy efficiency, but consume the necessary resources for any investment. Secondly, barriers to energy efficiency (i.e. general/intervention-dependent barriers) represent a hurdle for any investment in EEMs; thus, they can be investigated regardless of the specific EEMs to be considered. Finally, intervention-dependent barriers to energy efficiency should be investigated by considering specific EEMs. Hence, from a theoretical viewpoint, barriers affecting the adoption of EEMs represent a resistance to change in terms of corporate sustainability when applied to energy efficiency.

As summarised in Table 2, several authors have empirically dealt with barriers to industrial energy efficiency, adopting qualitative as well as quantitative approaches. Several broad studies have been conducted at the national level, such as Harris et al. (2000) for Australia, DeGroot et al. (2001) for the Netherlands, Schleich (2009) and Schleich and Gruber (2008) for Germany, Anderson and Newell (2004) for North America, Sardianou (2008) for Greece, and Apeaning and Thollander (2013) for a district in Ghana. The literature has also attempted to provide different perspectives according to firm size. In terms of larger enterprises, Cooremans (2012) examined electricity-intensive commercial and industrial sectors, Rohdin and Thollander (2006) analysed Swedish manufacturing enterprises, and Sorrell et al. (2000) compared the mechanical and brewing sectors in the UK, Ireland, and Germany. More recently, however, research has paid attention to smaller enterprises. Fleiter et al. (2012b) dealt with German SMEs that had participated in an audit programme, similar to the approach taken by Trianni et al. (2013a) for Italian ones. Kostka et al. (2013) and Muthulingam et al. (2011) analysed financial, information, and organisational barriers in Chinese and US SMEs, respectively. This attention on smaller companies can also be observed beyond the manufacturing sector, as shown by Schleich's (2004) work on industrial and commercial enterprises. Additionally, empirical studies have addressed barriers to energy efficiency in energy-intensive enterprises. Nagesha and Balachandra (2006) have focused on Indian foundry and brick and tile small clusters, while Rohdin et al. (2007) and Thollander and Ottosson (2008) considered the foundry and pulp and paper industries in Sweden, and Trianni et al. (2013b) investigated European foundries, respectively. Furthermore, research has also provided empirical evidence on barriers to energy efficiency in non-energy-intensive enterprises, with contributions from Irish (O'Malley and Scott, 2004), Italian (Trianni and Cagno, 2012), and UK companies (Walsh and Thornley, 2012). The literature is also now beginning to empirically explore the effects on barriers to energy efficiency of several firm characteristics, such as production complexity and the degree of firm innovativeness (Trianni et al., 2013b,c). Nonetheless, few empirical studies have so far investigated barriers to specific EEMs. In fact, only Reddy and Shrestha (1998) have attempted to study selected barriers to the adoption of electricity EEMs in Indian enterprises.

This literature review suggests that little empirical evidence has been provided towards understanding how the values of intervention-dependent barriers differ according to specific EEMs. This research gap allows us to formulate our research idea (as shown in Fig. 1): the perception of an intervention-dependent barrier may vary according to the level at which it is investigated (i.e. at company, by technology area, or at single EEM level). Therefore, intervention-dependent barriers to energy efficiency need to be investigated at the EEM level, in order to avoid providing misleading information with consequent distorted policies. Starting from a general understanding of which barriers most affect the investigated SMEs, our exploratory research aimed at deepening

Table 1
Synthesis of the taxonomy adopted for empirical investigation.

Category	Barriers	Origin I = internal E = external	Spectrum of influence G = general D = intervention-dependent
Technology-related	Technologies not adequate	E	D
	Technologies not available	E	D
Information-related	Lack of information on costs and benefits	E	D
	Information not clear by technology providers	E	D
	Trustworthiness of the information source	E	D
	Information issues on energy contracts	E	D
Economic	Low capital availability	I	G
	Investment costs	E	D
	External risks	E	G
	Intervention not sufficiently profitable	I/E	D
	Intervention-related risks	I/E	D
	Hidden costs	I/E	D
Behavioural	Other priorities	I	G
	Lack of sharing the objectives	I	G
	Lack of interest in energy-efficiency interventions	I	G
	Imperfect evaluation criteria	I	G
	Inertia	I	G
Organisational	Lack of time	I	G
	Divergent interests	I	G
	Lack of internal control	I	G
	Complex decision chain	I	G
	Low status of energy efficiency	I	G
Competence-related	Implementing the interventions	I	G/D
	Identifying the inefficiencies	I	G/D
	Identifying the opportunities	I	G/D
	Difficulty in gathering external skills	E	G/D
Awareness	Lack of awareness	I	G/D

Source: Cagno et al. (2013).

Table 2
Literature review of recent empirical studies focused on barriers to industrial energy efficiency.

Authors and year	Publication	Sector	Main barriers and findings
Reddy and Shrestha, 1998	International Journal of Energy Research	All sectors	Lack of awareness and high initial costs
Sorrell et al., 2000	Project Report	Industrial sector	Other priorities for capital investments, lack of time and technology not appropriate
Harris et al., 2000	Energy Policy	All sectors	Lack of capital and lack of time
DeGroot et al., 2001	Energy Economics	Selected industrial sectors	Other priorities for capital investments
Ostertag, 2003	Book	Electric motor market	Split incentives, lack of information, hidden costs
O'Malley and Scott, 2004	Book	Mechanical engineering industry	Other priorities for capital investments
Anderson and Newell, 2004	Resource and Energy Economics	Manufacturing industry	High investment costs
Rohdin and Thollander, 2006	Energy	Non-energy intensive manufacturing	Hidden costs, lack of time and other priorities for capital investments
Nagesha and Balachandra, 2006	Energy	Foundries, bricks and tiles industries	Economic, financial and behavioural barriers
Rohdin et al., 2007	Energy Policy	Foundry industry	Access to capital, technology-related risks
Sardianou, 2008	Journal of Cleaner Production	Industrial sector	Other priorities for capital investments, lack of knowledge of adequate energy-efficient technologies
Thollander and Ottosson, 2008	Energy Efficiency	Pulp and paper industry	Hidden costs, technologies not adequate, lack of time, other priorities.
Schleich and Gruber, 2008	Energy Economics	Commerce – services	Split incentives, lack of information about energy consumption patterns.
Schleich, 2009	Ecological Economics	Commerce – services	Lack of information about energy consumption patterns, lack of time, low status of energy efficiency
Muthulingam et al., 2011	Report	Manufacturing industries	High investment costs
Cooremans, 2012	Energy Efficiency	Electricity-intensive commercial and industrial sectors	Lack of interest in energy-efficiency interventions, other priorities for capital investments
Fleiter et al., 2012b	Energy Policy	Small industry	High investment costs, lack of capital
Trianni and Cagno, 2012	Energy	Non-energy intensive manufacturing	Access to capital, lack of information, unclear information, trustworthiness of the information source
Walsh and Thornley, 2012	Journal of Cleaner Production	Non-energy intensive process industry	High investment costs, hidden costs, technology-related risks
Apeaning and Thollander, 2013	Journal of Cleaner Production	Industrial sector	Lack of budget funding and access to capital
Kostka et al., 2013	Journal of Cleaner Production	Small industry	Information-related barriers
Trianni et al., 2013a	Energy	Manufacturing industry	Lack of interest in energy efficiency and other priorities
Trianni et al., 2013b	Journal of Cleaner Production	Foundry industry	Lack of capital, lack of time, other priorities for capital investments

the knowledge on how intervention-dependent barriers vary with respect to selected EEMs in cross-cutting technologies. In doing so, we have also examined the role of firm characteristics such as firm size, production complexity, and firm innovativeness in modifying the perception of these barriers. The research results could help to shape the most suitable energy efficiency policies and industrial practices for the adoption of specific EEMs.

3. Research methods

The research has been conducted by drawing the following steps: firstly, a selection of characteristic EEMs has been performed. Secondly, the cases have been selected according to several criteria. Finally, data were collected and analysed.

3.1. Selection of EEMs for cross-cutting technologies

We focused on selected EEMs for lighting, electric motors, compressed air, and HVAC systems, based on their aforementioned relevance. Starting from the substantial consistency shown by previous research in the number of suggestions, implementation rate, implementation costs and expected energy savings of EEMs within North American and Italian enterprises (Cagno and Trianni, 2012), the selection process was undertaken by analysing the Industrial Assessment Center database (2013), which maintains an extensive dataset on over 16,000 energy efficiency assessments for North American enterprises, with more than 120,000 recommended EEMs since 1981. Firstly, a subset of data from 2000 onwards of metalworking SMEs was extracted (see Section 3.2). Secondly, we took into account the first three highly recommended measures presenting the lowest implementation rates, as it could be reasonably expected that the lower the ratio, the larger the barriers hindering their adoption (Table 3).

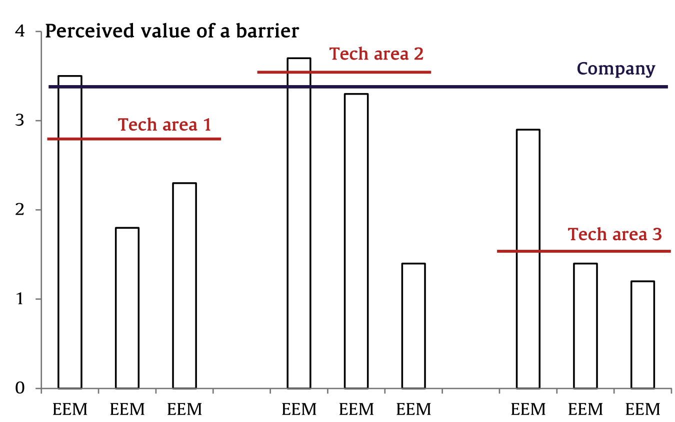

Fig. 1. Values of the same barrier are perceived differently at different levels (company, technology area, EEM).

Table 3
Selected EEMs and their attributes according to the characterisation.

ID	Description	Cross-cutting technology	Implementation costs	Payback time	Activity type	Ease of implementation
L1	Use more efficient light source	L	M	M	Ret	Not
L2	Reduce illumination to minimum necessary levels	L	L	S	Opt	Easy
L3	Install occupancy sensors	L	M	M	N	Easy
C1	Eliminate leaks in inert gas and compressed air lines/valves	C	L	S	Pro	Easy
C2	Install compressor air intakes in coolest locations	C	L	M	N	Dep
C3	Reduce the pressure of compressed air to the minimum required	C	L	S	Opt	Easy
M1	Use most efficient type of electric motors	M	M	M	Ret	Easy
M2	Utilise energy-efficient belts	M	M	S	Ret	Dep
M3	Use variable speed drives	M	M	M	Ret	Easy
H1	Install timers and/or thermostats	H	L	S	N	Dep
H2	Reduce space conditioning during non-working hours	H	L	S	Opt	Easy
H3	Use radiant heater for spot heating	H	L	M	N	Easy

Cross cutting technologies: *L* = lighting; *C* = compressed air; *M* = motors; *H* = HVAC.
Implementation costs: *L* = low; *M* = moderate; *H* = high; *N* = information not available.
Payback time: *S* = short; *M* = moderate; *L* = long; *N* = information not available.
Activity type: *N* = new installation; *Opt* = optimisation; *Ret* = retrofit; *Pro* = procedure.
Ease of implementation: *Easy* = easy to implement; *Not* = not easy to implement; *Dep* = depend on contextual conditions.
Source: Trianni et al., 2014.

3.2. Case selection procedure

Proper case selection aims at achieving replication and support the generalisability of our results, as recommended for multiple case empirical research (Yin, 2009). Given that this exploratory research has focused on barriers to energy efficiency in manufacturing SMEs in Italy, enterprises meeting these three requirements were chosen for the research. Additionally, we considered the relevance of the metalworking sector, which is economically strategic in the Lombardy region. Metalworking in Lombardy represents the major manufacturing sector in terms of employees (over one third, being more than 400,000 employees), accounting in 2008 also for 4.17% of all European metalworking employees, as shown in Fig. 3 (Eurostat, 2010). It also represents over 25% of Lombardy's SMEs (ISTAT, 2011). The metalworking sector "accounts for 10% of the value added, almost 20% of all enterprises and 12% of the employment in the EU manufacturing sector (406,000 enterprises and 4.24 million employees, respectively). Consequently, the sector is the largest employer in EU manufacturing" (EU, 2009). The investigation took place in a region that produces more than 20% of the national gross domestic product (GDP), with a figure per capita 33% higher than that of the EU27 in 2010 (Eurostat, 2013), as shown in Fig. 2. The preliminary list of potentially suitable case studies has been created from company databases available to the researchers from ISTAT (Italian National Institute of Statistics) as well as other market research institutes (e.g. AIDA, a database of Italian enterprises). The final selection was made by contacting the companies through e-mail and/or telephone to verify their suitability and to check their availability. Once their availability had been confirmed, a face-to-face meeting with the interviewers was arranged. Fifteen cases were selected. Given that the present study builds on a framework previously developed (Cagno et al., 2013) and given that the research is judged on it theoretical generalisability rather than its statistical generalisability (Eisenhardt and Graebner, 2007) the sample size was judged to be sufficient. Particular attention was devoted to analyse enterprises of different sizes, although all of them were SMEs.

3.3. Data collection

To establish equivalent operational measures and procedures for the fieldwork (Yin, 2009), data were collected through face-to-face semi-structured interviews with a senior representative from each company. Such a methodological approach is common in operations management research when investigating questions of "what, how, and why" in order to fully understand the complexity of an object of analysis (Voss et al., 2002). Details on each interviewee's role in his/her company were collected. In all cases, the selected interviewees were knowledgeable and responsible for energy issues and related investments at their sites, and therefore they were able to provide detailed information about the adoption of the selected EEMs in their companies and related barriers. Furthermore, their positions within the company and deep knowledge of products and production processes allowed them to evaluate their enterprise in terms of business characteristics (compared with existing competitors) as well as production complexity. The interviewees were identified before the interviews based on some preliminary contacts.

Interviews consisted of six main parts, which were audio-recorded and transcribed for analysis, with a questionnaire used as a guide. The questionnaire was developed in order to standardise the sequence in which the questions were asked and minimise the impact of contextual effects, as suggested by Patton (1990). The introductory part of the interview included questions on general company features (e.g. sector and sub-sector, number of employees,

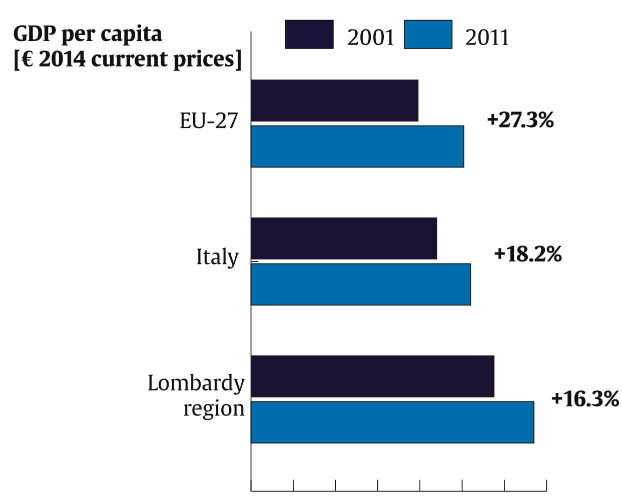

Fig. 2. GDP per capita in € 2014 current prices. A comparison between the average values for EU-27, Italy and Lombardy region. Years: 2001–2011.

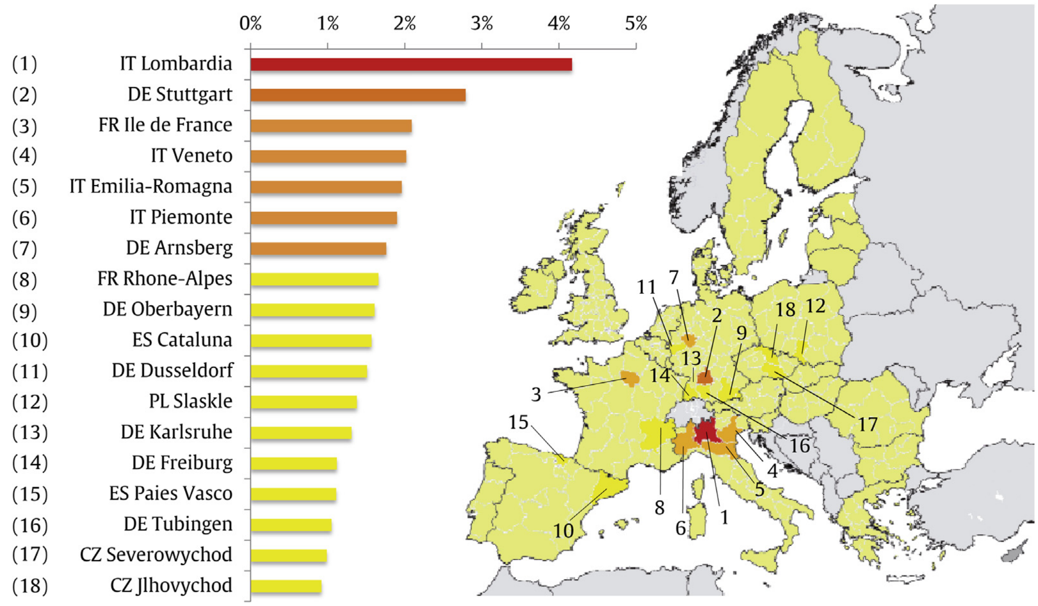

Fig. 3. Share of total employees in the European metalworking industries by most relevant regions.
Source. Elaboration from Eurostat (2010).

net annual turnover, annual energy expenditures). The interview then dealt with information on production characteristics, including the level of production complexity, production volumes, and a brief description of the production processes. Interviewees were then asked about the innovativeness of the enterprise. In the fourth part of the interview, interviewees dealt with general barriers to any investment and to investments in energy efficiency. The fifth part has deeply enquired into the barriers to the adoption of the selected EEMs. In the last part, respondents provided further details on their responses. This phase was crucial as it provided additional comments on the main motivations and barriers to the adoption of EEMs. Secondary data, such as from company website, were also collected and a case study database created, with detailed reports drafted to aid analysis (Voss et al., 2002; Eisenhardt and Graebner, 2007). This step allowed us to achieve data triangulation (Yin, 2009).

3.4. Data analysis

The large amount of qualitative and quantitative information gathered was categorised, based upon the interviewer's experience, on an even Likert-type scale from 1 (minimum value) to 4 (maximum value) in order to minimise social desirability bias (Garland, 1991). The choice of an even-numbered Likert-type scale forces to take position, thus avoiding a neutral one by placing in the middle. Additionally, for the relevant parameters for the research (i.e. production complexity and innovativeness) an average indicator was created. Furthermore, considering the exploratory nature of the investigation, a parameter with a score higher than 2.5 was evaluated as “high”. Finally, cross-case analysis was conducted (Miles and Huberman, 1994) and clusters of companies formed to identify patterns.

Fig. 4 reports how the clusters were populated with respect to size, production complexity and innovativeness. Firm size was evaluated, according to the EU definition of SMEs (European Council, 2003), by gathering data on annual employees and annual turnover. These clusters were populated of seven small (SEs) and eight medium-sized (MEs) enterprises. Besides, the production complexity was estimated through an indicator averaging the responses to contingent factors, taking inspiration from the framework proposed by Bozarth et al. (2009) and the suggestions of previous research (Trianni et al., 2013a): (i) production mix heterogeneity; (ii) production volume; and (iii) type of production process. Our sample was divided into two clusters: a high level (HCEs, five enterprises) and low level (LCEs, ten enterprises) of production complexity. Finally, an innovativeness index was calculated as the average score of six factors: (i) market competition intensity; (ii) market share controlled by large competitors; (iii) technological innovation required by the market; (iv) owner-managers' experience outside the firm; (v) degree of micromanagement; and (vi) innovativeness perceived by channel partners, following Trianni et al. (2013c). Thus, two clusters composed of nine low-innovative enterprises (LIEs) and six high-innovative enterprises (HIEs) were obtained.

Considering the exploratory nature of the study and limited sample size, once collected and evaluated, the responses about the barriers to the adoption of EEMs were put on average, as a first approximation. This operation has been performed both for the whole sample and for each cluster. Although the small number of

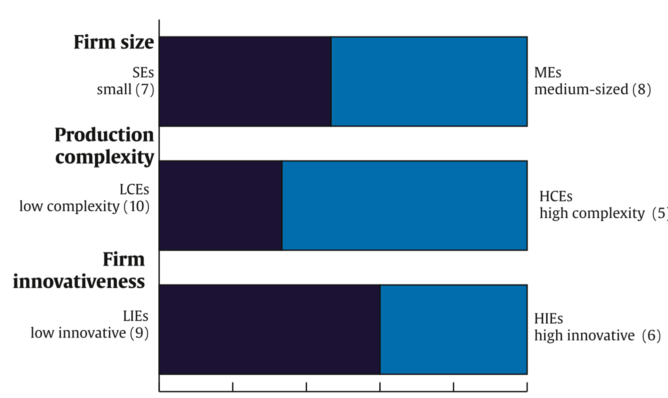

Fig. 4. Distribution of the investigated cases by firm size, production complexity and firm innovativeness.

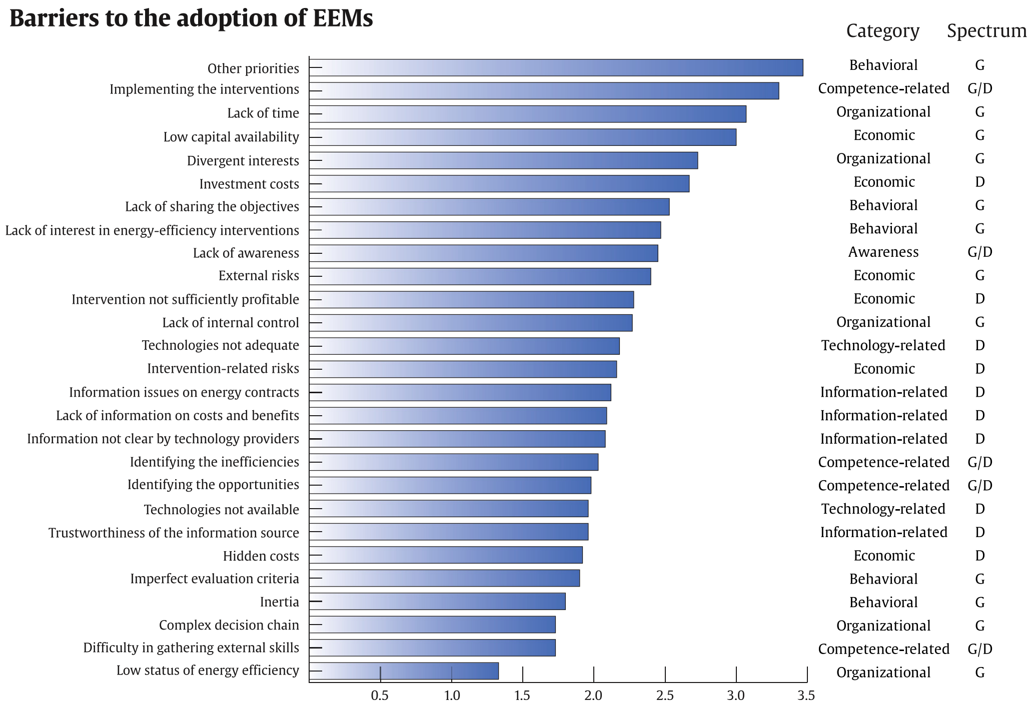

Fig. 5. Analysis of perceived barriers by total sample.

enterprises did not allow us to perform robust additional statistical analyses, the information provided in this exploratory stage was still considered to be of interest for the research, in order to show first indications about barriers to the adoption of EEMs.

Before discussing the results in detail, some methodological issues are worth to be addressed. Case studies should guarantee an external, internal and construct validity, as well as reliability (Yin, 2009). First, *external validity*, which refers to the extent of the generalisation of the results, was obtained by selecting the case studies according to several firm characteristics, as described in Section 3.2. Second, *internal validity* was achieved through pattern matching during data collection. Additionally, *construct validity* was obtained through the audio-recording of the interviews (then transcribed) as well as drafting and finalising a report for each case study. Finally, the *reliability* of the results was achieved thanks to a rigorous case study protocol as well as a structured database created for the analysis of the empirical case evidence.

4. Results and discussion

This section presents and discusses the findings according to several analyses. Firstly, we considered the cases as a whole in order to assess the relative importance of different barriers. Secondly, we clustered the cases with respect to the aforementioned firm characteristics in order to highlight the influence of those factors on barriers.

4.1. Analysis of barriers for the whole sample

The analysis was firstly devoted to investigating the values of the perceived barriers to energy efficiency for the whole sample (see Fig. 5). *Other priorities* (3.47) emerged as the most critical. This general barrier to energy efficiency reflects that decision-makers focus almost exclusively on a few core business activities. Therefore, they tend to evaluate EEMs investments with a considerable impact only on the main production system activities, thus disregarding energy efficiency issues. This finding is in accordance with Thollander et al., (2007), in which all the interviewed SMEs claimed that production-related issues had higher priority than energy-related issues, Trianni et al. (2013a) who investigated Italian manufacturing firms, as well as Thollander and Ottosson's (2010) investigation regarding the integration of energy management practices in energy-intensive industries. Furthermore, having other priorities for capital investments has been recognised as the most relevant barrier by the literature (Table 2). As suggested in the IPCC Third Assessment Report (2001), “energy efficiency investments are made to compete with other investment priorities”. Besides, devoting time to energy efficiency investigations does not lead to certain outcomes: thus, production efforts tend to have greater weighting, since they can lead to certain outcomes (Sorrell et al., 2000).

Implementing the intervention (3.30) ranked second, and it is a general and intervention-dependent barrier related to competences. The lack of skilled technical personnel was recognized to be among the top three barriers in the industry, particularly affecting SMEs, where most workers are busy maintaining production, thereby leading to difficulties in installing new energy-efficient equipment compared with the simplicity of buying energy (IPCC, 2001; Cagno and Trucco, 2008). Furthermore, *lack of time* and *capital availability*, two general barriers, scored slightly over 3. Similarly to Nagesha and Balachandra (2006) concerning brick and tile SMEs, most of the sampled SMEs operate in a competitive market, leaving little time to address energy efficiency issues as entrepreneurs are forced to spend the majority of their time in other relevant activities, e.g. marketing their products, booking orders, negotiating prices, and maintaining delivery schedules (Cagno et al., 2010). In addition, capital availability may be a major hurdle in investing in EEMs for SMEs because of their limited access to banking and financing mechanisms (IPCC, 2001; Reijnders, 2003). Sorrell et al. (2000) also showed that access to capital is a crucial barrier in “all sectors and all countries” (providing examples from the brewing and mechanical sectors of the UK, Germany and

Table 4
Perceived barriers by categories for the whole sample.

Barriers by category	Average score
Awareness	2.45
Behavioural	2.43
Competence-related	2.26
Economic	2.45
Information-related	2.06
Organisational	2.10
Technology-related	2.07

Ireland), but additional empirical evidence is apparent in the literature (Table 2). Nonetheless, in case of successful businesses (which, however, cannot be claimed in the present sample), capital could represent a minor issue (Rohdin and Thollander, 2006).

For what concerns minor barriers, *low status of energy efficiency* scored the lowest (1.33), but should be read considering that *other priorities* and *lack of time* rank first and third, respectively. This result might reflect the tendency of SMEs' owner-managers to take control of energy management and energy efficiency, that they nonetheless tend to overlook. Although the interviewed owner-managers were already overburdened by production issues, they contrarily felt themselves appropriate to be in charge of energy issues, too. The result finds confirmation in previous studies (Table 2).

The analysis of barriers by categories merits some further considerations. As reported in Fig. 5, this sample highlighted the major relevance of behavioural issues (appearing not only in first place in Table 4, but also three times in the first ten positions), followed by economic barriers. The investigated sample seems to start understanding that in addition to economic issues, other non-economic barriers seriously hinder the adoption of EEMs. This result suggests that future policy efforts should be directed not only in terms of economic subsidies, but also in terms of e.g. greater training and dissemination campaigns, aimed at increasing the knowledge of final users. Previous studies confirm the results. For instance, Nagesha and Balachandra (2006) highlighted the relevance of behavioural barriers, while Rohdin and Thollander (2006) and Cooremans (2012) pointed out the lack of time and lack of interest in energy efficiency interventions, respectively. Nonetheless, the sampled firms have not yet fully realised the importance of information and organisational issues when dealing with EEMs, differently from previous research, in which information issues are found to be among the most relevant. Referring exclusively to the most recent empirical works, some authors pointed out the relevance of information-related barriers in general terms (Kostka et al., 2013; Schleich and Gruber, 2008), notably the lack or form of information (Ostertag, 2003; Trianni and Cagno, 2012). Nevertheless, the characteristics of the sample analysed seem to partially explain here the results. Among others, in Trianni and Cagno (2012) the management was effectively committed towards energy efficiency and energy management issues, as all sampled enterprises voluntarily participated in small energy efficiency research projects, which was not the case here.

Fig. 5 illustrates that firms tended to perceive higher barriers when asked about their general attitudes towards energy efficiency (seven out of the ten first barriers are general, with an average value of over 2.8), ranking intervention-dependent barriers asked in average terms (i.e. not referring to a single EEM) in mid−low positions. Reasonably, firms tended to exacerbate problems that recur frequently in different contexts as opposed to specific energy efficiency issues.

Before presenting the analyses of barriers with respect to technology areas as well as single EEMs, we should acknowledge that, in the following, owing to the limited number of responses, only the largest differences between subsamples are presented and further discussed.

4.1.1. *Analysis of barriers by technology area*

Table 5 shows how the perception of general/intervention-dependent and intervention-dependent barriers differed among cross-cutting technologies. At first glance compressed air and HVAC systems presented higher barriers, followed by motors and, lastly, lighting systems.

Implementing the intervention was the highest perceived barrier, with similar scores (over 3) for all cross-cutting technologies. Similarly, the IPCC (2001) claimed a general shortage of skilled personnel in SMEs. Furthermore, Trianni and Cagno (2012) reported that 65% of their interviewed SMEs identified this as an important barrier.

The analysis by cross-cutting technologies has nonetheless allowed to appreciate several differences in the ranking of barriers. Firstly, *investment costs* was evaluated differently when considering motors with respect to other cross-cutting technologies, particularly in case of lighting systems. Similarly Reddy and Shrestha (1998) found that high initial cost constitutes an extremely important barrier to energy efficiency for motors, whereas a lower one when dealing with lighting technologies. Secondly, *lack of awareness* ranked lower for lighting systems compared with the other cross-cutting technologies. Reasonably, this could be the result of the wide information campaign on the diffusion of lighting technologies towards enterprises in previous years. Thirdly,

Table 5
Perceived barriers across cross-cutting technologies. A mark "(+)" in the column "Δ" indicates that the difference between the max and min value is at least 0.50 greater than the total average.

Rank	Barriers	Total average	Lighting	Compressed air	Motors	HVAC	Δ
1	Implementing the interventions	3.30	3.29	3.33	3.27	3.33	
2	Investment costs	2.67	2.45	2.60	3.02	2.60	(+)
3	Lack of awareness	2.45	2.04	2.60	2.53	2.73	(+)
4	Intervention not sufficiently profitable	2.28	2.23	2.27	2.24	2.40	
5	Technologies not adequate	2.18	1.92	2.20	2.04	2.51	(+)
6	Intervention-related risks	2.16	2.01	2.33	2.07	2.22	
7	Information issues on energy contracts	2.12	1.96	2.11	2.38	2.02	
8	Lack of information on costs and benefits	2.09	1.96	2.31	1.82	2.24	
9	Information not clear by technology providers	2.08	1.80	2.22	2.13	2.13	
10	Identifying the inefficiencies	2.03	1.85	2.13	2.00	2.13	
11	Identifying the opportunities	1.98	1.86	2.07	1.80	2.20	
12	Technologies not available	1.96	1.85	1.93	2.11	1.89	
13	Trustworthiness of the information source	1.96	2.05	2.18	1.69	1.96	
14	Hidden costs	1.92	1.87	1.64	2.07	2.07	
15	Difficulty in gathering external skills	1.73	1.81	1.87	1.67	1.60	

technologies not adequate emerged as more critical for HVAC compared with the other cross-cutting technologies: reasonably, this preliminary result might be driven by the nature of HVAC systems, less standardised than the other considered systems. Although the sample was limited, such results suggest that policymakers carefully consider the existence of differences in the ranking of barriers by technology area.

4.1.2. Analysis of barriers with respect to single EEMs

Differences in intervention-dependent barriers among the three EEMs of each cross-cutting technology have been investigated. For the sake of clarity, note that the following paragraphs discuss the EEMs with their identification keys presented in Table 3. Fig. 6 summarises the results of the barriers to single EEMs divided by cross-cutting technology.

4.1.2.1. Barriers to EEMs in lighting systems. Fig. 6(a) presents the findings related to the EEMs in lighting systems, showing that L1 ("Use a more efficient light source") had relevant differences from L3 ("Install occupancy sensors"), while L2 ("Reduce illumination to the minimum necessary levels") showed minor differences to both L1 and L3. The second-ranked barrier, *intervention not sufficiently profitable*, presented a significant difference between its maximum and minimum scores. This result could be explained by L3 involving a higher degree of innovativeness and therefore being perceived as more expensive than L1. Accordingly, L3 had every economic barrier greater than L1 (e.g. particularly *investment costs*). The substantial disinformation about L3 (as shown, information-related barriers are higher for L3 than they are L1) could also make the EEMs to be perceived as not sufficiently profitable. Furthermore, participants, beside the lack of information, highlighted a relevant difference in both the technology-related barriers related to L3 and L1 s (both *technologies not available* and *technologies not adequate*), attributing this issue to their technology providers.

4.1.2.2. Barriers to EEMs in compressed air systems. Fig. 6(b) displays the results for compressed air systems. C1 ("Eliminate leaks in inert gas and compressed air lines/valves") seemed to present the lowest barriers, while the distinction between C2 ("Install compressor air intakes in the coolest locations") and C3 ("Reduce the pressure of compressed air to the minimum required") was unclear. Again, *intervention not sufficiently profitable* has shown a significant difference, which could be explained by a lack of sufficient information about the benefits of implementing C2. Notably, this EEM had the greatest values in all information barriers related to technologies. In particular, higher values were given to *lack of information on costs and benefits*, *information not clear by technology providers*, and *trustworthiness of the information source*.

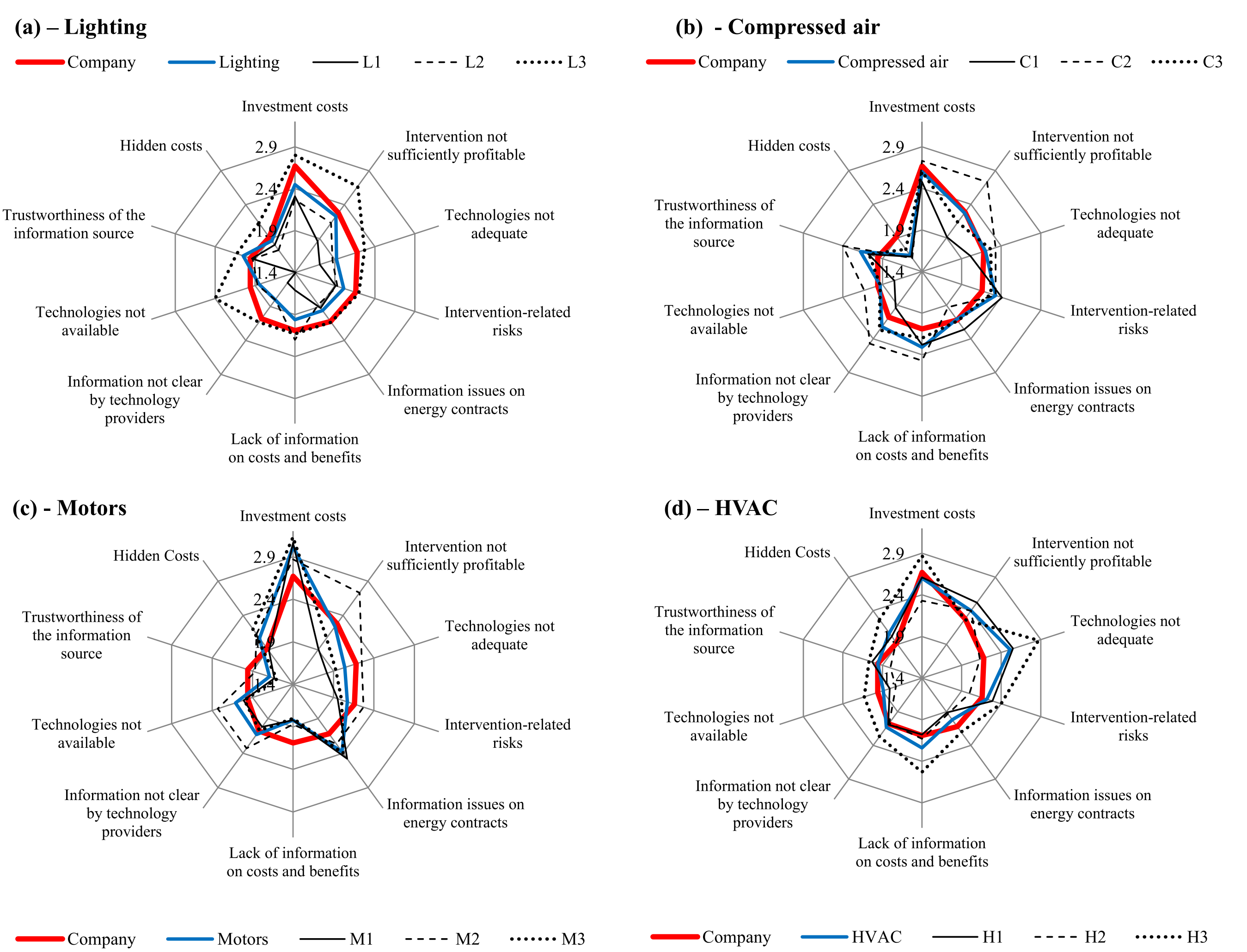

Fig. 6. Intervention-dependent barriers to EEMs: analysis with respect to selected cross-cutting technologies, namely: a) lighting system; b) air compressed system; c) motor systems; d) heating, ventilation and air conditioning system.

4.1.2.3. Barriers to EEMs in motor systems. As presented in Fig. 6(c) for EEMs in motor systems, M2 ("Utilise energy-efficient belts") seemed to show the highest perceived barriers, while it was hard to make a clear distinction between M1 ("Use the most efficient type of electric motors") and M3 ("Use variable speed drives"). Nonetheless, *intervention not sufficiently profitable* presented a significant difference in maximum and minimum values, i.e. between M2 and M1. The higher possible range of applicable technologies of M2, that involves more general assembly (i.e. transmission) could explain the difference with M1, that is the installation of specific equipment (i.e. high-efficiency motors). Furthermore, the differences in motor system technology were not numerous: as a clear distinction between the investigated EEMs was not neatly sensed from the interviews, the barriers affecting such EEMs could therefore be perceived with similar values.

4.1.2.4. Barriers to EEMs in HVAC systems. Looking at HVAC systems, Fig. 6(d) shows that H3 ("Use a radiant heater for spot heating") seemed to show the highest perceived barriers, followed by H1 ("Install timers and thermostats") and H2 ("Reduce space conditioning during non-working hours"). In particular, some differences could be appreciated in two cases. For the first time, *investment costs* did not represent the highest barrier for an EEM. When looking at H2, *investment costs* ranked second, immediately after the *intervention not sufficiently profitable* barrier. This finding is in accordance with the characteristics of H2, i.e. a procedure optimisation, whereas H1 and H3 involve equipment purchase and/or installation. Therefore, the former is mainly hindered by an evaluation of profitability, subject to imperfect evaluation criteria or routines, while the latter by their initial costs. Furthermore, the characteristics of H2 could lead to the difference in the inadequacy of technologies: as a procedure optimisation, H2 does not imply a change in the equipment installed.

To conclude, we can note frequent and relevant swaps in the ranking of barriers, when investigated in general terms, by technology areas and with respect to specific EEMs. Thus, this fact provides further confirmation that such differences should be taken into account when developing effective policies and industrial practices to increase industrial energy efficiency.

4.2. Analysis of barriers by firm characteristics

The study has then clustered enterprises according to their firm size and innovativeness, trying to explore whether those firm characteristics would be able to affect the perception of the barriers to energy efficiency. Figs. 7 and 8 summarise the pieces of evidence emerged, representing the barriers in general and by technology area, respectively.

4.2.1. Analysis of barriers by firm size

By looking at firm size, Fig. 7 shows that, in general terms, SEs tended to perceive higher barriers (most differences are negative). In particular, SEs presented greater values in the barriers *difficulties in implementing the intervention* and *imperfect evaluation criteria*, respectively a competence-related and behavioural barrier, confirming the findings of previous research (Trianni and Cagno, 2012; Trianni et al., 2013b). In this case, SEs should receive adequate support for implementing interventions as well as promoting procedures and tools to evaluate energy efficiency investments. Additionally, greater values have been perceived for *external risks* (economic barrier), reflecting that smaller energy consumers are reluctant to invest in energy demand reduction, which might happen with very fluctuating energy prices.

Analysing the effect of firm size on barriers to energy efficiency by cross-cutting technology, Fig. 8 shows several differences between SEs and MEs (one of which is significant), particularly between compressed air, electric motors and HVAC systems, whereas lighting systems seemed to be the least influenced. Within compressed air systems, a relevant difference was found in *investment costs*. This discrepancy might be due to the larger barriers in terms of *imperfect evaluation criteria* presented by SEs compared with MEs, since two out of the three selected EEMs in compressed air

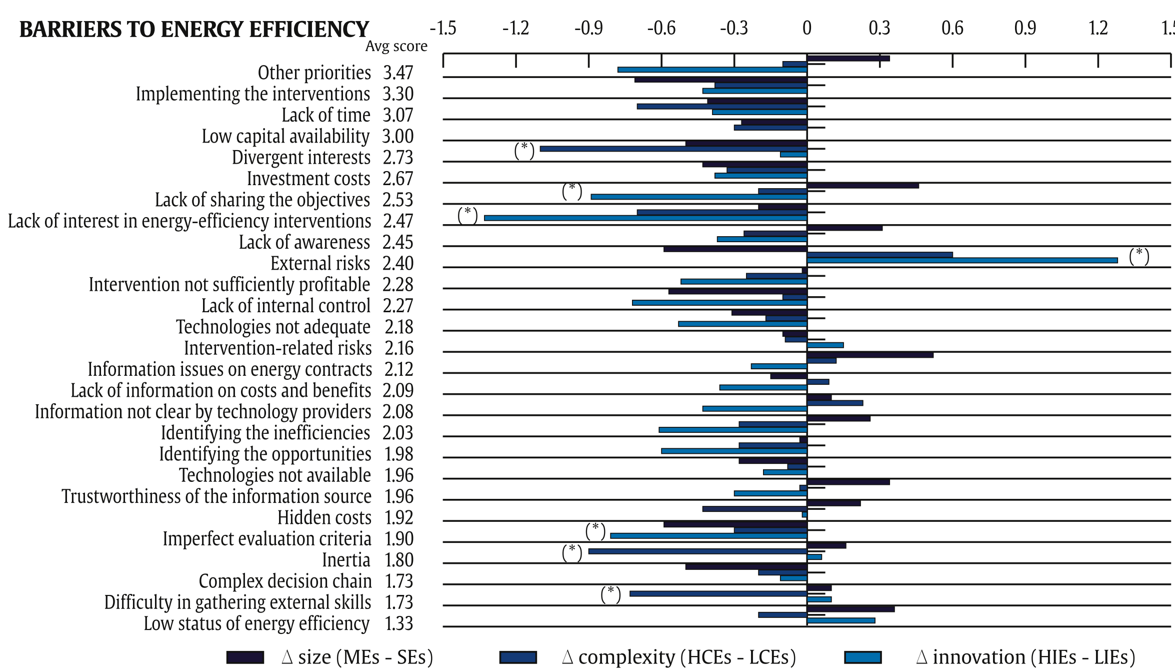

Fig. 7. Analysis by firm characteristics: barriers with differences according to firm size, production complexity and firm innovativeness. Δ Size reports the average difference between MEs and SEs; Δ Complexity reports the average difference between HCEs and LCEs; Δ Innovation reports the average difference between HIEs and LIEs; (*) indicates that the difference between the average cluster values is at least 35% greater than the average value for the whole sample.

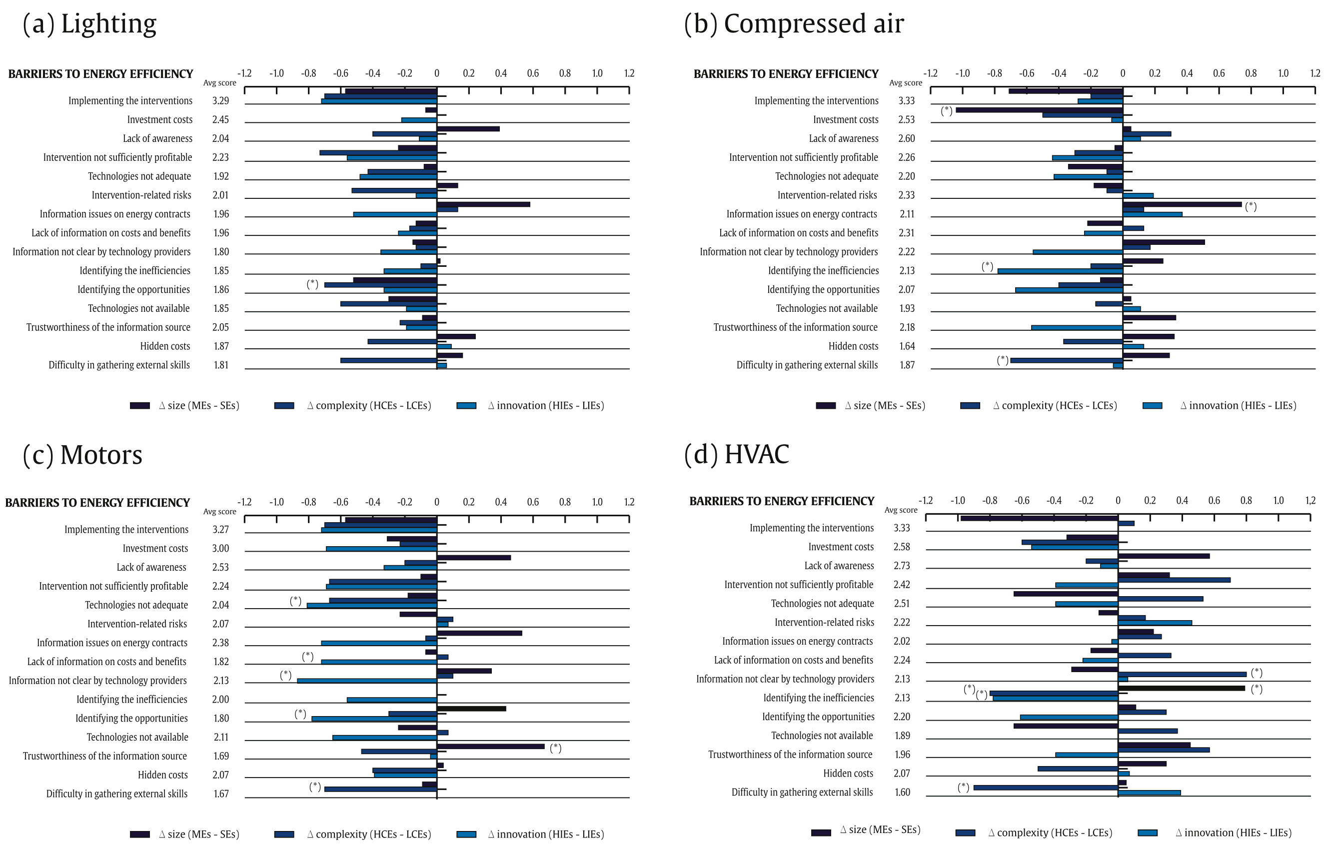

Fig. 8. Barriers to specific EEMs with respect to selected cross cutting technologies: analysis by firm size, production complexity and firm innovativeness. Δ Size reports the average difference between MEs and SEs; Δ Complexity reports the average difference between HCEs and LCEs; Δ Innovation reports the average difference between HIEs and LIEs; (*) indicates that the difference between the average cluster values is at least 35% greater than the average value for the cross-cutting technology.

systems involve the optimisation of existing equipment, commonly judged as having low initial costs (Kaya et al., 2002).

4.2.2. Analysis of barriers by firm production complexity

When considering production complexity, LCEs seemed to perceive higher barriers than HCEs (Fig. 7). In detail, concerning the difference in the *divergent interests* barrier, reasonably HCEs need to be more structured in order to manage the internal complexity. In line with this result, HCEs perceived lower values for the barriers *lack of internal control* and *lack of sharing the objectives*, showing to feel more responsible for energy consumption. Previous research has revealed that being accountable for energy costs makes users more aware of also being able to appropriate the benefits of energy efficiency improvements (Thollander and Ottosson, 2008). Among others, *inertia* and *difficulty in gathering external skills* presented large differences. They both may be interpreted as straightforward consequences of a more proactive attitude that HCEs display (Trianni et al., 2013c). In other words, being proactive decreases the endowment effect as well as the difficulties in finding external resources (Sorrell et al., 2000).

Among the cross-cutting technologies (see Fig. 8), HVAC systems seemed to be the most influenced by production complexity. In fact, the difference between LCEs and HCEs was particularly relevant for three barriers within HVAC systems relative to only one within lighting, compressed air, and electric motor systems. The discrepancy within *difficulty in gathering external skills* was considerable for compressed air, motor, and HVAC systems. Given that lighting technologies are usually more readily available than other cross-cutting technologies, the assumed enhanced proactivity of HCEs seemed to play a crucial role in decreasing the difficulty of gathering external competences.

4.2.3. Analysis of barriers by firm innovativeness

By clustering firms according to their innovativeness, Fig. 7 shows that LIEs seemed to perceive higher barriers than HIEs. Firstly, the difference in *lack of sharing the objectives* might reflect the tendency to avoid micromanagement in HIEs. Secondly, the difference in *lack of interest in energy efficiency interventions* was also relevant. Although less evident, two additional barriers were found to be higher for LIEs: *other priorities* and *lack of awareness*. Such results seem to show that HIEs were starting to look at energy efficiency improvements in their production processes as a means to increase competitiveness. Thirdly, lower values of *imperfect evaluation criteria* might provide evidence that HIEs are innovative not only in the adoption of new technologies, but also in their evaluation routines. On the contrary, *external risks* was the sole barrier – among the significant ones – for which HIEs perceived a higher value than LIEs. In this case, it is possible that HIEs had a wider perception of the related risks due to greater external uncertainties.

Regarding the influence of firm innovativeness on barriers by cross-cutting technology (see Fig. 8), electric motor systems pointed out four significant differences between HIEs and LIEs, whilst just one for both compressed air and HVAC systems. In particular, given the complexity of the structure and functioning of the electric motors market (DeAlmeida, 1998), several barriers presented higher values for LIEs, namely *technologies not adequate*, *lack of information on costs and benefits, information not clear by technology providers*, and *difficulties in identifying the opportunities*. This result suggests the importance of fostering activities like information campaigns as well as technical support in the identification and selection of the proper technology in order to promote the adoption of electric motor EEMs.

5. Conclusions

The results of our exploratory investigation provided several suggestions for policymakers and industrial managers. Firstly, we observed a tendency to exacerbate problems that recur frequently in different contexts (general barriers) as opposed to specific energy efficiency issues (intervention-dependent barriers). The greater relevance of behavioural barriers compared to specific economic and information-related ones seems to support such tendency. Nonetheless, our further analysis with respect to single EEMs showed that, punctually, intervention-dependent barriers might be relevant. These results suggest that policymakers distinguish the behavioural and organisational barriers, which might be addressed in general terms, from the economic and information-related ones, which should be better addressed considering a single EEM. To overcome such barriers, it seems crucial to get a better understanding of which drivers may arise internally and which represent external motivations or pressures to increase industrial energy efficiency. Furthermore, particular attention should be paid to understand how such driving forces may be interconnected and how they should be promoted, especially in complex and large organisations, where they could have an even more relevant impact. In doing so, modelling the mechanisms relating drivers to barriers (general and intervention-dependent) in the decision-making process, and investigating the role of the stakeholders involved in the supply chain of energy-efficient technologies and services could provide a relevant contribution to the development of tailored policies and industrial practices. In this direction, research could further explore the existing connections between approaches specifically focused on energy efficiency and others more generally related to increase firm sustainability.

Additionally, considering the importance of competence-related barriers, relevant 'stimuli' might be represented by programmes aimed at increasing the technical competences of final users, which only partially depend on the specific characteristics of a single EEM. Considering the implications for industrial managers and SMEs, in order to overcome competence-related barriers, strong efforts appear as necessary to appropriate the existing competences available in the market. Here the support of external stakeholders such as Energy Service Companies (ESCOs) and other technology providers is crucial, since the presence of technical staff in SMEs for managing energy efficiency issues is not mandatory, or the existing technical skills may be inadequate. On the contrary, managers should better understand which competences enterprises must develop internally and which need to acquire from external stakeholders.

Our sample, although not statistically representative, provided an interesting picture of the barriers and EEMs in cross-cutting technologies. Our exploratory study highlighted how the interviewed SMEs faced different barriers with respect to specific EEMs and that those barriers varied considerably according to some EEMs' characteristics. The sample highlighted that compressed air and HVAC system EEMs presented higher perceived barriers, particularly in terms of investment costs, trustworthiness of the information source, and hidden costs. In more detail, the interviewed firms differentiated the barrier intervention not sufficiently profitable with respect to EEMs, showing their capability to evaluate the investments' economic feasibility. Furthermore, when considering single EEMs, differences were observed for several barriers, such as technology-related barriers for lighting system, information-related barriers for compressed air system, and economic barriers for both motor and HVAC systems. The many swaps in barrier ranking suggest that energy efficiency policies addressing intervention-dependent barriers should refer to and be shaped by specific EEMs and according to their characteristics. Additionally, differences with respect to single EEMs call for future research into a better understanding of how the relative importance of barriers is influenced by EEM attributes (e.g. distance to core process or non-energy benefits). In this regard, research is currently providing new structured characterisations of EEMs that could be a significant support when performing investigations.

Although these analyses intended to offer a first understanding, our findings show that firm characteristics such as size, production complexity, and degree of innovativeness seemed to influence the perception of barriers not only in general terms but also with respect to single cross-cutting technologies. Here further research is needed: aside from firm size, only a few contributions in the literature have shown the importance of other factors, and further efforts are surely needed to gain a greater understanding of which and how some firm characteristics can modify the perception of barriers to energy efficiency.

The research had some limitations. Firstly, we should acknowledge that was conducted on a limited number of enterprises and on a delimited European region. Owing to such considerations, the research findings reflected a particular situation. Nonetheless, it is worth remarking that our approach aimed at evaluating the theoretical generalisability of the concept rather than its statistical generalisability. Hence, this research should be followed up with additional studies extending the approach and evaluating the research concept in a much broader sample, in different geographical as well as economic contexts. Such additional investigations could allow researchers to compare the findings and investigate the possible socioeconomic factors leading to commonalities and differences, using both qualitative and quantitative research approaches. In doing so, research should also explore the distinction between energy-intensive and non-energy-intensive companies. This crucial element might provide interesting insights into the diffused barriers in all industries with respect to highly process-specific barriers to industrial energy efficiency.

Furthermore, the evaluation of firm characteristics (production complexity as well as innovativeness) is subject to the interviewer's expertise and experience: this implies that the capability to evaluate a large amount of information concerning the firm processes and business might seriously bias the research findings and jeopardise the success of the investigation. The observer bias could be reduced thanks to simultaneous data analyses by several researchers. Such contributions, on the one hand, would strengthen the knowledge of the issues hindering the adoption of EEMs. On the other hand, the research on driving forces for increased energy efficiency and firm sustainability could benefit from being based on more solid contributions. Therefore, future research should be directed towards the diffusion of knowledge about barriers to energy efficiency and aimed at highlighting barriers to specific EEMs. In this regard, collaboration platforms to share information could play a relevant role in creating a knowledge and data hub, supported by semantic technologies if their capability is effectively realised in the future.

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References

Anderson, S.T., Newell, R.G., 2004. Information programs for technology adoption: the case of energy-efficiency audits. Resour. Energy Econ. 26 (1), 27–50.

Apeaning, R.W., Thollander, P., 2013. Barriers to and driving forces for industrial energy efficiency improvements in African industries – a case study of Ghana's largest industrial area. J. Clean. Prod. 53, 204–213.
Baumgartner, R.J., Zielowski, C., 2007. Analyzing zero emission strategies regarding impact on organizational culture and contribution to sustainable development. J. Clean. Prod. 15, 1321–1327.
Bozarth, C.C., Warsing, D.P., Flynn, B.B., Flynn, E.J., 2009. The impact of supply chain complexity on manufacturing plant performance. J. Oper. Manag. 27 (1), 78–93.
Bunse, K., Vodicka, M., Schönsleben, P., Brülhart, M., Ernst, F.O., 2011. Integrating energy efficiency performance in production management – gap analysis between industrial needs and scientific literature. J. Clean. Prod. 19, 667–679.
Cagno, E., Trianni, A., 2012. Analysis of the most effective energy efficiency opportunities in manufacturing primary metals, plastics, and textiles small- and medium-sized enterprises. J. Energy Resour. Technol. 134 (2), 021005.
Cagno, E., Trucco, P., 2008. Cleaner technology transfer in the Italian galvanic industry: economic and know-how issues. J. Clean. Prod. 16S1, S32–S36.
Cagno, E., Trucco, P., Trianni, A., Sala, G., 2010. Quick-E-scan: a methodology for the energy scan of SMEs. Energy 35 (5), 1916–1926.
Cagno, E., Worrell, E., Trianni, A., Pugliese, G., 2013. A novel approach for barriers to industrial energy efficiency. Renew. Sustain. Energy Rev. 19, 290–308.
C.E.C., 2002. Corporate Social Responsibility: a Business Contribution to Sustainable Development. Commission of the European Communities, Brussels, Belgium, p. 24.
Confindustria, 2011. Efficienza Energetica – Benefici per le imprese, un bene per l'ambiente. Available at: http://www.efficienzaenergetica.enea.it/ (in Italian).
Cooremans, C., 2012. Investment in energy efficiency: do the characteristics of investments matter? Energy Effic. 5 (4), 497–518.
DeAlmeida, E.L.F., 1998. Energy efficiency and the limits of market forces: the example of the electric motor market in France. Energy Policy 26 (8), 643–653.
DeCanio, S.J., 1993. Barriers within firms to energy-efficient investments. Energy Policy 21 (9), 906–914.
DeCanio, S.J., 1998. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 26 (5), 441–454.
DeGroot, F.H.L., Verhoef, E.T., Nijkamp, P., 2001. Energy saving by firms: decision-making, barriers and policies. Energy Econ. 23 (6), 717–740.
Del Rio González, P., 2005. Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. Bus. Strategy Environ. 14 (1), 20–37.
DeSimone, L.D., Popoff, F., 2000. Eco-Efficiency. The Business Link to Sustainable Development. MIT Press, Cambridge, MA, USA.
[EIA] U.S. Energy Information Administration, 2011. International Energy Outlook 2011. Washington, DC, US.
EIM Business & Policy Research, 2011. Do SMEs Create More and Better Jobs?. Brussels, Belgium.
Eisenhardt, K.M., Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. Acad. Manag. Rev. 50 (1), 25–32.
European Commission, 2008. Observatory of European SMEs Summary Survey of the Observatory of European SMEs.
[EC] European Council, 2003. Commission recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. Off. J. Eur. Union, 6.
[EC] European Council, 2012. Directive 2012/27/EU on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC, vol. 4, pp. 1–56.
European Union, November 2009. FWC Sector Competitiveness Studies – Competitiveness of the EU Metalworking and Metal Articles Industries. Available at: http://ec.europa.eu/enterprise/sectors/mechanical/.
Eurostat, 2010. Structural Business Statistics (SBS). Available at: http://epp.eurostat.ec.europa.eu (accessed on 07.02.14.).
Eurostat, March 2013. Regional GDP. Available at: http://epp.eurostat.ec.europa.eu (accessed on 07.02.14.).
Fleiter, T., Fehrenbach, D., Worrell, E., Eichhammer, W., 2012a. Energy efficiency in the German pulp and paper industry – a model-based assessment of saving potentials. Energy 40 (1), 84–99.
Fleiter, T., Schleich, J., Ravivanpong, P., 2012b. Adoption of energy-efficiency measures in SMEs – an empirical analysis based on energy audit data from Germany. Energy Policy 51, 863–875.
Garland, R., 1991. The mid-point on a rating scale: is it desirable? Mark. Bull., 3–6.
Harris, J., Anderson, J., Shafron, W., 2000. Investment in energy efficiency: a survey of Australian firms. Energy Policy 28 (12), 867–876.
Hasanbeigi, H., Morrow, W., Masanet, E., Sathaye, J., Xu, T., 2013. Energy efficiency improvement and CO_2 emission reduction opportunities in the cement industry in China. Energy Policy 57, 287–297.
[IEA] International Energy Agency, 2006. Light's Labour's Lost: Policies for Energy-Efficient Lighting. OECD/IEA, Paris.
[IEA] International Energy Agency, 2010. Energy Units. http://www.iea.org/interenerstat_v2/energy_unit.asp (accessed on 02.06.14.).
[IEA] International Energy Agency, 2011. Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems. Working paper. OECD/IEA, Paris.
[IAC] Industrial Assessment Centre, 2013. Industrial Assessment Center Field Manager [Online]. Available: iac.rutgers.edu (accessed 24.06.13.).
[IPCC] Intergovernmental Panel for Climate Change, 2001. Third Assessment Report: Barriers, Opportunities, and Market Potential of Technologies and Practices. Third assessment report. Cambridge University Press, Cambridge, UK.
[ISTAT] Istituto Nazionale di Statistica, 2004. 8° Censimento generale dell'industria e dei servizi. Rome, Italy (in Italian).
[ISTAT] Istituto Nazionale di Statistica, 2011. Struttura e dimensione delle unità locali delle imprese. Rome, Italy (in Italian).
Kaya, D., Phelan, P., Chau, D., Sarac, H.I., 2002. Energy conservation in compressed-air systems. Int. J. Energy Res. 26 (9), 837–849.
Kilponen, L., Ahtila, P., Parpala, J., Pihko, M., 2000. Improvement of Pulp Mill Energy Efficiency in an Integrated Pulp and Paper Mill. Laboratory of Energy Economics and Power Plant Engineering - Helsinki University of Technology, Helsinki.
Kostka, G., Moslener, U., Andreas, J., 2013. Barriers to increasing energy efficiency: evidence from small-and-medium-sized enterprises in China. J. Clean. Prod. 57, 59–68.
Linnenluecke, M.K., Russel, S.V., Griffiths, A., 2009. Subcultures and sustainability practices: the impact on understanding corporate sustainability. Bus. Strategy Environ. 18, 432–452.
Lozano, R., 2009. Orchestrating Organisational Change for Corporate Sustainability. Strategies to Overcome Resistance to Change and to Facilitate Institutionalization (PhD doctoral dissertation). University of Cardiff, Cardiff, Wales, UK.
Lozano, R., 2012. Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives. J. Clean. Prod. 25, 14–26.
Lozano, R., 2013. Are companies planning their organisational changes for corporate sustainability? An analysis of three case studies on resistance to change and their strategies to overcome it. Corp. Soc. Responsib. Environ. Manag. 20 (5), 275–295.
Lyon, D., 2004. How can you help organisations change to meet the corporate responsibility agenda? Corp. Soc. Responsib. Environ. Manag. 11, 133–139.
Madlool, N.A., Saidur, R., Hossain, M.S., Rahim, N.A., 2011. A critical review on energy use and savings in the cement industries. Renew. Sustain. Energy Rev. 15, 2042–2060.
Miles, M.B., Huberman, A.M., 1994. Qualitative Data Analysis: an Expanded Sourcebook. Sage, Thousand Oaks, CA.
Muthulingam, S., Corbett, C.J., Benartzi, S., Oppenheim, B., 2011. Investment in Energy Efficiency by Small and Medium-Sized Firms: an Empirical Analysis of the Adoption of Process Improvement Recommendations. Working paper. Anderson Graduate School of Management – Decisions, Operations, and Technology Management, UC Los Angeles.
Nagesha, N., Balachandra, P., 2006. Barriers to energy efficiency in small industry clusters: multi-criteria-based prioritization using the analytic hierarchy process. Energy 31 (12), 1969–1983.
Oda, J., Akimoto, K., Tomoda, T., Nagashima, M., Wada, K., Sano, F., 2012. International comparisons of energy efficiency in power, steel, and cement industries. Energy Policy 44, 118–129.
Ostertag, K., 2003. No-Regret Potentials in Energy Conservation – an Analysis of Their Relevance, Size and Determinants. Physica-Verlag, Heidelberg.
O'Malley, E., Scott, S., 2004. Production must go on: barriers to energy efficiency in the Irish mechanical engineering industry. In: Sorrell, S., O'Malley, E., Schleich, J., Scott, S. (Eds.), The Economics of Energy Efficiency. Edward Elgar Publishing, Cheltenham, UK, p. 349.
Patton, M., 1990. Qualitative Evaluation and Research Methods, second ed. Sage, Newbury Park, CA.
Perez-Lombard, L., Ortiz, J., Maestre, I.R., 2011. The map of energy flow in HVAC systems. Appl. Energy 88 (12), 5020–5031.
Radgen, P., Blaustein, E., 2001. Compressed Air Systems in the European Union – Energy, Emission, Savings Potential and Policy Actions. Fraunhofer ISI, p. 172.
Reddy, B.S., Shrestha, R.M., 1998. Barriers to the adoption of efficient electricity technologies: a case study of India. Int. J. Energy Res. 22 (3), 257–270.
Reijnders, L., 2003. Policies influencing cleaner production: the role of prices and regulation. J. Clean. Prod. 11 (3), 333–338.
Rohdin, P., Thollander, P., 2006. Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. Energy 31 (12), 1836–1844.
Rohdin, P., Thollander, P., Solding, P., 2007. Barriers to and drivers for energy efficiency in the Swedish foundry industry. Energy Policy 35 (1), 672–677.
Rosner, W.J., 1995. Mental models for sustainability. J. Clean. Prod. 3 (1/2), 107–121.
RWE npower, 2013. npower Business Energy Index 2013. Report no. npm10894/RF13568/04.13 available at: http://www.npower.com.
Sardianou, E., 2008. Barriers to industrial energy efficiency investments in Greece. J. Clean. Prod. 16 (13), 1416–1423.
Schleich, J., 2004. Do energy audits help reduce barriers to energy efficiency? An empirical analysis for Germany. Int. J. Energy Technol. Policy 2 (3), 226–239.
Schleich, J., 2009. Barriers to energy efficiency: a comparison across the German commercial and services sector. Ecol. Econ. 68 (7), 2150–2159.
Schleich, J., Gruber, E., 2008. Beyond case studies: barriers to energy efficiency in commerce and the services sector. Energy Econ. 30 (2), 449–464.
Shipley, A.M., Elliott, R.N., 2006. Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector. American Council for an Energy-Efficiency Economy, p. 38. Report no. IE 061.
Sorrell, S., Schleich, J., Scott, S., O'Malley, E., Trace, F., Boede, U., Ostertag, K., 2000. Reducing Barriers to Energy Efficiency in Public and Private Organizations. Energy Research Centre-Science and Technology Policy Research (SPRU), University of Sussex, Brighton.

Sorrell, S., O'Malley, E., Schleich, J., Scott, S., 2004. The Economics of Energy Efficiency. Edward Elgar Publishing, Cheltenham, UK, p. 349.
Thollander, P., Ottosson, M., 2008. An energy efficient Swedish pulp and paper industry – exploring barriers to and driving forces for cost-effective energy efficiency investments. Energy Effic. 1 (1), 21–34.
Thollander, P., Ottosson, M., 2010. Energy management practices in Swedish energy-intensive industries. J. Clean. Prod. 18 (12), 1125–1133.
Thollander, P., Danestig, M., Rohdin, P., 2007. Energy policies for increased industrial energy efficiency: evaluation of a local energy programme for manufacturing SMEs. Energy Policy 35 (11), 5774–5783.
Trianni, A., Cagno, E., 2012. Dealing with barriers to energy efficiency and SMEs: some empirical evidences. Energy 37 (1), 494–504.
Trianni, A., Cagno, E., Worrell, E., Pugliese, G., 2013a. Empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. Energy 49, 444–458.
Trianni, A., Cagno, E., Thollander, P., Backlund, S., 2013b. Barriers to industrial energy efficiency in foundries: a European comparison. J. Clean. Prod. 40 (2), 161–176.
Trianni, A., Cagno, E., Worrell, E., 2013c. Innovation and adoption of energy-efficient technologies: an exploratory analysis of Italian manufacturing SMEs. Energy Policy 61, 430–440.
Trianni, A., Cagno, E., De Donatis, A., 2014. A framework to characterize energy efficiency measures. Appl. Energy 118, 207–220.
Voss, C., Tsikriktsis, N., Frohlich, M., 2002. Case research in operations management. Int. J. Oper. Prod. Manag. 22 (2), 195–219.
Walsh, C., Thornley, P., 2012. Barriers to improving energy efficiency within the process industries with a focus on low grade heat utilization. J. Clean. Prod. 23 (1), 138–146.
Worrell, E., 1995. Advanced technologies and energy efficiency in the iron and steel industry in China. Energy Sustain. Dev. 2 (4), 27–40.
Worrell, E., Martin, N., Price, L., 2000. Potentials for energy efficiency improvement in the US cement industry. Energy 25 (12), 1189–1214.
Yin, R., 2009. Case Study Research: Design and Methods. Sage Publications, Thousand Oaks, CA.
Yuanyuan, L., Weiping, C., Dan, H., Jie, L., Zhe, L., Yongcheng, C., 2010. Energy conservation and emissions reduction strategies in foundry industry. China Foundry 7 (4), 392–399.
Zhang, J., Wang, G., 2008. Energy saving technologies and productive efficiency in the Chinese iron and steel sector. Energy 33, 525–537.