Business Strategy and the Environment

WILEY | Business Strategy and the Environment

RESEARCH ARTICLE OPEN ACCESS

Why Context Matters in Industrial Energy Efficiency: A Framework for Electric Motor Systems

Davide Accordini[1] | Enrico Cagno[1] | Andrea Trianni[2]

[1]Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy | [2]Faculty of Engineering and IT, University of Technology Sydney, Ultimo, Australia

Correspondence: Andrea Trianni (andrea.trianni@uts.edu.au)

Received: 28 November 2024 | **Revised:** 19 May 2025 | **Accepted:** 17 June 2025

Funding: Open access publishing was facilitated by University of Technology Sydney, as part of the Wiley–University of Technology Sydney agreement via the Council of Australian University Librarians.

Keywords: adoption context | decision-making | electric motor system | energy efficiency | energy efficiency measure | nonenergy benefits

ABSTRACT

Energy efficiency is one of the most effective means for achieving sustainability goals, yet its adoption, particularly in electric motor systems, remains limited. Insights into the dynamics between contextual elements and efficiency measures can lead to more informed decision-making. This paper presents a framework to explore the role of context in adopting these measures from the perspective of industrial decision-makers, considering both broader business settings and specific applications. The framework is validated through a comprehensive literature review and empirical investigation using semistructured interviews with experts in electric motor systems. The investigation indicates that context impacts both the characterization of an efficiency measure and its effects on company resources and operations. Crucial contextual characteristics, such as company size and process centrality, emerged as key factors in adopting energy efficiency measures in electric motor systems.

1 | Introduction

Industrial energy efficiency (EE) stands out as a major catalyst to drive both industrial decarbonization and sustainable development. Among the array of technologies utilized by industries, electric motor systems (EMS) play the lion's share, accounting for 70% of the total electrical energy consumption in industry (Gómez et al. 2020). As electricity costs account for about 95% of EMS lifecycle costs (Motor Decision Matter 2007), several energy efficiency measures (EEMs) can be adopted to control and improve EMS EE. In 2011, IEA has developed a comprehensive report around EMS and opportunities for improving EE of this crucial cross-cutting technology (IEA 2011). To boost the adoption of EEMs within EMS, several minimum efficiency policies have been deployed (De Almeida et al. 2019). As previous research noted, such EEMs are deemed overall profitable for companies (Cooremans 2012; Fleiter, Gruber, et al. 2012). Yet, the adoption of EEMs within EMS remains markedly low and far from the achievable potential (International Energy Agency 2018; International Energy Agency 2020).

Several efforts have been paid to stimulate the investigation of the multiple benefits stemming from the adoption of EEMs. In this regard, Europe is leading the way with emphasis of the principle 'energy efficiency first' within the recently revised Energy Efficiency Directive (European Commission [EC] 2023). Additionally, experiences such as EU project M-Benefits offer valuable insights for the identification of nonenergy benefits (NEBs) to increase the appeal of EEMs for industry decision-makers (EC 2021). In Europe, other projects

Abbreviations: ARC, Assessment Recommendation Code; EE, energy efficiency; EEMs, energy efficiency measures; EMS, electric motor systems; KPI, key performance indicator; NEBs, nonenergy benefits; PMS, performance measurement system.

such as EU-MORE aim at increasing awareness of several stakeholders (e.g., manufacturers, industry end-users and policymakers) on the benefits from the substitution of EMS (EUropean MOtor REnovation initiative [EU-MORE] 2025). Recently, research is also focused on developing new methodologies to more clearly assess the potential of EEMs in light of such multiple benefits, as in the case of the EU project KNOWnNEBs (2025).

However, in this field, research is far from being mature, calling to broaden the analysis of EEMs in EMS beyond a techno-economic analysis of costs and energy savings. Information-related barriers, along with uncertainties and risks associated with EEMs implementation, are deemed to be crucial for the adoption (Rohdin and Thollander 2006). Building upon previous literature that has extensively discussed productivity benefits to enhance EEMs's profitability—see, for example, Kalantzis and Niczyporuk (2021), and further detailed in Section 2—it is argued here that the specific context where EEMs in EMS are to be integrated might play a crucial role for their adoption. Context is here defined as the set of variables, conditions and factors surrounding and influencing production and operational activities within an organization. EMS being a cross–cutting technology, embedded into many different applications in industry, the decision-making process, for example, adopting an EEM in EMS for core processes, may differ from that for ancillary processes (Accordini et al. 2021). The literature points to a number of factors, identifiable here under the concept of adoption context, that could influence the decision-making process (Cooremans 2012; Fleiter, Gruber, et al. 2012), yet leaving some significant research gaps that research has largely overlooked as discussed in Section 2. In particular, the study addresses the following research questions:

i. What are the key factors describing the adoption context of an EEM (with particular reference to EMS)?

ii. What are the interactions of the adoption context with EEMs' characteristics and impacts on operational performance?

The present manuscript aims to address the aforementioned questions by presenting an innovative framework and conducting exploratory empirical research involving interviews with a panel of experts. The study seeks to elucidate, by taking the perspective of an industrial decision-maker, the influence of the context on the adoption of EEMs in EMS. In particular, the research aims at highlighting whether the contextual characteristics of a business, as well as the specific contextual circumstances of where an EEM is going to be adopted, may affect the characteristics and the impacts of an EEM. By doing so, the research aims at contributing to the literature stream which has previously discussed the behavioural and organisational barriers within organisations, including bounded rationality (Sorrell et al. 2000). According to such literature, decisions or responses may be influenced by an incomplete set of information about EEMs and subjective perceptions around the impact of EEMs in the process (Cagno et al. 2013), such as missing to consider in the decision-making process the existence of impacts in production, either positive (e.g., productivity benefits and NEBs) or negative. However, research has not explored yet whether the assessment of those impacts may be affected by the business context or the context in which the EEM is considered for application. For this reason, to the authors' knowledge, the study represents a first attempt to study the existence of relationships between the adoption context, the characteristics of EEMs and the impact on production resources.

The remainder of the manuscript is as follows. Following the literature overview in Section 2, the framework supporting the investigation is presented in Section 3. The methodology for the validation of the framework is detailed in Section 4, and the results are presented in Section 5. Section 6 delves into the findings; conclusions, research limitations and future research avenues are presented in Section 7.

2 | Literature Background

To shed light on the adoption process and support decision-makers, previous literature characterized EEMs through a set of descriptive factors, outlining differences related to, for example, the type of modification introduced (Fleiter, Hirzel, and Worrell 2012; González 2005) or the EEMs' lifespan (Fleiter, Hirzel, and Worrell 2012). Depending on the intervention, the complexity of adoption could also vary (Fleiter, Hirzel, and Worrell 2012), as does the involvement required of companies (Trianni et al. 2014). However, a comprehensive evaluation of EEMs should extend beyond energy impacts to consider their effects on a company's resources, including materials, personnel, technologies and finances (Cagno et al. 2022). For this reason, this manuscript has reviewed two main streams of literature: On the one hand, it discusses earlier studies focused on the elicitation and analysis of NEBs from EEMs; on the other hand, it reviews previous research discussing relevant EEM characteristics to support decision-making in industry.

2.1 | NEBs From EEMs

The positive impacts due to the adoption of EEMs in terms of, for example, productivity, operations and maintenance, working environment, waste and emissions (Rasmussen 2017), have been discussed in the literature under various terms: *productivity benefits* (Finman and Laitner 2001; Worrell et al. 2003), *ancillary and production benefits* (Lung et al. 2005), *NEBs* (Mills and Rosenfelds 1996; Nehler and Rasmussen 2016) and *multiple benefits* (Russell 2015). Conversely, potential downsides such as lost production or performance degradation have also been examined (Cagno, Moschetta, and Trianni 2019; Rohdin and Thollander 2006; Thollander and Ottosson 2008).

Evaluating EE investments in light of their NEBs greatly impacts their profitability (Lung et al. 2005; Pye and McKane 2000). Although financial criteria are important, Cooremans (2011) pointed out how they are not enough to explain the adoption rate of EEMs, as the main driver of decision-making is represented by the strategic nature of an investment, which is evaluated within the broader adoption context (Cooremans 2012). Similarly, Doyle and Cosgrove (2018) highlighted that financial criteria become more critical for investments not perceived as core to a company, such as EE, particularly for nonenergy-intensive companies (International Energy Agency 2014). Rasmussen (2017) has offered a systematic literature review around additional benefits of EE investments, discussing in a novel framework NEBs with respect to their quantifiability and time frame. However, it is worth noting how research advocates for an evaluation of specific NEBs at EEM level (Nehler 2018). Following that lead, research has also provided valuable empirical insights on NEBs for specific EEMs, such as compressed air systems (Nehler, Parra, and Thollander 2018). Research has also recently explored the impact of EEMs on other production resources, such as equipment, human resources and utilities (Hasan et al. 2022; Neves et al. 2022).

Besides scientific research, grey literature has also contributed to the discussion by providing valuable insights into methodologies for the specific identification and discussion of benefits in industrial settings. In this regard, the EU project H2020 M-Benefits discusses NEBs within the strategic framework of Value Proposition, Costs and Risks (Rohde et al. 2022). However, the quantification of the specific benefits is deemed quite challenging in various industry applications (Cooremans et al. 2023). Furthermore, the EU Project H2020 ICCEE investigates EEMs to support SMEs operating in the food and beverage cold chains, advocating for including NEBs in the tools to support industrial decision-makers (Zanoni et al. 2020). Similarly, in the United States, the National Renewable Energy Laboratory (NREL) has recently developed a toolkit to support companies in investigating NEBs in industrial facilities (NREL 2024).

2.2 | EEMs and Relevant Characteristics for Decision-Making

Characteristics and impacts provide a sound description, yet EEMs are installed in specific contexts, both internal and external to a company (Cooremans 2012), that might influence their adoption (Cagno et al. 2022; Fleiter, Hirzel, and Worrell 2012) and affect the value proposition of the investment (Bicknell and Skumatz 2007). At company level, the *industrial sector* and the *energy intensity* of a business generally affect the perceptions of an EEM and the barriers to its adoption (Sardianou 2008; Schleich 2009), especially in capital-intensive and continuous production contexts (Rohdin et al. 2007). Conversely, *energy intensity* drives interest towards EEMS and consequently their adoption rates (Backman 2017; Fleiter, Schleich, and Ravivanpong 2012) due to the substantial share of energy costs in total production costs (Trianni et al. 2016); cost reduction from adopting EEMs can represent a strategic investment for energy-intensive companies (Cooremans 2011). Additionally, as noted in the European Union, large energy-intensive companies might be subject to mandatory energy audits, leading to increased EEM adoption (Fleiter, Hirzel, and Worrell 2012). Research has indicated that company size also influences the adoption rate of EEMs (Schleich 2009; Trianni et al. 2013).

Within companies, specific applications related to the adoption of EEMs can influence decision-makers' perception and hence their adoption rate. EEMs adopted in close *proximity to the core business* of a company are generally perceived as riskier (Sandberg and Soderstrom 2003), since they can directly impact production (Backman 2017) and affect firms' competitiveness (Fleiter, Hirzel, and Worrell 2012). Consequently, companies often prefer adopting EEMs in ancillary processes (Energy and Strategy Group 2021; Fleiter, Hirzel, and Worrell 2012), such as in lighting systems (Mills et al. 2006), avoiding integrations in core processes despite potential performance reduction (Dieperink et al. 2004). However, auxiliary EEMs are characterized by less pronounced NEBs (Sauter and Volkery 2013) and may receive less attention from decision-makers and management (Accordini et al. 2021; Harris et al. 2000) as they are usually more focused on core processes (Trianni and Cagno 2015).

The *number of working hours* is deemed to influence EEM adoption, impacting energy savings (Worrell et al. 2010) and equipment conditions; for instance, continuously running motors perform differently than those used intermittently in terms of response to vibration or temperature changes (Ferreira et al. 2016). Operating hours also influence the perceived risk of disruption, more prominent in companies with continuous production, for example, pulp and paper (Thollander and Ottosson 2008) or foundry (Rohdin et al. 2007).

Moreover, *EMS specifications*, including age and construction, can influence the adoption (Trianni and Cagno 2015), sometimes presenting compatibility issues (De Almeida et al. 2014). The EMS *size* affects the benefits brought by EEMs, with smaller motors often providing insufficient benefits to justify the investment (Saidur, Rahim, Masjuki, et al. 2009). This is supported by the significant increase of the price-to-power ratio of EEMs as motor size decreases (Saidur et al. 2012), whereas the nominal efficiency limit is reduced (De Almeida et al. 2014). Motor size influences the adoption rate, especially for EEMs characterized by high investment cost, such as variable speed drives (VSDs), which are more frequently installed on large motors (10–100 kW) (De Almeida et al. 2003; Saidur, Rahim, Ping, et al. 2009). Additionally, the *number of EMS* acted upon influences unit costs by leveraging discounts for multiple purchases (Trianni and Cagno 2015). However, adopting many EEMs—or EEMs extended to the entire process or plant—can affect multiple divisions of a company, requiring different stakeholders to be involved in the decision-making, leading to a more complex adoption process (Tornatzky and Klein 1982; Sorrell et al. 2000).

2.3 | Research Gaps

Although literature has partially recognized the influence of the adoption context on EEMs, a systematic classification of influential contextual characteristics is still lacking, as well as the analysis of their impact on EEMs and their adoption. According to extant literature, EEMs are analysed without considering their inherent characteristics and impacts, or only a very limited set of them. Recent research by Cagno et al. (2022) has reviewed previous literature about EEM characteristics, as well as impacts. Although offering an interesting contribution to the academic literature, the study lacks consideration of whether there are relationships between EEMs, their characteristics and their impacts on production resources. Discussion is far from being mature in this area, calling for additional research. It is argued here that a thorough analysis of the contextual dimension is essential to highlight relevant implications for a successful EEM implementation. However, studies have failed to investigate the adoption of an EEM considering the context in which that EEM is going to be implemented, rather being limited to providing neutral considerations around EEMs. To date, research has not discussed whether important business contextual factors, such as firm size or energy intensity of a company, affect some relevant EEM characteristics or their impacts. Likewise, studies are lacking to highlight whether the operational context, for example, type of process where an EEM is installed, or the decision strategy employed by a company to install it, may influence the performance of the EEM too.

Ultimately, the research should investigate whether, without proper consideration of the context, incorrect decisions over the adoption of an EEM may be made, such as failing to implement or incorrectly selecting and implementing EEMs. Should that be the case, this would imply that characteristics and impacts of EEMs may significantly vary based on contextual conditions.

In order to address the aforementioned research gap, the manuscript presents an innovative framework with an exploratory analysis to shed light on (i) the contextual characteristics that should be considered for a thorough EEM assessment and (ii) their role in influencing the adoption of EEMs in EMS.

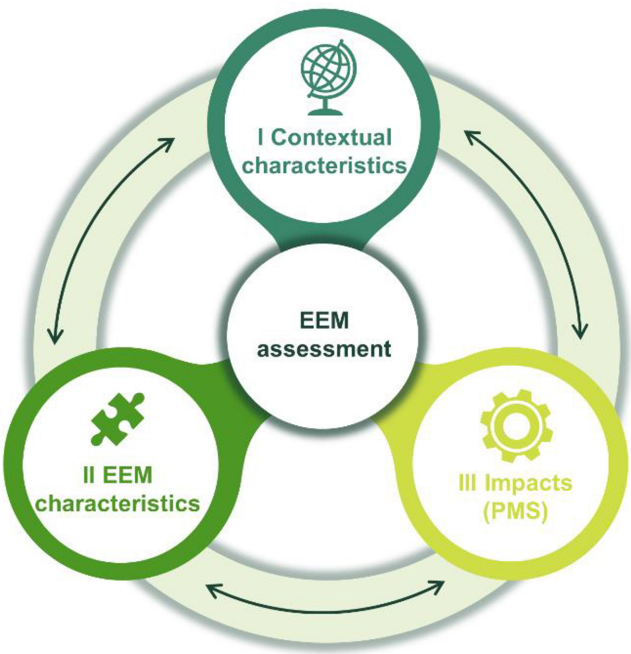

FIGURE 1 | Framework for the holistic assessment of an EEM.

3 | A Framework to Investigate EEMs, Contextual Characteristics and Impacts

Drawing inspiration from past literature, a theoretical framework to assess the adoption of an industrial EEM has been designed, with an enhanced focus on understanding the influence of contextual factors on EEM adoption. Figure 1 shows the framework encompassing three major dimensions to enable a holistic assessment of an EEM: (i) EEMs' characteristics (Table 1), (ii) EEMs' impacts (Table 2) and (iii) contextual characteristics (Table 3).

The characterization of an EEM encompasses the following aspects (Table 1): (i) objective and type, (ii) implementation-related characteristics, (iii) personnel-related characteristics, (iv) additional requirements and (v) economic aspects. Compared with previous literature, some critical characteristics have been added. The *lifetime* of an EEM, which indicates the stock turnover rate, constrains the adoption of new EEMs during replacement or substitution, as new devices replenish the stock once old ones are decommissioned (Fleiter, Hirzel, and Worrell 2012). For additional devices, such as retrofits, a longer lifetime increases the risk for companies since more efficient solutions may become available (Fleiter, Hirzel, and Worrell 2012). The *technological maturity* of an EEM (Worrell and Price 2001), its *level of acceptance* by a company's employees (Cagno et al. 2022) and its *complexity* (Trianni et al. 2014) are integrated into the framework, as they could act as barriers to adoption. Additionally, several economic characteristics are incorporated. These include the *implementation cost* of an EEM (Trianni et al. 2014), encompassing adaptation costs, equipment purchases and the decommissioning of old devices. Alongside the implementation cost, considering transaction costs associated with EEM adoption is crucial (Fleiter, Hirzel, and Worrell 2012). This involves evaluating costs such as information gathering (Schleich 2004), procurement expenses and the establishment of new operational routines (Fleiter, Hirzel, and Worrell 2012). To assess the investment, the simple *pay-back time* criterion is considered (Trianni et al. 2014), as it remains widely adopted in industry, even though it does not provide a comprehensive evaluation of an EEM's value over its entire lifetime (Sorrell et al. 2000).

In addition to energy savings, the adoption of an EEM is evaluated by assessing the *impacts* on other company resources and overall sustainability. These impacts are described within the reference framework (Cagno et al. 2022) through a sustainability Performance Measurement System (PMS) to encompass the production, social and environmental dimensions of sustainability. The set of indicators (key performance indicators; KPIs)—composed of 15 categories and 14 subcategories of KPIs—is specifically designed at the shop-floor level, considered the most relevant for assessing EEM adoption (Table 2).

The third pillar of the framework describes the *context* within which an EEM is considered (Table 3), limited to the boundaries of the company. The contextual characterization is developed by assessing (i) the business, (ii) the specific application and (iii) the decision-making approach for adoption. However, based on the literature overview presented in Section 2, several

TABLE 1 | Characteristic descriptive of EEMs, taking inspiration from Cagno et al. (2022). The novel characteristics introduced here have been marked with a (*) and in italics.

Categories	Characteristics	References	Attributes
Objective and type	Saving strategy	(Trianni et al. 2014; Vidmar 2010)	Efficiency, conservation
	Activity type	(Cagno et al. 2010; Cagno, Accordini, and Trianni 2019; Fleiter, Hirzel, et al. 2012; Roberts and Ball 2014; Trianni et al. 2014; Andrea Trianni et al. 2020)	Technology replacement, technology substitution, procedure or organizational EEM, add-on or retrofit
	Lifetime	*(Fleiter, Hirzel, and Worrell 2012)**	*Low (< 5 years), medium (5–20 years), high (> 20 years), unnecessary*
	Technological maturity	*(Worrell and Price 2001)**	*Low, high*
	Level of acceptance	*(Cagno et al. 2022)**	*Low, high*
Implementation-related	Implementation time	(Cagno, Accordini, and Trianni 2019; Roberts and Ball 2014)	E.g., hours, days, and weeks
	Check-up frequency	(Cagno, Accordini, and Trianni 2019; Trianni et al. 2014; Wulfinghoff 1999)	One-time check, periodic check
	Complexity	*(Trianni et al. 2014)**	*Low (simple or routine intervention), high (difficult or challenging intervention)*
Personnel-related	Corporate involvement	(Cagno, Moschetta, and Trianni 2019; González 2005; International Energy Agency 2015; Nehler, Thollander, et al. 2018; Sandberg and Soderstrom 2003; Worrell et al. 2010)	Limited, wide
	Knowledge required	(Cagno, Moschetta, and Trianni 2019; Finster and Hernke 2014; Fleiter, Hirzel, and Worrell 2012; González 2005; Roberts and Ball 2014; Woodroof et al. 2012)	Maintenance personnel, engineering personnel, technology expert
Additional requirements	Secondary devices necessary	(Accordini et al. 2021)	Implementation phase, service phase, unnecessary
	Synergies with other EEMs	(Accordini et al. 2021)	Implementation phase, service phase, unnecessary
Economic	*Implementation cost*	*(Trianni et al. 2014)**	*Low, medium, high*
	Transaction cost	*(Fleiter, Hirzel, and Worrell 2012; Schleich 2004)**	*Low, medium, high*
	Pay-back time	*(Lung et al. 2019; Sorrell et al. 2000)**	*Short (≤ 2 years), long (> 2 years)*

TABLE 2 | Impacts on a company sustainability from the adoption of an EEM.

Pillars	KPI categories	KPI subcategories	References
Production	Lead time		(Cagno, Neri, et al. 2019; Giachetti et al. 2003; Kang et al. 2016; Muthiah and Huang 2017; Neely et al. 2005; De Toni and Tonchia 2001; Upton 1998; Zhu et al. 2018)
	Process quality		(Finman and Laitner 2001; Gunasekaran et al. 2004; Huang et al. 2003; Jagoda et al. 2013; Kang et al. 2016; Lung et al. 2005; Mills et al. 2008; Muthiah and Huang 2017)
	Flexibility	Mix flexibility Volume flexibility Design flexibility Other flexibilities	(Lohman et al. 2004; Neely et al. 2005; De Toni and Tonchia 2001)
	Control and information		(Cagno, Neri, et al. 2019; Garbie 2014; Mills et al. 2008; Neely et al. 2005; Nehler, Parra, and Thollander 2018; Rasmussen 2017; Skumatz et al. 2000; Trianni et al. 2020; Trianni, Cagno, Neri, and Howard 2019)
	Equipment status and productivity	Bottleneck Throughput Downtime Status of the equipment	(Jagoda et al. 2013; Kang et al. 2016; Kutucuoglu et al. 2001; Mills et al. 2008; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Spider Strategies, n.d.; Trianni et al. 2020; Wagner et al. 2020; Zhu et al. 2018)
	Inventory		(Gunasekaran et al. 2001; Lohman et al. 2004; Neely et al. 2005; Wagner et al. 2020)
	Plant layout		(Lung et al. 2005; Nehler, Parra, and Thollander 2018; Wagner et al. 2020; Ernst Worrell et al. 2003)
Social	Customers	Delivery-related satisfaction Personalized products and services	(Ghalayini et al. 1997; Gomes et al. 2011; Gunasekaran et al. 2001, 2004; Gunasekaran and Kobu 2007; Muthiah and Huang 2017; Neely et al. 2005; Olsen and Ward 2006)
	Employees	Employees involvement Training	(Lilly and Pearson 1999; Lung et al. 2005; Muller and Papadaratsakis 2003; Neely et al. 2005; Rasmussen 2017; Skumatz et al. 2000; Soh et al. 2012; Trianni et al. 2020; Worrell et al. 2003)
	Operational health and safety (OHS)	Health and safety Working conditions	(Gomes et al. 2011; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Rasmussen 2017; Skumatz et al. 2000; Trianni et al. 2020; Wagner et al. 2020)
Environment	Water Material Energy Air emissions Waste		(Cagno, Moschetta, and Trianni 2019; Finman and Laitner 2001; Garbie 2014; Lilly and Pearson 1999; Lung et al. 2005; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Rasmussen 2017; Ryan and Campbell 2012; Trianni, Cagno, Neri, and Howard 2019; Wagner et al. 2020; Worrell et al. 2003)

(Continues)

TABLE 2 | (Continued)

Pillars	KPI categories	KPI subcategories	References
Production	Lead time		(Cagno, Neri, et al. 2019; Giachetti et al. 2003; Kang et al. 2016; Muthiah and Huang 2017; Neely et al. 2005; De Toni and Tonchia 2001; Upton 1998; Zhu et al. 2018)
	Process quality		(Finman and Laitner 2001; Gunasekaran et al. 2004; Huang et al. 2003; Jagoda et al. 2013; Kang et al. 2016; Lung et al. 2005; Mills et al. 2008; Muthiah and Huang 2017)
	Flexibility	Mix flexibility Volume flexibility Design flexibility Other flexibilities	(Lohman et al. 2004; Neely et al. 2005; De Toni and Tonchia 2001)
	Control and information		(Cagno, Moschetta, and Trianni 2019; Garbie 2014; Mills et al. 2008; Neely et al. 2005; Nehler, Parra, and Thollander 2018; Rasmussen 2017; Skumatz et al. 2000; Trianni et al. 2020; Trianni, Cagno, Neri, and Howard 2019)
	Equipment status and productivity	Bottleneck Throughput Downtime Status of the equipment	(Jagoda et al. 2013; Kang et al. 2016; Kutucuoglu et al. 2001; Mills et al. 2008; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Spider Strategies, n.d.; Trianni et al. 2020; Wagner et al. 2020; Zhu et al. 2018)
	Inventory		(Gunasekaran et al. 2001; Lohman et al. 2004; Neely et al. 2005; Wagner et al. 2020)
	Plant layout		(Lung et al. 2005; Nehler, Parra, and Thollander 2018; Wagner et al. 2020; Ernst Worrell et al. 2003)
Social	Customers	Delivery-related satisfaction Personalized products and services	(Ghalayini et al. 1997; Gomes et al. 2011; Gunasekaran et al. 2001, 2004; Gunasekaran and Kobu 2007; Muthiah and Huang 2017; Neely et al. 2005; Olsen and Ward 2006)
	Employees	Employees involvement Training	(Lilly and Pearson 1999; Lung et al. 2005; Muller and Papadaratsakis 2003; Neely et al. 2005; Rasmussen 2017; Skumatz et al. 2000; Soh et al. 2012; Andrea Trianni et al. 2020; Ernst Worrell et al. 2003)
	Operational health and safety (OHS)	Health and safety Working conditions	(Gomes et al. 2011; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Rasmussen 2017; Skumatz et al. 2000; Trianni et al. 2020; Wagner et al. 2020)
Environment	Water Material Energy Air emissions Waste		(Cagno, Moschetta, and Trianni 2019; Finman and Laitner 2001; Garbie 2014; Lilly and Pearson 1999; Lung et al. 2005; Nehler, Parra, and Thollander 2018; Pye and McKane 2000; Rasmussen 2017; Ryan and Campbell 2012; Trianni, Cagno, Neri, and Howard 2019; Wagner et al. 2020; Worrell et al. 2003)

Source: Cagno et al. (2022).

TABLE 3 | Characteristic descriptive of the context, based on Cagno et al. (2022). The additional or revised elements have been marked with a (*) and in italics.

Categories	Characteristics	References	Attributes
Business context	Company size	(Bicknell and Skumatz 2007; Cooremans and Schönenberger 2019; Gordon et al. 1999; International Energy Agency 2015; Killip et al. 2018)	Small companies (< 50 employees), medium companies (50–250 employees), large companies (> 250 employees)
	Energy intensity	(Cooremans and Schönenberger 2019; International Energy Agency 2014)	Energy-intensive (energy cost represent more than 2% of the company's annual revenue), nonenergy intensive
	Layout type	(Brundage et al. 2016)	Job-shop, cells, flow lines
	Working hours	*(Accordini et al. 2021)**	*One shift, two shift, continuous production*
	Regulatory context	*(Franzò et al. 2019)**	E.g., *white certificates*
Application context	Process centrality	(Davide Accordini 2018; Cooremans 2011, 2015; Ferreira et al. 2016; Fleiter, Hirzel, and Worrell 2012; Sauter and Volkery 2013; Trianni et al. 2014)	Core processes, ancillary processes
	Saturation level	/	Saturated, nonsaturated
	Automation level	*(Accordini 2018)**	*Manual, automatically assisted, semi-automatic, fully automatic*
	Numerosity of EEMs	(Davide Accordini 2018; Ernst Worrell et al. 2010)	One or few, many (the threshold among attributes is not univocally defined, since it depends on the specific EEM.)
	Dimension of the installation/area interested	(Davide Accordini 2018; Cagno, Moschetta, and Trianni 2019; Ferreira et al. 2016; Gordon et al. 1999)	Small, medium, large (it depends on the specific EEM.)
	Accessibility	(Andrea Trianni et al. 2020)	Easy, difficult, hazardous
	Level of acceptance (of an EEM by the employees of a company)	(Davis 1989)	Low, medium, high
Decisional context	Source strategy	(Roberts and Ball 2014)	In-source, out-source, mixed
	Implementation type	(Cagno, Accordini, and Trianni 2019)	Single intervention, multiple interventions

crucial characteristics have been incorporated to supplement the reference framework. Regarding the characterization of the business context, the number of *working hours* during normal operating conditions has been included (Accordini et al. 2021). This provides relevant insights, along with energy intensity and the company layout, pertaining to the nature of the production processes. Additionally, contextualization involves assessing the *regulatory landscape* within which the company operates, encompassing obligations, incentives and certification schemes (Franzò et al. 2019). Furthermore, for the specific application of an EEM, contextual description includes evaluating the predominant *level of automation* in the production processes.

4 | Research Methods

The validation of the framework tests its capability to assess the adoption of an EMS EEM and, as shown in Figure 2, consists of two subsequent steps: a theoretical validation followed by an empirical one.

The theoretical validation of the framework is based on the assessment of a selected set of EEMs applied to EMS, conducted through a literature review, as recommended by previous research (Trianni et al. 2020). The EEMs' characteristics and their impacts on a company's resources are analysed, providing a concrete basis for developing the empirical validation. The literature notably lacks contextual information and its influence on adoption, necessitating a subsequent empirical analysis to comprehensively validate the framework.

The theoretical validation tests the ability of the framework to assess the adoption of an EEM in EMS, described through the EEMs' characteristics and their impacts on a company's resources. For this purpose, a heterogeneous sample of five EMS EEMs has been identified as a reference. EEMs were selected to cover all major types of recommendations considered in the

US Industrial Assessment Center database for motors (U.S. Department of Energy 2020), focusing on those with a high number of recommendations. The selected types of recommendation, identified in the database through the Assessment Recommendation Code (ARC) developed by the US DOE Industrial Assessment Centre (IAC), are presented in Table 4. So far, the IAC represents the world's largest programme regarding energy audits in the manufacturing context, with more than 22,000 assessments and more than 160,000 associated EE recommendations in Northern America (US DOE IAC 2025). As part of this programme, the IAC has developed a valuable coding of the major groups of EEMs, that is, ARC. We have selected the five most important recommendations from that list regarding Energy Motor Systems.

An extended literature review, encompassing both grey and academic sources, was conducted to analyse the selected EEMs with respect to the proposed framework. This involved assessing the characteristics of EEMs and their impacts on companies' operational performance. As part of this task, the research has assessed the EEMs considering the proposed framework, by seeking to provide attributes to each characteristic as reported in Table 1. Furthermore, based on the literature insights, it has been noted whether the value reported of the considered characteristic was strongly dependent upon the specific context. Such assessment would provide an understanding of whether a characteristic of an EEM—and its related impact—would be affected by specific contextual elements, that is, the business or the specific application. Impacts have been marked across the three different pillars of Production, Social and Environment as per Table 2. In doing so, the theoretical validation from literature has noted if an EEM had a positive or negative effect across the KPIs considered, or rather, such impact depended on the specific situation, which would infer that the impact is affected by the EEM business or application context.

Given the significant lack of information regarding the contextual influence on EEM adoption in existing literature, an empirical investigation was necessary. Interviews with panel of experts were selected to study the contextual influence on adoption over interviews with industrial decision-makers (Accordini et al. 2021), given that the latter tend to possess competences limited to a very narrow context. Expert panels are frequently used to gain knowledge and orientation in unknown or scarcely known fields (Döringer 2021). By drawing from experiences across multiple companies, experts can provide comparative insights into how different contexts affect EEM adoption. According to Bogner and Menz (2009), expert interview allows

TABLE 4 | Sample of EEMs selected for the theoretical validation of the framework.

ARC code	EEMs
2.4111	Utilize energy-efficient belts and other improved mechanisms (EEM1)
2.4131	Replace over-sized motors [and pumps] with optimum sized (EEM2)
2.4133	Use most efficient type of electric motors (EEM3)
2.4146	Use adjustable frequency drive or multiple speed motors on existing system (EEM4)
2.4157	Establish a predictive maintenance programme (EEM5)

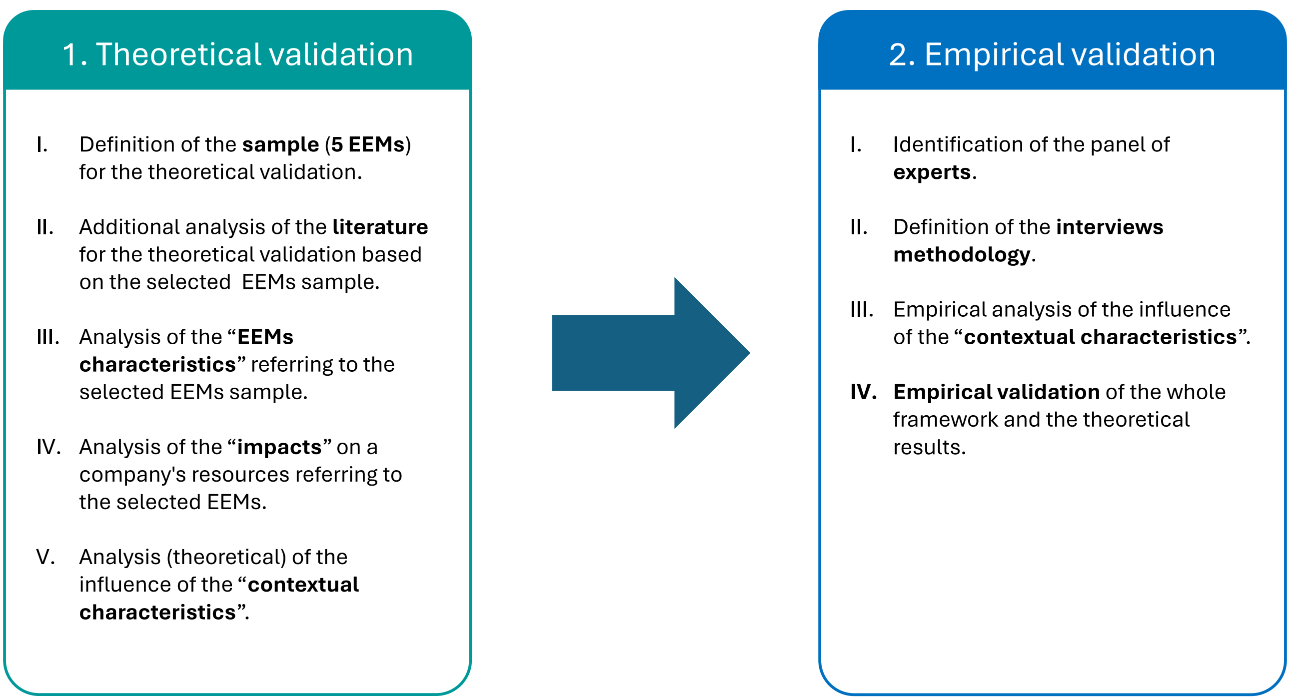

FIGURE 2 | Flowchart of the methodology process.

TABLE 5 | Panel of expert for the empirical validation of the framework.

Expert	Background	Degree	Experience
Expert 1 (E1)	Industrial consultant (expertise in engineering and EE)	MSc (Mechanical Engineering)	Practitioner with 10+ years of industrial experience and member of an industrial trade association. Accredited energy auditor, he provides consulting services on EE (particularly focusing on SME).
Expert 2 (E2)	Industrial consultant (expertise in engineering and EE)	MSc (Mechanical Engineering)	Senior industrial practitioner, provides consulting services on EE and overall companies' sustainability, working mainly with large companies.
Expert 3 (E3)	Academic (Full Professor—Industrial Engineering school)	PhD (Management Engineering)	Senior academic with 30+ years of expertise in EE and industrial sustainability, authored hundreds of publications in international peer-reviewed journals.
Expert 4 (E4)	Academic (Associate Professor—Industrial Engineering school)	PhD (Management Engineering)	Senior academic with 20+ years of expertise in industrial EE and sustainability, with several collaborations in industry and research publications
Expert 5 (E5)	Academic (Full Professor—Industrial Engineering school)	PhD (Management Engineering)	Senior academic with 30+ years of expertise in EE and energy strategy. Expert 5 managed dozens of industrial and research projects, having full visibility of the sector, and collaborates with industrial associations. Expert 5 has authored hundreds of publications in national and international journals.
Expert 6 (E6)	Academic (Associate Professor—Industrial Engineering school)	PhD (Management Engineering)	Academic with 15 years of expertise in energy management. Expert 6 works regularly with agencies and the local government to improve energy use and management.
Expert 7 (E7)	General manager (consulting firm with a focus on energy and EE)	MSc (Mechanical Engineering)	Industrial practitioner with 35 years of experience, general manager of a company focused on providing EE services (from diagnostic to design and implementation of EE projects).

[Correction added on 08 August 2025, after first online publication: Table 5 was updated in this version.]

for the collection of structured and comprehensive knowledge, encompassing both technical knowledge of a field and processual knowledge, based on practical experience acquired from one's own context of action.

The panel consists of seven experts in the fields of industrial EE, operations management and corporate sustainability (Table 5), with thorough knowledgeability on the specific issues under investigation (Döringer 2021). Following this definition, the seven experts were selected from both academic and industrial backgrounds, each possessing over a decade of experience in the Italian manufacturing sector.

In-depth interviews represent a widely used research methodology in the literature when dealing with the assessment of EEMs (Nehler 2018) and the preferred research approach for generating knowledge in the area of management (Gibbert et al. 2008). Researchers have conducted semistructured interviews (Bernard 2006) to guide respondents through the framework while allowing a degree of flexibility, which is necessary given the exploratory nature of the analysis. An interview guide, along with the framework of analysis, was drafted and shared with the interviewees beforehand to help them become familiar with the broad research and overall questions (Nehler, Parra, and Thollander 2018). Furthermore, the researchers have developed a flexible interview protocol to allow for the collection of any free comments or themes emerging during the conversation (Dicicco-Bloom and Crabtree 2006), also encouraging respondents to address specific aspects by providing informative empirical evidence (Timmermans and Tavory 2012). The interviews were recorded upon obtaining participants' consent, and researchers took notes during the interviews. Following a general introduction to the framework and the results of the theoretical validation, the interviews progressed by analysing the influence of each contextual characteristic in relation to the EEMs' characteristics and their impacts on a company's resources (Tables 1, 3 and 4). Experts were further encouraged to elaborate on how context influences the adoption, and an inductive approach, supported by a coding scheme, was used to analyse responses to the questions (Eisenhardt 1989; Corbin and Strauss 1990). The interviews were conducted individually, and a second round of interviews was carried out to gather additional information as required. Taking inspiration from previous research, the coding of the responses has been performed independently by at least two researchers (Neri et al. 2023), with a final structure consolidated and agreed upon by all authors with following rounds of discussion.

5 | Results

The outcomes of the theoretical validation are presented in the following. The assessment focused on the EEMs' characteristics (Table 6) and the impacts generated on a company's overall resources (Table 7).

The values derived from theoretical validation serve as general guidelines and considerations. However, several contextual characteristics can significantly influence the decision to adopt an EEM in EMS. For instance, the economic evaluation of an investment in EE is highly contingent on characteristics such as the size of the EMS and the number of operating hours; below a certain threshold, the investment may no longer be viable for a company. Therefore, a thorough empirical analysis of such characteristics and their impacts has been conducted. The empirical results are presented in Table 8 and subsequently discussed.

The interviews with experts highlighted the significant relevance of the context when adopting an EEM (Table 8). Although the individual factors—both characteristics and impacts—are relevant when considering the adoption, the results reveal a network of complex interrelationships that were not fully captured by previous research (Figure 1). A more precise graphical representation of contextual influence on EEM adoption, derived from the empirical results, is provided in Figure 3. Figure 3 illustrates the inherent heterogeneity within category clusters and offers insights into how context may affect both the relationships among EEMs' characteristics and the impacts on a company's overall resources.

Several interesting considerations emerge from Table 8 and Figure 3. Firstly, the empirical validation shows that both EEMs' characteristics and contextual ones can be further divided into two distinct elements. The EEMs' characteristics can be categorized as either *fixed*, inherent of an EEM (e.g., the type of activity represented by an EEM), or *variable,* influenced by the surrounding environment (e.g., the complexity of an EEM or its implementation time, which might vary according to the size of a company). Similarly, experts highlighted the need to distinguish between the *business context* (e.g., the size and energy intensity of a company) and the *application and decisional context* (e.g., the type of process where an EEM is installed, or the decision-strategy employed by a company to install it). The detailed organization of characteristics is reported in Table 9.

Secondly, it appears that mutual relationships exist between these clusters. The business context does not seem to be significantly affected by other factors, as it describes the company and the macro-context in which it operates. However, the business context seems to affect the fixed EEMs' characteristics, not by altering their value, rather by influencing the type of EEMs considered by the companies. For instance, experts highlighted that EEMs with a low technological maturity or a high lifetime are often preferred by larger companies. Therefore, this insight could provide initial guidance for decision-makers interested in considering such EEMs in light of their specific context for adoption.

Thirdly, the business context and fixed EEMs' characteristics seem to influence the application and decision context, for example, highlighting a connection between the sourcing strategy employed for the implementation of an EEM and the size of the corresponding company. In turn, our investigation reveals that business context, application and decision context and fixed EEMs' characteristics seem to affect the variable EEMs' characteristics. For instance, the complexity of an EEM might be affected by the company size or the decisional strategy employed for the adoption. Details on these alleged relationships are extensively reported in Table 8, with a mapping of these relationships presented in Table 9.

Fourthly, the context appears to influence the impacts generated by an EEM on a company's overall resources. For instance, adopting an EEM that affects a company's core process can *directly* impact productivity, such as lead time or process volume flexibility. The context might also exert an *indirect* influence by acting on other direct relationships. For instance, the direct relationships between the time required to install an EEM and the resulting production downtime might be influenced by a set of contextual characteristics (e.g., process centrality, implementation type and number of EEMs to be installed). This result implies an obvious yet neglected implication in many cases: For instance, production downtime should be mitigated or avoided by focusing on ancillary processes or fragmenting the installation into several steps. Results are detailed in Table 8, with Table 10 summarizing the relationships and their nature.

Overall, the results highlight that complex relationships exist between the different factors, mostly neglected or oversimplified by previous research. Understanding such relationships helps illuminate the influence of the context on adopting an EEM. This knowledge, complemented with information about EEMs' characteristics and impacts, could support industrial decision-makers in performing a holistic and sound assessment of EEM adoption, a key step in promoting EE in industry.

6 | Discussion

The research contributes to the academic discussion over the adoption of EEMs. Results of the study confirm that EEMs' characteristics and the impacts generated on a company's operational performance are key factors for EEM assessment in light of the context in which adoption occurs. This is confirmed by the relevance of certain contextual characteristics and their interwoven relationships with other key factors descriptive of an EEM, potentially leading to different assessment and prioritization (Richter et al. 2023). In this regard, earlier literature has attempted to note some of these relationships, although

TABLE 6 | Theoretical validation of the EEMs' characteristics. "*" means that the value is strongly dependent upon the specific context.

Utilize energy-efficient belts and other improved mechanisms (ARC 2.4111)

Categories	Characteristics	Values			
Objective and type	Saving strategy	Efficiency		Conservation	
	Activity type	Technology replacement	Technology substitution	Procedure or organizational EEM	Add-on or retrofit
	Lifetime	Short	Medium	Long	Unnecessary
	Technological maturity	Low		High	
	Level of acceptance	Low		High	
Implementation-related	Implementation time	Short*	Medium	Long	Unnecessary
	Check-up frequency	One-time check		Periodic check	
	Complexity	Low*		High	
Personnel-related	Corporate involvement	Limited		Wide	
	Knowledge required	Maintenance personnel	Engineering personnel*	Technology expert	
Additional requirements	Secondary devices	Implementation phase	Service phase	Unnecessary	
	Synergies with other EEMs	Implementation phase	Service phase	Not present	
Economy	Cost	Low*	Medium	High	
	Transaction cost	Low	Medium	High	
	Pay-back time	Short*		High	
References	(Accordini et al. 2021; Cagno et al. 2022; De Almeida and Greenberg 1995; ETSU et al. 1998; Gates Corporation 2014; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy: Advanced Manufacturing Office 2014; U.S. Department of Energy DOE 2000, 2012)				

Use most efficient type of electric motors (ARC 2.4133)

Categories	Characteristics	Values			
Objective and type	Saving strategy	Efficiency		Conservation	
	Activity type	Technology replacement	Technology substitution	Procedure or organizational EEM	Add-on or retrofit
	Lifetime	Short	Medium	Long	Unnecessary
	Technological maturity	Low		High	
	Level of acceptance	Low		High	

(Continues)

TABLE 6 | (Continued)

Use most efficient type of electric motors (ARC 2.4133)

Categories	Characteristics	Values			
Implementation-related	Implementation time	Short	Medium*	Long	Unnecessary
	Check-up frequency	One-time check		Periodic check	
	Complexity	Low		High	
Personnel-related	Corporate involvement	Limited		Wide	
	Knowledge required	Maintenance personnel	Engineering personnel	Technology expert	
Additional requirements	Secondary devices	Implementation phase	Service phase	Unnecessary	
	Synergies with other EEMs	Implementation phase	Service phase	Not present	
Economy	Cost	Low	Medium*	High	
	Transaction cost	Low	Medium	High	
	Pay-back time	Short*		High	
References	(Accordini et al. 2021; Akbaba 1999; Fleiter, Hirzel, and Worrell 2012; Motor Decision Matter 2007; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy Motor Challenge 2014b; Worrell et al. 2010)				

Establish a predictive maintenance programme (ARC 2.4157)

Categories	Characteristics	Values			
Objective and type	Saving strategy	Efficiency		Conservation	
	Activity type	Technology replacement	Technology substitution	Procedure or organizational EEM	Add-on or retrofit
	Lifetime	Short	Medium	Long	Unnecessary
	Technological maturity	Low		High	
	Level of acceptance	Low		High	
Implementation-related	Implementation time	Short	Medium	Long	Unnecessary
	Check-up frequency	One-time check		Periodic check	
	Complexity	Low		High	
Personnel-related	Corporate involvement	Limited		Wide	
	Knowledge required	Maintenance personnel	Engineering personnel	Technology expert	
Additional requirements	Secondary devices	Implementation phase	Service phase	Unnecessary	
	Synergies with other EEMs	Implementation phase	Service phase	Not present	

(Continues)

TABLE 6 | (Continued)

Establish a predictive maintenance programme (ARC 2.4157)					
Categories	**Characteristics**	**Values**			
Economy	Cost	Low*	Medium	High	
	Transaction cost	Low	Medium	High	
	Pay-back time	Short*		High	
References	(Accordini et al. 2021; Cagno et al. 2022; Motor Decision Matter 2007; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019)				

Replace over-sized motors and pumps with optimum sized (ARC 2.4131)					
Categories	**Characteristics**	**Values**			
Objective and type	Saving strategy	Efficiency		Conservation	
	Activity type	Technology replacement	Technology substitution	Procedure or organizational EEM	Add-on or retrofit
	Lifetime	Short	Medium	Long	Unnecessary
	Technological maturity	Low		High	
	Level of acceptance	Low		High	
Implementation-related	Implementation time	Short	Medium*	Long	Unnecessary
	Check-up frequency	One-time check		Periodic check	
	Complexity	Low		High	
Personnel-related	Corporate involvement	Limited		Wide	
	Knowledge required	Maintenance personnel	Engineering personnel	Technology expert	
Additional requirements	Secondary devices	Implementation phase	Service phase	Unnecessary	
	Synergies with other EEMs	Implementation phase	Service phase	Not present	
Economy	Cost	Low	Medium*	High	
	Transaction cost	Low	Medium	High	
	Pay-back time	Short*		High	
References	(Accordini et al. 2021; ETSU et al. 1998; Ferreira and De Almeida 2012; Saidur 2010; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy Motor Challenge 2014a, 2014b)				

TABLE 6 | (Continued)

Use adjustable frequency drive or multiple speed motors on existing system (ARC 2.4146)					
Categories	**Characteristics**	**Values**			
Objective and type	Saving strategy	Efficiency		Conservation	
	Activity type	Technology replacement	Technology substitution	Procedure or organizational EEM	Add-on or retrofit
	Lifetime	Short	Medium	Long	Unnecessary
	Technological maturity	Low		High	
	Level of acceptance	Low		High	
Implementation-related	Implementation time	Short	Medium	Long	Unnecessary
	Check-up frequency	One-time check		Periodic check	
	Complexity	Low		High	
Personnel-related	Corporate involvement	Limited		Wide	
	Knowledge required	Maintenance personnel	Engineering personnel*	Technology expert	
Additional requirements	Secondary devices	Implementation phase	Service phase	Unnecessary	
	Synergies with other EEMs	Implementation phase	Service phase	Not present	
Economy	Cost	Low	Medium*	High	
	Transaction cost	Low	Medium	High	
	Pay-back time	Short*		High	
References	(Accordini et al. 2021; Akbaba 1999; Cagno et al. 2022; Carbon Trust 2007, 2018; Integral Advanced systems 2001; Saidur and Mekhilef 2010; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy: Advanced Manufacturing Office 2008; United States Department of Energy 2008)				

TABLE 7 | Theoretical validation of the impacts on a company's resources coming from the adoption of EEMs.

Pillars	KPI categories	KPI subcategories	EEM1	EEM2	EEM3	EEM4	EEM5
Production	Lead time		I			I	
	Process quality	Mix flexibility	I			I	
		Volume flexibility	I	I	I	I	I
		Design flexibility					
		Other flexibilities					
	Control and information	Bottleneck	I			I	I
		Throughput	I			I	
		Downtime	I	I	I	I	I
		Status of the equipment	I	I	I	Dep	I
	Inventory						
	Plant layout					Dep	
Social	Customers	Delivery-related satisfaction					
		Personalized products and services					
	Employees	Employees involvement		I		I	
		Training					
	Operational health and safety (OHS)	Health and safety					
		Working conditions	Dep	I	I	Dep	I
Environment	Water						
	Material						
	Energy		I	I	I	I	I
	Air Emissions		I	I	I	I	I
	Waste		I			I	
References			(Accordini et al. 2021; Cagno et al. 2022; Carbon Trust 2018; Gates Corporation 2014; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy: Advanced Manufacturing Office 2014; U.S. Department of Energy DOE 2000, 2012)	(Accordini et al. 2021; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019)	(Abdelaziz et al. 2011; Accordini et al. 2021; Trianni, Cagno, and Accordini 2019; U.S. Department of Energy Motor Challenge 2014b; Worrell et al. 2010)	(Accordini et al. 2021; Cagno et al. 2022; Carbon Trust 2018; Integral Advanced systems 2001; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019; U.S. DOE AMO2008)	(Accordini et al. 2021; Cagno et al. 2022; Trianni et al. 2014; Trianni, Cagno, and Accordini 2019)

Abbreviations: Dep: depending on the specific situation; I: improved; W: worsened.

TABLE 8 | Results of the empirical validation of the framework. ✓ represents comments highlighted/confirmed by the expert.

Characteristic and related impacts	Contextual characteristic	Description of the influence	E1	E2	E3	E4	E5	E6	E7
Objective and type	Company size	SME generally adopt simpler EEMs.					✓	✓	✓
		SME prefer simpler and more reversible retrofits of existing machinery to new installations.		✓			✓	✓	✓
		EEMs characterized by longer lifetimes are usually preferred by larger companies, as they assume a longer-term vision.	✓				✓	✓	
		After a modification of the equipment, SME do not usually verify the compliance with the standards (e.g., safety standard).	✓						✓
		SME are usually less innovative and skilled for new technologies.			✓		✓	✓	✓
		SME outsource more often the EEMs			✓		✓	✓	✓
	Energy intensity	Energy-intensive companies tend to choose EEMs tailored for their processes, despite the complexity.	✓				✓	✓	✓
		Energy-intensive companies optimize the energy savings performance of an EEM			✓		✓	✓	✓
	Working hours	Companies that work more than one daily shift are more interested in the adoption of EEMs.				✓	✓	✓	✓
	Accessibility	The type of EEM may be influenced by the adoption location and accessibility (e.g., AFDs or devices that reduce motor speed are not recommended for intake fans working in explosive atmosphere).	✓					✓	✓
	Regulatory context	The type of EEM may be affected by the existing regulations		✓			✓	✓	✓
		EEMs lead energy savings might imply the loss of profitable government subsidies that support energy-intensive companies.	✓				✓		
	Sourcing strategy	Innovative EEMs, when managed internally without proper competences, could worsen the productivity performance.		✓				✓	✓
Implementation related	Process centrality; process saturation	A downtime for the installation of EEMs is particularly critical in the case of machinery acting on the company's core business, as it could lead to a production stop.	✓	✓	✓	✓	✓	✓	✓
		The inability to recover losses from a production stop is higher in the case of a highly saturated processes.	✓	✓	✓	✓	✓	✓	✓
		In case of high risk of downtime and production losses, companies take greater advantage of already scheduled downtimes.	✓		✓		✓	✓	✓
	Implementation type	Fragmenting the installation of an EEM into multiple interventions may allow to take advantage of other planned downtimes.	✓						✓
		The fragmented adoption is especially used in the case of extended EEMs or EEMs directly affecting the core activities.	✓						✓
		The fragmented installation of a large number of devices allows for risk reduction through the observability of partial results.	✓						✓
		The fragmented installation of an EEM increases its organizational complexity.				✓		✓	✓

(Continues)

TABLE 8 | (Continued)

Characteristic and related impacts	Contextual characteristic	Description of the influence	E1	E2	E3	E4	E5	E6	E7
	Acceptability	The acceptability of an EEM by operators facilitates its adoption.	✓				✓	✓	✓
		Increased well-being could be reflected in productivity gains.		✓			✓	✓	✓
		EEMs that decrease comfort and operators' well-being might be poorly accepted and their adoption prevented				✓	✓	✓	
	Company size	Core EEMs are more usually adopted by large companies.		✓	✓		✓	✓	✓
		Large companies are more experienced and able to recognize how the nonenergy impacts could boost their business.		✓			✓	✓	✓
		SMEs tend to act on ancillary processes and general services, less risky for business performance.		✓					✓
		Large companies are more organized for the implementation of EEMs, taking advantage of already planned plant downtime to prevent further disruption to production.		✓			✓	✓	✓
		SME tend to outsource the adoption more often due to scarcity of internal resources and competences.	✓	✓	✓	✓	✓	✓	✓
	Company size and numerosity	The organizational complexity to implement many EEMs simultaneously is higher.			✓		✓	✓	✓
	Sourcing strategy	Outsourced EEMs tend to be more complicated, as it is necessary to manage an external team.		✓	✓		✓	✓	✓
		The planning phase for an EEM could become more difficult and take longer in case of outsourcing.	✓				✓	✓	
		The overall adoption time for outsourced EEMs is generally higher.			✓	✓	✓	✓	✓
		Frequency of check-ups might be influenced by the sourcing strategy (e.g., due to costs or contract requirements)		✓					✓
		Outsourcing core processes' EEMs might lead to productivity deterioration and increased costs			✓		✓	✓	
		If in-house expertise is lacking, outsourcing reduces the need to manage training activities, avoids EEMs mismanagement and overall performance degradation.	✓	✓		✓	✓	✓	✓
	Working hours	Companies operating continuously (e.g., process industries) reduce the EEMs installation downtime, which would be difficult to recover, taking advantage of already planned downtime.		✓			✓	✓	✓
	Layout and type of process	EEM adoption is less critical in production layouts more resilient to downtimes (e.g., alternative cycles in a job shop)				✓	✓		✓
		Production recovery is easier in companies that produce by parts compared to process companies.				✓	✓	✓	
		Plant layout might influence the impact of implementation time workforce utilization.			✓				✓
		More design flexibility for the adoption of an EEM is allowed with a job-shop.			✓				✓

(Continues)

TABLE 8 | (Continued)

Characteristic and related impacts	Contextual characteristic	Description of the influence	E1	E2	E3	E4	E5	E6	E7
	Numerosity	More EEMs being implemented simultaneously increase the length of the worksite, while the implementation time for the single EEM remains unaffected.	✓				✓	✓	✓
	Extension	The implementation time might be influenced by the extension of the EEM.				✓	✓	✓	✓
		Extended EEMs (e.g., over a department) require a construction site to be implemented, to the detriment of the activities and the people working in the area.		✓	✓		✓	✓	✓
		Extended EEMs might lead to a production downtime even when not directly acting on the core process.		✓				✓	✓
	Accessibility	Hard-to-access locations can complicate removal of any old devices and installation of new ones more .			✓		✓	✓	✓
		Low accessibility could result in extended downtimes.				✓		✓	✓
Personnel related	Company size	Large companies employ highly specialized personnel, while in SME every EEMs is managed by the same persons.	✓	✓	✓	✓	✓	✓	✓
		More people and hierarchical level might participate in the adoption of EEMs in larger companies.		✓	✓	✓	✓	✓	✓
		Team size participating in the adoption varies with the cost of lost production.	✓				✓		✓
		The implementation downtime affects more people in larger enterprises.			✓			✓	
	Energy intensity	Energy-intensive companies have more in-house expertise available when it comes to EEM adoption			✓	✓	✓	✓	✓
		Nonenergy intensive companies outsource more often the adoption of EEMs		✓			✓	✓	
	Numerosity, dimension/ extension of EEM	The number of devices to be adopted, together with their dimension, extension and complexity, may affect the type of personnel involved (e.g., higher hierarchical levels in the organization).		✓	✓	✓	✓	✓	✓
		The number of devices could affect the role held in the company by the decision-maker.				✓	✓		✓
		The number of devices to be implemented could possibly affect the number of people involved in the adoption.	✓		✓		✓	✓	✓
	Automation level and layout type	In highly automated processes, more skilled and trained staff are required to perform the adoption of EEMs.			✓				✓
		Costs are usually higher to intervene on a highly automated process.			✓				
	Company size	Larger companies are usually more automated.				✓	✓	✓	✓
		The production process layout might influence the level of required training (e.g., less training for job shop operators).			✓		✓	✓	✓
Economy	Numerosity	The purchasing cost of the single EEM might decrease as the number to be installed increase.		✓			✓	✓	✓

(Continues)

TABLE 8 | (Continued)

Characteristic and related impacts	Contextual characteristic	Description of the influence	E1	E2	E3	E4	E5	E6	E7
Other impacts	Numerosity	The set-up time of the single EEM decrease as the number of devices increases.	✓						
	Dimension, working hours	The size of the EMS and the number of working hours influence the energy savings and the pay-back time of the investment.			✓		✓	✓	✓

not systematically. Earlier research noted the relevance of the complexity of EEM (Fleiter, Hirzel, and Worrell 2012), however missing to consider the implications on other resources, which may be relevant for the adoption (Trianni et al. 2021). Also, EE may be perceived not as a core investment (Doyle and Cosgrove 2018), attributing low importance and high impact to upfront costs. However, the focus was mainly kept on EEMs acting on ancillary processes (e.g., EMS powering compressors). Conversely, when EEMs target core processes, the investment might be seen as core and strategic (Cooremans 2012) also due to more evident NEBs (Johansson et al. 2019) (e.g., increased productivity or reliability of the equipment; Sauter and Volkery 2013). Nevertheless, our study reveals that a far more comprehensive assessment would be allowed by considering the context in which an EEM is adopted as a variable to be systematically included in the analysis, improving in turn the decision-making process (Trianni, Cagno, and Accordini 2019). For this reason, a holistic framework to thoroughly assess them and support decision-making was still missing to effectively capture a user-centric perspective necessary to drive EE transformation in industries (McMillan and Wachs 2024). Also, the present study contributes to research in supporting decision-makers with increased information towards an increased adoption of EEMs (Miserocchi et al. 2023).

As our review and empirical investigation showed by examining the complex relationships within the framework, previous studies have often oversimplified these connections (Cagno et al. 2022), which may partially explain the low implementation of EEMs (Hanes et al. 2019). It is argued here that characteristics descriptive of EEMs can be influenced not only by the EEM itself but also by the specific adoption context, thus requiring additional clarification for thorough assessment and prioritization (Richter et al. 2023), which is a rather unexplored literature stream (Knayer and Kryvinska 2022). Furthermore, contextual characteristics conceal mutual relationships. Results show that not all the interactions between the context, the EEMs' characteristics and the impacts are direct, differently from previous literature (Hasan and Trianni 2023). Our preliminary findings suggest the existence of indirect relationships, where the context acts by modifying direct relationships existing between other elements, similarly to the effect of moderators or mediating factors (Aguinis et al. 2017). For instance, one could consider the influence of the context on the relationship between an EEM implementation time and corresponding production downtime, which can be mediated or moderated by characteristics such as the process centrality, the saturation level or the type of implementation.

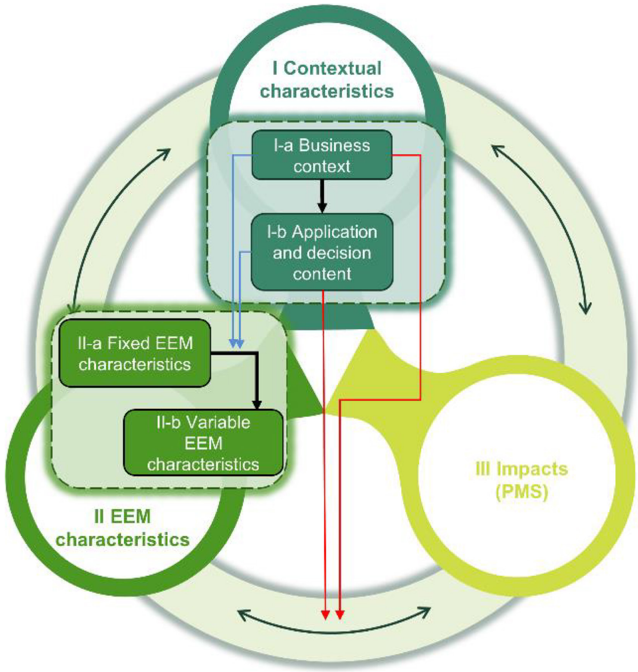

FIGURE 3 | Framework with the relationships as suggested by the empirical results of the analysis.

The preliminary findings reveal that the motivations driving EEM adoption may vary according to the context (König et al. 2020), and such factors may be relevant for the adoption, in line with previous research considering energy management practices (Hasan et al. 2022). For instance, energy-intensive companies may adopt EEMs primarily to reduce energy consumption, especially in the case of SMEs, which typically face higher energy prices compared with larger companies (International Energy Agency 2015). Conversely, in nonenergy intensive companies, the driver for adoption may be sought elsewhere, such as improved production performance. In fact, increasing EE in companies with a low share of the energy costs over total production costs is usually seen as an operational rather than a strategic investment (International Energy Agency 2014). Hence, statements that NEBs represent the main driver for adoption (Mills and Rosenfelds 1996) remain overall valid; however, the present research argues that they should be further assessed in light of the context. Depending on the adoption context and the stakeholders to be considered, the value proposition of an EEM should be sought accordingly (Bicknell and Skumatz 2007).

TABLE 9 | Representation of the relationships between characteristics as derived from the empirical validation. The direction of the relationships is from the column (characteristics between brackets) to the rows, where the influenced characteristics are reported.

		Business context (I-a)	**Fixed EEM characteristic (II-a)**	**Application and decisional context (I-b)**	**Variable EEM characteristic (II-b)**
Business context (I-a)	Company size				
	energy intensity				
	Layout type				
	Working hours				
	Regulation				
Fixed EEM characteristic (II-a)	Saving strategy	**D** (energy intensity)			
	Activity type	**D** (company size, regulation); **I** (company size)			
	Technological maturity	**D** (company size)			
	Level of acceptance				
	Secondary devices necessary				
	Lifetime	**D** (company size)			
Application and decisional context (I-b)	Process centrality	**D** (company size)			
	Saturation Level				
	Automation level	**D** (company size)			
	Numerosity				
	Dimension/Area interested				
	Accessibility		**D** (activity type)		
	Source strategy	**D** (company size; energy intensity; numerosity); **I** (technological maturity)			
	Implementation type	**D** (process centrality; dimension; numerosity)			

(Continues)

TABLE 9 | (Continued)

		Business context (I-a)	Fixed EEM characteristic (II-a)	Application and decisional context (I-b)	Variable EEM characteristic (II-b)
Variable EEMs' characteristics (II-b)	Implementation time	**I** (company size; layout type; working hours)		**D** (numerosity; source strategy; dimension/area interested; accessibility); **I** (process centrality; saturation level; dimension/area interested; accessibility; implementation type)	
	Synergies with other EEMs	**I** (company size; layout type; working hours)		**I** (process centrality; saturation level)	
			Check-up frequency		
	Knowledge required			**D** (automation level; numerosity; dimension/area interested); **I** (implementation type)	**D** (complexity)
	Complexity	**D** (company size)	**D** (activity type)	**D** (dimension/area interested; source strategy; implementation type)	
	Corporate involvement	**D** (company size)		**D** (numerosity)	**D** (implementation time)
	Cost			**D** (automation level; numerosity)	
	Transaction cost (new)	**D** (company size)		**D** (source strategy)	
	Pay-back	**D** (working hours)		**D** (automation level; numerosity; dimension/area interested)	

Abbreviations: D, direct effect; I, indirect effect.

TABLE 10 | Representation of the relationships between characteristics and impacts as derived from the empirical validation. The direction of the relationships is from the column (characteristic in brackets) to the rows.

Impacts (III)		Business context (I-a)	Application and decision context (I-b)	Fixed EEM characteristic (II-a)	Variable EEM characteristic (II-b)
Production	•Lead Time		**D** (process centrality; numerosity); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Process Quality		**D** (process centrality); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Flexibility				
	•Mix Flexibility				
	•Volume Flexibility		**D** (process centrality); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Design Flexibility	**D** (layout type)			
	•Other flexibilities				
	•Control and Information				
	•Equipment status and productivity				
	•Bottleneck		**D** (process centrality); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Throughput		**D** (process centrality); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Downtime	**I** (company size; layout type; working hours: implementation time, synergy → downtime)	**I** (process centrality; saturation level; dimension/area interested; accessibility: implementation time, synergy downtime); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (implementation time; synergy; knowledge required)
	•Status of the equipment		**I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Inventory				
	•Plant layout				

(Continues)

TABLE 10 | (Continued)

Impacts (III)		Business context (I-a)	Application and decision context (I-b)	Fixed EEM characteristic (II-a)	Variable EEM characteristic (II-b)
Social	•Customers				
	•Delivery-related satisfaction				
	•Personalized products and services				
	•Employees				
	•Employees involvement	**I** (layout type: implementation time → employees' involvement)			**D** (implementation time)
	•Training	**D** (layout type)	**D** (automation level; source strategy)		
	•Operational health and safety (OHS)				
	•Health and safety	**I** (company size; accessibility: activity type OHS)		**D** (activity type)	
	•Working Conditions			**D** (level of acceptance)	
Environment	•Water				
	•Material				
	•Energy	**D** (energy intensity; working hours)	**D** (dimension/area interested); **I** (source strategy: technological maturity, knowledge required → production performance)	**D** (technological maturity)	**D** (knowledge required)
	•Air Emissions				
	•Waste				

Abbreviations: D, direct effect; I, indirect effect.

7 | Conclusions

The present study contributes to the academic discussion around industrial EE by suggesting that EEM assessment and adoption should be considered within the broader company's operations, contextualized into a specific business and operational environment.

Thanks to a novel framework developed to support an investigation with industry and academic experts, several preliminary relationships emerged, though these should be further assessed for statistical generalization and should be considered yet as hypotheses until tested further. Different from earlier literature, key contextual characteristics (e.g., company size or the process centrality of an EEM) emerge as pivotal, with complex relationships affecting a wide array of framework factors, including other contextual characteristics, EEM characteristics and impacts. The adoption context might affect the perception of EEMs by influencing characteristics typically considered inherent, such as cost or complexity, and the decision-making process underlying the adoption outcome (e.g., sourcing strategy). Moreover, the impacts attributed to an EEM on company resources might also be influenced (e.g., impacts on personnel and assets availability). Although the influence of individual contextual characteristics has not been statistically validated, the study confirms and reinforces the need to account for the adoption context for the holistic assessment of an EEM, as it significantly changes its perception from the company perspective.

Decision-makers, by understanding the influence of the context on the characteristics and impacts of an EEM, can make a holistic assessment of an EEM and better anticipate the outcomes of an EEM adoption. The framework could also be of interest for policymakers, supporting targeted EE policies to the specific needs of stakeholders.

The study is not without caveats. Firstly, the framework is not intended to be exhaustive, and additional factors could be added, as its comprehensiveness cannot be fully demonstrated, nor is it claimed here. In fact, EEM characteristics present attributes to predefined categories, although in some instances, such attributes may be considered differently (e.g., pay-back time is here only short vs. long, whereas there may be additional values). Additionally, the impact on sustainability KPIs has been based on existing frameworks; however, other frameworks for assessing impact in the operations may be adopted. Thirdly, the impact on sustainability performance is limited within the boundaries of a single factory, not discussing broader implications, for example, supply chain and/or corporate social responsibility. Additionally, further research in this research domain would be needed by performing a systematic assessment of all potential relationships. Indeed, although the existence of relationships between the elements of the framework is validated, the individual relationships are exploratory findings and thus not generalizable. In this regard, additional research methodologies could be applied to investigate the statistical generalizability of the findings, for example, causality between factors and the nature of influence with quantitative methods, involving a larger sample of industrial companies, to provide also different findings according to relevant contextual characteristics such as activity and firm size.

Acknowledgements

Open access publishing facilitated by University of Technology Sydney, as part of the Wiley - University of Technology Sydney agreement via the Council of Australian University Librarians.

References

Abdelaziz, E. A., R. Saidur, and S. Mekhilef. 2011. "A Review on Energy Saving Strategies in Industrial Sector." *Renewable and Sustainable Energy Reviews* 15, no. 1: 150–168. https://doi.org/10.1016/j.rser.2010.09.003.

Accordini, D., E. Cagno, and A. Trianni. 2021. "Identification and Characterization of Decision-Making Factors Over Industrial Energy Efficiency Measures in Electric Motor Systems." *Renewable and Sustainable Energy Reviews* 149, no. June: 111354. https://doi.org/10.1016/j.rser.2021.111354.

Accordini, D. 2018. *Toward a Better Understanding of Energy Efficiency Measures in Motor Systems: An Explanatory Overview*. Politecnico di Milano.

Aguinis, H., J. R. Edwards, and K. J. Bradley. 2017. "Improving Our Understanding of Moderation and Mediation in Strategic Management Research." *Organizational Research Methods* 20, no. 4: 665–685. https://doi.org/10.1177/1094428115627498.

Akbaba, M. 1999. "Energy Conservation by Using Energy Efficient Electric Motors." *Applied Energy* 64, no. 1–4: 149–158. https://doi.org/10.1016/S0306-2619(99)00051-3.

Backman, F. 2017. "Barriers to Energy Efficiency in Swedish Non-Energy-Intensive Micro- and Small-Sized Enterprises—A Case Study of a Local Energy Program." *Energies* 10, no. 1: 100. https://doi.org/10.3390/en10010100.

Bernard, H. R. 2006. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Rowman Altamira.

Bicknell, C., and L. A. Skumatz. 2007. "Non-Energy Benefits (NEBs) in the Commercial Sector: Results From Hundreds of Buildings." In *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings*, 10–22. American Council for Energy Efficient Economy.

Bogner, A., and W. Menz. 2009. "The Theory-Generating Expert Interview: Epistemological Interest, Forms of Knowledge, Interaction." In *Interviewing Experts*, 43–80. Palgrave Macmillan UK.

Brundage, M. P., Q. Chang, Y. Li, J. Arinez, and G. Xiao. 2016. "Implementing a Real-Time, Energy-Efficient Control Methodology to Maximize Manufacturing Profits." *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 46, no. 6: 855–866. https://doi.org/10.1109/TSMC.2015.2450679.

Cagno, E., D. Accordini, and A. Trianni. 2019. "A Framework to Characterize Factors Affecting the Adoption of Energy Efficiency Measures Within Electric Motors Systems." *Energy Procedia* 158: 3352–3357. https://doi.org/10.1016/j.egypro.2019.01.962.

Cagno, E., D. Moschetta, and A. Trianni. 2019. "Only Non-Energy Benefits From the Adoption of Energy Efficiency Measures? A Novel Framework." *Journal of Cleaner Production* 212: 1319–1333. https://doi.org/10.1016/j.jclepro.2018.12.049.

Cagno, E., A. Neri, M. Howard, G. Brenna, and A. Trianni. 2019. "Industrial Sustainability Performance Measurement Systems: A Novel Framework." *Journal of Cleaner Production* 230: 1354–1375. https://doi.org/10.1016/j.jclepro.2019.05.021.

Cagno, E., P. Trucco, A. Trianni, and G. Sala. 2010. "Quick-E-Scan: A Methodology for the Energy Scan of SMEs." *Energy* 35, no. 5: 1916–1926. https://doi.org/10.1016/j.energy.2010.01.003.

Cagno, E., D. Accordini, A. Trianni, M. Katic, N. Ferrari, and F. Gambaro. 2022. "Understanding the Impacts of Energy Efficiency Measures on a Company's Operational Performance: A New Framework." *Applied Energy* 328: 120118. https://doi.org/10.1016/j.apenergy.2022.120118.

Cagno, E., E. Worrell, A. Trianni, and G. Pugliese. 2013. "A Novel Approach for Barriers to Industrial Energy Efficiency." *Renewable and Sustainable Energy Reviews* 19: 290–308. https://doi.org/10.1016/j.rser.2012.11.007.

Carbon Trust. 2007. "Variable Speed Drives—Introducing Energy Saving Opportunities for Business." https://www.carbontrust.com/media/13063/ctg070_variable_speed_drives.pdf.

Carbon Trust. 2018. *Motors and Drives—Introducing Energy Saving Opportunities for Business*. Taylor and Francis Group. https://doi.org/10.1201/9780203747902-8.

Cooremans, C. 2011. "Make It Strategic! Financial Investment Logic Is Not Enough." *Energy Efficiency* 4, no. 4: 473–492. https://doi.org/10.1007/s12053-011-9125-7.

Cooremans, C. 2012. "Investment in Energy Efficiency: Do the Characteristics of Investments Matter?" *Energy Efficiency* 5, no. 4: 497–518. https://doi.org/10.1007/s12053-012-9154-x.

Cooremans, C. 2015. "Competitiveness Benefits of Energy Efficiency: A Conceptual Framework." In *Proceedings of the ECEEE Summer Study*, 123–131. Toulon, France.

Cooremans, C., J. P. Bonardi, G. Killip, and R. B. Lung. 2023. "Integrating the Non-Energy Benefits of Energy Efficiency Into Business Decision-Making: Results of 23 Pilot Assessments in European Companies." *ACEEE Summer Study on Energy Efficiency in Industry* 2023: 1–17.

Cooremans, C., and A. Schönenberger. 2019. "Energy Management: A Key Driver of Energy-Efficiency Investment?" *Journal of Cleaner Production* 230: 264–275. https://doi.org/10.1016/j.jclepro.2019.04.333.

Corbin, J., and A. Strauss. 1990. "Grounded Theory Research: Procedures, Canons and Evaluative Criteria." *Zeitschrift für Soziologie* 19, no. 6: 418–427. https://doi.org/10.1515/zfsoz-1990-0602.

Davis, F. D. 1989. "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology." *MIS Quarterly* 13, no. 3: 319–339. https://doi.org/10.2307/249008.

De Almeida, A., J. Fong, C. U. Brunner, R. Werle, and M. Van Werkhoven. 2019. "New Technology Trends and Policy Needs in Energy Efficient Motor Systems—A Major Opportunity for Energy and Carbon Savings." *Renewable and Sustainable Energy Reviews* 115, no. September: 109384. https://doi.org/10.1016/j.rser.2019.109384.

De Almeida, A. T., F. J. T. E. Ferreira, and A. Q. Duarte. 2014. "Technical and Economical Considerations on Super High-Efficiency Three-Phase Motors." *IEEE Transactions on Industry Applications* 50, no. 2: 1274–1285.

De Almeida, A. T., P. Fonseca, and P. Bertoldi. 2003. "Energy-Efficient Motor Systems in the Industrial and in the Services Sectors in the European Union: Characterisation, Potentials, Barriers and Policies." *Energy* 28, no. 7: 673–690. https://doi.org/10.1016/S0360-5442(02)00160-3.

De Almeida, A. T., and S. Greenberg. 1995. "Technology Assessment: Energy-Efficient Belt Transmissions." *Energy and Buildings* 22: 245–253. https://doi.org/10.1016/0378-7788(95)00926-O.

De Toni, A., and S. Tonchia. 2001. "Performance Measurement Systems." *International Journal of Operations & Production Management* 21, no. 1–2: 46–70. https://doi.org/10.1108/01443570110358459.

DiCicco-Bloom, B., and B. F. Crabtree. 2006. "The Qualitative Research Interview." *ASME Medical Education* 40, no. 44: 314–321. https://doi.org/10.1111/j.1365-2929.2006.02418.x.

Dieperink, C., I. Brand, and W. Vermeulen. 2004. "Diffusion of Energy-Saving Innovations in Industry and the Built Environment: Dutch Studies as Inputs for a More Integrated Analytical Framework." *Energy Policy* 32, no. 6: 773–784. https://doi.org/10.1016/S0301-4215(02)00341-5.

Döringer, S. 2021. "'The Problem-Centred Expert Interview'. Combining Qualitative Interviewing Approaches for Investigating Implicit Expert Knowledge." *International Journal of Social Research Methodology* 24, no. 3: 265–278. https://doi.org/10.1080/13645579.2020.1766777.

Doyle, F., and J. Cosgrove. 2018. "An Approach to Optimising Compressed Air Systems in Production Operations." *International Journal of Ambient Energy* 39, no. 2: 194–201. https://doi.org/10.1080/01430750.2016.1269685.

Eisenhardt, K. M. 1989. "Buuilding Theories From Case Study Research." *Academy of Management Review* 14, no. 4: 532–550. https://doi.org/10.2307/258557.

Energy & strategy Group. 2021. "Digital Energy Efficiency Report—La sfida della transizione verso il futuro."

ETSU, Harwell, and Didcot. 1998. "Energy Savings With Motors and Drives (Good Practice Guide), 53."

European Commission (EC). 2021. "Valuing and Communicating Multiple Benefits of Energy-Efficiency Measures." https://doi.org/10.3030/785131.

European Commission (EC). 2023. "Energy Efficiency Directive." https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

EUropean MOtor REnovation initiative (EU-MORE). 2025. https://eu-more.eu/.

Ferreira, F. J. T. E., G. Baoming, and A. T. De Almeida. 2016. "Reliability and Operation of High-Efficiency Induction Motors." *IEEE Transactions on Industry Applications* 52, no. 6: 4628–4637. https://doi.org/10.1109/TIA.2016.2600677.

Ferreira, F. J. T. E., and A. T. De Almeida. 2012. "Induction Motor Downsizing as a Low-Cost Strategy to Save Energy." *Journal of Cleaner Production* 24: 117–131.

Finman, H., and J. A. Laitner. 2001. "Industry, Energy Efficiency and Productivity Improvement." In *Proceedings of the ACEEE Summer Study on Energy Efficiency in Industry*, 41–50. New York, USA.

Finster, M. P., and M. T. Hernke. 2014. "Benefits Organizations Pursue When Seeking Competitive Advantage by Improving Environmental Performance." *Journal of Industrial Ecology* 18, no. 5: 652–662. https://doi.org/10.1111/jiec.12106.

Fleiter, T., E. Gruber, W. Eichhammer, and E. Worrell. 2012. "The German Energy Audit Program for Firms—A Cost-Effective Way to Improve Energy Efficiency?" *Energy Efficiency* 5, no. 4: 447–469. https://doi.org/10.1007/s12053-012-9157-7.

Fleiter, T., S. Hirzel, and E. Worrell. 2012. "The Characteristics of Energy-Efficiency Measures—A Neglected Dimension." *Energy Policy* 51: 502–513. https://doi.org/10.1016/j.enpol.2012.08.054.

Fleiter, T., J. Schleich, and P. Ravivanpong. 2012. "Adoption of Energy-Efficiency Measures in SMEs—An Empirical Analysis Based on Energy Audit Data From Germany." *Energy Policy* 51: 863–875. https://doi.org/10.1016/j.enpol.2012.09.041.

Franzò, S., F. Frattini, E. Cagno, and A. Trianni. 2019. "A Multi-Stakeholder Analysis of the Economic Efficiency of Industrial Energy Efficiency Policies: Empirical Evidence From Ten Years of the Italian White Certificate Scheme." *Applied Energy* 240, no. February: 424–435. https://doi.org/10.1016/j.apenergy.2019.02.047.

Garbie, I. H. 2014. "An Analytical Technique to Model and Assess Sustainable Development Index in Manufacturing Enterprises." *International Journal of Production Research* 52, no. 16: 4876–4915. https://doi.org/10.1080/00207543.2014.893066.

Gates Corporation. 2014. "Energy Savings From Synchronous Belts." 1–5. https://designcenter.gates.com/files/Gates-Energy-Saving-from-Synchronous-Belt-Drives-White-Paper.pdf.

Ghalayini, A. M., J. S. Noble, and T. J. Crowe. 1997. "An Integrated Dynamic Performance Measurement System for Improving Manufacturing Competitiveness." *International Journal of Production Economics* 48: 207–225. https://doi.org/10.1016/S0925-5273(96)00093-X.

Giachetti, R. E., L. D. Martinez, O. A. Saenz, and C.-S. Chen. 2003. "Analysis of the Structural Measures of Flexibility and Agility Using a Measurement Theoretical Framework." *International Journal of Production Economics* 86: 47–62. https://doi.org/10.1016/S0925-5273(03)00004-5.

Gibbert, M., W. Ruigrok, and B. Wicki. 2008. "What Passes a Rigorous Case Study?" *Strategic Management Journal* 29, no. 13: 1465–1474. https://doi.org/10.1002/smj.722.

Gomes, C. F., M. M. Yasin, and J. Lisboa. 2011. "Performance Measurement Practices in Manufacturing Firms Revisited." *International Journal of Operations & Production Management* 31, no. 1: 5–30. https://doi.org/10.1108/01443571111098726.

Gómez, J. R., E. C. Quispe, R. del Pilar Castrillón, and P. R. Viego. 2020. "Identification of Technoeconomic Opportunities With the Use of Premium Efficiency Motors as Alternative for Developing Countries." *Energies* 13, no. 20: 5411. https://doi.org/10.3390/en13205411.

González, P. d. R. 2005. "Analysing the Factors Influencing Clean Technology Adoption: A Study of the Spanish Pulp and Paper Industry." *Business Strategy and the Environment* 14, no. 1: 20–37. https://doi.org/10.1002/bse.426.

Gordon, F., J. Peters, J. Harris, and B. Scales. 1999. "Why Is the Treasure Still Buried? Breaching the Barriers to Compressed Air System Efficiency." In *Proceedings of the 3rd ACEEE Summer Study on Energy Efficiency in Industry: Industry and Innovation in the 21st Century*, 709–718. Pacific Energy Associates, Inc.

Gunasekaran, A., C. Patel, and R. E. Mcgaughey. 2004. "A Framework for Supply Chain Performance Measurement." *International Journal of Production Economics* 87, no. 3: 333–347. https://doi.org/10.1016/j.ijpe.2003.08.003.

Gunasekaran, A., C. Patel, and E. Tirtiroglu. 2001. "Performance Measures and Metrics in a Supply Chain Environment." *International Journal of Operations & Production Management* 21, no. 1: 71–87. https://doi.org/10.1108/01443570110358468.

Gunasekaran, A., and B. Kobu. 2007. "Performance Measures and Metrics in Logistics and Supply Chain Management: A Review of Recent

Literature (1995–2004) for Research and Applications." *International Journal of Production Research* 45, no. 12: 2819–2840. https://doi.org/10.1080/00207540600806513.

Hanes, R., A. Carpenter, M. Riddle, D. J. Graziano, and J. Cresko. 2019. "Quantifying adoption rates and energy savings over time for advanced energy-efficient manufacturing technologies." *Journal of Cleaner Production* 232: 925–939. https://doi.org/10.1016/j.jclepro.2019.04.366.

Harris, J., J. Anderson, and W. Shafron. 2000. "Investment in Energy Efficiency: A Survey of Australian Firms." *Energy Policy* 28: 867–876.

Hasan, A. S. M. M., A. Trianni, N. Shukla, and M. Katic. 2022. "A Novel Characterization Based Framework To Incorporate Industrial Energy Management Services." *Applied Energy* 313: 118891. https://doi.org/10.1016/j.apenergy.2022.118891.

Hasan, A. S. M. M., and A. Trianni. 2023. "Boosting the Adoption of Industrial Energy Efficiency Measures Through Industry 4.0 Technologies To Improve Operational Performance." *Journal of Cleaner Production* 425: 138597. https://doi.org/10.1016/j.jclepro.2023.138597.

Huang, S. H., J. P. Dismukes, J. Shi, et al. 2003. "Manufacturing Productivity Improvement Using Effectiveness Metrics and Manufacturing Productivity Improvement Using Effectiveness Metrics and Simulation Analysis." *International Journal of Production Research* 41, no. 3: 513–527. https://doi.org/10.1080/0020754021000042391.

Integral Advanced systems. 2001. "Application Guide for AC Adjustable Speed Drive Systems." In *National Electrical Manufacturers Association*. NEMA standards publications.

International Energy Agency (IEA). 2011. "Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems." https://www.iea.org/reports/energy-efficiency-policy-opportunities-for-electric-motor-driven-systems.

International Energy Agency. 2014. "Capturing the Multiple Benefits of Energy Efficiency." https://doi.org/10.1787/9789264220720-en.

International Energy Agency. 2015. "Accelerating Energy Efficiency in Small and Medium-Sized Enterprises. Powering SMEs to Catalyse Economic Growth. Policy Pathway Series." https://www.iea.org/publications/freepublications/publication/SME_2015.pdf.

International Energy Agency. 2018. Energy Efficiency 2O18—Analysis and Outlooks to 2040, Market Report Series.

International Energy Agency. 2020. "Energy Efficiency 2020." *Energy Efficiency* 2020: 105.

Jagoda, K., R. Lonseth, and A. Lonseth. 2013. "A Bottom-Up Approach for Productivity Measurement and Improvement." *International Journal of Productivity and Performance Management* 62, no. 4: 387–406. https://doi.org/10.1108/17410401311329625.

Johansson, I., N. Mardan, E. Cornelis, O. Kimura, and P. Thollander. 2019. "Designing Policies and Programmes for Improved Energy Efficiency in Industrial SMEs." *Energies* 12, no. 7: 1338.

Kalantzis, F., and H. Niczyporuk. 2021. "Can European Businesses Achieve Productivity Gains From Investments in Energy Efficiency?" EIB Working Papers. https://ideas.repec.org/p/zbw/eibwps/202107.html%0Ahttps://ideas.repec.org//p/zbw/eibwps/202107.html.

Kang, N., C. Zhao, J. Li, and J. A. Horst. 2016. "A Hierarchical Structure of Key Performance Indicators for Operation Management and Continuous Improvement in Production Systems." *International Journal of Production Research* 54, no. 21: 6333–6350. https://doi.org/10.1080/00207543.2015.1136082.

Killip, A. G., C. Cooremans, and T. Fawcett. 2018. "M-Benefits: D2.2 Guidelines for Protocols, Interventions and Evaluations. Multiple Bene."

Knayer, T., and N. Kryvinska. 2022. "An Analysis of Smart Meter Technologies for Efficient Energy Management in Households and Organizations." *Energy Reports* 8: 4022–4040. https://doi.org/10.1016/j.egyr.2022.03.041.

KNOWnNEBs. 2025. "Integration of Non-Energy Benefits Into Energy Audit Practices to Accelerate the Uptake of Recommended Measures." LIFE21-CET-AUDITS-KNOWnNEBs/101076494. https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE21-CET-AUDITS-KNOWnNEBs-101076494/integration-of-non-energy-benefits-into-energy-audit-practices-to-accelerate-the-uptake-of-recommended-measures.

König, W., S. Löbbe, S. Büttner, and C. Schneider. 2020. "Establishing Energy Efficiency—Drivers for Energy Efficiency in German Manufacturing Small- and Medium-Sized Enterprises." *Energies* 13, no. 19: 5144. https://doi.org/10.3390/en13195144.

Kutucuoglu, K. Y., J. Hamali, Z. Irani, and J. M. Sharp. 2001. "A Framework for Managing Maintenance Using Performance Measurement Systems." *International Journal of Operations & Production Management* 21, no. 1: 173–194. https://doi.org/10.1108/01443570110358521.

Lilly, P., and D. Pearson. 1999. "Determining the Full Value of Industrial Efficiency Programs." In *Proceedings of the 3rd ACEEE Summer Study on Energy Efficiency in Industry: Industry and Innovation in the 21st Century*, 349–362. ACEEE Washington DC.

Lohman, C., L. Fortuin, and M. Wouters. 2004. "Designing a Performance Measurement System: A Case Study." *European Journal of Operational Research* 156: 267–286. https://doi.org/10.1016/S0377-2217(02)00918-9.

Lung, B., S. Nimbalkar, and T. Wenning. 2019. *Multiple Benefits of Industrial Energy Efficiency—Lessons Learned and New Initiatives*. Industrial Energy Technology Conference (IETC).

Lung, R. B., A. McKane, R. Leach, and D. Marsh. 2005. "Ancillary Savings and Production Benefits in the Evaluation of Industrial Energy Efficiency Measures." In *In Proceedings of the ACEEE Summer Study on Energy Efficiency in Industry: Cutting the High Cost of Energy*, vol. 6, 103–114. West Point.

McMillan, C. A., and L. Wachs. 2024. "Industrial Process Heat Decarbonization: A User-Centric Perspective." *Energy Research & Social Science* 112: 103505. https://doi.org/10.1016/j.erss.2024.103505.

Mills, E., S. Kromer, G. Weiss, and P. A. Mathew. 2006. "From Volatility to Value: Analysing and Managing Financial and Performance Risk in Energy Savings Projects." *Energy Policy* 34, no. 2 SPEC. ISS: 188–199. https://doi.org/10.1016/j.enpol.2004.08.042.

Mills, E., and A. R. T. Rosenfelds. 1996. "Consumer Non-Energy Benefits as a Motivation for Making Energy-Efficiency Improvements." *Energy* 21, no. 7/8: 707–720. https://doi.org/10.1016/0360-5442(96)00005-9.

Mills, E., G. Shamshoian, M. Blazek, et al. 2008. "The Business Case for Energy Management in High-Tech Industries." *Energy Efficiency* 1, no. 1: 5–20. https://doi.org/10.1007/s12053-007-9000-8.

Miserocchi, L., A. Franco, and D. Testi. 2023. "An Integrated Framework for Energy Performance Improvement in Manufacturing: From Mapping to Optimization." *Journal of Cleaner Production* 411: 137387. https://doi.org/10.1016/j.jclepro.2023.137387.

Motor Decision Matter. 2007. "Motor Planning Kit—Strategies, Tools and Resources for Developing a Comprehensive Motor Management Plan. Energy." Boston, MA.

Muller, M. R., and K. Papadaratsakis. 2003. "Self-Assessment Workbook for Small Manufacturers." Center for Advanced Energy Systems. https://iac.university/technicalDocs/selfassessment.pdf.

Muthiah, K. M. N., and S. H. Huang. 2017. "A Review of Literature on Manufacturing Systems Productivity Measurement and Improvement." *International Journal of Industrial and Systems Engineering* 1, no. 4: 461–484. https://doi.org/10.1504/IJISE.2006.010387.

Neely, A., M. Gregory, and K. Platts. 2005. “Performance Measurement System Design: A Literature Review and Research Agenda.” *International Journal of Operations and Production Management* 25, no. 12: 1228–1263. https://doi.org/10.1108/01443570510633639.

Nehler, T. 2018. “A Systematic Literature Review of Methods for Improved Utilisation of the Non-Energy Benefits of Industrial Energy Efficiency.” *Energies* 11, no. 12: 6–8. https://doi.org/10.3390/en11123241.

Nehler, T., R. Parra, and P. Thollander. 2018. “Implementation of Energy Efficiency Measures in Compressed air Systems: Barriers, Drivers and Non-Energy Benefits.” *Energy Efficiency* 11, no. 5: 1281–1302. https://doi.org/10.1007/s12053-018-9647-3.

Nehler, T., and J. Rasmussen. 2016. “How Do Firms Consider Non-Energy Benefits? Empirical Findings on Energy Efficiency Investments in Swedish Industry.” *Journal of Cleaner Production* 113: 472–482. https://doi.org/10.1016/j.jclepro.2015.11.070.

Nehler, T., P. Thollander, L. Fredriksson, S. Friberg, and T. Nordberg. 2018. “Non-Energy Benefits of Swedish Energy Efficiency Policy Instruments—A Three-Levelled Perspective.” In *ECEEE Industrial Summer Study Proceedings, 2018-June*, 139–149.

Neri, A., M. Negri, E. Cagno, V. Kumar, and J. A. Garza-Reyes. 2023. “What Digital-Enabled Dynamic Capabilities Support the Circular Economy? A Multiple Case Study Approach.” *Business Strategy and the Environment* 32, no. 7: 5083–5101. https://doi.org/10.1002/bse.3409.

Neves, F. O., H. Ewbank, J. A. F. Roveda, A. Trianni, F. P. Marafao, and S. R. M. M. Roveda. 2022. “Economic and Production-Related Implications for Industrial Energy Efficiency: A Logistic Regression Analysis on Cross-Cutting Technologies.” *Energies* 15, no. 4: 1382. https://doi.org/10.3390/en15041382.

NREL. 2024. “Better Climate Challenge Working Groups Non-Energy Benefits of Energy Projects-Improving Financial Payback.” https://www.nrel.gov/docs/fy25osti/92410.pdf.

Olsen, E. O., and T. W. Ward. 2006. “Performance Measurement in System Simplicity.” *International Journal of Manufacturing Technology and Management* 8, no. 4: 330–354. https://doi.org/10.1504/IJMTM.2006.009243.

Pye, M., and A. McKane. 2000. “Making a Stronger Case for Industrial Energy Efficiency by Quantifying Non-Energy Benefits.” *Resources, Conservation and Recycling* 28, no. 3–4: 171–183. https://doi.org/10.1016/S0921-3449(99)00042-7.

Rasmussen, J. 2017. “The Additional Benefits of Energy Efficiency Investments—A Systematic Literature Review and a Framework for Categorisation.” *Energy Efficiency* 10, no. 6: 1401–1418. https://doi.org/10.1007/s12053-017-9528-1.

Richter, B., G. Marcondes, N. Monteiro, et al. 2023. “Industrial Energy Efficiency Assessment and Prioritization Model – An Approach Based on Multi-Criteria Method PROMETHEE.” *International Journal of Sustainable Energy Planning and Management* 37: 41–60. https://doi.org/10.54337/ijsepm.7335.

Roberts, S. J. F., and P. D. Ball. 2014. “Developing a Library of Sustainable Manufacturing Practices 5th CIRP Conference on Assembly Technologies and Systems.” *Procedia CIRP* 15: 159–164. https://doi.org/10.1016/j.procir.2014.06.054.

Rohde, C., Z. Toth, C. Glenting, and O. Rapf. 2022. *Multiple Benefits of Energy Efficiency Investments for Financial Institutions*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/d30ea98d-03e9-11ed-acce-01aa75ed71a1/language-en.

Rohdin, P., and P. Thollander. 2006. “Barriers to and Driving Forces for Energy Efficiency in the Non-Energy Intensive Manufacturing Industry in Sweden.” *Energy* 31, no. 12: 1836–1844. https://doi.org/10.1016/j.energy.2005.10.010.

Rohdin, P., P. Thollander, and P. Solding. 2007. “Barriers to and Drivers for Energy Efficiency in the Swedish Foundry Industry.” *Energy Policy* 35, no. 1: 672–677. https://doi.org/10.1016/j.enpol.2006.01.010.

Russell, C. 2015. “Multiple Benefits of Business-Sector Energy Efficiency: A Survey of Existing and Potential Measures.” In *Energy's Multiple Benefits*. ACEEE (January), 35.

Ryan, L., and N. Campbell. 2012. *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements*. International Energy Agency, (May).

Saidur, R. 2010. “A Review on Electrical Motors Energy Use and Energy Savings.” *Renewable and Sustainable Energy Reviews* 14, no. 3: 877–898. https://doi.org/10.1016/j.rser.2009.10.018.

Saidur, R., and S. Mekhilef. 2010. “Energy Use, Energy Savings and Emission Analysis in the Malaysian Rubber Producing Industries.” *Applied Energy* 87, no. 8: 2746–2758. https://doi.org/10.1016/j.apenergy.2009.12.018.

Saidur, R., S. Mekhilef, M. B. Ali, A. Safari, and H. A. Mohammed. 2012. “Applications of Variable Speed Drive (VSD) in Electrical Motors Energy Savings.” *Renewable and Sustainable Energy Reviews* 16, no. 1: 543–550. https://doi.org/10.1016/j.rser.2011.08.020.

Saidur, R., N. A. Rahim, H. H. Masjuki, S. Mekhilef, H. W. Ping, and M. F. Jamaluddin. 2009. “End-Use Energy Analysis in the Malaysian Industrial Sector.” *Energy* 34, no. 2: 153–158. https://doi.org/10.1016/j.energy.2008.11.004.

Saidur, R., N. A. Rahim, H. W. Ping, M. I. Jahirul, S. Mekhilef, and H. H. Masjuki. 2009. “Energy and Emission Analysis for Industrial Motors in Malaysia.” *Energy Policy* 37, no. 9: 3650–3658. https://doi.org/10.1016/j.enpol.2009.04.033.

Sandberg, P., and M. Soderstrom. 2003. “Industrial Energy Efficiency: The Need for Investment Decision Support From a Manager Perspective.” *Energy Policy* 31: 1623–1634. https://doi.org/10.1016/S0301-4215(02)00228-8.

Sardianou, E. 2008. “Barriers to Industrial Energy Efficiency Investments in Greece.” *Journal of Cleaner Production* 16, no. 13: 1416–1423. https://doi.org/10.1016/j.jclepro.2007.08.002.

Sauter, R., and A. Volkery. 2013. “Review of Costs and Benefits of Energy Savings.”

Schleich, J. 2004. “Do Energy Audits Help Reduce Barriers to Energy Efficiency? An Empirical Analysis for Germany.” *International Journal of Energy Technology and Policy* 2, no. 3: 226–239. https://doi.org/10.1504/IJETP.2004.005155.

Schleich, J. 2009. “Barriers to Energy Efficiency: A Comparison Across the German Commercial and Services Sector.” *Ecological Economics* 68, no. 7: 2150–2159. https://doi.org/10.1016/j.ecolecon.2009.02.008.

Skumatz, L. A., C. A. Dickerson, and B. Coates. 2000. “Non-Energy Benefits in the Residential and Non-Residential Sectors: Innovative Measurements and Results for Participant Benefits.” In *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings: Energy Efficiency & Sustainability*, 353–364.American Council for and Energy Efficient Economy.

Soh, C. H., S. H. Ding, and S. Kamaruddin. 2012. “Shop Floor Performance Measurement—A Case Study in Injection Moulding Industry.” *International Journal of Agile Systems and Management* 5, no. 3: 103–121. https://doi.org/10.1504/IJASM.2012.046892.

Sorrell, S., J. Schleich, S. Scott, et al. 2000. “Reducing Barriers to Energy Efficiency in Private and Public Organisations.” In *Final Report to DG Research Under the Project Barriers to Energy Efficiency in Private and Public Organisations*, edited by B. SPRU (Science and Technology Policy), University of Sussex. University of Sussex.

Spider Strategies. n.d. Manufacturing KPIs. Accessed 26 April 2021 https://kpidashboards.com/kpi/industry/manufacturing/.

Thollander, P., and M. Ottosson. 2008. "An Energy Efficient Swedish Pulp and Paper Industry—Exploring Barriers to and Driving Forces for Cost-Effective Energy Efficiency Investments." *Energy Efficiency* 1, no. 1: 21–34. https://doi.org/10.1007/s12053-007-9001-7.

Timmermans, S., and I. Tavory. 2012. "Theory Construction in Qualitative Research: From Grounded Theory to Abductive Analysis." *Sociological Theory* 30, no. 3: 167–186. https://doi.org/10.1177/0735275112457914.

Tornatzky, L. G., and K. J. Klein. 1982. "Innovation Characteristics and Innovation Adoption-Implementation: A Meta-Analysis of Findings." *IEEE Transactions on Engineering Management* EM-29, no. 1: 28–45. https://doi.org/10.1109/TEM.1982.6447463.

Trianni, A., E. Cagno, and D. Accordini. 2019. "Energy Efficiency Measures in Electric Motors Systems: A Novel Classification Highlighting Specific Implications in Their Adoption." *Applied Energy* 252, no. May: 113481. https://doi.org/10.1016/j.apenergy.2019.113481.

Trianni, A., E. Cagno, and A. De Donatis. 2014. "A Framework to Characterize Energy Efficiency Measures." *Applied Energy* 118: 207–220. https://doi.org/10.1016/j.apenergy.2013.12.042.

Trianni, A., D. Accordini, and E. Cagno. 2020. "Identification and Categorization of Factors Affecting the Adoption of Energy Efficiency Measures Within Compressed Air Systems." *Energies* 13, no. 5116: 1–51. https://doi.org/10.3390/en13195116.

Trianni, A., and E. Cagno. 2015. "Diffusion of Motor Systems Energy Efficiency Measures: An Empirical Study Within Italian Manufacturing SMEs." *Energy Procedia* 75: 2569–2574. https://doi.org/10.1016/j.egypro.2015.07.302.

Trianni, A., E. Cagno, and S. Farné. 2016. "Barriers, Drivers and Decision-Making Process for Industrial Energy Efficiency: A Broad Study Among Manufacturing Small and Medium-Sized Enterprises." *Applied Energy* 162: 1537–1551. https://doi.org/10.1016/j.apenergy.2015.02.078.

Trianni, A., E. Cagno, J. Dolšak, and N. Hrovatin. 2021. "Implementing Energy Efficiency Measures: Do Other Production Resources Matter? A Broad Study in Slovenian Manufacturing Small and Medium-Sized Enterprises." *Journal of Cleaner Production* 287: 125044. https://doi.org/10.1016/j.jclepro.2020.125044.

Trianni, A., E. Cagno, A. Neri, and M. Howard. 2019. "Measuring Industrial Sustainability Performance: Empirical Evidence From Italian and German Manufacturing Small and Medium Enterprises." *Journal of Cleaner Production* 229: 1355–1376. https://doi.org/10.1016/j.jclepro.2019.05.076.

Trianni, A., E. Cagno, E. Worrell, and G. Pugliese. 2013. "Empirical Investigation of Energy Efficiency Barriers in Italian Manufacturing SMEs." *Energy* 49, no. 1: 444–458. https://doi.org/10.1016/j.energy.2012.10.012.

U.S. Department of Energy. 2020. Industrial Assessment Center (IAC) Database. Accessed 23 August 2020 https://iac.university/download.

U.S. Department of Energy. 2025. "Industrial Assessment Centers (IAC)." Accessed 12 May 2025. https://iac.university.

U.S. Department of Energy DOE. 2000. "Replace V-Belts With Cogged or Synchronous Belt Drives. Motor Systems Tip Sheet #3, 2–3."

U.S. Department of Energy DOE. 2012. "Replace V-Belts With Notched or Synchronous Belt Drives. Motor Systems Tip Sheet #5."

U.S. Department of Energy Motor Challenge. 2014a. "Buying an Energy-Efficient Elecrtic Motor."

U.S. Department of Energy Motor Challenge. 2014b. "Replacing an Oversized and Underloaded Electric Motor."

U.S. Department of Energy: Advanced Manufacturing Office. 2008. "Improving Motor and Drive System Performance: A Sourcebook for Industry." Washington, DC, USA.

U.S. Department of Energy: Advanced Manufacturing Office. 2014. "Continuous Energy Improvement in Motor Driven Systems—A Guidebook for Industry, 144." DOE/GO-102014-4357.

United States Department of Energy. 2008. "Magnetically Coupled Adjustable Speed Motor Drives. Motor Systems Tip Sheet #13."

Upton, D. 1998. "Just-In-Time and Performance Measurement Systems." *International Journal of Operations & Production Management* 18, no. 11: 1101–1110. https://doi.org/10.1108/01443579810231688.

Vidmar, K. 2010. "Importance of Finding and Defining Energy Conservation Measures." *Strategic Planning for Energy and the Environment* 30, no. 2: 45–63. https://doi.org/10.1080/10485236.2010.10132375.

Wagner, C., M. Obermeyer, and R. Lüchinger. 2020. "A Methodology for the Assessment of Multiple Benefits of Industrial Energy Efficiency Measures." *SN Applied Sciences* 2, no. 2: 1–16. https://doi.org/10.1007/s42452-020-2071-2.

Woodroof, E. A., W. C. Turner, W. Heffington, and B. Capehart. 2012. "Energy Conservation Also Yields: Capital, Operations, Recognition, and Environmental Benefits: "Core" Benefits Are Highly Probable and Worth a Double-Digit Improvement to Energy Savings." *Energy Engineering: Journal of the Association of Energy Engineering* 109, no. 5: 7–26. https://doi.org/10.1080/01998595.2012.10531820.

Worrell, E., and L. Price. 2001. "Policy Scenarios for Energy Efficiency Improvement in Industry." *Energy Policy* 29, no. 14: 1223–1241. https://doi.org/10.1016/S0301-4215(01)00069-6.

Worrell, E., T. Angelini, and E. Masanet. 2010. "Managing Your Energy an ENERGY STAR® Guide for Identifying Energy Savings in Manufacturing Plants." Berkeley, CA.

Worrell, E., J. A. Laitner, M. Ruth, and H. Finman. 2003. "Productivity Benefits of Industrial Energy Efficiency Measures." *Energy* 28, no. 11: 1081–1098. https://doi.org/10.1016/S0360-5442(03)00091-4.

Wulfinghoff, D. R. 1999. *Energy Efficiency Manual: For Everyone Who Uses Energy, Pays for Utilities, Controls Energy Usage, Designs and Builds, Is Interested in Energy and Environmental Preservation*. Energy institute press. 0965792676.

Zanoni, S., B. Marchi, F. Puente, et al. 2020. "Improving Cold Chain Energy Efficiency: EU H2020 Project for Facilitating Energy Efficiency Improvements in SMEs of the Food and Beverage Cold Chains." In *6th IIR International Conference on Sustainability and the Cold Chain. Nantes, France*. International Institue of Refrigeration. https://doi.org/10.18462/iir.iccc.2020.292878.

Zhu, L., C. Johnsson, M. Varisco, and M. M. Schiraldi. 2018. "Key Performance Indicators for Manufacturing Operations Management—Gap Analysis Between Process Industrial Needs and ISO 22400 Standard." *Procedia Manufacturing* 25: 82–88. https://doi.org/10.1016/j.promfg.2018.06.060.