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The Strategic Role of Energy Efficiency and Industry 4.0 Interventions in Manufacturing

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Abstract

Energy efficiency measures and Industry 4.0 investments are prominent drivers of business competitiveness and sustainability, working toward sustainable development goals and decarbonization commitments. We analyzed data from a survey of 239 Italian manufacturing firms conducted in 2021. The survey was designed to identify drivers of energy efficiency measures and Industry 4.0 measures, as well as barriers to their implementation. We also examined interventions on key business variables such as business model sustainability, corporate social responsibility, business economics, public image, reputation, and market positioning. Energy efficiency intervention drivers are correlated with sustainable corporate social responsibility and cost reduction, whereas Industry 4.0 intervention drivers are associated with production optimization variables. Prominent barriers to energy efficiency interventions relate to economic feasibility, regulatory uncertainty, and financial issues. Similarly, key barriers to Industry 4.0 interventions are economic feasibility, enabling infrastructures, and regulatory uncertainty. The implication of energy efficiency measures and Industry 4.0 investments are discussed to pave the way for complementarity, overlap, and contrasting effects of measures. The paper has business implications given that it benefits decision-makers to reduce the risk of strategic drift and increases the probability of meeting sustainable development goals and decarbonization targets of Sustainable Development Goal 11.

Keywords: energy efficiency; industry 4.0; ESG; business sustainability

1. Introduction

Following global commitments to keep the temperature rising by 1.5 degrees above pre-industrial levels (Brecha et al., 2022), climate policies in response to warming comprise, among others, transitions in energy and industrial systems. Moving toward greener industrial systems requires institutional, financial, and industrial efforts aimed at increasing the optimal use of resources. Thus, the roles of energy efficiency (EE) and Industry 4.0 (I4.0) in the sustainability and resilience of manufacturing firms have increased significantly. At a global level, there is a discussion on the validity of policy instruments to incentivize the implementation of EE interventions (Di Foggia, 2016) and investments in I4.0 innovations (Kumar, Bhamu, & Sangwan, 2021). As such, interest in analyzing the relationships between policies that favor the increase of EE and those oriented to business development from an I4.0 perspective has increased (Javied, Bakakeu, Gessinger, & Franke, 2018).

EE in the industrial sector plays a key role in improving environmental sustainability and economic performance (Tanaka, 2011), and different approaches can be used to enhance understanding of industrial EE (Palm & Thollander, 2010). Decarbonization and increasing energy efficiency are key economic challenges (Misztal, Kowalska, Fajczak-Kowalska, & Strunecky, 2021). Focusing on the European decarbonization path, EE improvements could bridge the time until low-carbon or even carbon-free technologies mature to commercial scale—their rapid development is essential (Förster et al., 2013). In addition to the desired acceleration of the development of clean technologies in the sectors that most require it, i.e., transport, building, and industry, a reference point for accelerating the transition is the role of I4.0.

Ever since the early stages of industrialization, technological leaps have led to paradigm changes known as industrial revolutions (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). The emergence and development of I4.0 technologies have been named the fourth industrial revolution. Such improvements are rapid, providing manufacturing firms with new opportunities for digital transformations to offer products and services at more competitive costs (Stentoft, Wickstrøm, Philipsen, & Haug, 2021). Previous studies have examined the effects of

I4.0 and found that there are still many knowledge gaps on the uses of I4.0-enabling technologies in manufacturing firms (Zheng, Ardolino, Bacchetti, & Perona, 2021).

In light of commitments to meet the UN 2030 agenda for sustainable development and policies aimed at mitigating climate change, the implementation of more EE interventions in buildings, tertiary, transport, and industrial sectors requires sound information regarding drivers and barriers of EE investments (Di Foggia, Beccarello, Borgarello, Bazzocchi, & Moscarelli, 2022).

EE management has become an obligatory step to solve critical issues that require firms directly involving the core business of firms and, therefore, elevation in the priorities and decision-making hierarchy. The United Nations put I4.0 and sustainability in global Sustainable Development Goals 7 and 9 (Hidayatno, Destyanto, & Hulu, 2019). Whereas innovations in the context of I4.0 promote the competitiveness of the production sector by stimulating its technological and managerial growth, the spread of new technologies allows the acquisition, control, and storage of process and consumption data, leading to greater knowledge of production processes, their operation, and consumption (Maggiore et al., 2021). Despite the relevance of the relationship between I4.0 and EE, the existing literature is fragmented, and more insights are needed for steering the complementary implementation of EE and I4.0 measures (Wolniak, Saniuk, Grabowska, & Gajdzik, 2020). Strategic drift may emerge when the interlinkage between EE and I4.0 is omitted.

There are many sectors in which EE and I4.0 may bring substantial benefits (Lasi et al., 2014), and we focused on the industrial sector. This article is based on an empirical survey conducted with the collaboration of 239 manufacturing firms. The survey comprised two main sections: EE and I4.0. We analyzed drivers and barriers for EE and I4.0 on key business variables such as costs, image, reputation, market, and strategy. Sustainability, corporate social responsibility, and economic aspects were considered important due to energy efficiency measures. By contrast, image, reputation, and economic aspects were tagged as highly important outputs of I4.0 interventions.

The rest of the article is organized as follows. Section 2 contains some previous literature on EE interventions and I4.0 investments along with the description of the methodology used to run the analysis and the sample definition and analysis. Section 3 reports the results of our analyses and is divided in two subsections to focus on EE first and I4.0 then. Section 4 discusses the and compare results to extrapolate useful insights for all the interested stakeholders' convenience: scholars, managers, or policymakers alike. The conclusion section closes the article.

2. Background and Research Methods

One of the most important energy policy objectives is energy efficiency, which is crucial for limiting climate change and meeting decarbonization targets (Pérez-Lombard, Ortiz, & Velázquez, 2013). It is acknowledged that the paths toward decarbonization have to be complemented by energy efficiency improvements (Román-Collado & Economidou, 2021). However, energy efficiency investment decisions may remain vague despite the large potential for enhancing EE in different sectors (Cooremans & Schönenberger, 2019). Firms struggle to identify digital energy services that best suit their strategies to stay competitive and to align with energy efficiency policy targets (Goldbach, Rotaru, Reichert, Stiff, & Gölz, 2018).

The I4.0 offers several opportunities for energy sustainability (Ng & Ghobakhloo, 2020). Introducing I4.0 innovations to manufacturing processes can offer many benefits for reducing energy consumption (Mohamed, Al-Jaroodi, & Lazarova-Molnar, 2019). Promising methods to increase energy efficiency in manufacturing production include I4.0 technologies (Nota, Nota, Peluso, & Toro Lazo, 2020). Indeed, the development of I4.0 innovations and services are shaping business models. Sustainable development requires building new managerial skills (Miśkiewicz, Rzepka, Borowiecki, & Olesiński, 2021).

To leverage the potential of EE and I4.0 interventions, an empirical analysis was performed based on a robust sample of Italian firms. We designed and ran an online survey to obtain empirical insights from firms. The survey was designed following common rules (Brace, 2004; Couper, 2008) and included both closed and open questions; 307 firms participated in the survey. The number of valid responses was 239 and the threshold we chose to consider valid answers obtained by firms was 75% of the questionnaire completed. Most of the questions did not require a mandatory response to avoid forcing any response from the firms that were willing to participate. The survey focused on manufacturing firms that represent the cohort (DeForge, 2010) of this analysis.

Slightly more than half of the sample, 52.8%, had only one factory in Italy, whereas 25% had two factories and approximately 20% had three or more factories. Regarding ownership, 76 firms belonged to a multinational group, and in 51.3% of the cases, the parent company of these groups was foreign; 63% of firms had more than 50 employees, and approximately half had more than 250 employees. The size of the firms is shown in Table 1 and the energy cost on the turnover of the samples is in Table 2.

Table 1. Sample by number of employees

	< 10	11–100	101–500	> 500
Number of firms	81	70	45	23

Table 2. Incidence of energy costs on the turnover (%)

	< 5%	6–15%	16–30%	> 30%
Number of firms	93	75	45	21

Source: own elaboration.

Our research method merged quantitative and qualitative analysis. We used an online questionnaire to collect the data (Couper, 2008). The survey was designed to guarantee clearness, correctness in items, order, and effectiveness of the items contained (Brace, 2004). Questions of the questionnaire were combined into different sections according to their main domains: general information, EE, and I4.0. Over the 2 months, we completed two data collection campaigns. For questions related to EE and I4.0, most of the variables were designed to get ordinal answers, typically using 1–2 or 1–5 Likert scale questions.

3. Results

3.1 Energy Efficiency

Considering the EE, the most frequent EE interventions implemented over the last 10 years were those related to lighting, followed by measures aimed at electric motors and inverters and those applied to compressed air systems. On average, interventions on thermal renewables were less frequent, as well as those on cogeneration or trigeneration and pumping systems (Figure 1).

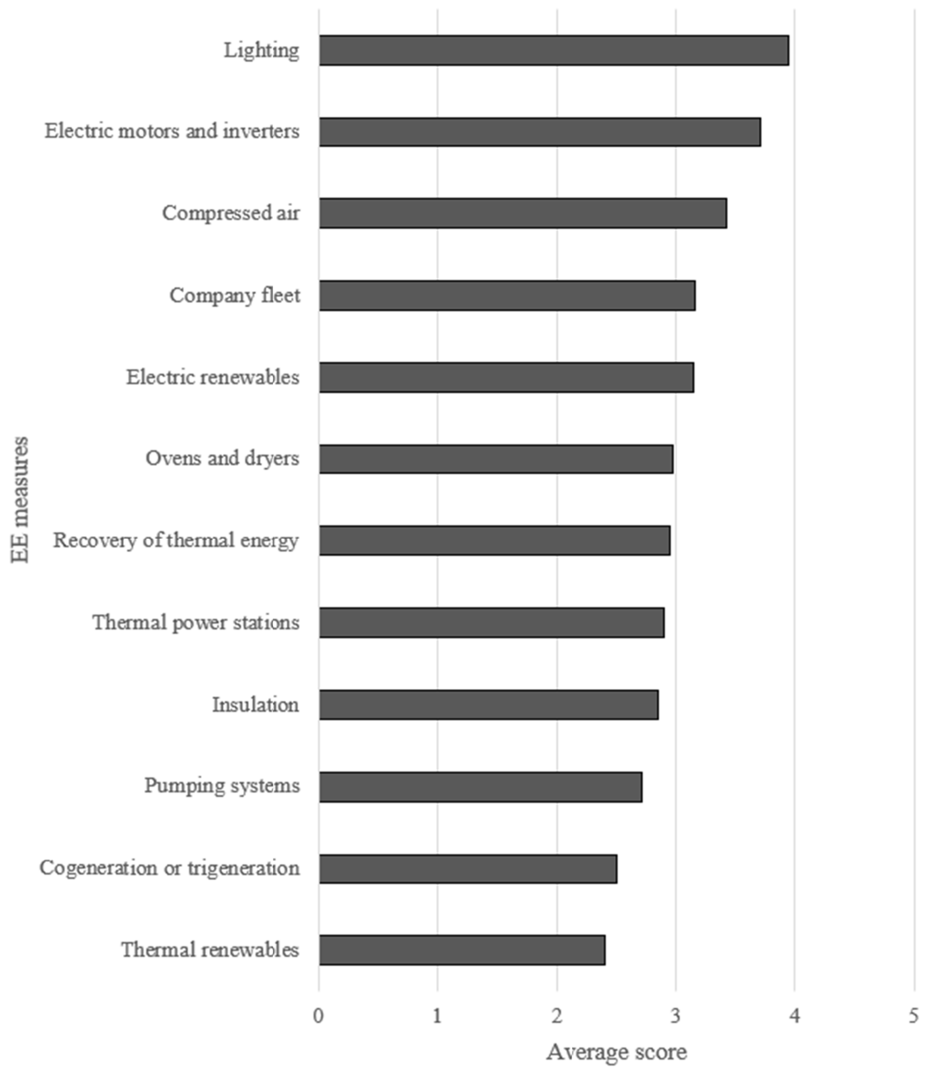

Figure 1. EE interventions

EE Interventions on electric motors and inverters were generally associated with interventions on compressed air and thermal energy, which correlated with interventions on cogeneration or trigeneration and interventions on furnaces, kilns, and dryers. Interventions on centralized energy management systems were often carried out at the same time as other interventions to improve the efficiency of pumping systems.

Almost 60% of the firms stated that they had used an incentive tool. Among these, almost 80% made use of white certificates. Regarding the presence of an energy manager, 46.81% of firms did not have one. Where it was present, in most cases (41%), its presence was foreseen by law and not by company policy. Similarly, 21.80% of firms were ISO 5001 certified; however, more than half of the firms were not certified and had no plans to get certified. One-third of the respondents indicated that EE interventions had a significant effect on cost reduction. However, it is noteworthy that 25% of the firms responded that the measures had little or no effect on cost reduction. For the EE interventions, in general, the EE interventions implemented during the reference period had positive cost reduction results.

Considering thermal consumption, 23% of respondents indicated a reduction by up to 5%, an additional 18.65% of respondents indicated a slight cost reduction, and 12% of respondents indicated consumption was reduced by up to 10%. Half of the respondents indicated reductions in electricity consumption by up to 5%, in addition to an additional 16% of those who indicated a reduction in consumption between 5% and 10%. Regarding water consumption and waste management costs, almost half of the respondents indicated a neutral impact. Less than one respondent out of five suggested a cost reduction of up to 5%. Considering the costs attributable to labor, 47% revealed a neutral impact of EE interventions, and over 30% said they did not know the impact of interventions on this cost. However, in this case, unlike the other four cases, approximately 6% of respondents experienced an increase in labor costs. This is still a relatively small percentage but still significant since the other four types of costs do not exceed 2%.

We note that the EE interventions implemented over time were considered important for environmental sustainability but obvious for corporate social responsibility (Figure 2). The only case in which the score dropped below 3 was for the attractiveness of products and services sold by firms. All in all, this is not surprising since these were interventions that were not directly visible to the market but internal to the company.

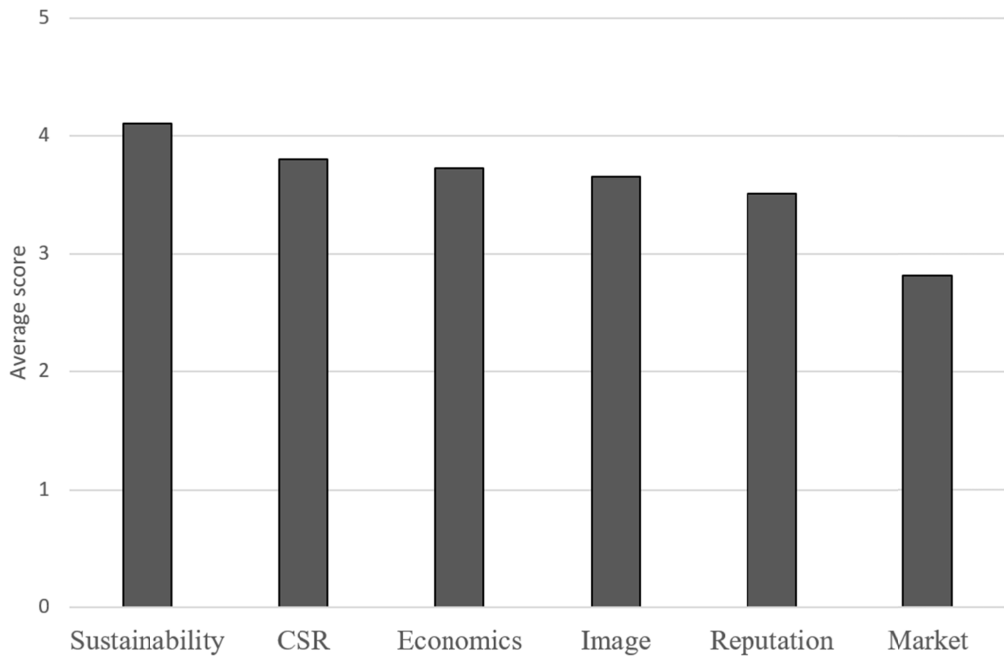

Figure 2. Impact of EE interventions on some key market drivers

Concerning the relationships between the impact of EE interventions on costs and a series of variables related to the competitiveness of the company, no significant relationships emerged. There were significant correlations only within the cluster related to competitiveness. As expected, there was a high correlation between the image and the company's reputation resulting from implementing EE interventions. There was also a significant correlation between economic sustainability and environmental sustainability, which is a sign of the essential link between these areas. This was also indicated by the fact that environmental sustainability is significantly correlated with corporate social responsibility.

The main barriers are shown in Figure 3. The highest was economic and political aspects of a regulatory and fiscal nature. Note that the values reported in the bar chart in Figure 3 represent the average of the questionnaire evaluations reported by the respondents. This was corroborated by the fact that the variable corresponding to technological risk was the lowest. The main barriers hindering the implementation of EE interventions were mainly financial, economic, and regulatory.

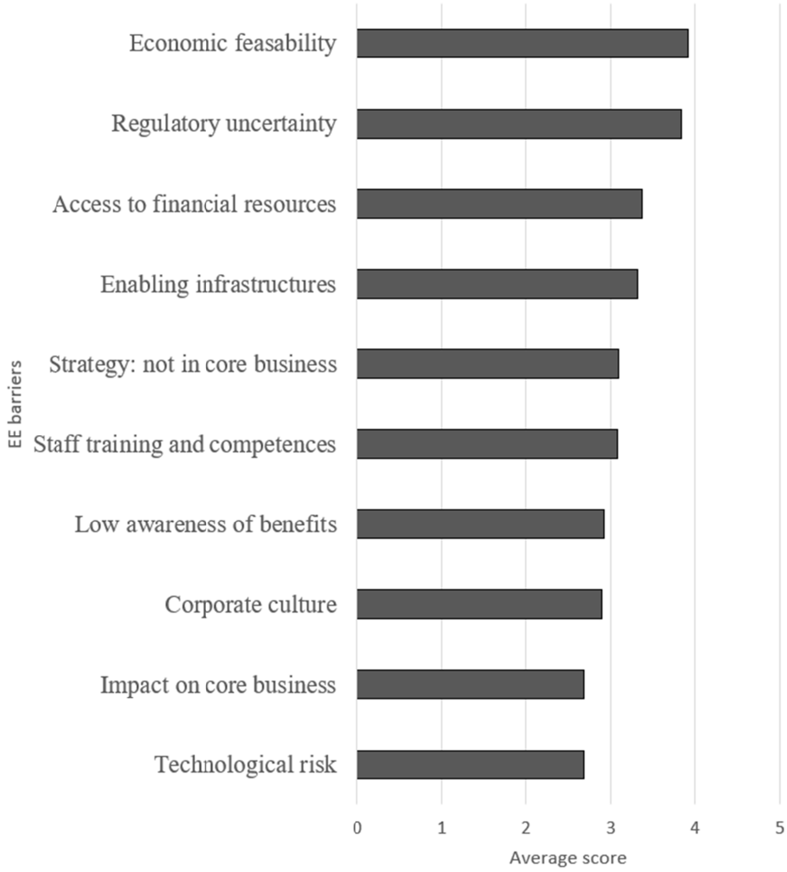

Figure 3. EE barriers

The three barriers in terms of importance represented in Table 3 are correlated. There was a strategic and cultural problem within the firms themselves.

Table 3. Correlation of barriers to the implementation of EE interventions

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Access to financial resources	[1]	1.00								
Economic feasibility	[2]	0.62	1.00							
Strategy: not in core business	[3]			1.00						
Corporate culture	[4]			0.67	1.00					
Technological risk	[5]				0.47	1.00				
Impact on core business	[6]			0.41	0.45	0.67	1.00			
Staff training and competencies	[7]		0.40	0.43	0.48	0.47	0.47	1.00		
Reduced awareness of benefits	[8]			0.50	0.63			0.60	1.00	
Regulatory uncertainty	[9]		0.58			0.41		0.50		1.00
Enabling infrastructures	[10		0.50	0.40				0.42		0.61

3.2 Industry 4.0

Regarding the I4.0 interventions implemented in the last three years, the main interventions in terms of frequency are those related to cybersecurity, followed by advanced automation and advanced manufacturing solutions (Figure 4). On average, interventions concerning augmented reality, simulation systems, and cloud manufacturing were less frequent.

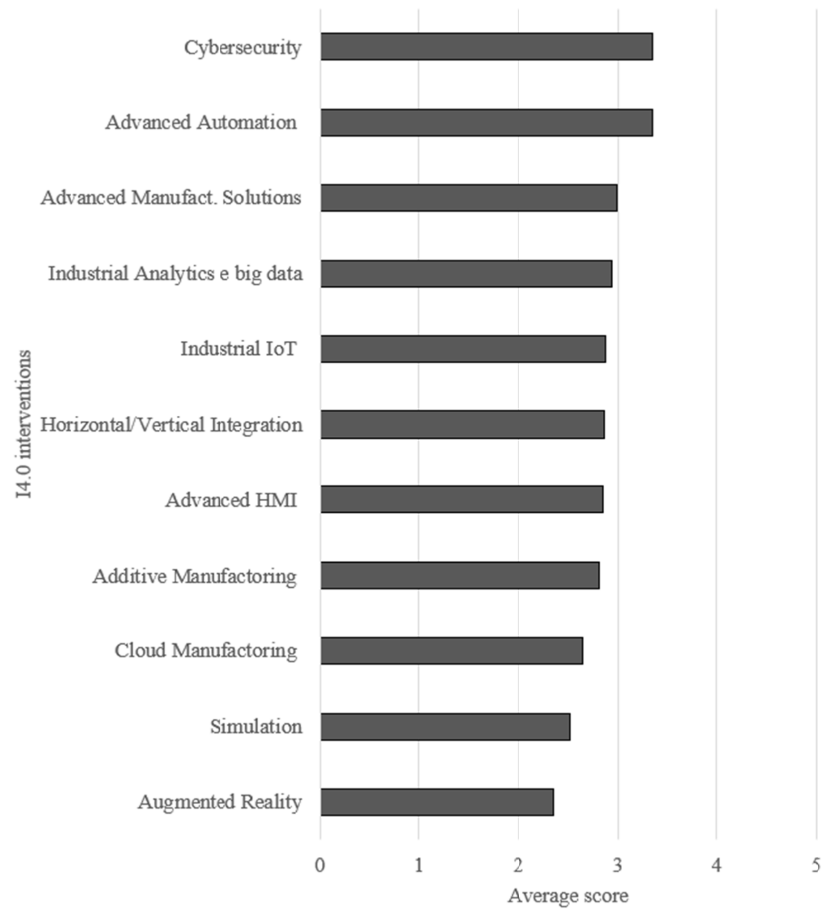

Figure 4. I4.0 interventions

For the EE interventions, we analyzed the correlations between the 4.0 interventions implemented in the last three years. First, we noticed the existing relationship between the interventions of advanced HMI and advanced automation, as well as the relationship between interventions of cloud manufacturing and augmented reality. Worth noting is the relationship that appeared between interventions classified as IoT and analytics and big data. Almost half of the respondents indicated that the I4.0 interventions did not affect cost reduction. However, approximately 30% of the firms responded that the interventions had influenced this.

For EE, in half of the cases, thermal consumption was indicated as neutral; however, a quarter of the cases indicated reductions in thermal consumption. For electric consumption, the percentage of answers indicating a reduction in such consumption exceeds 30%. As far as water consumption and waste management costs are concerned, in most cases, the answers were medium importance The percentage of firms that indicated an increase in labor costs was close to 5%.

Market variables such as corporate image and reputation benefitted from I4.0 interventions. The role of environmental variables was reduced. I4.0 interventions contributed to significant innovations in technology; therefore, if communication is well managed, this can serve as a source of stable and long-lasting competitive advantage. This is illustrated in Figure 5.

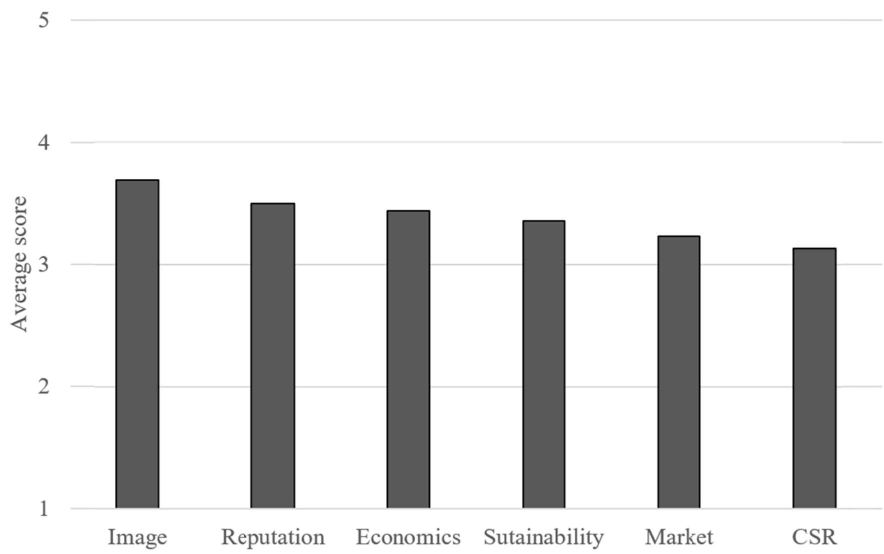

Figure 5. Impact of I4.0 interventions on some key market drivers

Regarding the relationship between the impact of I4.0 interventions on costs (thermal, electrical, water and waste) and variables related to the firm's competitiveness, no significant relationships emerged between the two clusters. By contrast, important relationships emerged within the clusters themselves. In contrast to what emerged in the section dedicated to EE, in I4.0 there were significant correlations within both clusters. There was a high correlation between the image and reputation of the company resulting from implementing EE interventions. This is consistent with previous research (Cordova & Celone, 2019; Rajesh, 2020). Another relationship emerged between economic sustainability and environmental sustainability, indicated by the fact that environmental sustainability is significantly correlated with corporate social responsibility.

Following previous literature on EE barriers (Sorrell, Mallett, & Nye, 2011), the main barriers that appeared in the case of EE also appeared for I4.0 interventions (Figure 6). In this case, in addition to the economic and regulatory aspects, a technological element emerged, i.e., the limited enabling infrastructure. This extends a recent article on I4.0 technologies related to the achievement of the Sustainable Development Goals (M. Mabkhot et al., 2021).

Figure 6 also shows that it was not the access to financial resources that limited the development of I4.0 interventions but cost-effectiveness in the strict sense, measured by reference to the pay-back and the internal rate of return. Such consideration was also considered in previous literature where financial factors played a partial role in investment decisions and the strategic character of investments was more important (Cooremans, 2011).

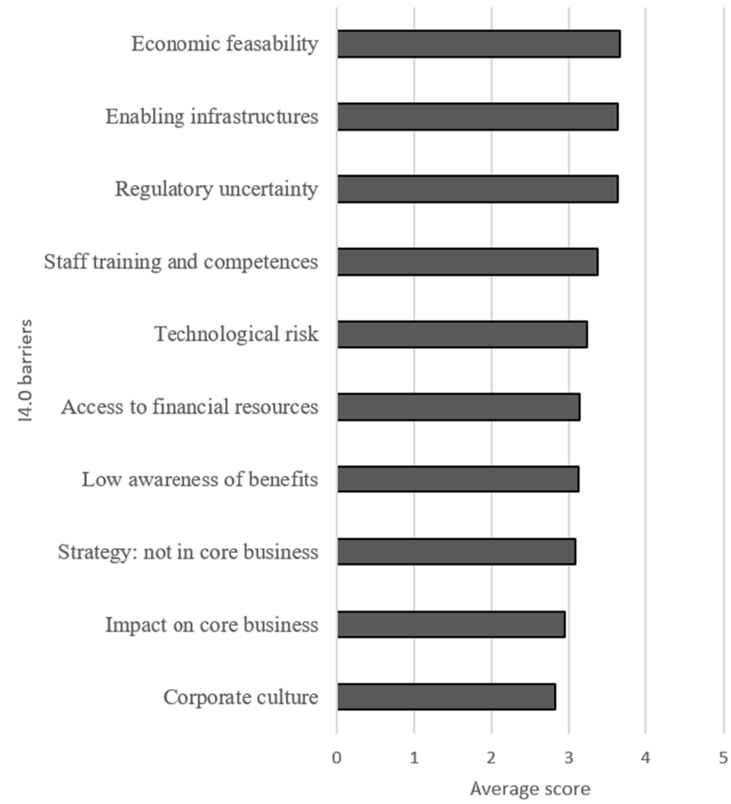

Figure 6. I4.0 barriers

Previous literature proposed several barriers to I4.0 adoption (Chauhan, Singh, & Luthra, 2021). In this article, the top three barriers in terms of frequency are also significantly correlated (Table 4). This further indicates that economic and policy barriers are the main obstacle to implementing I4.0 interventions. They are equally important to internal barriers related to the awareness of the implications of such interventions on the company's core business. Regulatory and policy barriers are, in turn, related to the availability of I4.0 enabling infrastructures.

Table 4. Correlation of barriers to the implementation of I4.0 interventions

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Access to financial resources	[1]	1.00								
Economic feasibility	[2]	0.48	1.00							
Strategy: not in core business	[3]			1.00						
Corporate culture	[4]			0.78	1.00					
Technology risk	[5]			0.46	0.42	1.00				
Impact on core business	[6]			0.47	0.45	0.71	1.00			
Staff training and skills	[7]						0.41	1.00		
Corporate culture	[8]			0.63	0.58			0.51	1.00	
Regulatory uncertainty	[9]		0.51					0.44		1.00
Enabling Infrastructures	[10]									0.50

Previous studies have analyzed drivers of I4.0 technology adoption (Stentoft et al., 2021). In this article, the main drivers identified by the firms were related to the optimization of the production process. The first three drivers in terms of importance were the optimization of production, the reduction of production time, and the increased flexibility. All drivers identified were significant. The evaluation obtained by the individual drivers ranged from a minimum of 3.5 to a maximum of 4.2. The main benefits can be attributed to greater flexibility in production, greater speed from prototype to series production through innovative technologies, greater productivity through shorter lead times and optimization of production, greater competitiveness, and attractiveness of products. Figure 7 also shows drivers related to economic aspects, e.g., cost reduction, had intermediate scores. Most drivers for I4.0 interventions were found to be significant. For example, there was a relationship between increased production flexibility and production optimization. Similarly, there was a relationship between product customization and responsiveness to market demands.

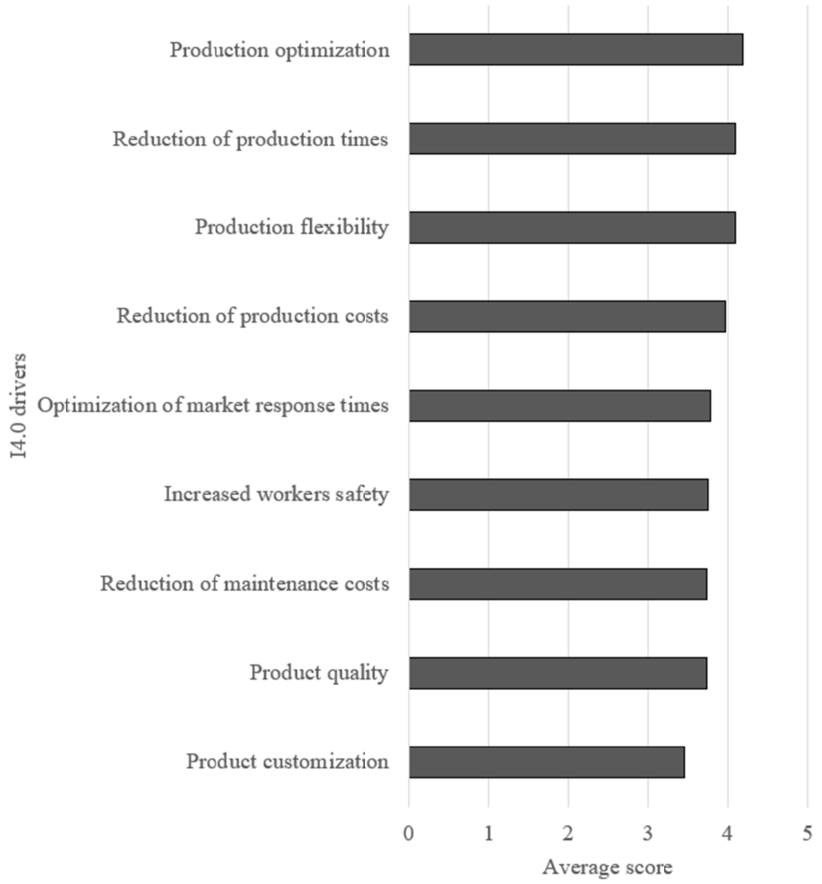

Figure 7. Key I4.0 drivers

4. Comparative Analysis

Figure 7 cross-references the responses obtained in the EE section and the responses obtained in the I4.0 section. The impact on costs is notable when considering EE. The percentage of medium-high responses indicates a strong impact on cost reduction—exceeding 50% of responses. This result is slightly higher than 10% if we consider I4.0. There were substantial increases in negative responses for I4.0.

Figure 8 represents a comparative focus on the impact of EE and I4.0 interventions on consumption costs. Specifically, responses with reduction values from 1% to 20% were extracted and aggregated. The greatest reduction in consumption costs and costs indicated are attributable to EE interventions rather than those of I4.0. This is true for electrical consumption, thermal consumption, water consumption, and waste management.

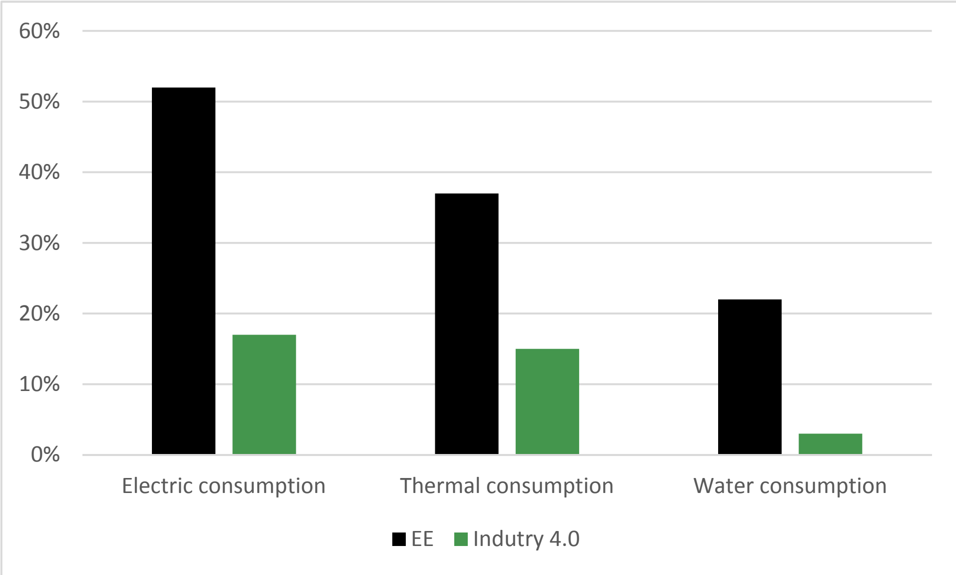

Figure 8. Impact on consumption and costs

Next, we consider the impact of EE interventions and I4.0 on the reduction of costs. In the case of thermal consumption, we note that the EE intervention impact was slightly higher than that of I4.0; in both cases, firms with more than 250 employees considered this impact higher than did firms with fewer than 250 employees. A similar situation can be seen in electricity consumption, where the difference was even higher—the average was 3.55 in the case of EE interventions compared to 3.1 for I4.0. Considering only EE interventions in Table 5, firms with more than 250 employees considered the reduction of thermal consumption to be more significant than firms with fewer than 250 employees. Considering electrical consumption, smaller firms indicated greater savings in electricity. For I4.0 interventions, there tended to be a greater impact for firms with more than 250 employees.

Table 5. Enterprise size and impact of interventions on turnover

	EE			I4.0		
	Up to 249	over 250	Total	Up to 249	over 250	Total
Thermal consumption	3.32	3.36	3.33	3.11	3.29	3.16
Electricity consumption	3.60	3.43	3.55	3.04	3.32	3.11
Water consumption	3.16	3.37	3.23	2.97	3.12	3.01
Manpower	2.85	2.94	2.88	2.93	3.22	3.01

Regarding the impact of EE and I4.0 policies on cost reduction, Table 6 presents a cross-section based on whether the company has an energy manager. For thermal consumption, there were no large differences in the answers. For electrical consumption, the values are slightly higher in firms that do not have an energy manager. The competence of the energy manager is important in the evaluation of I4.0 interventions. Unlike for EE interventions, in all five types of costs considered, there is a higher value where there is an energy manager.

Table 6. Presence of an energy manager and impact of interventions on turnover

	EE			I4.0		
	No	Yes	Total	No	Yes	Total
Thermal consumption	3.30	3.36	3.34	3.04	3.20	3.13
Electricity consumption	3.65	3.46	3.54	2.88	3.23	3.08
Water consumption	3.12	3.29	3.22	2.96	3.03	3.00
Manpower	2.92	2.84	2.88	2.95	3.09	3.02

For I4.0, larger firms gave less importance to barriers than smaller firms, except in two cases. The first is the impact of the intervention on the company's core business, and the second is the technological risk. An explanation is that larger firms tend to have a more complex organizational structure. Therefore, the strategic pact of a single intervention is not directly visible (as in the cases of smaller firms). The same could be said for technological risks. Larger firms have to face higher investments; therefore, they have a higher sensitivity to this type of risk, which is a more important barrier than smaller firms. The article has policy implications deriving from the fact that investments in EE-related innovations bring positive externalities from environmental and economic points of view (Beccarello & Di Foggia, 2022).

5. Conclusions

The article provided a combined analysis of barriers and drivers of EE and I4.0 interventions. The article focused on the impacts of such measures and interventions on key business variables, specifically production costs, business image and reputation, market positioning, and strategy. The article also reported information on the role of energy managers, the size of firms, and certification. Regarding the impact on costs, energy efficiency measures were indicated as critical, whereas I4.0 mainly impacts competitiveness and production optimization variables.

The importance of barriers was also investigated. Economic feasibility ranked first in both EE and I4.0, whereas regulatory uncertainty ranked second in EE. In I4.0 the role of enabling infrastructure emerged to be particularly important. Another important result related to the drivers for I4.0 investments—the first three drivers related to production improvement; ranked first was production optimization, second was the reduction of production times, and third was production flexibility.

Considering the impact of energy efficiency and I4.0 interventions on key competitiveness drivers, noteworthy differences arose. Sustainability, corporate social responsibility, and economic aspects were considered highly important due to energy efficiency measures. By contrast, image, reputation, and economic aspects were highly important as a consequence of I4.0 interventions.

This paper has both managerial and policy implications. Managers may benefit from new insights provided to compare the impact of EE and I4.0 interventions. This is useful to design data-driven strategies on sustainability and innovation. Similarly, results also help policymakers to design or fine-tune supporting policies and incentives based on insights from firms. Economic feasibility and policy uncertainty are common barriers to overcome. Future research should focus on the complementarity, overlap, and contrasting effects of measures to limit the risk of strategic drift and increase the probability of meeting sustainable development goals and work toward decarbonization.

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