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Implementing energy efficiency measures: do other production resources matter? A broad study in Slovenian manufacturing small and medium-sized enterprises

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A B S T R A C T

Literature has largely investigated barriers to energy efficiency in industrial firms. Recently, research is looking at the non-energy benefits accompanying the adoption of energy efficiency measures that may contribute to overcoming these barriers. In our study we take an innovative perspective by specifically exploring the relationships between energy efficiency measures and other production resources, being assessed by their importance and capability of firms to manage them efficiently. By analysing 10% of Slovenian small and medium-sized manufacturing firms, our exploratory findings show that decision-makers carefully look at the multiple effects (either positive or negative) energy efficiency measures may have on a number of other production resources, particularly on those closer to the production (shop floor). Additionally, companies seem to struggle in efficiently managing the most important production resources, thus suggesting that energy efficiency measures should be looked in close consideration to other resources, which represents a new barrier to energy efficiency not accounted by previous research. Further, we could not detect significant differences between clusters of small versus medium-sized firms and energy intensive versus non-energy intensive ones, differently from previous research that was emphasizing the larger perception of barriers in smaller and less energy intensive firms. Our findings may challenge the discussion over incentive schemes for energy efficiency measures by promoting those with the largest (positive) implications for other production resources.

1. Introduction and background of the study

Industrial energy efficiency is crucial for sustainable development and industrial competitiveness. However, recent analyses show that global energy efficiency improvements are slowing (International Energy Agency, 2019). In fact, if the improvement of energy efficiency is attributable to the adoption of Energy Efficiency Measures (EEMs), their adoption by companies is still very low (Abbas et al., 2018) and is becoming increasingly difficult, as the most trivial situations have been resolved, despite a huge potential remains still untouched (up to 35% according to the International Energy Agency, 2019). The adoption rate of EEMs is even lower if contextualized in small-sized and medium-sized Enterprises (SMEs), intrinsically characterized by lack of a rigorous structure as well as internal resources and competences (Cagno and Trianni, 2012). In this sense, scientific and industrial literature has already pointed out and analysed several EEMs in a broader sense (Abdelaziz et al., 2011). The topic has been further explored with respect to specific technologies for industrial applications, such as, e.g., motor systems (Saidur, 2010; Trianni et al., 2019), or compressed air systems (Saidur et al., 2010). Studies have been carried out in various contexts, looking at specific sectors: among others, authors explored textile industry (Hasanbeigi and Price, 2012), cement (Worrell et al., 2000; Hasanbeigi et al., 2010), steel (Worrell et al., 2001; Johansson and Söderström, 2011). Further, previous studies have investigated the adoption of EEMs across SMEs (Thollander et al., 2015; Trianni et al., 2016), also more recently as a result of national energy audits programmes (Kubule et al., 2020).

Research has also recognised that some EEMs can bring valuable expected energy and economic performance for organizations (so-

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called “low hanging fruit”) (Bergmann et al., 2017; Özbuğday et al., 2020). Nevertheless, the adoption of such EEMs is still low by companies (Anderson et al., 2004; Cagno and Trianni, 2012), therefore leading to the so-called “energy efficiency gap” (Jaffe and Stavins, 1994). Interestingly, authors have slightly revised the concept by further including in this gap also “energy management components”, so to further clarify the need to combine investments in hardware equipment by more proper management of energy in the operations (Backlund et al., 2012). In order to shed the light on this issue, literature has already explored the characteristics of EEMs to best support an industrial decision-maker in taking more aware decisions and facilitate EEMs adoption by offering a broader spectrum of information regarding the effect of such EEMs in the operations (Trianni et al., 2014; Fleiter et al., 2012).

Similarly, several studies have discussed barriers preventing companies from the adoption of EEMs (Sorrell et al., 2004 Cagno et al., 2013) with insights from behavioural economics (Laibson and List, 2015; Hobman et al., 2016) and also analysing the role of policy interventions (Cattaneo, 2019). Barriers have been largely empirically investigated in either manufacturing firms (Cagno et al., 2016), but also in specific contexts such as: foundries (in Sweden, Rohdin et al., 2007; in European industries, Trianni et al., 2013a,b,c), pulp and paper (Thollander and Ottosson, 2008) and cement industry (Zuberi and Patel, 2017). Moreover, research noted that firm size could be an important contextual factor (Trianni and Cagno, 2012).

Additionally, research has explored which drivers could best support industrial decision-makers in companies to overcome such barriers (Johansson and Thollander, 2018; Trianni et al., 2016), also analysing local energy efficiency programmes focused on SMEs (Palm and Backman, 2020). Additionally, many studies have contributed to the discussion regarding the role of policy-makers to promote and stimulate the diffusion of EEMs (Tanaka, 2008; Malinauskaite et al., 2019). Recently, research has reviewed domestic and international energy efficiency policies illustrating valuable approaches for the support of EEMs (Safarzadeh et al., 2020).

Moreover, a number of studies have been carried out on the literature over non-energy benefits (NEBs), attempting to highlight additional benefits (beyond energy) from the adoption of EEMs (Pye and McKane; Hasanbeigi et al., 2013), also by means of Conservation Supply Curves (CSCs) (Worrell et al., 2003). Rasmussen (2017) has offered a valuable systematic review of the NEBs, also trying to sketch a framework for their categorisation. Despite a wealth of studies highlighting NEBs (Nehler, 2018) also with empirical evidence (Nehler and Rasmussen, 2016), only a few contributions have pointed out the possible existence of also negative impacts from the adoption of EEMs (Cagno et al., 2019), that should be encompassed in the decision-making (Skumatz and Gardner, 2005), calling for more updated empirical research to better assess the impact of EEMs (Freed and Felder, 2017).

By analysing all three areas of contributions (namely, characteristics of EEMs, a barrier/driver for EEMs adoption, and impacts stemming from EEM adoption) and their different attempts to address the issue, it is apparent the aim for a better understanding of the relationships between the EEMs adoption and the environment in which the EEMs are adopted (in manufacturing, production-related). Thus, it is argued that, for an industrial decision-maker, energy can be a crucial production resource (Zhou et al., 2016; Akan et al., 2019) and more information about energy costs is crucial (Mickovic and Wouters, 2020), also for the development of control strategies (Müller et al., 2014; Diaz et al., 2019). Nevertheless, it should be analysed in relation to the wider spectrum of resources needed for the production (Özbuğday et al., 2020) to recognise its effective impact on shop-floor production operations (Herrmann and Thiede, 2009; Bogdanski et al., 2013) and contribution for sustainable manufacturing (Duflou et al., 2012; Bhatt et al., 2020). Hence, the relationship between energy and other resources (Li et al., 2012) looks crucial in the adoption of an EEM. For this reason, assessing the impact that improved energy efficiency may have on the use and efficiency of other resources – beyond energy itself – is of utmost importance (Sola and Mota, 2020). Additionally, research has pointed out that energy efficiency performance should be better integrated in production management (Bunse et al., 2011). Improved integration of performance monitoring system could not only also serve as a means to foster energy awareness (Sučić et al., 2015), but also extendable beyond the strictly connected production activities, thus looking at the impact on production facilities as a whole, following what previous research investigated specifically for non-residential buildings (Kljajić et al., 2016). Such improved integrated monitoring could well support companies also in their journey towards ISO 50001 certification and, more broadly for their transition towards improved sustainability (Thakur and Mangla, 2019; Siegel et al., 2019). This could potentially be boosted by the industrial internet of things (Sisinni et al., 2018) as well as big data analytics methodologies (Bevilacqua et al., 2017), also supported by energy information systems (Effenberger and Hilbert, 2018).

By looking at previous literature, we can draw several interesting insights calling for further research. Firstly, too little focus has been given by previous studies to the possible relationships between the use and efficiency of the energy resource, with respect to other production resources. In this regard, the contribution by Cosgrove et al. (2019)is extremely interesting, where we can see an attempt of looking at additional non-energy impacts, such as productivity, by implementing low-cost changes in operational behaviour in procedures, suggesting a possible link between the energy resource and operational working staff. Also, recent research has preliminarily observed that EEMs should be assessed in a greater perspective of industrial sustainability (Cagno et al., 2018). But, to our knowledge, at the moment there is a lack of studies trying to specifically address the inclination of companies to implement EEMs when such EEMs may deliberately affect other production resources.

Secondly, the vast majority of previous contributions with a preliminary quantification of the non-energy benefits is either limited to foundries (Worrell et al., 20013) or more recently energy-intensive industries (Nehler and Rasmussen, 2016), or to the implementation of specific technologies such as compressed air systems (Nehler, 2018). This represents a crucial gap in the literature, since the attention for both positive *and* negative impacts should be even greater for non-energy intensive enterprises, where the contribution brought by the mere reduction of energy expenditures to business profitability is minor. In those contexts, other resources may assume greater importance and the impact of energy efficiency on them should be carefully assessed. And, not to forget, non-energy intensive activities are deemed to cover a non-negligible portion of industrial energy consumption (about 40%, but with share highly variable according to different contexts (US DOE/EIA, 2020)) and they have received less attention from policy-makers and research – similar to SMEs, as recently observed by Fawcett and Hampton (2020) –, thus offering a valuable potential for energy efficiency improvements.

Therefore, we can see a major research gap: research has overlooked so far whether a company would be willing to adopt an EEM in case of an impact – either positive or negative – on other production resources. Additionally, research has not yet investigated such willingness to adopt an EEM in light of the importance of a single resource and the efficiency of managing that resource within the company. For this reason, in the present study, we aimed at fulfilling the aforementioned research gaps by preliminarily investigated a broad set of Slovenian manufacturing SMEs (217, representing about 10% of total Slovenian manufacturing SMEs), distributed according to different energy intensity and firm size within SMEs. More specifically, we have explored:

- whether and to what extent companies would be willing to adopt an EEM in case of a positive/negative impact on other production resources; and
- what is importance and capability to effectively manage production resources (including energy) and their correlation.

In the following section, we detail the research setting, data collection and research methods adopted in the investigation, followed by results and a discussion of our findings. Concluding remarks for industry and policy-makers as well as suggestions for further research are provided in the final section.

2. Research setting, data and methods

We have focused our research on manufacturing SMEs located in Slovenia. This research setting is particularly interesting because Slovenia presents growth performance below that of regional peers (OECD, 2017). Furthermore, the industry in Slovenian economy is crucial, given that it exports more than 80% of its production, with prevalence to EU markets, mainly due to its low labour cost (OECD, 2017), and presents the 22nd World's industrial production growth rate (+8.6%) in 2017, according to CIA (2020).

The Slovenian industrial sector accounts for more than one third of the labour force and stands second after transport in the final energy use with 26% share, closely followed by households (24%) (Ministry of Infrastructure, 2017). Although the total final energy consumption in the Slovenian industry had seen a decline of 9% between 2002 and 2017, the energy intensive industrial sectors (primary metals, non-metallic minerals, paper, chemical) have witnessed a 5% increase, from 64% to 69% in the same period (ODYSSEE-MURE, 2020). For the period 2007–2012 the Slovenian National Energy Efficiency Action Plan 2014–2020 (Ministry of Infrastructure, 2015) reports energy savings achieved in 13 sectors of the manufacturing industry, the largest in the manufacture of metal products except for machinery and equipment, followed by chemicals and chemical products and computer, electronics and optical products, while ten sectors contributed to the negative energy savings (e.g., increased specific energy consumption), the largest in basic metals and rubber and plastic products. The energy efficiency in the industrial sector improved by more than 10 percentage points between 2005 and 2008, as seen in the drop of the Energy Efficiency Index ODEX. However, this positive trend seems to stop after 2008, as no significant changes in the ODEX value could be observed until 2015 (Ministry of Infrastructure, 2017), indicating the persistence of the energy efficiency gap in the industry.

Additionally, we have focused on manufacturing SMEs given that the share of SMEs in Slovenian industrial economy, in terms of both total revenue and number of employees, is quite large, about 38% and 42% respectively (SORS, 2020). As the energy efficiency gap has been found to prevail primarily in Slovenian less energy intensive SMEs (Hrovatin et al., 2016), the Slovenian integrated National Energy and Climate Plan calls for the design and implementation of policy measures that would foster adoption of EEMs and renewable energy sources in particular in SMEs by reducing barriers hindering their wider deployment (Government of the Republic of Slovenia, 2020). This clearly demonstrates the need for additional research that would give a deeper insight into the energy efficiency behaviour and inclination to deploy EEMs in SMEs given mutual interlinks between production resources and possible impacts of the EEMs on the use of these resources.

Therefore, for our research we have selected enterprises meeting the three requirements of being located in Slovenia, belonging to the manufacturing sector and being classified as SMEs, as per the EC classification (European Commission, 2003). We have collected data by conducting a survey, administered with the support of a market research agency, which first prepared the list of all manufacturing SMEs in Slovenia from the BISNODE GVIN database, reporting a total list of 2164 SMEs. The BISNODE GVIN database[1] uses official data from the Slovenian Business Register to provide credit ratings, financial data and other information from companies' annual reports needed for managerial decision making and market analyses. The Slovenian Business Register is a central public database containing information on all business firms, their subsidiaries, and other profit and not-for profit organizations located in Slovenia. Such register is managed by the publicly authorised and funded Agency of the Republic of Slovenia for Public Legal Records and Related Services (AJPES[2]).

Further, our enterprises for the survey were randomly sampled from the base of all manufacturing SMEs respecting the sector distribution, contacting them via e-mail or telephone. In this first contact, enterprises have been invited to participate in the research, presenting the objectives and the research questions, and we have sought for their availability to follow up with more detailed questions. This first screening has allowed to create our final sample of investigation, composed by a total of 217 companies (refereed as the whole sample in Section 3). Fig. 1 reports the main descriptive statistics for our sample.

Companies in the sample are distributed across the whole range of manufacturing sectors, well respecting domestic distribution, with major importance of C25 (primary metal manufacturing, 55 enterprises) and C22 (rubber and plastic manufacturing, 23 enterprises).

For further analysis, the sample was divided into two large clusters (small and medium enterprises), taking inspiration from previous research that highlighted possible different issues (Trianni and Cagno, 2012), with 169 small and 48 medium enterprises. Interestingly, the sample composition, for what concerns firm size, also very well reflects that of Slovenian companies, covering 10.2% of small-sized and 9.6% of medium-sized enterprises, so the 10.0% of Slovenian manufacturing SMEs. Additionally, the sample was divided in two clusters regarding the firm energy intensity. Energy intensity has been measured considering the ratio between energy expenditures and production costs, with a threshold of 3.5% for energy intensive firms, taking inspiration from previous literature (Rohdin and Thollander, 2006; Ramírez et al., 2005). Similarly to size, our sample is equally balanced in terms of energy intensity, with 104 energy intensive (EI) companies and 113 non-energy intensive (NEI), respectively.

The survey (interviews) have used a questionnaire as a guide and were divided into three main phases, for a total of more than 30 min. The first phase was aimed at gathering preliminary information about the company. Respondents have thus offered a general description of their company, such as size, ownership, market competition, financing and performance, together with main processes in place. Respondents have also confirmed their role within the company and their responsibility for energy efficiency investment decisions. Given the sample composition, we have mainly

[1] For more information on BISNODE GVIN database see https://www.bisnode.si/produkti/bisnode-gvin/.

[2] More information about AJPES and the Slovenian Business Register could be found on the AJPES official web page: https://www.ajpes.si/?language=english.

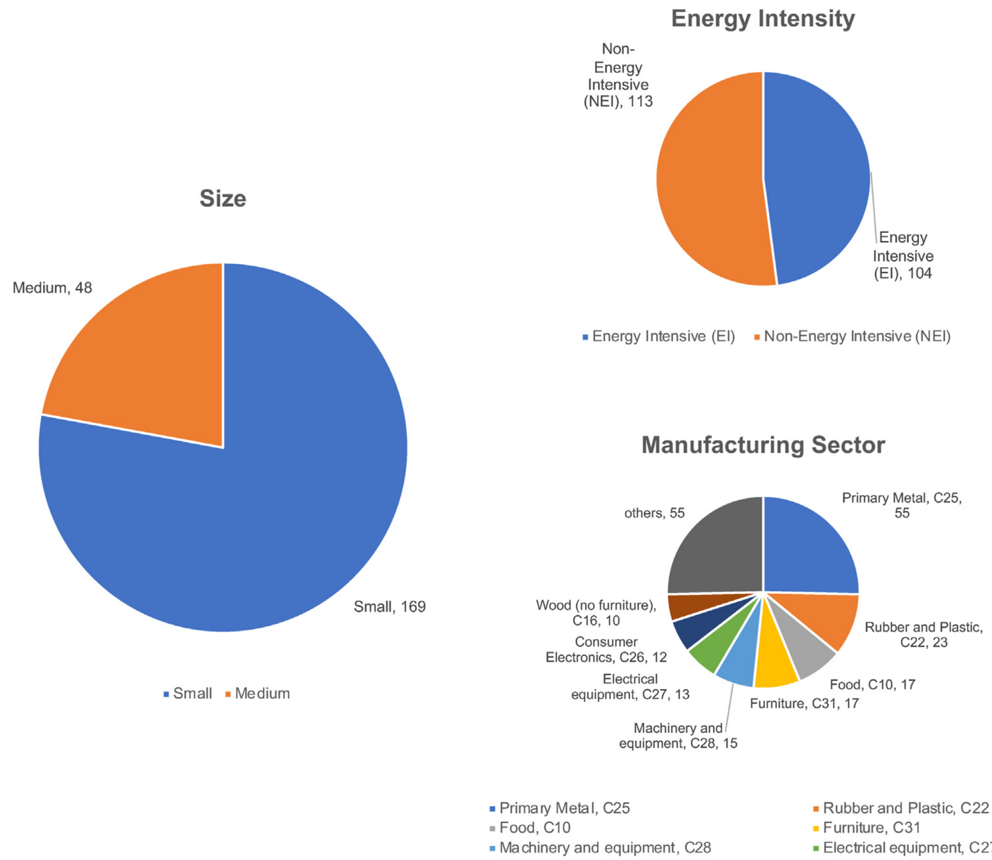

Fig. 1. Distribution of investigated sample by size, energy intensity and manufacturing sector.

interviewed the company's owners, but in some cases also operations managers, maintenance managers, etc. However, all respondents had full knowledgeability about the issues under investigation. Additionally, in this first phase we have also asked some information to determine the energy intensity of the company, such as annual energy expenditures and production costs.

During the second phase of the interview we have asked questions related to the energy efficiency awareness and measures adopted or considered to be adopted in the company. In particular, on the one hand, we have asked whether the company would consider the adoption of an EEM if this could have a positive impact on another production resource.

Respondents were asked to answer by using an even Likert scale, ranging from 1 ("We would not consider adopting the EEM" in case of the positive impact on the production resource) to 4 ("We would strongly recommend that the EEM is adopted" in case of the positive impact on the production resource). The use of even scale forces respondents to take a clear stance, thus limiting the *central tendency bias*, as noted by previous research (Stevens, 1971). On the other hand, we have asked interviewees whether their company would consider the adoption of an EEM if this could have a negative impact on the same set of production resources (assessed by a single resource), using the same Likert scale. The set of common production resources that has been related to the adoption of an EEM includes:

- Water;
- Raw materials;
- Employed managers;
- Staff employed;
- Key production facilities/machines;
- Auxiliary devices (e.g., HVAC, compressed air systems, etc.);
- Hazardous waste; and
- Other waste (i.e. non-hazardous waste).

The third phase of the interview was devoted to gathering a better understanding concerning the importance of the production resources for the company business, as well as how the company would consider its efficiency in managing different production resources in the given set. In this third phase, in addition to the aforementioned production resources, we have also asked interviewees considerations with respect to *Energy*, as a production resource. The importance/efficiency in managing each production resource in the set was again assessed on a 4-point Likert scale, ranging from 1 (not important/inefficient) to 4 (very important/very efficient).

Finally, in data collection, we have integrated the information gathered from interviews with additional information (secondary data) from the BISNODE GVIN database (Voss et al., 2002; Eisenhardt and Graebner 2007) for data triangulation purposes and results' reliability (Yin, 2009). To answer the research questions, stated in the Introduction, we have been conducting the research analysis in five steps, depicted in Fig. 2, using the data collected for the representative sample of 217 manufacturing SMEs.

In the first step we have explored if companies (whole sample) would consider the adoption of the EEM should the adoption have a positive (+) or a negative (−) impact on other production resources by looking at a single resource. This step has intended to identify if the positive/negative impact of the EMS on other production resources could represent an additional, until now in the literature

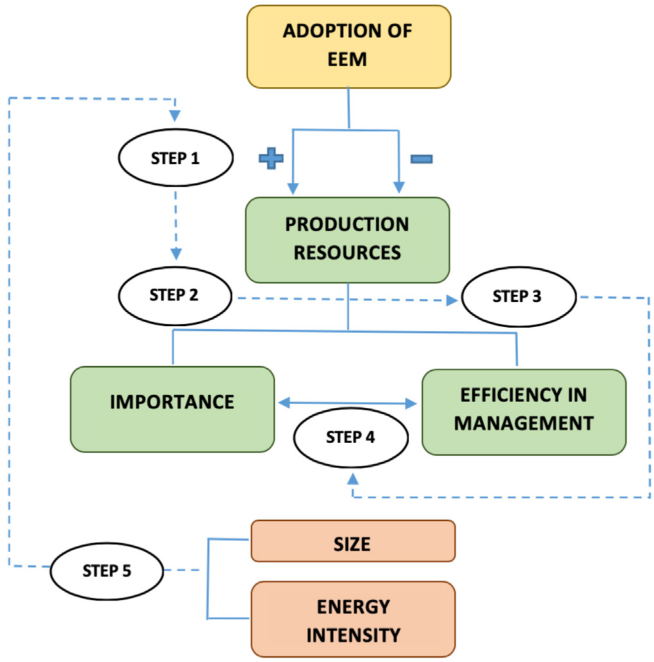

Fig. 2. Research steps in exploring the role of production resources in the adoption of EEMs.

overlooked determinant (a barrier or driver) in adopting the EEMs.

In the second step we have examined if companies perceive any differences in the importance of production resources for their production processes, while in the third step the resources have been explored in terms of the perceived efficiency in their use. This has been followed by step 4, looking at the relationship between the importance of resources and efficiency in their management. We would expect that companies manage more efficiently those resources that they deem as more important for their operations. In all steps 1 to 4 we have been using the statistical analysis, first, the frequency analysis of responses (being measured on the Likert scale 1–4), followed by correlation analysis.

In step 5 we have repeated the analysis from steps 1–3 by investigating the clusters of enterprises with respect to the firm size (small and medium SMEs) and with respect to the energy intensity (EI, NEI) to control for firms' characteristics that were found important for the firms' inclinations to adopt EEMs in previous studies.

3. Results

In this section we present the findings from our exploratory investigation, first by looking at the whole sample (Section 3.1), followed by insights on clusters of companies divided by firm size and energy intensity (Section 3.2).

3.1. Analysis of the total sample

We have investigated the willingness by companies to adopt an EEMs in case of a positive/negative impact on other production resources, followed by an investigation of the importance of different production resources and their efficiency in managing them, employing a frequency analysis (Section 3.1.1). In Section 3.1.2 we have further explored the research objective by conducting a correlation analysis.

3.2. Analysis by frequencies

Firstly, we have investigated whether companies would consider the adoption of an EEM should it have a positive impact on other production resources. As shown by Fig. 3 (upper part), sampled enterprises are in general very keen to adopt an EEM should this bring a positive impact: for most of the resources, values are on average around 3.5. In particular, by looking at the single resources, we can note particularly high values for key production facilities and machines, materials, staff and ancillary. The result was somehow expected, since it seems reasonable that companies are favourable in considering EEMs with positive synergies over other production resources, and even more those closer to core production activities.

Secondly, we have asked the investigated SMEs whether they would still consider the adoption of an EEM in case of a negative impact over other production resources (Fig. 3, lower part). Again, also in this case we can see a finding that looks somehow expected, given that the vast majority of the companies are not willing to consider the adoption in case of negative effects on other production resources, with average values of about 1.7.

However, an interesting finding emerges by comparing the frequencies of responses. If the number of companies that are reluctant to adopt an EEM in case of a positive impact on other resources is extremely low (ranging from 13 – employees staff and key production facilities/machines - to 33 for hazardous waste), the number of companies that would still at least recommend to consider the EEM in case of a negative impact is much higher. Indeed, from our exploratory findings we can note that about (and above) 50 companies in the sample are keen to still consider the adoption of an EEM, seeming to indicate that the intervention is still interesting and important, but they want to carefully assess such impact. Therefore, by looking at the whole picture, it seems that investigated SMEs do consider the adoption of EEMs in relation to its impact on other production resources.

We have also investigated the importance of the different production resources for the companies (Fig. 4, upper part). In this respect, the investigated sample seems quite heterogeneous. Generally, the sampled SMEs highlight as with higher importance employed managers (average score of 3.37), auxiliary devices (3.33), employed staff (3.32), followed by materials (3.17) and key production facilities/machines (3.09). Lower importance is given to hazardous waste and water (2.4 and 2.58 respectively).

Further, Fig. 4 (lower part) shows the efficiency in managing the production resources. We can note that companies deem to be adequately efficient in their management (all values above 2.75 over 4). Interestingly, sampled SMEs seem to point out a very good efficiency in managing ancillary (3.29), managers (3.22) and staff (3.16), materials (3.12) and machines (3.08). Other waste (3.04), hazardous waste (3.00) and water (2.77) present the lowest values: however, by coupling these findings with what emerged above, it can be noted that they are also the production resources with lower importance.

Finally, by looking simultaneously at the importance versus the efficiency in managing the production resources, we can appreciate an interesting pattern: for all the resources, on the one hand, companies perceive themselves more efficient in being capable of managing resources that they deem as more important. On the other hand, for the resources deemed as most important (employed managers and staff and auxiliary devices), their efficiency in managing them is slightly lower than the importance. Such findings seem to highlight that companies self-perceive to be less efficient in managing the production resources deemed to be more important. Besides, concerning the resources deemed as least important (i.e., water, hazardous waste), their efficiency in

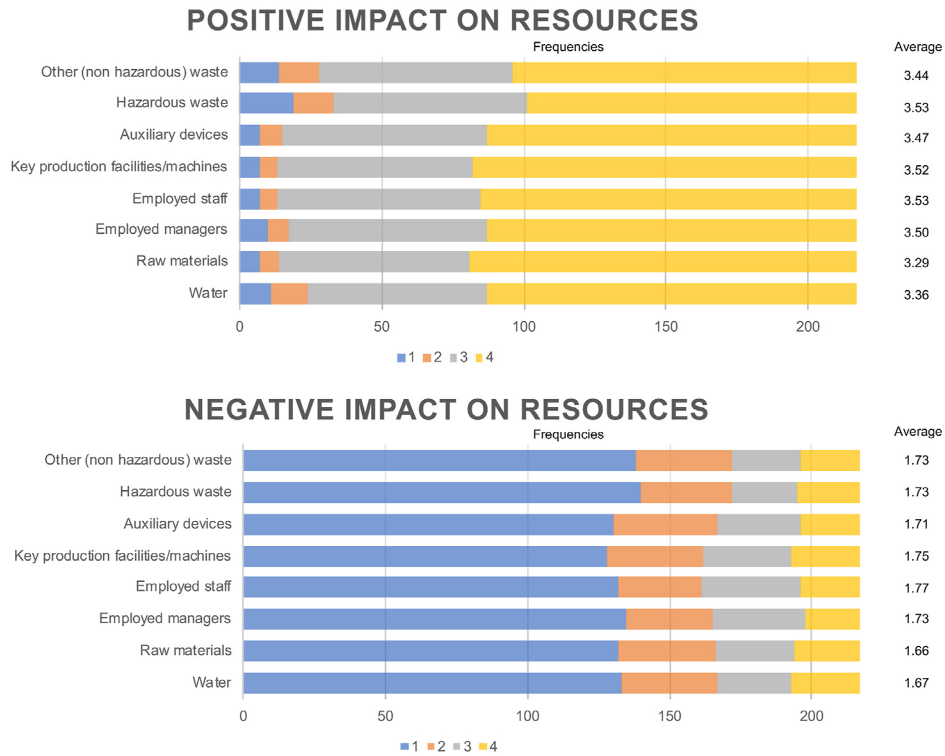

Fig. 3. Whole sample – Frequencies of responses to willingness to adopt an EEM should it have a positive (upper part) or negative (lower part) impact on other production resources.

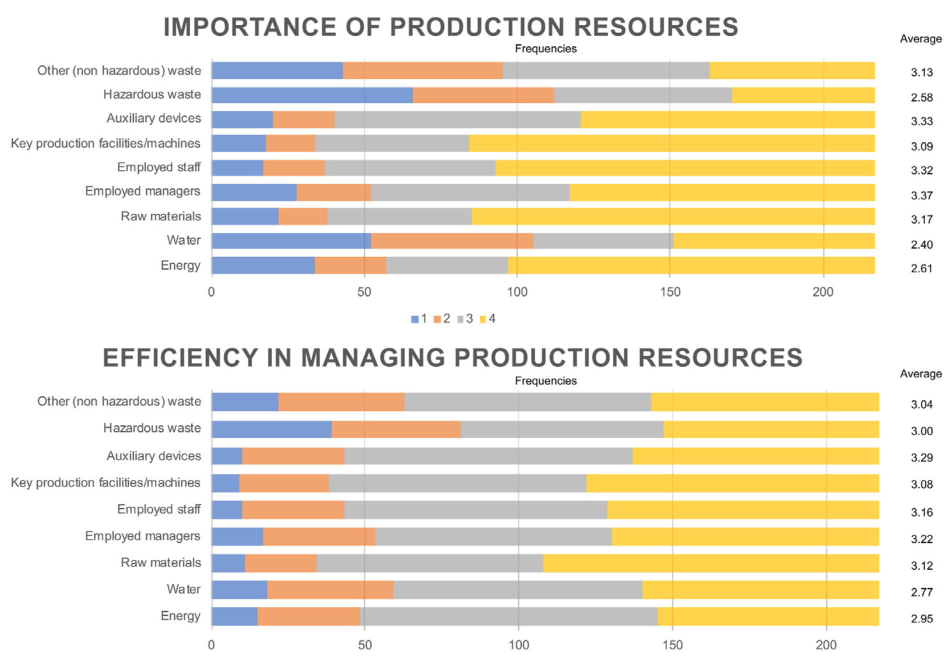

Fig. 4. Whole sample – Frequencies of responses of the importance (upper part) and efficiency in managing (lower part) considered production resources.

managing the resource seems higher than the importance they deem the resource to have, thus seeming to point out that efforts are more than adequate, energy included (importance of 2.61/4, efficiency of 2.95/4).

3.2.1. Correlation analysis

We have also performed a correlation analysis between different variables that have been investigated, so to highlight possible links. Given the exploratory nature of our study, we have marked correlation values respectively equal or higher than 0.75 (in *italics*) and 0.9 (in **bold**) to highlight only major correlations, taking inspiration from previous literature (Cagno et al., 2017).

Firstly, we have analysed the correlations between the importance and the efficiency in managing the production resources (Table 1). We can note that all production resources are positively correlated. By looking at the importance of resources, we can appreciate some relevant correlations (with values higher than 0.75), in particular, the relationship between raw materials – key production facilities/machines (0.8), employed staff - key production facilities/machines (0.8), key production facilities/machines - auxiliary devices (0.78), energy - raw materials (0.77) and employed manager - staff employed (0.76). The results look logical, in the sense that they seem to link on the one hand the coordinated importance of the production resources more closely connected to the production technologies (either for core processes and ancillary systems), on the other hand the workforce (shop floor as well as production management and coordination), followed by two important environmental resources (energy and raw materials).

By looking at the efficiency in managing the resource, several important correlations may be appreciated. From our exploratory research, several resources seem to be correlated to the efficiency in managing key production facilities/machines, such as the correlation with auxiliary devices (0.89), with employed staff (0.86), as well as with raw materials (0.8). Additionally, we can note strong relationships between the efficiency in managing auxiliary devices, with staff (0.84), raw materials (0.78) and energy (0.76) resources, respectively. Further, we can note additional correlations between employed managers and staff (0.82), raw material – employed staff (0.76), energy - water (0.76) and energy - raw material (0.75). Such findings, that look rational, can be explained with the use of such resources in production operations, such as maintenance procedures.

In a nutshell, employed staff, auxiliary devices and energy present several correlations with the other production resources. As a conclusion, our exploratory findings seem to reveal that, in order to be more efficient in a resource that is deemed as important (e.g., energy), it is not sufficient to intervene on the resource itself (e.g., through the implementation of EEMs), but also on other production resources that have an impact and may affect that resource.

By looking at the cross-correlation between the importance and the efficiency in managing the resource, with a look at single resources, in the analysis of the whole sample we cannot find particularly high values. Therefore, the absence of such high correlation seems to indicate a non-homogeneous perception between the importance of a specific resource with the capability of managing it efficiently.

We have also performed a correlation analysis between the willingness to adopt an EEM should it have a positive or negative impact on production resources (Table 2). By looking at the negative and positive impacts stemming from the adoption of an EEM, values are quite correlated. Concerning negative impacts, in many cases the correlation coefficient is higher than 0.9 (with some exceptions being for hazardous waste and other waste). Regarding the correlation between positive impacts, we can note several cases with values higher than 0.75. Among them, several impacts are related to the employed staff and key production facilities/machines, with very high correlation values (greater than 0.9). Lower correlations can be noted for hazardous waste (and, partially for other waste and water). Finally, the positive impact on machines and staff is highly correlated to materials and ancillary.

To sum up our analysis for the whole sample, the negative impacts seem to be low (on average) and highly correlated, whilst the positive ones are much higher and with correlations on a more focused and limited set of production resources. In conclusion, in order to promote energy efficiency, our exploratory findings seem to suggest that it is important to look at the multiple effect on a set of other resources in the operations, and particularly to those closer to the production (shop floor).

3.3. Analysis by clusters of enterprises

We have explored whether two important contextual factors, such as firm size and energy intensity, could be related to differences in the attitude of companies to recommend the adoption of an EEM in case of positive/negative impact on other production resources, also in light of possible differences in the importance (and efficiency) in managing a given production resource.

By looking at the firm size (Fig. 5 and Fig. 6), at first sight we cannot appreciate substantial differences. However, we can note that small companies seem to be slightly more positive in recommending an EEM in case of negative impacts and, on the contrary, slightly less positive in recommending an EEM in case of positive synergies with other production resources. However, it should be noted that differences are indeed minimal at this preliminary investigation and do not allow for more robust considerations, however offering an interesting avenue for further research. Similarly, this first investigation does not seem to show large differences according to firm size when it comes to consider both the importance and the efficiency in managing a given production resources. It should be noted that when analysing barriers and drivers to the adoption of an EEM several differences results when size changes in SMEs (Trianni and Cagno, 2012; Cagno and Trianni, 2013).

We have also tried to look at possible differences in companies according to an important element for decision-making purposes about EEMs, such as energy intensity (Fig. 7 and Fig. 8). The very first – and somewhat unexpected – finding is the lack of a substantial difference among the two clusters (EI and NEI companies). Indeed, both by looking at average values, as well as frequencies, regarding the recommendation to adopt an EEM should it bring positive (or negative) impact on other resources, differences are very small. Similarly, regarding the importance of production resources, we cannot appreciate large differences between the two clusters. However, it is worth noting that EI sampled companies seem to show a general greater importance of the production resources, in particular when it comes to consider water, raw materials and key production facilities/machines. Furthermore, despite differences are minimal and our preliminary findings call for additional research, EI companies seem to point out in general a lower perceived efficiency in managing production resources.

4. Discussion

We have conducted a first-of-a-kind investigation by exploring the willingness to adopt an EEM in light of possible positive/negative impact on other production resources. Our findings reveal that deepened knowledge and understanding of the impacts of EEMs in production is extremely important and so far neglected. In previous research, we can find valuable attempts to monetise the productivity benefits and displayed through CSCs, such as Worrell et al. (2003) and Pye and McKane (2000). However, their approach is limited to a very specific context and hard to be extended elsewhere, due to a number of reasons. To begin with, our study allowed to clearly point out a multitude and variety of either positive or negative impacts, which has not been acknowledged by previous literature. Further, quantitatively monetising the impacts by means of CSCs may look inadequate due to the size of the investment needed or due to the amount of information to be collected and processed, representing another barrier (Rohdin and Thollander, 2006; Trianni and Cagno, 2012). Additionally, the quantification and monetisation of the impacts could be affected by a severe uncertainty in accounting energy consumption and

Table 1
Whole sample – Correlation analysis between perceived recommendation according to negative-positive impact of EEM on production resources.

		IMPORTANCE of Resources									EFFICIENCY in Managing resource								
		Energy	Water	Raw materials/ material	Employed managers	Staff employed	Key production facilities/ machines	Auxiliary devices	Hazardous waste	Other (non haz waste)	Energy	Water	Raw materials/ material	Employed managers	Staff employed	Key production facilities/ machines	Auxiliary devices	Hazardous waste	Other (non haz waste)
IMPORTANCE of Resource	Energy	**1.00**																	
	Water	0.54	**1.00**																
	Raw materials/ material	*0.77*	0.46	**1.00**															
	Employed managers	0.46	0.34	0.58	**1.00**														
	Staff employed	0.63	0.40	*0.75*	*0.76*	**1.00**													
	Key production facilities/ machines	0.70	0.42	*0.80*	0.62	*0.80*	**1.00**												
	Auxiliary devices	0.65	0.45	0.70	0.56	0.68	*0.78*	**1.00**											
	Hazardous waste	0.34	0.38	0.34	0.23	0.27	0.31	0.33	**1.00**										
	Other (non haz waste)	0.51	0.38	0.49	0.42	0.43	0.48	0.54	0.69	**1.00**									
EFFICIENCY in Managing resource	Energy	0.37	0.20	0.37	0.35	0.46	0.46	0.47	0.07	0.19	**1.00**								
	Water	0.26	0.26	0.30	0.34	0.38	0.38	0.38	0.04	0.18	*0.76*	**1.00**							
	Raw materials/ material	0.32	0.16	0.45	0.42	0.53	0.52	0.44	0.03	0.18	*0.75*	0.64	**1.00**						
	Employed managers	0.30	0.16	0.34	0.61	0.47	0.40	0.40	0.13	0.30	0.65	0.62	0.68	**1.00**					
	Staff employed	0.40	0.17	0.43	0.45	0.58	0.50	0.49	0.10	0.25	0.73	0.62	*0.76*	*0.82*	**1.00**				
	Key production facilities/ machines	0.39	0.25	0.44	0.38	0.54	0.55	0.45	0.11	0.24	0.73	0.61	*0.80*	0.71	*0.86*	**1.00**			
	Auxiliary devices	0.41	0.23	0.40	0.38	0.49	0.52	0.51	0.11	0.30	*0.76*	0.61	*0.78*	0.72	*0.84*	*0.89*	**1.00**		
	Hazardous waste	0.27	0.23	0.25	0.28	0.30	0.26	0.24	0.42	0.34	0.45	0.48	0.41	0.54	0.54	0.53	0.55	**1.00**	
	Other (non haz waste)	0.40	0.26	0.35	0.40	0.39	0.40	0.40	0.23	0.42	0.56	0.56	0.57	0.65	0.66	0.65	0.69	0.74	**1.00**

Table 2
Whole sample − Correlation analysis between perceived recommendation according to negative-positive impact of EEM on production resources.

		NEGATIVE impact of EEMs on Resources								POSITIVE impact of EEMs on Resources							
		Water	Raw materials/ material	Employed managers	Staff employed	Key production facilities/ machines	Auxiliary devices	Hazardous waste	Other (non haz waste)	Water	Raw materials/ material	Employed managers	Staff employed	Key production facilities/ machines	Auxiliary devices	Hazardous waste	Other (non haz waste)
NEGATIVE Impact on production resources	Water	**1.00**															
	Raw materials/ material	**0.94**	**1.00**														
	Employed managers	**0.90**	**0.93**	**1.00**													
	Staff employed	**0.92**	**0.93**	**0.97**	**1.00**												
	Key production facilities/ machines	**0.93**	**0.95**	**0.94**	**0.96**	**1.00**											
	Auxiliary devices	**0.93**	**0.94**	**0.92**	**0.94**	**0.95**	**1.00**										
	Hazardous waste	*0.86*	*0.85*	*0.88*	*0.89*	*0.89*	**0.90**	**1.00**									
	Other (non haz waste)	**0.90**	***0.90***	**0.91**	*0.89*	*0.89*	**0.94**	**0.94**	**1.00**								
POSITIVE Impact on production resources	Water	0.08	0.09	0.06	0.04	0.07	0.10	0.13	0.13	**1.00**							
	Raw materials/ material	0.11	0.12	0.09	0.08	0.11	0.08	0.10	0.09	0.84	**1.00**						
	Employed managers	0.08	0.09	0.14	0.11	0.11	0.09	0.09	0.09	0.71	*0.75*	**1.00**					
	Staff employed	0.09	0.09	0.12	0.11	0.12	0.10	0.09	0.07	0.73	*0.84*	**0.92**	**1.00**				
	Key production facilities/ machines	0.11	0.12	0.11	0.11	0.12	0.10	0.09	0.09	*0.75*	*0.86*	*0.87*	**0.97**	**1.00**			
	Auxiliary devices	0.11	0.08	0.07	0.06	0.07	0.09	0.09	0.09	0.73	*0.83*	*0.86*	**0.94**	**0.94**	**1.00**		
	Hazardous waste	0.00	0.01	0.03	0.05	0.04	0.00	0.14	0.08	0.64	0.62	0.55	0.61	0.63	0.66	**1.00**	
	Other (non haz waste)	0.01	0.01	0.03	0.07	0.06	0.00	0.07	0.10	0.68	0.64	0.68	0.71	0.72	*0.78*	*0.84*	**1.00**

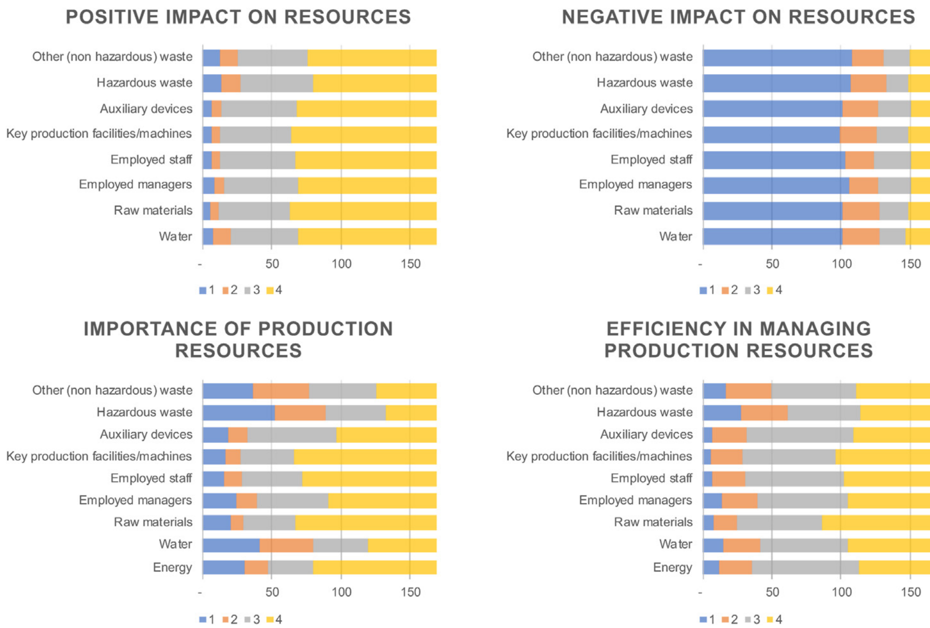

Fig. 5. Small enterprises – Frequencies of responses for the investigated items Willingness to adopt an EEM should it have positive – upper part/left -, negative – upper part/right, importance of production resources – lower part/left, efficiency in managing production resources – lower part/right.

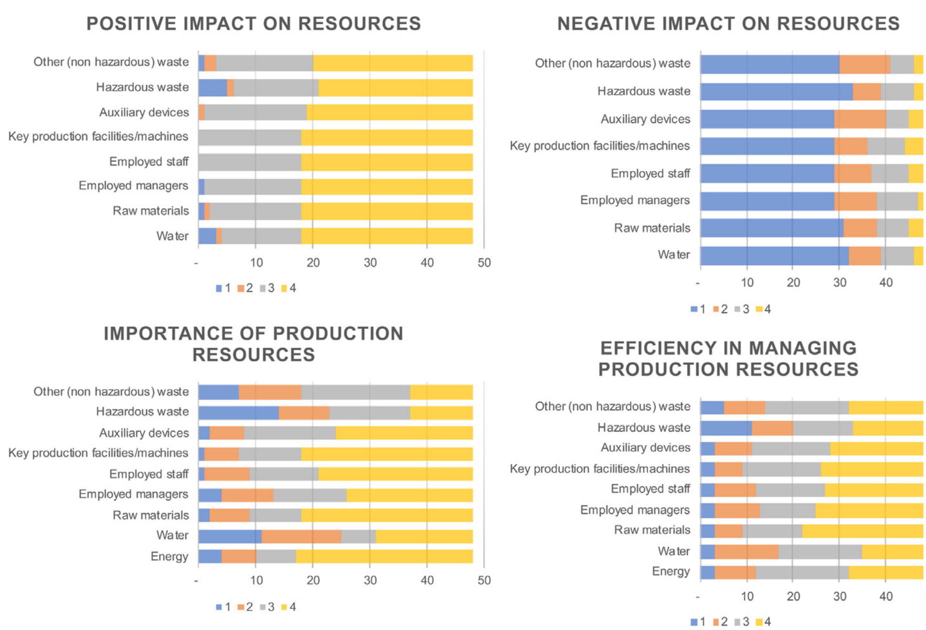

Fig. 6. Medium enterprises – Frequencies of responses for the investigated items Willingness to adopt an EEM should it have positive – upper part/left -, negative – upper part/right, importance of production resources – lower part/left, efficiency in managing production resources – lower part/right.

expenditures, thus differently from Akan et al. (2019). In this regard, as recently reviewed by Mickovic and Wouters (2020), providing accurate and detailed information of energy expenditures and how they are allocated, still represents a major hurdle for most companies, especially SMEs.

Still, more detailed knowledge about such positive impacts can play an important qualitative role in investment decisions (Nehler and Rasmussen, 2016): if on the one hand our empirical findings seem to confirm previous research (Sola and Mota, 2020), on the other hand also extends the range of impacts to negative implications, neglected by most of previous energy efficiency literature. In this regard, only a very limited number of studies have discussed negative impacts (Cagno et al., 2016), and our study represents the first empirical investigation exploring the adoption of EEMs in case of negative implications on other production resources, despite "net positive and negative" impacts should be incorporated in EEMs decisions (Skumatz and Gardner, 2005). In fact, our findings seem to highlight that companies do consider the impact on other production resources when assessing the implementation of an EEM.

Hence, despite the growing interest in and attention to energy efficiency in manufacturing, other resources should be carefully considered. To this extent, our findings give a genuine contribution to the academic discussion not only in the industrial energy efficiency literature, but also in other streams more focused on eco-

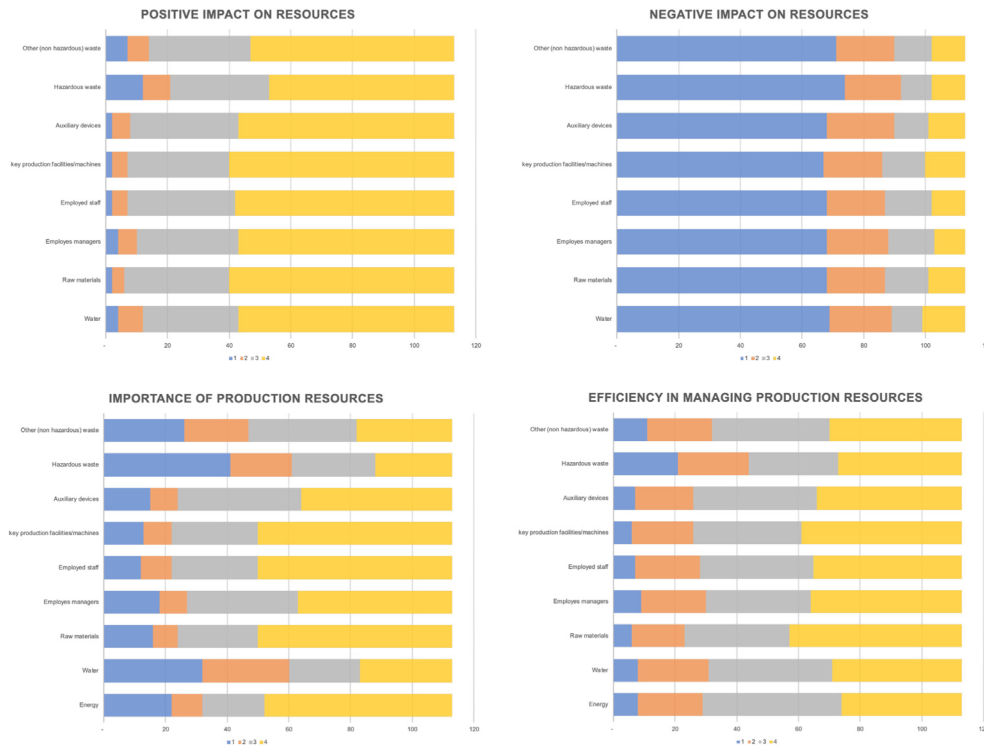

Fig. 7. Non-energy intensive companies – Frequencies of responses for the investigated items Willingness to adopt an EEM should it have positive – upper part/left -, negative – upper part/right, importance of production resources – lower part/left, efficiency in managing production resources – lower part/right.

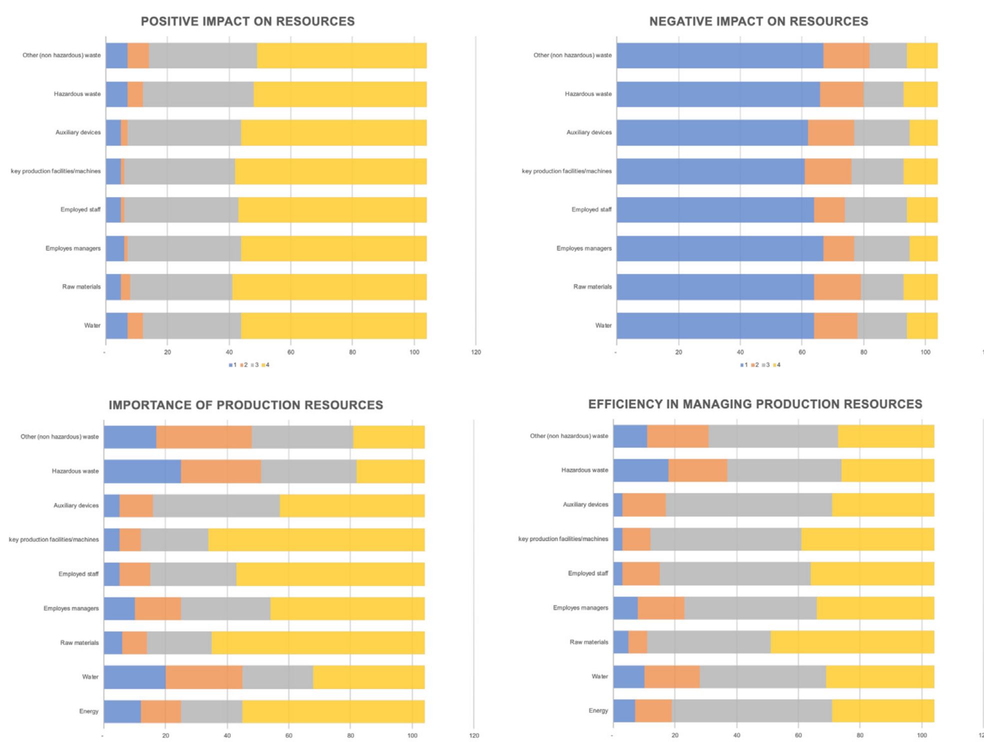

Fig. 8. Energy intensive companies – Frequencies of responses for the investigated items Willingness to adopt an EEM should it have positive – upper part/left -, negative – upper part/right, importance of production resources –lower part/left, efficiency in managing production resources – lower part/right.

efficiency and sustainable manufacturing (Bhatt et al., 2020). We can see that in such areas several approaches have been developed, although with a different perspective, more oriented to the specific production process than industrial operations (Duflou et al., 2012; Zhou et al., 2016). Earlier, Li et al. (2012)in developing an integrated approach to evaluate eco-efficiency within manufacturing processes, highlighted the relevance of linking energy efficiency to other production resources, as also noted by Herrmann and Thiede (2009). More recently, the relationship between energy efficiency and other resources is becoming quite interesting for research, also thanks not only to the opportunities offered but also the challenges posed by Industry 4.0 (Diaz et al., 2019). Authors seem to also start exploring the synergies between more efficient use of production resources and benefits in terms of increased efficiency and sustainability (Siegel et al., 2019), spanning from a variety of resources, including staff and operators (Thakur and Mangla, 2019). However, also thanks to the contribution offered in the present study, it seems clear that further research in this domain is needed, with holistic approaches aimed at accounting for the variety of resources and their multiple interdependencies. In doing so, our findings seem to highlight the need to extend the view to the industrial operations taking inspiration from extant approaches such as, e.g., energy value stream mapping (Bogdanski et al., 2013) that are quite production process-centred (Müller et al., 2014). Additionally, the present research seems to highlight the need to further integrate energy management information into companies' existing information systems, in order to best support decision-makers in undertaking more aware decisions (Bevilacqua et al., 2017; Effenberger and Hilbert 2018), in light of the opportunities and challenges related to the internet of things (Sisinni et al., 2018).

The lack of significant differences across the two clusters (EI-NEI) is unexpected and new compared to extant literature contributions in this field. Despite our investigation is exploratory and more research is needed in this area, findings seem to suggest that, even for energy-intensive activities, companies do pay very much attention when the adoption of an EEM could bring negative impacts on other production resources. Our findings somewhat differ from previous research: earlier studies noted that for EI companies energy efficiency was perceived as an issue with higher priority, therefore indicating lower barriers in implementing EEMs (Trianni and Cagno (2012). However, it should be remarked that research questions in those studies were different, and a specific focus on other production resources was not made, thus representing a further element of novelty of the present study.

Our results could also shed new light on the discussion over barriers to energy efficiency, that have been largely modelled by previous literature (Sorrell et al., 2004; Cagno et al., 2013) and have been largely investigated in energy-intensive sectors. In this regard, research has discussed barriers to energy efficiency in foundries (Trianni et al., 2013a,b,c; Rohdin et al., 2007) as well as pulp and paper (Thollander and Ottosson, 2008), but also more recently in cement industry (Zuberi and Patel, 2017). Further, empirical evidence can be found also for non-energy intensive sectors (Rohdin and Thollander, 2006). In particular, previous studies have largely discussed the bounded rationality barrier, arguing that decisions may not be made by individuals as assumed by economic models, rather subject to constraints on attention and means to support decisions (e.g., time and money), as well as the ability to process information (Sorrell et al., 2004; Cattaneo, 2019). Our findings do not contradict any previous theory related to *bounded rationality* barrier that, as widely discussed by valuable research, may be an important barrier (Hobman et al., 2016; Laibson and List, 2015). However, in contexts where high complexity and high information costs – two typical conditions when bounded rationality barrier is high (Sorrell et al., 2004) –, companies may widen their considerations looking at EEMs with impact on other resources, even if energy represents a considerable resource for their competitiveness. Therefore, our exploratory findings seem to suggest that the low implementation rate of EEMs highlighted by previous studies (Anderson et al., 2004; Cagno and Trianni, 2012) and the widely discussed existence of an energy efficiency gap (Jaffe and Stavins, 1994; Backlund et al., 2012), may be due to a sufficient lack of consideration of the impact that EEMs have on other production resources, not necessarily an issue related to bounded rationality. Indeed, this represents an important, yet preliminary finding emerged thanks the innovative approach conducted in this study, that has looked at the willingness of adoption an EEM in case of a negative impact on other production resources.

5. Conclusions

Our exploratory investigation in manufacturing Slovenian SMEs has allowed drawing several interesting conclusions. First, companies, regardless of their energy-intensity, do pay attention when considering the adoption of an EEM to the impact this may have on other production resources. Second, the findings from our exploratory research seem to point out the need to further investigate productivity impacts from the adoption of an EEM, so to better assess their performance. Third, but partially related to the second, our findings point out that measuring (in broader sense) the impact of EEMs would be really crucial also for research and policy-making purposes to have a better understanding of a more realistic energy efficiency gap and related barriers to the implementation, rather than merely blaming industrial final users from not undertaking energy efficiency investments that are energy efficient and just outwardly economically efficient, due to a limited consideration of their impact on other important production resources. Fourth, our findings could also contribute to the discussion over incentive schemes for EEMs. Indeed, as recent research has analysed (Franzò et al., 2019), the adoption of EEMs and related services has deeply revised the whole energy efficiency market, with a change in terms of stakeholders, players and role. Therefore, it would be interesting to analyse possible incentive schemes according to different impacts of EEMs on production resources, so to better tune policies in support of EEMs by promoting those with largest positive implications on other production resources. This could be done by, e.g., offering additive or multiplicative factors leading to additional financial or economic incentives in case of proven positive sustainability-related implications. Otherwise, it could be done by prescribing the adoption of EEMs with proven positive effect especially on social and environmental sustainability dimensions. As a very recent research analysing a number of industrial energy efficiency programs has pointed out, "hybrid approaches addressing financial, managerial and behavioural aspects of energy efficiency improvements" appeared as an effective approach (Safarzadeh et al., 2020).

We would like to acknowledge a few limitations of our study. To begin with, we were unable to interview multiple people in the company so to gather multiple perspectives from the same company and possible misalignments. Further, our investigation has been limited to a very specific context, Slovenia, that may not reflect other differently developed and industrialised contexts and regions. With respect to this, the study opens several opportunities for further research, by analysing other contexts and how other contextual factors (such as the presence of an energy manager) may affect the considerations from the companies. Additionally, our research is limited by asking in general terms whether a company would adopt an EEM should it have a positive/negative impact on another resource, without neither distinguishing amongst the variety of EEMs, nor whether this would vary according to a more (or less) severe impact (either positive or negative) on a given production resource. Finally, we have limited our investigation to SMEs, and in this preliminary study we could not appreciate any major difference between smaller enterprises and medium ones, differently from previous research dealing with barriers to energy efficiency in SMEs where some differences could be noted, as discussed earlier.

In conclusion, we would like to sketch some further research avenues related to our study. First, a future study could extend the scope of the investigation to larger enterprises, characterized by more complex organisational structures, so to grasp a better understanding of different perceptions in the relationships between EEMs and other production resources according to firm size. Likewise, a deeper investigation could shed light on different perceptions according to other contextual factors such as industrial sector, presence of an energy manager, ISO140001 and or ISO 50001 certifications, etc. Secondly, future studies should focus more on the quantification of the impacts between EEMs and other production resources, for EEMs requiring either technological, behavioural, or managerial changes. In particular, we can note that scarce attention has been given yet to industrial energy management, with a number of energy management practices such as maintenance of technological equipment that, by nature, has several implications beyond energy consumption itself, affecting reliability, plant availability, noise, etc. Thirdly, further research could explore the impact of EEMs adoption on production resources mapping out the possible links between EEMs and resources by means of the operational performance. Fourthly, future research could better explore the impact of EEMs on industrial operations by looking at the opportunities offered by industry 4.0. As earlier discussed, some contributions are emerging, but the academic debate is yet far from being mature. Advanced knowledge in these areas would be extremely needed by industry and policy-makers in order to further boost cleaner production, competitiveness as well as the sustainability of industrial activities.

CRediT authorship contribution statement

A. Trianni: Conceptualization, Methodology, Visualization, Investigation, Writing - review & editing. **E. Cagno:** Conceptualization, Methodology, Visualization, Investigation, Writing - review & editing. **J. Dolšak:** Conceptualization, Methodology, Visualization, Investigation, Writing - review & editing. **N. Hrovatin:** Conceptualization, Methodology, Visualization, Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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