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How important are perceived barriers and drivers versus other contextual factors for the adoption of energy efficiency measures: An empirical investigation in manufacturing SMEs

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ABSTRACT: This study examines determinants of adoption of energy-efficiency measures (EEMs) in small and medium-sized enterprises (SMEs) in the manufacturing sector, where the energy-efficiency gap is more likely to persist ac- cording to findings in previous literature. By simultaneously examining the relevance of multiple groups of perceived barriers and drivers and several other objectively measurable contextual factors, this research aims to fill the noted gap in econometric evidence. Discrete choice models are applied to a representative sample of 220 Slovenian manufacturing SMEs, comprising 10% of all manufacturing SMEs in the country to validate the relevance of barriers and drivers for both past adoptions of EEMs and firms' plans for adoption in the future. In line with previous empirical findings, results show that economic incentives, namely cost reductions for past investments and the potential for energy savings for future investments, are among the key drivers, while limited financial resources in more indebted firms blocked decisions to implement EEMs. Interestingly, energy- efficiency-related determinants play a more significant role than other self-perceived barriers and drivers. The importance firms place on energy efficiency, running energy-efficiency awareness programs for employees in the firms and obtaining information through external advice or energy audits triggered past company investments. Energy-intensive and innovative firms that are more aware of the importance of energy efficiency and those that have carried out investments in the past are more prone to adopt EEMs in the future, also confirming the path- dependency of energy efficiency activities. Lessons for policy-makers and managerial implications lie in spreading awareness about energy efficiency among managers and employees, building competence, and providing information on the potentials for energy efficiency improvements and on the availability of public and private funds.

Keywords: Energy efficiency measures; Barriers; Drivers; SMEs; Manufacturing; Discrete choice models

1. Introduction

Energy efficiency, globally recognised as one of the policy priorities on the path to a carbon-neutral society, is one of the seven building blocks of the EU energy and climate policy (European Commission, 2019), part of the Getting to Zero US policy agenda (Center for Climate and Energy Solutions, 2021), and in China's path to a carbon-neutral society by 2060 (Chen et al., 2020). Almost half of the reported energy-efficiency measures (EEMs) in the EU member states' national energy and climate action plans are, for example, linked to decarbonisation, indicating the strong interaction between these two dimensions of the EU Energy Union (Economidou et al., 2020).

The potential impacts of energy-efficiency improvements have extended well beyond its key role in economic and social development. They encompass various benefits for stakeholders and in different spheres under the umbrella of multiple benefits (International Energy Agency, 2019), providing additional incentives to reduce the well-documented persistence of the energy-efficiency gap (Jaffe and Stavins, 1994; Allcott and Greenstone, 2012; Gerarden et al., 2017). In this context, industrial energy efficiency has been of particular interest to academics, researchers, managers, and policy-makers. Several theoretical taxonomies tried to explain the nature of potential barriers that hinder investments, while empirical studies attempted to validate their impacts in firms, industries, and countries. On the other hand, it was also acknowledged that certain drivers contribute to overcoming the energy efficiency gap.

While existing literature explores barriers and drivers in specific industries, particularly in larger and energy intensive companies, SMEs deserve special attention due to several distinctive features. These features include the saliency of individual beliefs and values associated with the concentration of management functions, the lack of time and technical skills to address energy-efficiency opportunities and process needed information (Fawcett and Hampton, 2020), the large untapped potential for energy savings due to fewer resources available for energy monitoring and energy-efficiency projects, and energy receiving lower management priority (Mickovic and Wouters, 2020).

The role of SMEs in the global economy is vital as they account for a large proportion of all businesses and employ around 60% of the labour force (International Energy Agency, 2017). SMEs are responsible for more than 13% of final energy consumption and could save up to 30% of energy through cost-effective EEMs (International Energy Agency, 2015). Their true potentials, however, are difficult to assess due to the lack of energy consumption data (Fresner et al., 2017; Mickovic and Wouters, 2020), which calls for a harmonised general taxonomy of bottom-up data collection at local, national, and international levels (Thollander et al., 2015).. As many SMEs, operate in non-energy-intensive sectors, and therefore their interest in energy-saving measures may be discouraged by low energy bills, high risk, and the capital-intensive nature of energy-efficiency investments, more research is needed to reveal barriers in this area to prevent growing energy consumption and carbon emissions associated with insufficient interest paid to non-energy-intensive sectors (Ramírez et al., 2005). This is even more true as policies in the EU member states have induced the highest energy savings in the industrial sector, but mostly in industries with a relatively small number of operators and with high energy-intensive plants (Bertoldi and Mosconi, 2020).

Improving energy efficiency in SMEs not only significantly reduces overall final energy consumption, but also increases their profitability and competitiveness (International Energy Agency, 2015), contributes to cleaner production through large reductions in greenhouse gas (GHG) emissions (Nadel and Ungar, 2019), and to broader policy objectives (IEA, 2015). This paper examines barriers and drivers to the adoption of EEMs in manufacturing SMEs, which appear to be large users of industrial energy, ranging from 50% in the US to 70% in Italy, consuming 50% of electricity in Australian businesses and 2.5 times the energy consumption of large manufacturing enterprises in China (IEA, 2015).

Many empirical studies have tried to validate barriers and drivers in manufacturing SMEs, mainly using descriptive/statistical analyses, while econometric studies seem less represented. They have been analysing the relevance of determinants of EEMs adoption from different perspectives and in various contexts either by looking at different barriers to EEMs adoption in individual sectors (Schleich and Gruber, 2008) or by focusing on the relevance of a limited number of barriers (Kostka et al., 2013), also reduced to principal components (Cantore, 2017; Fleiter et al., 2012). Studies sometimes encompass also non-industrial firms (e.g., Schleich and Gruber, 2008; Schleich, 2009; Fleiter et al., 2012). Often, research is limited only to companies that have participated in publicly funded audit programs (Anderson and Newell, 2004; Abadie et al., 2012, Blass et al., 2014, Fleiter et al., 2012). Another stream relates the diffusion of EEMs to the managerial context, seeking to establish the link between the involvement of managers at different levels and the EEMs acceleration (Blass et al., 2014) or the impact of management practices on energy intensity as a proxy for energy (in) efficiency (Boyd and Curtis, 2014). It has been noted that the research neglected the role of drivers in favour of barriers and has focused only on a few barriers rather than examining the impact of multiple barriers and drivers (Meath et al., 2016). This paper aims at overcoming the noted gap in empirical work by applying a more systematic and comprehensive approach to examine both sides, the multiple barriers and drivers that enable or impede the adoption of EEMs, simultaneously.

Econometric analysis has been employed to identify relevant factors of the decision to adopt EEMs on a representative sample of 220 firms, covering 10% of all firms in the manufacturing industry in Slovenia, which ensures generalisability of the results in this research setting. Factors (barriers and drivers) for the models were selected from theoretical taxonomies and empirical evidence for SMEs, mainly in the manufacturing sector. This research is particularly interested in establishing the importance of perceived as opposed to objectively measurable or "real" barriers in deterring firms from adopting EEMs. A similar approach is pursued to check the validity of potential drivers in promoting EEMs. Econometric analysis is particularly useful in considering these relationships because it examines the role of potential influencing factors simultaneously rather than observing their effects partially or sequentially, as often done in previous studies. While some earlier studies try to distinguish between perceived and objective (real) barriers in the econometric (Fleiter et al., 2012) and statistical (Trianni et al., 2013b) frameworks, this is among a few attempts to apply a more systematic and comprehensive approach in exploring the simultaneous impact of both barriers and drivers, objectively measured (real) or perceived, on the adoption of EEMs in manufacturing SMEs.

Another contribution of this study relates to the fact that it separately examines past energy-efficiency investment behaviour and the relevance of factors, barriers and drivers, to the future adoption of EEMs. In this way, not only possible differences in the relevance of investigated factors for past and planned adoption of EEMs could be determined but also whether there is a path-dependency in the way that past EE investment decisions trigger future EE investments.

The paper is organised as follows. Section 2 covers the literature review with the presentation of a theoretical background of the study and empirical findings on the barriers and drivers for the adoption of EEMs in SMEs. The third section presents the econometric methods applied in the analysis, then proceeds with the explanation of arguments for the choice of variables in the models, drawing on theoretical taxonomies and empirical findings, and finally moves on to present the data collection and description. In the fourth section, the results of the econometric analysis for past and future adoption of EEMs are presented and discussed. Recommendations for policy design and future research are also elaborated. Finally, in the Conclusions, the research findings are briefly summarised.

2. Literature review

2.1. Energy efficiency gap and theoretical taxonomies of barriers and drivers

This paper draws on the energy efficiency gap, which is evident in reality in the insufficient adoption of energy-efficient technologies that are financially and economically justified for firms. A vast body of literature has been dealing with a theoretical explanation of this apparently irrational behaviour by consumers and firms, trying to find and classify barriers that prevent the adoption of EEMs and realisation of both energy efficiency and economic benefits. Building on the resource-based view of the firm (Hart, 1995), literature also acknowledged a crucial role of energy efficiency in boosting the competitiveness and sustainability of firms and industries (Haddad et al., 1998). Yet this link has somehow received more attention from the policy side (European Council for an Energy Efficient Economy, 2013) than in theory.

Theoretically, several explanations and taxonomies of barriers that slow down the adoption of EEMs have been proposed (e.g., Reddy, 1991; Weber, 1997; Reddy, 2002; Sorrell et al., 2000; Sorrell et al., 2004; Chai and Yeo, 2012; Cagno et al., 2013; Reddy, 2013).[1] Among the taxonomies, one of the pioneering concepts widely known among scholars comes from Sorrell et al. (2000). Taking an interdisciplinary approach from orthodox (neoclassical), transaction costs and behavioural economic theories, they have explained and classified barriers into the following groups: risk, imperfect information, hidden costs, access to capital, split incentives, and bounded rationality. In the attempt to make the groups of barriers more operational for empirical investigation, also avoiding their possible overlaps and implicit interactions, Cagno et al. (2013) proposed a new taxonomy with the following categories: economic, behavioural, organisational, barriers related to competence, awareness, technological, and informational. One of the most recent attempts to survey the theoretical and empirical literature on the energy efficiency gap is of Gerarden et al. (2017), who suggest three categories of explanations for the existence of the energy efficiency gap: (1) market failures, (2) behavioural explanations, and (3) modelling flaws. They have explained these categories by answering four fundamental questions and twenty-three sub-questions, mostly looking from the consumer side. As there is no unique consensus on the theoretical explanation of the energy efficiency gap and the taxonomy of barriers, this paper draws on Cagno et al. (2013), who adapted the pioneering taxonomy of Sorrell's et al. (2000) for empirical investigation in industrial firms.

Empirically, it was recognised that not only barriers but also drivers matter for accelerating the diffusion of EEMs in industrial firms. However, in distinction to barriers, less systematic theoretical foundations have been laid out for their explanation and categorisation. One of the first categorisations comes from Thollander and Ottosson (2008), who grouped them to market-related drivers, current and potential energy policies, and organisational and behavioural drivers. These groups were further supplemented by financial, informational, and external drivers (Thollander et al., 2013). In another more recent attempt by Trianni et al. (2017), four categories of drivers by type of action were suggested (regulatory, economic, informative, and vocational training) and were further subdivided into internal or external, depending on their origin. These groups contain various drivers drawn from the literature review, several of which are accounted for in our study.

2.2. *Summary of empirical findings*

Empirical research has examined the nature of determinants of energy-efficiency investments in different contexts, in relation to different firm characteristics (e.g., size, energy intensity), countries, and industries, also using different methodological approaches, often departing from taxonomies and taking a more pragmatic approach to their practical formulation and measurement. While a systematic empirical literature review has been conducted for drivers (Solnørdal and Foss, 2018), this has not been done in the same way for barriers, yet a number of works provide useful summary reviews for companies of all sizes (e.g., Fleiter et al., 2012; Brunke et al., 2014; Hrovatin et al., 2016; Trianni et al., 2016) and for specific countries (e.g., Johansson and Thollander, 2018).

Empirical studies, confined to energy efficiency improvements as a dependent variable, find two categories of internal drivers, firstly management, competence and organisation-related factors, and secondly, economic drivers, most prominent for manufacturing firms (Solnørdal and Foss, 2018). The two external categories, market forces (competition, information, and networks) and policy instruments seem to be less relevant. Less conclusive summary findings exist for barriers. This is why scholars (e.g., Fleiter et al., 2012 and Trianni et al., 2017) argue that barriers of various nature inside and outside the firm and their interdependencies, together with contextual factors, the nature of EEMs, and firm characteristics, obstruct firms from adopting EEMs. In terms of the frequency of their found importance in empirical studies, economic barriers related to non-market failures ranked first, followed by economic-market failures and organisational barriers, while behavioural barriers were reported more rarely (Hrovatin et al., 2016). Another review emphasises the relevance of internal barriers, such as management commitment or cost reduction through lower energy use, in combination with external barriers, such as public incentives and the threat of rising energy prices (Trianni et al., 2017).

When looking at studies in different methodological frameworks solely for SMEs, similar to all companies, large differences in the methodological approach, country, industry, and variable coverage could be observed, which makes comparisons a difficult task. Nonetheless, after careful consideration, economic barriers notably score high in terms of the frequency of their occurrence in previous work, especially high investment costs, lack of funding and/or access to capital, low profitability, and long payback periods. Energy price uncertainty and other risks seem to play a lesser role. Economic barriers are followed by behavioural (other priorities, lack of interest, top management commitment), organisational (lack of time, split incentives due to rented space, lack of an energy manager and energy management system), and informational barriers, while awareness, competence, and technology-related barriers are not perceived as prominent in most studies. Lack of regulations and policies are also not seen as having a great hindering role.

For manufacturing SMEs, the same order of importance emerges for drivers, with economic drivers again coming first, among which cost reductions from energy savings take the leading role. Other economic drivers are mostly reported in individual studies. The same is true for most other categories of drivers, which appear in the following order of relevance: behavioural, awareness, organisational, and informational. Regulation and policy drivers are mentioned as influential in only a few studies (Cagno and Trianni, 2013; Cagno et al., 2015, 2017), while technology and competence-related are in none. A review of econometric studies on EEMs adoption for SMEs covering firms in manufacturing is presented in Table A1 in the Appendix.

A more detailed explanation of individual barriers and drivers, their groups, and empirical findings about their impacts are given in Section 3.2, which provides the argumentation for the selection of variables.

3. Methods and data

This section first outlines the econometric methods used (in 3.1), then explains the selection of variables by looking at taxonomies of barriers and drivers and their validation in empirical studies (in 3.2), which is followed by the presentation of data collection and description of the sample (in 3.3).

3.1. *Econometric model*

For this analysis, discrete choice modelling (McFadden, 1976) is used, which is often applied to model the probability of decisions, especially in binary choice models. The relationship between the investment decision and factors that potentially influence that decision is typically modelled using various econometric models, such as linear probability, logit, and probit regression models. The linear probability model is defined as follows:

$$y_i = \beta X_i + \varepsilon \quad (1)$$

where X_i is a vector of explanatory variables, β is a vector of regression coefficients to be estimated, and ε is a random error term that is independently and normally distributed.

The study estimates two versions of the models. The first examines factors affecting past investment decisions to adopt EEMs (*past EEMs*),

[1] For a review of the theoretical background and explanation of taxonomy groups, see, e.g., Cagno et al. (2013) and Hrovatin et al. (2016). For a detailed explanation of theoretical grounds of Sorrell et al. (2000) taxonomy of barriers see also Sorrell et al. (2004) and Sorrell et al. (2011).

and the second identifies factors that may impact planned investment decisions (*future EEMs*). For *past EEMs*, the dependent variable y_i is a binary variable indicating the choice made. It takes the value of one if the firm has invested in EEMs in the last three years and zero otherwise. The dependent variable in the model for *future EEMs* is similarly defined with a value of one if the firm plans to implement EEMs in the next two years and zero otherwise. The explanatory variables in both versions consist of a wide range of relevant determinants of EEMs adoption identified in previous literature and explained in detail in Section 3.2.

The linear probability model might face heteroscedasticity problems, but in practice, this can be easily addressed by using a robust estimator (Chamberlain, 1980). Another problem with this model is that the estimated values of the dependent variable may take values outside the sensible range [0, 1], and the linearity property does not make much sense in the model conceptualisation. Both problems can be addressed by applying the logit probability model:

$$P(y_i = 1 | X_i) = \frac{e^{\beta X_i}}{1 + e^{\beta X_i}} \quad (2)$$

where $P(y_i = 1 | X_i)$ is the probability that the firm invested (or plans to invest) in energy efficiency.

For both *past* and *future EEMs*, the linear probability model and the logit model have been estimated, where the maximum likelihood method is applied to the latter.

3.2. Selection of variables

This study relies on theoretical premises and considers factors that have proven to be most relevant in empirical studies. A wide range of explanatory variables has been selected and categorised into three groups: 1*) firm and business-related characteristics*, 2) *energy and energy efficiency-related characteristics*, and 3*) perceived barriers and drivers*. Drawing on the empirical observation that there is a discrepancy in the impact of real and perceived barriers by firms, this paper addresses this issue by grouping all perceived barriers and drivers in a separate category to distinguish them from objectively measurable ones. By grouping real barriers in another two categories, firm and business-related and energy and energy efficiency-related, the analysis also touches on the resource-based perspective of the energy efficiency gap (Haddad et al., 1998), which underlines the differences between firms and industries in resource investments which could help identify the underlying barriers and bring diversity to policy suggestions. Nevertheless, in the selection of variables, it was ensured that all relevant categories from theoretical taxonomies have been covered, as seen in a summary of variables at the end of this section. Variables in these three groups and their measurement and descriptive statistics are presented in Table 1, while Fig. 2 presents frequencies and means of perceived barriers and drivers.

Empirically, there is no clear indication of the direction of impact of some company and business-related characteristics, such as firm *size*. Nagesha and Balachandra (2006) explicitly acknowledge the small size of firms in foundries and the brick and tiles sector act as a barrier to EEM adoption. This complements Kostka et al. (2013) that larger Chinese firms are more willing to invest in energy efficiency. Several studies typically distinguish between small and medium-sized firms. Medium-sized firms are expected to be more likely to invest due to the availability of resources, such as finance, competence, and time. Low capital availability, for example, has been explicitly identified as a barrier in smaller SMEs (Trianni et al., 2013b). Larger firms also have lower perceptions of time constraints (lack of time) and other priorities (Trianni and Cagno, 2012). In general, smaller firms tend to strongly perceive most barriers (Schleich, 2004; Cagno and Trianni, 2014). Firm size may also affect the perception of different groups of drivers (Cagno and Trianni, 2013). On the other hand, some studies have failed to confirm that size has an impact on SMEs (Schleich and Gruber, 2008; Schleich, 2009; Fleiter et al., 2012).

Table 1
Description of variables used in econometric models.

Variables	Variable description	Mean	St. dev.	Min	Max
Dependent variable Past EEMs	Binary; 1 = the firm adopted EEMs in the last three years, 0 = did not adopt	0.65	0.48	0	1
Future EEMs	Binary; 1 = the firm is planning to conduct at least one EEM in the following 2 years, 0 = does not plan	0.52	0.50	0	1
Company and business-related characteristics					
Size	Dummy, 1 = medium-sized firm, 0 = small firm	0.23	0.42	0	1
Profitability	ROA (return on assets, in %)	5.75	8.40	-43.55	51.81
Debt	Debt/total assets (in %)	48.58	27.94	2.64	223.75
Foreign market	Dummy; 1 = the firm sells mostly in foreign markets (EU or outside EU), 0 = if the firm sells most of its products in its region or in the Slovenian market	0.52	0.50	0	1
Competition	Dummy; 1 = the firm perceives moderate or strong competition, 0 = weak or no competition	0.92	0.27	0	1
Ownership of premises	Dummy, 1 = the firm owns premises, 0 = does not own premises	0.86	0.35	0	1
Innovativeness	Dummy; 1 = the firm invested in R&D in the last year, 0 = did not invest	0.42	0.49	0	1
Risk	Dummy; 1 = the firm evaluates its overall attitude to investment risk as moderate or nil, 0 = the firm is sensitive or very sensitive to the investment risk taking (risk averse)	0.20	0.40	0	1
Energy and energy efficiency-related characteristics					
Energy-intensity	Share of energy costs in total costs (%)	2.61	2.35	0	17.53
EE status	Dummy; 1 = the firm perceives EE equally or more important than other matters in the firm, 0 = less important	0.85	0.36	0	1
Energy person	Dummy; 1 = the firm has an expert or a trained person responsible for energy issues, 0 = does not have	0.21	0.41	0	1
EE importance in the future	Dummy, 1 = the firm thinks EE	0.51	0.50	0	1

(*continued on next page*)

Table 1 (*continued*)

Variables	Variable description	Mean	St. dev.	Min	Max
	importance will increase in the future, 0 = EE importance will decrease or remain the same				
Employee EE awareness raising	Dummy, 1 = the firm increases employees EE awareness, 0 = no)	0.83	0.38	0	1
EMS (Energy management system)	Dummy, 1 = the firm has a systematic approach to EE improvements, 0 = no such approach	0.40	0.49	0	1
Potential for energy savings	Dummy, 1 = very high or high, 0 = low or very low	0.35	0.48	0	1
Energy audit	Dummy, 1 = the firm obtained an external advice/audit, 0 = no	0.45	0.50	0	1
Perceived barriers and drivers					
Perceived barriers	Likert scale 1–4 (1 – not important, 4 – very important)				
High investment costs		3.22	0.84	1	4
Low return (on EE investments)		3.03	0.88	1	4
Competence-related		2.51	0.99	1	4
Informational		2.45	1.00	1	4
Behavioural		2.46	1.05	1	4
Technological		2.56	1.01	1	4
Organisational		2.54	1.01	1	4
Perceived drivers	Likert scale 1–4 (1 – not important, 4 – very important)				
Cost reduction (due to lower energy consumption)		3.44	0.73	1	4
Fear of rising energy prices		3.15	0.84	1	4
Ambition of managerial staff (in relation to EE)		3.19	0.80	1	4
Public funding		3.14	0.90	1	4
Legal requirements		3.16	0.81	1	4

The next two variables, *profitability* (i.e., return on assets - ROA) and *debt* (captured by the debt to assets ratio), reflect access to capital, either external or internal, which is one of the pillars in the taxonomy of barriers of Sorrell et al. (2000). Better performing firms would have more internal resources and better access to external funds that could be used for all types of investments, including energy-efficiency ones. Despite the general expectation that firms with higher profitability would face lower financial constraints and therefore be more inclined to adopt EEMs, empirical evidence for SMEs has failed to confirm this assumption, also because this variable is rarely seen among explanatory factors and is related to the difficulties in obtaining the data. Lack of budget funding/access to capital has been identified in several studies as a primary economic barrier for all firms operating in different sectors (Hrovatin et al., 2016), while studies on manufacturing SMEs lack evidence of its impact.

Another included variable, *ownership of premises,* is commonly used to capture another pillar of the taxonomy of barriers of Sorrell et al. (2000), namely split incentives that exist when the investor cannot appropriate the benefits of the investment in the case of rented premises. The ownership of premises would presumably trigger diffusion, as opposed to a rented space, a confirmed barrier in the metal sector (Schleich and Gruber, 2008; Schleich, 2009), and in woodworking and processing (Schleich and Gruber, 2008). On the other hand, larger and more energy-intensive companies with completed energy audits by engineering firms effectively mitigated this barrier (Schleich, 2004), or it was even found not to be a barrier (Fleiter et al., 2012).

Inspired by the theoretical taxonomy that recognises international competition as one of the three market-related drivers (Thollander and Ottosson, 2008) and empirical findings that emphasise its role (Thollander et al., 2007 - for Swedish manufacturing SMEs), the dummy variable *foreign market* is employed with the value of one if the firm sells the majority of its products abroad, either in the EU or non-EU markets. As strong *competition* creates incentives for energy-efficient behaviour (Trianni et al., 2013b), a possible effect of the strength of competition in the market is also investigated with the dummy variable taking the value of 1 if the firm perceives its market as moderately or strongly competitive.

Motivated by the behaviour of Italian SMEs (Cagno and Trianni, 2013) where more innovative firms are more proactive in adopting EEMs, the dummy variable *innovativeness* is included with a value of one if the firm has made investments in research and development (R&D) in the recent past. Product and process innovation, a more innovative external context, and more innovative firm markets reduce perceptions of barriers, although the effect may be heterogeneous and vary in magnitude across barriers (Trianni et al., 2013a). *Risk* is another important firm-specific factor that constitutes one of the pillars in taxonomies (e.g., Sorrell et al., 2000; Cagno et al., 2013). Not only can energy-efficiency investments pose a higher technical and financial risk, therefore requiring shorter payback periods and blocking adoption, but risk aversion can also discourage firms from considering energy-efficiency improvements.

In the second group, *energy intensity*, measured as the share of energy cost in total production costs, is assumed to accelerate investment decisions as more energy-intensive firms expect higher energy savings, which ultimately translates into lower energy costs. In some cases, empirical studies have confirmed this presumption (Kostka et al., 2013; Henriques and Catarino, 2016; Fresner et al., 2017), yet there is also some contrary evidence (Schleich and Gruber, 2008; Fleiter et al., 2012). Energy-efficiency awareness, someone responsible for energy in the firm, and the presence of an Energy Management System (EMS) in the company are among the important behavioural and organisational factors for the EEMs adoption. *EMS* in place, a constituent element of the Thollander and Ottosson taxonomy (2008), in practice acts as a driver (e.g., Thollander et al., 2007, for Swedish manufacturing SMEs), but its relevance may vary depending on firm size. For example, an *EMS* may be perceived as more important in smaller and non-energy-intensive Italian manufacturing SMEs (Cagno et al., 2017), or it may even hamper the diffusion of EEMs (e.g., in a sample of firms from Vietnam, the Philippines, and Moldova; Cantore, 2017).

Employing a person in charge of energy *(energy person)* in the company contributes to better information about energy use and costs, gives higher priorities to energy, and can provide better access to energy-efficiency experts, which are all considered important in the taxonomy of drivers (Cagno and Trianni, 2013). The absence of such person presents a barrier (Henriques and Catarino, 2016; Fresner et al., 2017) but may also have no effect, such as in German SMEs participating in the Sonderfonds energy audit program (Fleiter et al., 2012).

Raising employee awareness of energy efficiency helps spread a culture of energy efficiency in the company. This awareness could eventually lead to an increase in internal competence (Cagno and Trianni, 2013), assist in creating the environmental company profile as a further incentive for the adoption of EEMs (Thollander and Ottosson, 2008), and alleviate one of the biggest barriers – the lack of interest in energy efficiency (Trianni et al., 2013b). It could also boost diffusion, as staff working in the production process could come up with information and ideas on how to improve energy efficiency in existing procedures or by installing more efficient technologies (Fresner et al., 2017). On the other hand, according to empirical research, the lack of personnel awareness and management is not an obstacle (e.g., in Italian non-energy-intensive manufacturing SMEs; Trianni and Cagno, 2012). Similarly, in Vietnamese, Filipino, and Moldovan companies, running an employee awareness program does not significantly influence energy conservation measures (Cantore, 2017).

Energy audits, especially publicly funded ones, act as an energy policy instrument in the taxonomy of drivers (Thollander and Ottosson, 2008) with a confirmed positive role in many papers (Anderson and Newell, 2004; Cagno and Trianni, 2013; Paramonova and Thollander, 2016) and/or their quality (Fleiter et al., 2012). Their positive effects were also determined in the US publicly sponsored audit program (Tonn and Martin, 2000; Anderson and Newell, 2004; Abadie et al., 2012 and Blass et al., 2014) and recognised in German SMEs where they significantly reduced the strength of various barriers, particularly in engineering firms (Schleich, 2004). Publicly funded audits make audits affordable, especially for smaller firms, and help them recoup costs on smaller energy-efficiency investments (Fresner et al., 2017). Broader forms of energy advice that raise information on EEMs, such as information received at seminars, are also instrumental in encouraging companies to join energy-efficiency networks (Paramonova and Thollander, 2016). Energy audits thus help overcome information-related barriers of various kinds, which are crucial inhibiting factors in SMEs (Schleich, 2004; Trianni and Cagno, 2012; Kostka et al., 2013; Trianni et al., 2013a, 2013b; Cagno et al., 2015, 2017; Fresner et al., 2017).

In the models for *future EEMs*, the dependent variable from the models for *past EEMs* appears among explanatory variables, as past adoption in terms of path dependency, emerged stimulative for future energy-efficiency saving measures (Cantore, 2017). Learning by doing fosters capacity and competence building and reduces the cost of future adoption, spurring companies to make continuous improvements. The opposite countervailing effect may, however, also prevail if past investments have already exhausted potential energy-efficiency projects (Fleiter et al., 2012).

Drawing on the taxonomy of drivers (Thollander and Ottosson, 2008) and previous empirical research (Tonn and Martin, 2000; Anderson and Newell, 2004; Abadie et al., 2012), *potential for energy savings* should also not be ignored as an important enabler and are therefore accounted for in these econometric estimations. The same applies to two additional determinants, namely, the importance attached to energy efficiency in the firm relative to other matters (*EE status*) and the firm's expectations about its importance in the future (*future EE importance*). They appear to be important dimensions of an energy-efficiency climate, a constituent part of a cultural-institutional framework for energy-efficiency decision-making in industrial companies (König, 2020). Low priority of energy efficiency is a significant behavioural barrier that can distract companies from energy-efficiency activities (Fleiter et al., 2012), contribute to the lack of interest in EEMs (Trianni et al., 2013a), and push other priorities ahead, thereby making energy-efficiency activities less likely (Gruber and Brand, 1991; Thollander et al., 2007; Trianni et al., 2013a; Cagno and Trianni, 2014; Fresner et al., 2017). For this reason, appropriate motivational strategies are needed to address behavioural barriers (Henriques and Catarino, 2016).

Finally, the influence of the self-assessed importance of multiple groups of barriers and drivers is controlled by applying the categorisation of barriers of Cagno et al. (2013). Among economic barriers, the two with the highest mean scores have been considered (too) *high investment costs* and *low return* on energy-efficiency investments. High investment cost is the most frequently cited economic barrier in SMEs, as mentioned earlier (e.g., Anderson and Newell, 2004; Shi et al., 2008; Fleiter et al., 2012; Blass et al., 2014). Investment cost is closely followed by unsuitable return on investment, lack of profitability (e.g., Anderson and Newell, 2004; Fleiter et al., 2012), and high required profitability (Fresner et al., 2017). Other barriers include the following taxonomy groups*: competence-related, information, behavioural, technological, and organisational.*

In assessing the importance attached to different drivers, this research refers to Cagno and Trianni (2013) by distinguishing between internal and external drivers in terms of their origin. Those with high perceived importance and whose values vary sufficiently across firms have been selected for the estimation. Earlier empirical research has highlighted the significance of three internal drivers employed in this study: *cost reduction* due to lower energy consumption (e.g., Abadie et al., 2012; Cagno et al., 2015), *fear of rising energy prices* (e.g., Cagno and Trianni, 2013), and *ambition of managerial staff* regarding energy efficiency (e.g., Thollander et al., 2007; Cagno and Trianni, 2013). Current energy prices can also be a trigger for EEMs (Anderson and Newell, 2004), while there is no consensus on the role of energy price uncertainty in practice. Although it is likely to motivate energy-efficiency activities, evidence on SMEs suggests that it may also hinder uptake (Schleich, 2004 - in smaller SMEs; Fleiter et al., 2012) or be ineffective (Schleich and Gruber, 2008 and Schleich, 2009 - for possible variation in energy costs in the future).

External drivers, on the other hand, come from the market or are imposed by the policy. In this case, two important drivers with confirmed positive effects in the empirical literature (e.g., public financing, allowances or public energy-efficiency investment subsidies in Cagno and Trianni, 2013; Cagno et al., 2015 and Cagno et al., 2017) have been identified: *public funding* and *legal requirements.* Meanwhile, the lack of economic incentive policies, too lax enforcement of environmental regulations, and the lack of government support considerably reduce the propensity to consider EEMs adoption (Shi et al., 2008; Kostka et al., 2013). It is, therefore, surprising why EEMs are included in only a few national industrial stimulus packages (International Energy Agency, 2020).

In sum, the set of our explanatory variables covers most factors in established theoretical taxonomies. Regarding the barriers, perceived barriers capture all groups of the theoretical taxonomy of Cagno et al. (2013). In addition, economic barriers (*profitability* and *debt* that account for the access to capital, *ownership of premises* for split incentives, and *risk*), which can be objectively measurable, have been included in company and business-related characteristics. Considering drivers, all categories have also been included from the recognised taxonomy of Thollander and Ottosson's (2008): (1) market-related driving forces (*cost reduction* due to lower energy use, the threat or *fear of rising energy prices,* and international competition (*foreign market*); (2) current and potential energy policies (*public funding*, *energy audits*, *legal requirements*); and (3) organisational and behavioural factors (*ambition of managerial staff in relation to EE*, *EMS* in place, *energy manager*, *employee EE awareness-raising*, *EE status*, *EE importance in the future*). Inspired by empirical findings which also revealed the importance of some firm-specific characteristics (contextual factors) in the role of either barriers or drivers, this study also examines the impact of the firm *size*, *innovativeness*, *energy intensity,* and *potential for energy savings* on the EEMs adoption.

3.3. Data collection and sample description

Manufacturing SMEs in Slovenia appear as useful research settings in terms of data collection, reliability, and representativeness of the sample. Moreover, a previous study in Slovenian industrial firms calls for further research, especially in manufacturing SMEs, where the energy-efficiency gap is most widespread (Hrovatin et al., 2016). SMEs account for only 4.9% of all Slovenian enterprises but employ almost 40% of the labour force, generate 38.8% of industrial income (Statistical Office of the Republic of Slovenia, 2020), and are responsible for 43% of energy consumption in the industry (Government of the Republic of Slovenia, 2017).

In the Slovenian manufacturing sector, SMEs represent 11.6% of all enterprises in 2019, employ 42.8% of the labour force, and generate 93.8% of manufacturing income (Statistical Office of the Republic of Slovenia, 2020). Moreover, industrial energy efficiency in Slovenia is one of the main areas of future policy interventions aimed at reducing the energy and resource productivity gap by almost 20% compared to the EU average (Institute of Macroeconomic Analysis and Development, 2020). It is, therefore, not surprising that Slovenia stands among the EU countries with the highest interaction between the two aforementioned dimensions of the Energy Union, energy efficiency, and decarbonisation (Economidou et al., 2020). Improvements in energy efficiency are intended to reduce fossil fuel consumption and its energy import dependence (Government of the Republic of Slovenia, 2020).

The dataset consists of two data sources. The first was a self-administered survey using extensive questionnaires conducted via telephone interviews in 2019, and the second was the Slovenian Business Register, an official statistical database of all business entities in Slovenia. The companies were randomly selected by the market research agency to ensure the representativeness of the sample. In total, the questionnaire contained about 50 questions pertaining to the firms' general characteristics, energy and energy-efficiency related characteristics, adoption of EEMs in the past and plans for the future, perception of barriers and drivers, and use and importance of production resources.[2] The official firm-level data from Slovenian Business Register, containing data from balance sheets and income statements, was used to measure some firm-specific characteristics and performance indicators to ensure data reliability.

The sample includes 21 manufacturing sectors out of 22 (Fig. 1a) and around 10% of all manufacturing SMEs. Only one sector (pharmaceuticals), with 0.3% share in the population, is not included in the sample. As seen from the comparison between the sample (Fig. 1a) and the population (Fig. 1b), the sample represents Slovenian manufacturing SMEs very well. Metal products manufacturers are the most represented (25%), followed by rubber and plastics (11%), furniture (8%), food (8%), machinery and equipment (7%), electrical equipment (6%), consumer electronics (5%), and wood (5%). In terms of size, composition, and sector coverage, the sample assures the generalisation of results for all Slovenian manufacturing SMEs.

Regarding past and *future EEMs* (Table 1), 65% of companies implemented EEMs at least once in the last three years, and 52% of them have plans to do so in the next two years. More than three-quarters (77%) are small firms, which do well in representing the size structure of the manufacturing sector with the same proportion of small firms in the overall population. While covering 10.2% of manufacturing SMEs in the country, the sample contains 10.3% of SEs and 9.6% of MEs. The average profitability is 5.75%. On average, firms have around half of their debt in financing. More than half are export-oriented and almost all (92%) perceive strong competition in the market. 42% can be described as innovative, and most are risk-averse, with only about 20% willing to take a high or moderate risk when investing.

The average share of energy costs in the total costs of the firm is 2.61%, which is below the 3.5% threshold suggested in the literature for energy-intensive firms (e.g., Rohdin and Thollander, 2006). 85% of the companies consider energy efficiency important relative to other issues, yet only 21% employ a person in charge of energy. Just over half (51%) expect EE to become increasingly important in the future. In 83% of the firms, there is employee awareness-raising on energy efficiency, and 40% of the firms have implemented EMS. Just over a third (35%) believe they have good potential for energy-efficiency improvements, and 45% of firms have already carried out an energy audit or received external advice.

The frequency and average values of perceived barriers and drivers are shown in Fig. 2. The two strongest perceived barriers appear to be the economic barriers of high investment costs (3.22) and low return on investment, with average scores well above the other barriers. Technological, organisational, and competence-related barriers follow with fairly similar scores (2.56, 2.54, and 2.51, respectively). Behavioural and informational barriers are perceived as the least relevant. By far, the most important driver is also economic in nature – cost reduction (3.44). Managerial ambition (3.19) is noticeably behind economic drivers and somewhat leads all other drivers, with fairly similar mean scores.

The highest investment activity by sector (Fig. 3) is in the electrical equipment, machinery and equipment, primary metals, and furniture sectors. The rubber and plastics and food sectors show the lowest energy-efficiency investment activity.

4. Results and discussion

Table 2 presents the results of the linear probability and logit regression models for *past* and *future EEMs,* respectively. The results are robust to alternative model specifications, as the comparison between the logit and linear probability regression models does not reveal any major differences. Nevertheless, the highly significant likelihood ratio test with a p-value around zero indicates that using the logit model instead of the linear probability model is also appropriate. Multicollinearity was also checked using the variance inflation factor (VIF) test and proved not to present concern in the estimated models.

The results for the *past EEMs* adoption show that, among the *firm and business-related variables,* only *debt* affects the probability of adopting EEMs, with the expected negative and significant parameter estimate. This suggests that access to capital, one of the pillars of the theoretical taxonomy of Sorrell et al. (2000), may be an issue among real economic barriers. SMEs face even greater difficulties in servicing debt due to a relatively larger share of liabilities, higher exposure to the domestic market (i.e., slower recovery of the Slovenian economy after the last financial and economic crisis), and more limited access to financial resources, in addition to their lag behind other business groups in creating financial restructuring measures (Institute of Macroeconomic Analysis and Development, 2020). Firm *innovativeness, ownership of premises, foreign market,*and *competition* turned out to be insignificant, different from theoretical presumptions, such as how Sorrell et al. (2000) emphasise split incentives and Thollander and Ottosson (2008) suggest the importance of international competition.

Energy and energy-efficiency related characteristics were found to have a stronger effect on energy-efficiency investment decisions compared to the first group. While *energy intensity* is not significant in either model for *past EEMs*, the main incentive evident in positive and significant parameter estimates of both variables appears to come from the high *status of energy efficiency* and the anticipation of its *growing importance* in the future. Firms that have implemented some type of *employee energy-efficiency awareness programs* are also more likely to adopt EEMs and related practices. In contrast to some studies that failed to confirm the important motivating role of staff awareness programs (Cantore, 2017), several studies identified the lack of awareness as an important inhibiting factor (Trianni et al., 2017; Fresner et al., 2017), thus supporting these results.

In addition, as hypothesised, firms that have received *external energy advice* or have carried out an *energy audit* are more likely to implement

[2] The questions in the last part (use and importance of production resources) were used in the study examining the energy-efficiency investment behaviour in terms of the impact of EEMs adoption on other production resources, differentiated by their importance for the company (Trianni et al., 2021).

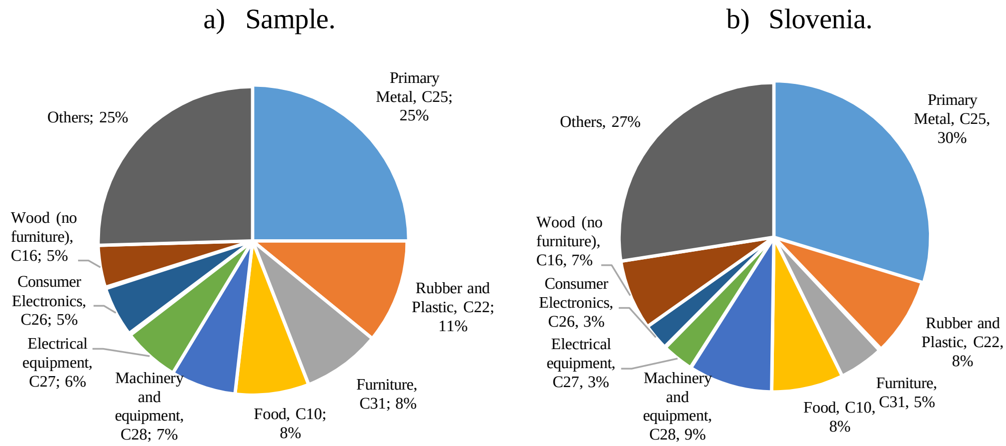

Fig. 1. Distribution of manufacturing SMEs by sectors.
Source: Statistical Office of the Republic of Slovenia (2020).

EEMs,[3] which complements findings of Cantore (2017), Cagno et al. (2017–in the initial decision-making steps), and Fleiter et al. (2012–audit quality). This study, thus, confirms the relevance of certain drivers belonging the energy policies (energy advice/audits) and organisational and behavioural groups of the propositions of Thollander and Ottosson's (2008).

The results regarding *perceived barriers and drivers* are somewhat surprising. Contrary to expectations, none of the barriers in the linear probability model and only *competence-related barriers* in the logit model statistically significantly hinder EEMs implementation. Their hindering role was also confirmed by Cagno and Trianni (2014), Kostka et al. (2013-the lack of skilled labour), and Henriques and Catarino (2016-cognitive capacities and the lack of human resources). On the other hand, the significant positive estimated parameter of *cost reduction* underpins theoretical presumptions (Thollander and Ottosson, 2008) and other empirical findings that cost reduction is one of the primary drivers in SMEs, along with expected savings and opportunities to realise long-term benefits (e.g., Abadie et al., 2012; Cagno and Trianni, 2013; Cagno et al., 2015).

Turning to the *future EE investments*, among *firm-specific characteristics*, financial constraints (access to capital) cease to be a barrier, according to the non-significant negative parameter estimates of *debt* and *profitability*. On the other hand, the firm's ability to innovate now becomes relevant in the logit model, reflected in the positive and significant variable *innovativeness*, supporting findings of Cagno and Trianni (2013). Plans for introducing EEMs in the future are more likely to be found in firms with research and development culture and practice.

In the group of *energy and energy-efficiency related determinants*, several turn out to be significant. In contrast to *past EEMs*, *energy-intensive* firms are more likely to take up EEMs in the future, which is consistent with the confirmed triggering role (or in the case of low energy intensity, the hindering role) of energy intensity in many studies (e.g., Fleiter et al., 2012; Kostka et al., 2013; Henriques and Catarino, 2016; and Fresner et al., 2017).

The *potential for energy savings*, exhibiting a significant positive impact on future investments in both future models, indicates a rational energy-efficiency planning behaviour. Firms expecting the growing importance of energy efficiency and those with past EEMs are also more likely to consider EEMs in the future. Unlike *past EEMs*, the *energy audit* does not act as a driver for *future EEMs*. A possible explanation could be that past investment experiences with learning by doing provide the company with sufficient information on energy consumption and potential savings, thus making the energy audit redundant for future investment planning. Another important determinant of future investment plans in energy efficiency is completed energy efficiency investments in the near past (*past EE investments*). Firms that have invested in the last three years are more likely to plan the further deployment of EEMs in the next two years. This finding is consistent with the path-dependency nature of EE investments (Cantore, 2017).

Future EEMs somehow show a different pattern than past investments, particularly concerning the role of *perceived barriers and drivers*. Several parameter estimates now become significant, yet some opposite to the expected sign. Two groups of perceived barriers, *competence-related* and *organisational* (in the logit model), increase the likelihood of diffusion. This may be because firms, aware of the generally high importance of these two groups within the domain of the firm, would seek to build competence and introduce necessary organisational changes to alleviate them, thereby laying foundations for the successful realisation of planned investments. The high perception of these barriers seems to be beneficial to firms. By taking the necessary steps to remove them internally, companies are efficiently transforming their weaknesses in this area into advantages for the future acceleration of EEMs.

According to the results of this study, perceived *behavioural* and *technological barriers* (the latter in the logit model) significantly reduce the probability of future diffusion. The negative impact of behavioural barriers when it comes to future adoption is not surprising, as the importance of barriers changes through the decision/implementation steps, with behavioural and awareness barriers being particularly important in the first step involving the identification of needs and opportunities (Cagno et al., 2017). If the firm perceives *behavioural barriers*, such as inertia and lack of interest, to be high within the organisation, it may be less interested in considering EEMs planning. *Technological barriers*, such as inadequate or unavailable technology, are even more difficult to overcome as they are outside the control of the firm, thus severely slowing down future adoption decisions.

Finally, according to the non-significant parameter estimates, none of the *perceived drivers* in this study matter for future implementation. The assessment of *potential for energy savings* has now taken the role of enabler, replacing the perceived driver of cost reduction, which accelerated past investments. Indeed, in the planning step, the identification of potential is crucial, while the sustainability analysis that comes after the planning step (Cagno et al., 2017) helps identify the exact level of cost reductions that have encouraged *past EEMs* adoption.

Findings of this research seem to suggest that in manufacturing SMEs, the firm internal culture and climate of being proactive in relation

[3] The endogeneity problem may overstate the influence of this variable, as it may be that firms that have already decided to make energy-efficiency investments take up the energy audit. Using an instrumental variable instead of the energy audit would address this problem, but since it is difficult to find a suitable variable, this problem is usually not circumvented in studies.

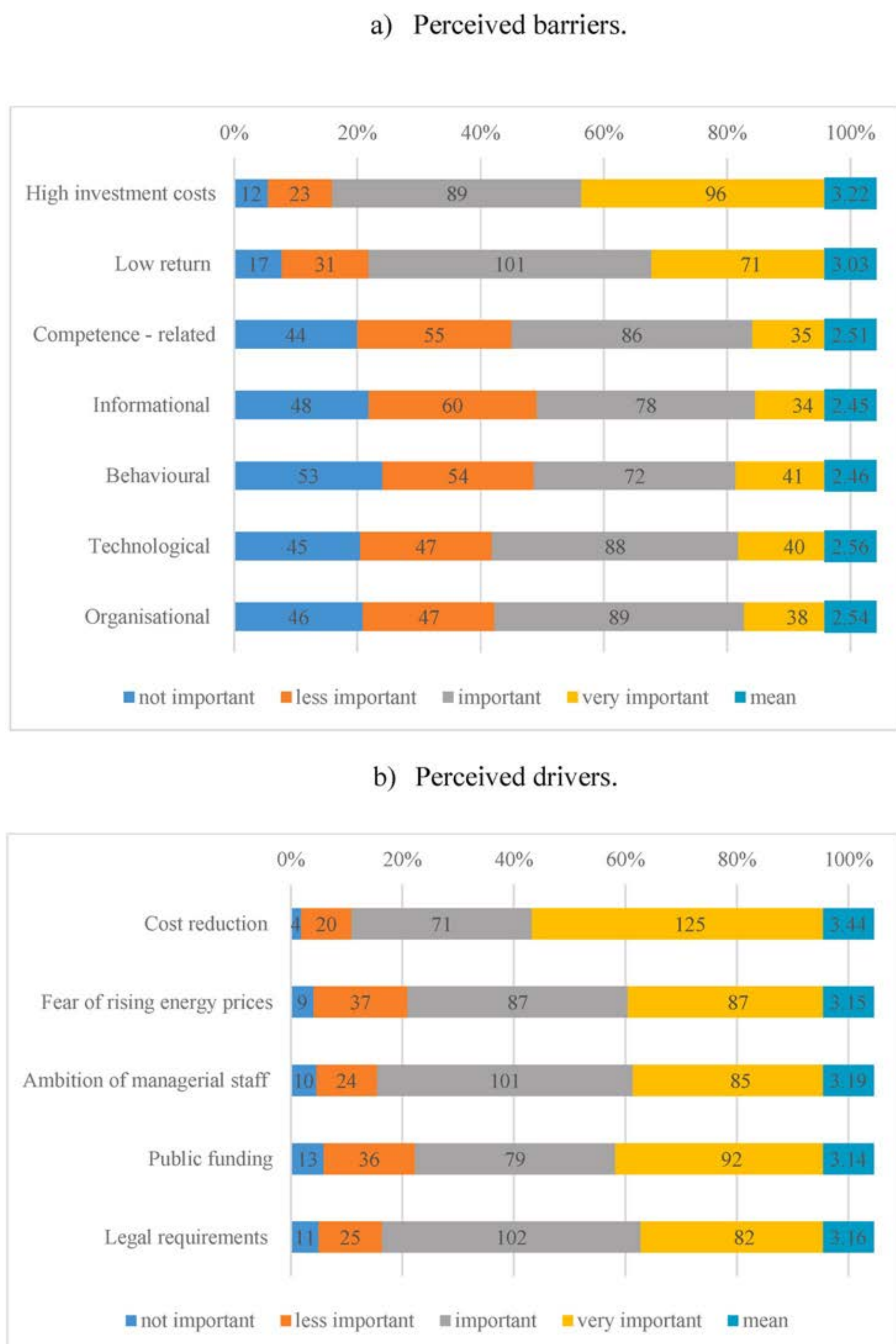

Fig. 2. Perceived barriers and driver of EEMs adoption – frequency and mean.

to innovation, giving importance to energy conservation, engaging employees in energy-efficiency related communication, seeking ways to improve energy efficiency through various channels of external advice, and conceiving investment in energy efficiency as an ongoing business activity complement either objective (energy intensity and energy-saving potential) or perceived economic drivers (cost reduction). Some of these motivators may change their strength over time, from past to future adoption decisions, but appear to be replaced by similar drivers that effectively overcome multiple barriers. These outcomes offer valuable implications for the design of energy-efficiency policies in manufacturing SMEs. Indeed, hybrid policy instruments have been proposed as a new effective approach in industrial firms (Safarzadeh et al., 2020), but the unveiled role of barriers/drivers in this study seems to provide arguments for some prioritisation concerning manufacturing SMEs. The high status of EE in the firm and its expected growing meaning in the future, raising employee awareness, and obtaining external advice/audit are all important triggers, implying that companies should be aware, informed, and equipped with calculations to conduct EEMs.

Therefore, a lesson for policy-makers is that disseminating the importance of EEMs and awareness-raising campaigns, e.g., through business networks and energy chambers in collaboration with respective ministries and government agencies, seems to lead closer to accomplishing ambitious energy-efficiency targets. Social capital embedded in networks (Herr and Nettekoven, 2018) and the possibility of more customised, long-term, and active firm engagement, as well as

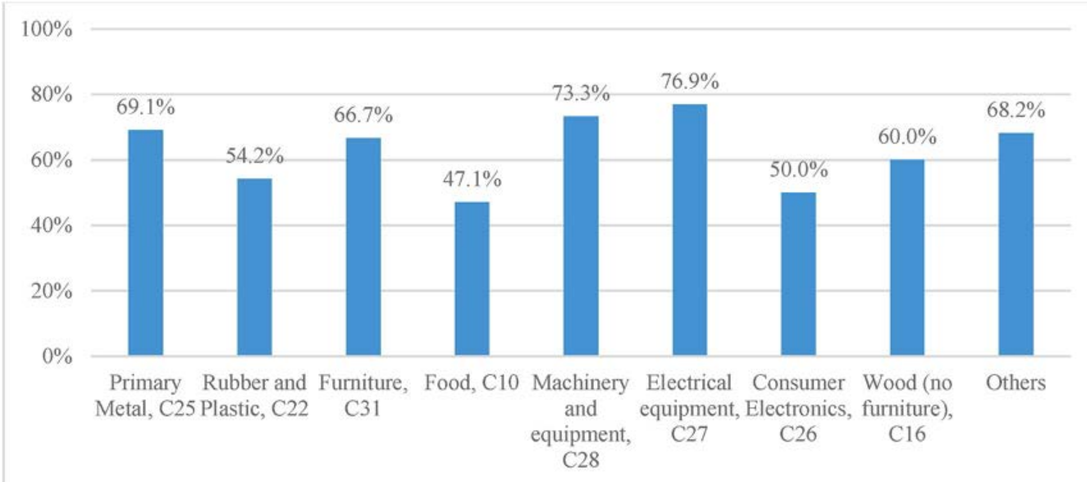

Fig. 3. Share of firms investing in EEMs by sectors.

Table 2
Results of discrete choice models for past and future adoption of EEMs.

	Past EEMs				Future EEMs			
	Linear probability model		Logit model		Linear probability model		Logit model	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	-0.085	0.275	-3.251	1.549	0.608**	0.286	0.816	1.501
Company and business related characteristics								
Size	0.005	0.081	0.022	0.461	0.045	0.085	0.207	0.443
Profitability	0.003	0.004	0.022	0.024	-0.001	0.004	-0.002	0.024
Debt	-0.004***	0.001	-0.024***	0.008	-0.002	0.001	-0.012	0.007
Foreign market	0.070	0.065	0.433	0.378	-0.015	0.068	-0.098	0.353
Competition	-0.090	0.124	-0.534	0.675	-0.106	0.129	-0.538	0.625
Ownership of premises	0.088	0.091	0.573	0.491	0.010	0.095	0.108	0.522
Innovativeness	0.103	0.067	0.577	0.394	0.112	0.070	0.719*	0.369
Risk	0.042	0.077	0.360	0.466	0.071	0.080	0.317	0.418
Energy and energy efficiency related characteristics								
Energy-intensity	-0.001	0.014	-0.005	0.076	0.026*	0.014	0.171**	0.084
EE status	0.148	0.091	0.878*	0.504	-0.036	0.095	-0.281	0.498
Energy person	0.032	0.093	0.389	0.592	0.048	0.097	0.245	0.488
EE importance in the future	0.142**	0.065	0.808**	0.374	0.259***	0.069	1.356***	0.356
Employee EE awareness raising	0.194**	0.092	0.987**	0.503	0.043	0.096	0.267	0.526
EMS	-0.005	0.071	-0.053	0.400	0.032	0.074	0.226	0.380
Potential for energy savings	0.016	0.069	0.230	0.414	0.135*	0.072	0.777**	0.385
Energy audit	0.166**	0.066	1.048***	0.381	0.062	0.070	0.385	0.360
Past EEMs					0.131*	0.075	0.703*	0.385
Perceived barriers								
High investment costs	0.028	0.048	0.238	0.279	-0.002	0.050	-0.052	0.256
Low return	0.057	0.045	0.339	0.269	-0.006	0.047	0.005	0.235
Competence - related	-0.092	0.056	-0.542*	0.323	0.150**	0.059	0.904**	0.356
Informational	-0.003	0.054	-0.011	0.299	-0.079	0.056	-0.523	0.327
Behavioural	0.046	0.045	0.268	0.280	-0.086*	0.047	-0.535**	0.256
Technological	0.010	0.049	0.010	0.299	-0.082	0.051	-0.479*	0.280
Organisational	0.020	0.051	0.095	0.309	0.083	0.053	0.509*	0.301
Perceived drivers								
Cost reduction	0.104*	0.056	0.673**	0.331	-0.013	0.059	-0.051	0.297
Fear of rising energy prices	-0.062	0.045	-0.445	0.282	-0.045	0.047	-0.254	0.237
Ambition of managerial staff	0.025	0.049	0.110	0.285	-0.023	0.051	-0.139	0.256
Public funding	-0.029	0.040	-0.184	0.247	-0.037	0.042	-0.230	0.218
Legal requirements	0.001	0.043	-0.017	0.251	0.017	0.045	0.087	0.232
Model fit indicators								
RSE	0.439				0.457			
R Squared	0.268		0.240		0.279		0.239	
Adjusted R-Squared	0.161		0.038		0.169		0.042	
F-statistic	2.495				2.532			
p-value	<0.001		<0.001		<0.001		<0.001	

*, **, *** significant at 10%, 5% and 1%, respectively.

knowledge and experience sharing, make information communication through networks more effective than traditional third-party audits (Palm and Backman, 2020). Networks also provide a platform for a more value-based and emotive approach as an effective policy design for the heterogeneous group of SMEs (Fawcett and Hampton, 2020), in turn, eliminating information barriers and addressing other categories, such as awareness, competence, and behavioural-related barriers. Based on the evidence of policy measures in several countries, improving information policies through decentralised actions has been suggested as a key policy measure, especially for SMEs (de Mello Santana and Bajay, 2016).. Networks also open up opportunities to create standardised solutions for energy-saving measures, especially for supporting processes (e.g., lighting, heating, and cooling). These are similar across SMEs, and handling large energy use in all SMEs (Fresner et al., 2017). In this way networks could be instrumental in establishing benchmarks and exchanges of best practises.

A step further would be to establish voluntary agreements with such networks, which appear to be more effective in smaller companies facing high information barriers (Cornelis, 2019). Local voluntary agreements could replace national agreements in SMEs, as seen in Sweden, where they were expected to save 15% of energy in SMEs by 2020. In Switzerland, training sessions, knowledge sharing, and exchange of best practices have also been carried out through local voluntary agreements. Sharing information through networks and/or voluntary agreements on EU legislative acts, recommendations, and legal requirements on targets imposed on countries and industries in the EU, together with more precise instructions on how to access government and EU-supported funds, would accelerate the SMEs outreach. More so, if these policies are successful in encouraging SMEs to adopt EEMs, given the documented path-dependency of investment in this study, this promises the continuation of such practices in the future. Continuity entails the strategic nature of energy-efficiency investments, which increases the probability of their adoption (Cooremans, 2012).

Finally, some limitations of this study should be pointed out, which also offer ideas for future research. Analysis in this paper is limited to one country, so further research should expand the scope to other research settings in national and international contexts, encompassing SMEs from across the spectrum of industries besides manufacturing to account for variations in perceptions of barriers/drivers and differences in contextual factors. Gathering evidence from different environments would allow a deeper understanding of the phenomena, avoiding possible country- and industry-biased conclusions. In response to the well-documented evidence of the neglected impacts of non-energy benefits and losses (Pye and McKane, 2000; Nehler and Rasmussen, 2016; Rasmussen, 2017; Cagno et al., 2019), taxonomies of barriers and drivers should be upgraded to place EEMs in a broader context of industrial sustainability (Cagno et al., 2018). Synthetic measures for these factors should also be formulated to facilitate their inclusion in econometric modelling. Finally, to overcome another overlooked element in the literature, namely the impact of EEMs adoption on other production resources (Trianni et al., 2021), the implementation of a more holistic resource-situated approach in future research is advocated. In addition, the adoption of EEMs should also be studied from the perspective of their relationship to product quality and safety (IEA, 2015). Measuring and incorporating these missing elements and their interactions poses a challenge for future econometric modelling. Nevertheless, it promises a better understanding of energy-efficiency forces as part of the resource efficiency improvement endeavours inevitable on the journey to cleaner and sustainable production processes. Finally, it is crucial for a greater generalisability of results.

5. Conclusions

This study is among the first attempts in the literature to systematically identify the relevance of a broad range of perceived barriers and drivers to EEMs adoption in manufacturing SMEs, in interaction with other firm-specific and business-related forces, that may represent real obstacles or motivations for firms noted in the literature. In line with previous evidence, SMEs are identified as holding a large potential for energy savings, which stems from the prevailing energy-efficiency gap. Therefore, discrete choice models are employed on a representative sample of Slovenian manufacturing SMEs to simultaneously investigate the determinants of energy-efficiency investments. Both adopted and planned EEMs are investigated to establish possible differences in the relevance of various barriers and drivers for past and future investment decisions.

The empirical results indicate that energy and energy-efficiency-related characteristics stand out with the strongest influence on the adoption of EEMs, over-shading, in particular, the perceived barriers and most of the perceived drivers. The high status of energy efficiency in the firm is positively associated with the past energy-efficiency investments, while expectations of its increasing future importance are critical for both past and present investments. Companies are also more likely to have adopted EEMs in the past when the latter is complemented by enhancing energy-efficiency awareness among employees and raising information about energy use and opportunities for improvement through external audits or other external sources of advice. Additionally, future EEMs are found to be positively influenced by adopted EEMs in the past, confirming the path-dependency in energy-efficiency investments.

While past investments are more likely to be constrained by available financial resources, as reflected by higher corporate debt in financing, future investments seem to be more likely associated with higher energy intensity and expected energy savings. Consistent with previous empirical research, this clearly shows that economic drivers continue to play the main role. Cost reductions from lower energy use also emerged as the most influential self-assessed economic driver for past EEMs. Other perceived barriers and drivers appear to be mainly at work in decision-making steps for future EEMs. Competence barriers can be seen as the reason for postponing the adoption of EEMs to a future date, while perceived behavioural and technological barriers impede the adoption of future EEMs.

Looking from the theoretical perspective, this study highlights the role of economic barriers, in particular, access to capital and perceived behavioural and technological barriers. On the side of drivers, the potential for energy savings and cost reductions among economic drivers along with the behavioural and organisational drivers related to the status of EE in the firm play a crucial role. The results largely confirm findings from similar empirical studies on the unexploited potential for energy savings in SMEs due to the lack of financial resources, skilled staff, and low management priority given to energy efficiency.

The study also provides valuable policy and managerial implications. In order to close the energy-efficiency gap in SMEs, it is essential to raise awareness about energy efficiency among managers and employees, build competencies, and provide information on the potentials for improvements in energy efficiency and the availability of public and private funds. Networks of SMEs and local voluntary agreements should be promoted as they allow to take advantage of the embedded social capital and a more value-based and emotive approach while also providing a platform for benchmarking and exchange of best practices across a heterogeneous group of SMEs.

CRediT authorship contribution statement

Nevenka Hrovatin: Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Enrico Cagno:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Janez Dolšak:** Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition. **Jelena Zorić:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Supervision.

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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Appendix

Table A1
Overview of econometric studies examining barriers and drivers of EEMs adoption in industrial SMEs.

Study	Country/sample	Econometric model/dependent variable	Main findings [1]	
			Barriers	Drivers
Anderson and Newell (2004)	USA SMEs, manufacturing, 39,920 IAC* project recommendations in 9034 plants (*US Department of Energy's Industrial Assessment Center)	Fixed effect logit Dependent variable: project adoption (binary)	Payback period, project (investment) cost. Energy savings (driver) are much less important than investment costs (barrier). Project costs (barrier) have more than double effect than energy prices (driver) [2].	Annual savings, quantity of energy saved, price of energy. Motor systems projects have the highest adoption probability.
Schleich and Gruber (2008) [3]	Germany 2848 SMEs, small industrial and services	Logit for each sub-sector Dependent variable: binary - active adopters	In metal sector: unknown split of energy consumption between thermal and electricity, rented space (split incentives). In wood working and processing: rented space.	No explicit analysis. Energy intensity and size are not significant barriers/drivers in manufacturing.
Schleich (2009) [3]	Germany 2848 SMEs (the same as in Schleich and Gruber, 2008)	Logit and probit (for sector and sub-sectors 2 dependent variables: 1) active adopters in the past; 2) active adopters in the past and planning in the future.	In metal sector (for active adopters in the past and future): rented space.	No explicit analysis.
Abadie et al. (2012)	USA SMEs, manufacturing, 101,286 project recommendations in 13,462 IAC assessments	Probit Dependent variable: implemented project recommendation (binary)	Payback time, number of recommendations, location (states with higher GDP in manufacturing), natural gas as a primary resource stream of EE.	Cost reductions, expected savings (benefits), electricity as a primary resource stream in EE investments, location (states with greater greenhouse gas (GHG) emissions).
Fleiter et al. (2012)	Germany 542 SMEs, industrial and non-industrial in energy audit program Sonderfonds	Fractional logit, factor analysis Dependent variable: adoption rate (share of adopted EEMs in all recommended)	High investment costs (subjective and objective), lack of capital (for larger investments) [4].	Audit quality (in one model); energy intensity (in one of 3 models).
Kostka et al. (2013)	China 480 SMEs, multisector	Ordinary least squares (OLS) Dependent variable: total EE activities (binary) – normalised sum of 5 dummies for EE activities	None [5].	Size, energy cost (intensity), energy manager, informed business manager, firm's growth ambition, energy loan, labour-intensive sector.
Blass et al. (2014)	USA SMEs, manufacturing, 5836 recommendations in 752 IAC assessments	Logit Dependent variable: 1) adopted recommendations (binary); 2) adopted process and equipment change recommendations (binary)	Investment cost.	Involvement of operations manager (for process and equipment change recommendations).
Boyd and Curtis (2014)	USA 321 MEs, manufacturing	Multivariate regressions Dependent variable: energy intensity (as a proxy for energy (in)efficiency)	Strong production targets in high energy firms. Low impact of management practices and targets in low energy industries.	Lean manufacturing operations. Higher impact of good management practises in high energy industries.
Cantore (2017)	Viet Nam, the Philippines, Moldova 214 ME and LE (116 in the model), manufacturing and other industrial sectors	Logit, Principal component analysis (PCA) (on 8 groups of variables) Dependent variable: planned investments in the EE projects over next 5 years (binary)	Energy certification (EMS), microeconomic constraints (principal component); top management commitment.	Energy audit, past investments in EE (in the last 2 years), planning/considering energy management innovation.

Notes.

[1] Variables in the models that show a significant negative impact on EEMs adoption are listed as barriers and those with significant positive signs as drivers. Only models on the adoption of EEMs from listed studies are considered in the table.

[2] Barriers from the statistical analysis: economic (unsuitable return on investment), institutional (inertia, adverse to change, bureaucratic restrictions); financing (limited cash-flow).

[3] The main findings in the table are reported for manufacturing sectors only.

[4] Barriers from the statistical analysis: high investment costs, low priority of energy efficiency, lack of profitability of EEMs, energy price uncertainty.

[5] Barriers from the qualitative analysis based on survey and interviews: financial and organizational barriers, the role of family ownership structures, lax enforcement of government EE regulations and the absence of government support, lack of skilled labour.

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