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The Role of Contextual Characteristics in the Adoption of Energy Efficiency Measures in Electric Motors Systems: An Exploratory Analysis

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ABSTRACT

The presence of barriers, mainly related to the information and economic spheres, limits the diffusion of industrial energy efficiency. To overcome this situation, industrial decision-makers should perform comprehensive assessments of energy efficiency measures, including the analysis of the contextual dimension in which their adoption should be embedded. Indeed, contextual characteristics have been shown to strongly influence the descriptive characteristics of energy efficiency measures and their multiple impacts coming from their adoption, e.g., by increasing their criticality based on distance from the firms' core business or on firm size. Given the lack of in-depth analysis in the literature, this empirical study represents an initial exploratory analysis of the influence of the context on the adoption of energy efficiency measures. The results clearly point to the need for future research on the topic and the development of a framework for industrial decision-makers and policy-makers to systematically analyse the influence of contextual characteristics on the descriptive characteristics of energy efficiency measures and their multiple impacts on operations, productivity and overall firm's sustainability.

Keywords: electric motors, energy efficiency measures, adoption process, decision making, characterization impacts, context.

NOMENCLATURE

Abbreviations	
EMS	Electric Motor Systems
EEMs	Energy Efficiency Measures

1. INTRODUCTION

Numerous efforts have been made to improve energy efficiency in industrial electric motor systems (EMS), in light of its recognized importance. Unfortunately, an energy efficiency gap still exists [1], with energy efficiency measures (EEMs) that are deemed to be economically efficient still largely overlooked [2]. Literature shows that motivation can be found primarily in information and economic barriers [3]. In this regard, studies have been developed to characterize EEMs [4-8] to shed light on aspects of their adoption and facilitate overcoming information barriers. In addition, literature has begun to link these characteristics to the multiple impacts (both benefits [9] and losses [10]) that adoption has been seen to have on operations and productivity and overall firm's sustainability [11].

Previous literature has started to suggest that the context where an EEM is to be implemented (both the broader business and the specific shop floor ones) can provide further insights to better understand the perception that industrial decision-makers have of EEMs, in addition to the descriptive characteristics of EEMs and their multiple impacts [12]. By context here we refer, for instance, to the role of the industrial sector on barriers to and drivers for energy efficiency, with capital-intensive sectors perceiving adoption as risky from a production disruption perspective [13], or energy-intensive sectors paying more attention to reducing energy consumption [12]. Firm size affects the adoption rate, as larger firms are usually keener to adopt EEMs [15] for various reasons (e.g., trained personnel [16], financial resources [14], temporal constraint [17]).

Referring to the specific applications, the distance from the core process of a firm might influence the

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adoption rate, with EEMs applied on core processes perceived as risky [18], as they could involve an interruption of some core production activities to allow external personnel to access the equipment and, e.g., install new and more efficient technologies [8]. However, on the other hand, core EEMs could provide competitive advantage to firms [19], therefore lowering the barriers to their adoption [20].

Recently, some studies have begun to characterize the adoption context and highlight its influence on the specific EEMs characteristics and their multiple impacts; at first glance, it would appear to be able to play a moderating role towards the latter [21]. Nevertheless, there is still a lack of empirical studies thoroughly analysing the role of contextual characteristics. Building on the theoretical framework developed by Cagno et al. [11] and considering the aforementioned literature gaps, this study aims at offering a contribution to the discussion by providing an exploratory empirical study to analyse the role of key contextual characteristics with respect to the characteristics of EEMs and their multiple impacts.

2. METHODS

The empirical study was based on interviews with a panel of four experts in both the fields of energy efficiency and industrial operations, in order to ensure a comprehensive assessment of the dimensions of interest (see Tab.1 for details). The experts have been chosen to come half from academia and half from industry (consultants or members of trade associations). This choice is reflected in the attempt to interview experts who can boast transversal visibility over a large number of contexts rather than industrial decision-makers, bounded to a single firm context. This decision would allow to compare different situations and draw insights directly from the experts without having to resort to a large sample of heterogeneous firms.

Expert1 and Expert2	Industrial expert and members of trade associations consulting for a number of industrial firms on energy efficiency and overall firms' sustainability.
Expert3 and Expert4	Academic experts with hundreds of peer-reviewed publications on industrial energy efficiency, sustainability and operations management.

Tab. 1. Panel of experts

Since the work expands on the study of Cagno et al. [11], we opted for semi-structured interviews based on the contextual characterization they proposed (Tab. 2). Experts were asked about the influence that each of the contextual characteristics might have on EEMs characteristics and their multiple impacts, and eventually on the EEMs adoption.

Interviews were conducted referring to a general EMS EEM, given the still exploratory nature of the study. Notwithstanding, to facilitate understanding and reasoning for the experts, examples referring to specific EEMs were given during the interviews. In particular, we referred to the following five EMS EEMs, sufficiently general to be applied in various contexts and among the most widely implemented in industry to ensure expert familiarity [22]:

- utilize energy-efficient belts and other improved mechanisms;
- use Adjustable Frequency Drive;
- establish a predictive maintenance program;
- use most efficient type of electric motors;
- replace over-size motors.

Firm-related characteristics	Firm size Energy intensity
Application-related characteristics	Layout type Distance to core process Saturation level Numerosity Dimension/Area interested Accessibility Level of acceptance
Decisional characteristics	Source strategy Implementation type

Tab. 2. Contextual characteristics identified by [6]

Eventually, the text analysis has been conducted through the qualitative method of coding, that is the analytic process of examining data looking for concepts, i.e., significant events, experiences, feelings and so on [23].

3. RESULTS

Tab.3 summarizes the results of the research by highlighting the overall level of influence of each contextual characteristic with respect to the characteristics of EEMs and their impacts.

Firm size has a strong influence on the type of personnel performing EEMs according to all four experts. Large firms usually employ highly trained personnel specialized for particular EEMs, while in smaller firms there is usually a single team assigned to all EEMs. Expert2 interestingly connected size to EEMs characteristics, pointing out how smaller firms tend to perform more retrofits, being easier to be implemented but proportionally more expensive in the long run and

Contextual Characteristics	Expert1	Expert2	Expert3	Expert4
Firm size	+++	+++	+++	+++
Energy intensity	+++	+++	+++	+++
Layout type	/	+	++	++
Distance to core process	++	+++	+++	+++
Saturation level	++	+++	+++	+++
Numerosity	+++	+++	+++	+++
Dimension/Area interested	++	++	++	++
Accessibility	++	+	+	+
Level of acceptance	+	+	+	+
Source strategy	+	++	++	++
Implementation type	++	/	/	++
Working hours	++	++	++	++
Level of automation	+	/	++	+
Regulatory context	+++	+++	/	/

Tab. 3. Overall influence of the contextual characteristics on EEMs adoption according to the experts, from little influence (+) to very high influence (+++).

also riskier from a quality and reliability viewpoint. In addition to simplifying EEMs, according to all experts, smaller firms tend to outsource the adoption due to lack of internal competences. Furthermore, the number of people involved in the adoption could be higher for larger firms and different hierarchical levels could be affected (Expert2). The influence on personnel extends to the issue of health and safety, on which larger firms pay more attention (Expert2). For instance, in the case of EEMs that modify existing machines (e.g., retrofit), their type-approval should be reassessed: according to Expert1, this is done by large firms only, as in smaller firms no one is in charge of control. Referring to the implementation time of EEMs, Expert2 testified that larger firms tend to be more organized when it comes to scheduling plant downtime, during which they could absorb EEMs implementation times and avoid further production downtime. On the other hand, smaller firms could face more difficulties given the need to manage external teams, considering EEMs are often outsourced. This issue is especially crucial when multiple EEMs are carried out simultaneously (Expert2).

We noticed a strong agreement on the increased focus towards reduced consumption by *energy-intensive* firms. However, if according to Expert3 energy-intensive firms optimize the performance of the adopted EEMs, Expert2 argues instead that the performance of EEMs does not depend on the energy intensity of a firm. Expert1 added to this that energy-intensive firms usually look for solutions tailored for their specific situation, optimizing the choice of the EEMs. Indeed, Expert3 and Expert4 suggest that the type of personnel required to perform an EEM and their competences vary according to the energy intensity of the firm, with personnel in energy-intensive firms less inclined to outsource the adoption process (Expert2).

Regarding the characteristics of the specific application, Expert3 notes the type of *layout* of the process may affect the training and personnel required to carry out an EEM (e.g., job-shop operators tend to have more extensive core competencies than line operators). Conversely, Expert4 does not see a strong link between layout type and type of personnel or training required to adopt EEMs, which are rather influenced by the skills of the individual operator. Moreover, the layout type influences the adaptability of the EEM, since some configurations provide extremely superior layout flexibility (Expert3). Also, considering the cost of lost production due to downtime for EEMs implementation, the layout could affect the economics (e.g., possibility to use alternate cycles, Expert4).

Production downtime usually occurs when EEMs are implemented on a *core process* or a process that can directly affect the firm's core business. However, both Expert1 and Expert3 agree that in such circumstances the adoption time issues can be overcome by exploiting the synergies with other planned plant downtime. Expert2, on the other hand, points out how EEMs installed on the core process are usually adopted by larger firms, which have the expertise to appreciate their positive impacts on productivity and which have already had experience with EEM on service processes. Conversely, smaller firms increase the energy efficiency of service processes but are not trusted to change core processes. Such considerations are even more critical in the case of core and *highly saturated processes*, where the lack of production cannot be recovered, and therefore represents a cost for the firms.

The *numerosity* of devices could also influence the type of personnel and skills required for the adoption (Expert2). Expert3 confirms the influence on the type of personnel, adding that the number of people involved could also change. Differently, numerosity has no impact on the number of people employed in adoption (both internal and external), Expert1 notes. According to Expert4, the EEMs numerosity may influence the type of personnel responsible for the adoption decision, while the type of personnel performing the installation varies more with the complexity of the EEMs. Regarding the implementation time, the numerosity of EEMs does not change the time associated with the implementation of a single intervention, but the total worksite could be longer (Expert1).

Also, the implementation time is influenced by the *dimension* or *area interested* by the EEM (Expert4). In addition, in the case of extensive EEMs, it is necessary to create a workspace, which could require a downtime even in the case of EEMs which does not influence directly the core process (Expert2). As usual, synergies could be exploited to carry out the adoption during other downtimes planned by the firm.

The implementation time is also influenced by the *accessibility* of the locations where EEMs are installed (Expert3). According to Expert2, low accessibility could increase the downtimes related to EEMs implementation; this is especially true for non-extensive EEMs or EEMs deployed in small firms with low working hours, i.e. in situations where EEMs implementation is not always hidden by other planned downtimes. In addition, due to low accessibility, downtimes already planned and leveraged to implement an EEM may not be sufficient, requiring firms to further lengthen downtimes, which therefore could become unplanned (Expert4). Expert1 highlights that in cases of low accessibility due to hazardous environments, the adoption of some EEMs may be limited. For instance, the use of AFDs on intake fans located in a potentially explosive atmosphere is usually discouraged, since a reduction in energy consumption corresponds to an increase in risk.

The *level of acceptance* of an EEM can moderate the impacts on personnel coming from its adoption. Expert2 highlights the positive side since EEMs adopted with the goal of increasing worker well-being could improve their performance. On the other hand, Expert4 warns against EEMs that may not be well seen by people, as productivity may be affected, although these changes are difficult to measure.

Regarding the decisional characteristics, all the experts agree on the existence of a link between *sourcing strategy* and time related to EEMs. Expert1 believes that the outsourcing of an EEM does not modify the time required for its implementation but can affect the planning time in case the firm has no experience of the EEM. Expert3 and Expert4 confirm that, in presence of internal competences, outsourcing activities could rather dilate the implementation time because of the necessity to manage external staff. However, when in-house are lacking (e.g., smaller firms), outsourced EEMs implementation may be the only viable alternative (Expert3). Also, for difficult EEMs, firms usually choose to outsource avoiding the need for in-house training (Expert4). In addition, sourcing strategy can moderate the relationship between an EEM technological maturity and its impacts on the business. Indeed, according to Expert 2, beside avoiding the cost of training, in case of lack of in-house expertise, outsourcing could also avoid costs associated with poor EEMs management. However, problems may also arise with the need for external experts. In fact, an expert in the technology may not necessarily be knowledgeable in the production process in which the EEM is positioned, leading to additional costs and negative performance (Expert3). The sourcing strategy (in-house vs outsourcing) also influences the relationship between the frequency of check-ups (e.g., for maintenance) and the related costs (Expert2).

The *implementation type* is another contextual characteristic related to firm decision-making. Fragmenting an EEM and implementing it in multiple steps is a strategy usually used by firms to avoid production downtime, especially in the case of extended or core business-facing EEMs (Expert1). Additionally, according to Expert1, fragmented implementation is used by firms to evaluate the effectiveness of an EEM before completing its adoption, therefore lowering its risk. On the other hand, such an implementation strategy could increase the technical but also organizational complexities of the adoption (Expert4).

In addition to the contextual characterization provided by Cagno et al. [11], the interviews with the experts allowed us to highlight additional contextual elements that should be considered during decision-making, given their ability to influence EEMs performance and their adoption.

The number of *working hours* of a firm is recognized by all experts as a crucial moderating characteristic affecting energy consumption, consumption of other materials, and emissions (Expert3). Interestingly, Expert2 has evidenced as, similarly to what pointed out for larger firms, firms with a larger number of working hours are more structured in the organization of the production downtime, during which they can hide the EEMs implementation time, avoiding further production losses.

In addition, the level of *process automation* could moderate the impacts of adopting EEMs aimed at increasing automation (e.g., AFD). Expert4 highlights a strong dependence on firm size since larger firms are usually more automated. Expert3 also notes the link between the level of process automation and the cost of intervention, since it is usually more expensive to modify a highly automated process, and with less than proportional additional benefits. Interestingly, the level of automation could affect the relationships between EEM and its impacts on personnel, in terms of e.g., higher specialized maintenance personnel specifically devoted (Expert3), or less involvement of labour (Expert1).

Finally, the regulatory context in which firms operate represents an important contextual characteristic, capable in some cases of influencing the EEMs adoption. For instance, Italian energy-intensive firms are guaranteed contributions in proportion to their consumption. Expert1 confirms that these firms, should they implement all the EEMs that are economically advantageous, would risk losing part of these contributions, which from an economic viewpoint are greater than the monetary energy savings achievable. Consequently, some EEMs with high potential savings are not considered to the detriment of smaller EEMs, which would not involve risks in terms of loss of contributions. Similarly, Expert2 notes that some types of EEMs (e.g., retrofit) are more advantageous than others (e.g., redesign) from a regulatory perspective, as they are eligible for white certificates, although this does not always correspond to better performance in terms of reduction of energy consumption.

4. DISCUSSION

From the analysis of these preliminary results, it clearly emerges how much the context may have a profound influence on the EEMs adoption. Therefore, for a thorough assessment, it is fundamental to know the descriptive characteristics of EEMs [4-8], the multiple impacts on the firm's sustainability, both benefits [9] and losses [10], and possibly their relationships [11]. However, these elements must also be analysed considering the context that, as highlighted by the panel of experts, can deeply influence their values.

The results highlight the novelty of this exploratory study by bringing out insights not sufficiently addressed by earlier literature. Contextual characteristics such as firm size have been identified by previous studies, e.g., showing that smaller firms are resource-constrained [14] and generally less innovative than larger firms [15]. However, literature does not explore the details of the EEMs adoption and does not study the implications at the level of characteristics and multiple impacts of individual EEMs, such as the need for small firms to simplify interventions or to outsource the adoption due to lack of in-house expertise. Moreover, earlier studies have not explored yet that, e.g., outsourcing may have consequences in terms of safety or production disruption.

EEMs characteristics have been widely analysed in the literature (e.g., see Fleiter et al. [8]), which however does not investigate the role of the context. For instance, Fleiter et al. [8] assess the type of personnel required for the adoption, without however investigating how the availability of the roles change within the firms according to, e.g., firm size, nor the consequences in terms of sourcing strategy that should be adopted. Cooremans [19] is inspiring by advocating the need to present EEMs at a strategic level to involve the firm's management in the adoption decision and increase the adoption rate; however, the study does not mention contextual characteristics such as the numerosity of the EEMs or their extension, which have shown to be able to uplift the discussion to a higher hierarchical level or to increase the number of personnel involved in the adoption.

On the other hand, the multiple impacts of EEMs have been extensively investigated by literature (e.g., [9]). However, in past studies, no reference is made to the influence that context (e.g., number of devices or working hours) might have on the magnitude of such impacts. Worrell et. al [9] pinpoint the productivity benefits of EEMs while, on the contrary, Thollander and Ottosson [13] highlighted the disruption risk brought by EEMs. However, information concerning, e.g., the type of process (i.e., core or ancillary) or the layout of the process is lacking, which does affect the outcome. According to Backman [24], acting on the core process is too risky and firms realize EEMs mainly on ancillary processes. While this could be generally true, our exploratory study reveals that different behaviours may occur according to e.g., firm size, with larger firms more prone to adopting core EEMs to gain advantage in terms of productivity.

5. CONCLUSIONS

To improve industrial energy efficiency, it is essential to thoroughly assess EEMs, analysing their characteristics and impacts with the intent to overcome information and economic barriers that today strongly limit their adoption. However, for a comprehensive overview of the adoption, decision-makers and policy-makers should analyse EEMs not only in absolute terms but also according to the context in which they are adopted. Preliminary results from the interviews with a panel of experts reveal how the characteristics of the context can influence the characteristics of EEMs and the impacts they generate on firms' overall sustainability, and therefore the perception of different firms over EEMs. Nevertheless, a framework to systematically assess EEMs in light of the contextual dimension is still lacking in the literature. Future research should further elaborate and eventually corroborate these preliminary findings by providing statistical significance on the moderating role of contextual characteristics on the EEMs characterization and their multiple impacts.

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