sciendo

Zagreb International Review of Economics & Business, Vol. 29, No. 1, pp. 7-26, 2026

Faculty of Economics and Business, University of Zagreb and Sciendo. Printed in Croatia.
ISSN 1331-5609; UDC: 33+65
DOI: 10.2478/zireb-2026-0001

Towards More Sustainable Manufacturing – How Important are Innovation Activities?

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Abstract: *Although sustainable manufacturing practices are often implemented due to regulatory pressure, extant findings indicate that the benefits of their implementation are evident in firms whose behaviour is truly oriented towards environmental protection and sustainability. This paper aims to contribute to existing knowledge on sustainable manufacturing by understanding the role of innovation activities, which are recognised as an inevitable part of the transformation to sustainability, in implementing and maintaining long-term sustainable manufacturing orientation. The hypothesis is that innovation activity determines firms' decisions regarding the future implementation of sustainable manufacturing techniques. The results show that continuous focus on sustainable manufacturing is most likely in firms that innovate with process and organisational innovations, as well as those that report higher R&D intensity. The most relevant predictor of orientation towards sustainable manufacturing is process innovation that encourages firms to implement these techniques continuously but also decreases the probability of complete aversion towards sustainable manufacturing.*

Keywords: sustainable manufacturing techniques; innovation; research and development (R&D)

JEL Classification: O30

Introduction

We have witnessed the rapid growth of consumption in recent decades, accompanied by a shortening of product life cycles. This enabled companies to improve their performance and to grow. On the other hand, the current situation generates a variety of environmental issues related to the use of resources, waste, energy consumption,

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etc., and jeopardises life conditions as well as the potential for growth in the future. Significant decrease in consumption is not in the interest of business, or economic growth for that matter. This fosters other solutions for growing environmental problems, such as the adoption of technologies characterised by more efficient use of energy and resources and reduced emissions.

Global concerns about the environment and sustainable development nowadays challenge firms to consider contributing to environmental protection. Firms should focus not only on profit and wealth, but also on the effects of their production on the environment and society. O´Brien (1999) emphasised that firms should rely on sustainable production and support society's need not only to create wealth but to do so in a way that will support sustainable economic development. A shift towards more sustainable operating requires several changes, one of which is cleaner production and the introduction of sustainable production technologies in manufacturing processes. These changes should be conducted in the early stages of a firm's transformation towards environmental sustainability (Shrivastava, 1995).

According to Despeisse et al. (2012, pp. 355), sustainable manufacturing is "*a new paradigm developing socially and environmentally sound techniques to transform materials into economically valuable goods*". Sustainable production implies the minimisation of waste and the use of natural resources, raw materials and energy so that present society's needs are satisfied without endangering the ability of future generations to satisfy theirs (de Ron, 1998). Sustainable manufacturing strategies a firm can implement range from simple waste minimisation, material efficiency, resource efficiency, to eco efficiency as the highest-level strategy that refers to social, economic and environmental sustainability (Abdul Rashid et al., 2008). Firms can adopt sustainable production principles by increasing their recycling rates, reducing waste, minimising resource extraction, and preserving indirect amenity services (Swisher, 2006).

Firms´ motives for adopting environment-friendly behaviour include economic benefits and competitiveness improving, compliance with regulations and ecological (environmental) responsibility (Bansal & Roth, 2000; Kara et al., 2014). Sustainable manufacturing practices have great potential to contribute to economic, social, and environmental performance (Opoku et al., 2023). Rennings (2000) argues that environment-friendly practices and solutions are driven by technology push (technological development that may reduce resource consumption), market pull (customers' demand for more resource-efficient products), and regulatory push or pull (regulatory frameworks and environmental policies) determinants. This implies active involvement of firms, as well as customers and regulatory bodies in achieving environmental outcomes.

Effects of green practices on environmental and organisational performance draw significant attention in the literature on sustainable manufacturing (Bhatt et al., 2020). Reduced costs, improved quality, and better organisation as a result of sus-

tainable practices give firms an advantage over competitors, whilst customers' green orientation leads to an increase in market share (de Ron, 1998).

Although environmental innovations integrated in processes have benefits for business performance, such as an increase in total factor productivity (van Leeuwen & Mohnen, 2017), most of the changes related to environmentally friendly behaviours in firms come about because of regulatory pressure. Companies are indeed under growing pressure from both legislation and consumers to implement principles of sustainable manufacturing (Bogue, 2014), and they tend to promote their compliance with environmental legislation as sustainable behaviour (Peattie & Crane, 2005). However, Adebanjo et al. (2016) find that compliance with regulations improves environmental outcomes but does not contribute to the improvement of manufacturing performance. Firms are required to create and improve their green identity, environmental commitment, and legitimacy to benefit from environmental innovations (Chang & Chen, 2013).

Above-cited literature testifies that most of the sustainable practices are implemented due to regulatory pressure, while the best results are evident in firms whose behaviour is truly environmentally friendly and motivated by reasons other than legislation. If implementation of sustainable manufacturing techniques remains an occasional activity that occurs under regulatory pressure, both economic and environmental benefits are likely to be limited. Continuous implementation of sustainable manufacturing techniques is essential for both achieving environmental benefits as well as improving business performance. Therefore, this paper is focused on factors that are likely to affect firms' decisions on sustainable manufacturing implementation.

Innovation activities emerge as crucial for sustainability at the firm level. New business models oriented toward sustainability are fostered by technological innovations (Bocken et al., 2014). Innovation, research and development (R&D) and patents contribute significantly to the sustainable performance of firms that follow principles of the circular economy (Zhang et al., 2022). Hence, this paper aims to contribute to existing knowledge on sustainable manufacturing by understanding the role of innovation activities in implementing and maintaining long-term sustainable manufacturing orientation.

In this study, sustainable manufacturing refers to the implementation of environmentally friendly technological solutions in production processes that contribute to more efficient use of materials and energy, as well as reduced emission of pollutants.

The structure of the paper is as follows. After the introduction in the first section, the second section gives an overview of related literature and develops the research question. The third section explains methodology. Results of the analysis are provided and discussed in the fourth section. The paper ends with concluding remarks.

Background literature and research question

Implementation of sustainable manufacturing practices, including their drivers, has attracted significant attention from scholars in recent years. An in-depth review of both internal and external factors that drive the implementation of sustainable manufacturing in firms is provided by Abdul-Rashid et al. (2017). According to Baines et al. (2021), drivers of sustainable production can be summarised into three categories: regulation compliance, market value creation and potential cost savings.

Despite potential benefits for the environment and society, sustainable solutions often remain undervalued. Literature points out that innovation with potential to contribute to sustainability requires substantial support by the government (Ullah et al., 2021). Governments are expected to provide both motives (in terms of regulations) and support for sustainable practices to be introduced. Garrido-Prada et al. (2021) argue that SMEs need support from the government as they lack resources and knowledge to engage in green practices. However, public funding of environmental innovation is effective only if firms have their own funds (Cecere et al., 2020).

Contrary to these findings, adoption of sustainability principles largely depends on firms' leadership and their commitment to sustainability (Sohal & De Vass, 2022), and it is greatly spurred by firms' desire to outperform competitors as well as by the organisational culture they implement (Abdul-Rashid et al., 2017).

The implementation of sustainable manufacturing is also encouraged by the knowledge about the circular economy (Moktadir, 2018). Maxwell and Van den Vorst (2003) argue that the successful implementation of sustainable product development requires a strategy-level approach. Furthermore, firms implement sustainable manufacturing due to environmental pressures from stakeholders, management support and the engagement of employees, not because of environmental regulations (Aboelmaged, 2018). Whether a firm will indeed benefit from the implementation of proactive environmental strategies depends on the uncertainty and complexity of the general business environment, as well as on perceived organisational effects and decision response uncertainties (Aragón-Correa & Sharma, 2003).

To summarise the above-cited literature, sustainable manufacturing occurs in response to the requirements of a changing environment, with adequate management support, knowledge, resources, and capabilities that are adapted to market dynamics. The implementation of sustainable manufacturing practices can be analysed and understood within the context of the dynamic capability view (Teece & Pisano, 1994; Teece, Pisano, & Shuen, 1997).

This concept recognises that rapid change in the environment prompts firms to adapt, renew, and reconfigure their resources and competencies to achieve sustainable competitive advantage. According to Wang and Ahmed (2007), the dynamic capabilities are not the process but rather the behavioural orientation focused on integration, reconfiguration, renewal and recreation of a firm's resources and capabilities

as a response to the changing environment. The dynamic capabilities view emphasises the development of new knowledge adjusted to specific situations (Eisenhardt & Martin, 2000). It is appropriate for providing "*a closer picture of the action patterns towards renewal of the firm*" (Borch & Madsen, 2007, p. 111).

One extension of dynamic capability theory is the sustainability-oriented dynamic capabilities perspective (Dangelico et al., 2017). This perspective emphasises the importance of creating or adopting new capabilities in firms that adhere to sustainability principles. According to Arend (2014), dynamic capabilities are crucial for a firm's social and environmental performance, as they enable the necessary adjustments for achieving sustainability. The relevance of sustainability aspects in contemporary business resulted in the development and conceptualisation of dynamic capabilities for sustainability (Zollo et al., 2016; Ortiz-Avram et al., 2024).

Teece (2007) emphasises that dynamic capabilities imply constant innovation activity compatible with market needs and technological opportunities. Sustainability paradigm and principles (such as circular economy, for example) require innovative solutions in production as well as in consumption (Prieto-Sandoval et al., 2018). Innovative solutions such as big data analytics and artificial intelligence are highly relevant to the implementation of sustainable manufacturing practices (Bag et al., 2021). According to Mikhno et al. (2021), technology and innovation development are an essential part of becoming a green economy.

Innovation activity for sustainability can be focused on meeting regulatory requirements but can also encompass significantly more effort to contribute to environmental protection and sustainability. Hofstra and Huisingh (2014), for example, argue that innovative solutions with environmental benefits can be exploitative (i.e., mostly focusing on meeting new regulations), but also restorative (new solutions for environmental damage done so far), cyclical and regenerative. However, Nidumolu et al. (2009) view compliance with environmental regulations as an opportunity for experimenting with sustainable techniques and innovation if companies go beyond meeting immediate regulatory requirements.

In this paper, it is hypothesised that innovation activity affects firms' future sustainability practices. This differs from the prevailing approach that typically views sustainability as a driver of innovation activity (Nidumolu et al., 2009; Dangelico & Vocalelli, 2017; Saunila et al., 2018). The importance of innovativeness for long-term implementation of sustainable manufacturing techniques is further supported by findings that firms whose overall innovativeness is higher are likely to perceive fewer barriers to environment-friendly solutions such as energy-efficient technologies (Trianni et al., 2013). R&D intensity reduces environmental concerns over time, especially in large firms that are in a better position to experiment with the implementation of sustainability practices (Kabongo, 2019).

The literature on innovation often emphasises the importance of understanding innovation in broader terms that go beyond new technology and include changes in

organising business activity and performing marketing activities (for more details, see, for example, Schmidt & Rammer, 2007). In the context of this study, a better understanding of how innovation activity affects decisions on sustainable manufacturing practices can be achieved by distinguishing among types of innovation (product, process, marketing and organisational innovation).

Furthermore, it requires a closer examination of the reasons behind innovation activities, including sources of innovation ideas and knowledge, as well as environmental issues and upcoming regulations. Research findings show that firms open to external knowledge are more prone to environmental innovation (Mothe & Nguyen-Thi, 2017). It is therefore expected that firms that monitor customer requirements and/or competitors' activities and innovate in response to these are more likely to adopt sustainable manufacturing techniques.

Change towards sustainability-driven business models requires the cooperation of all actors at the macro and manufacturing network levels, as well as network partners (Valkokari et al., 2014). Interestingly, SMEs do not prioritise collaboration with stakeholders in their transition towards sustainability (Holzer et al., 2021). However, both internal and external collaboration are more essential for the development of environmental innovations than for conventional innovations (Petruzzelli et al., 2011). Collaboration with suppliers and environmental activities within the supply chain led to the implementation of environmental practices in firms (Vachon & Klassen, 2006). Considering these findings, the impetus for innovation activities by various stakeholders (i.e., customers, competitors, and/or suppliers) can potentially determine how firms approach sustainable manufacturing techniques.

Implementation of sustainable manufacturing is a complex issue that encompasses a vast number of enablers (Hariyani & Mishra, 2022). Although the sustainability practices are not necessarily introduced for financial reasons, firms hesitate to implement them if they do not generate financial benefits (Gajanayake et al., 2022). The implementation inevitably requires adequate financial resources, and the financial performance of the firms can potentially influence the decision to implement sustainable manufacturing techniques in practice. Mature firms face fewer financial constraints and can overcome them more easily, which makes them more successful in green technologies implementation (Leoncini et al., 2019). This implies that the experience gained from years of operating can significantly influence the decision on sustainable manufacturing.

Implementation of sustainability principles may also vary depending on firm size. A comprehensive list of drivers of sustainability practices in SMEs is provided in Yadav et al. (2018). SMEs generally face resource constraints and need to develop the necessary dynamic capabilities to manage social, environmental and economic performance (Eikelenboom & de Jong, 2019). Although SMEs are somewhat heterogeneous in their engagement in environmental practices (Hoogendoorn et al., 2015), their commitment to environmental issues and environmental innovation is substan-

tially lower than in large manufacturing firms (Chang & Chen, 2013). This can be due to challenges in improving their economic and social performance through the adoption of sustainable practices (Dey et al., 2022). For some SMEs, factors such as client perception, costs, and risks of using sustainable materials are reasons why they are reluctant to turn to sustainable solutions (Thorpe et al., 2008). Furthermore, a lack of support from customers as well as strong competition forces SMEs to favour economic performance over environmental and social aspects of sustainability (Malesios et al., 2021).

Taking into account the above-cited literature, this study addresses the following research question: How do innovation activity (measured in terms of product, process, marketing and organisational innovation as well as R&D intensity) and reasons for innovation activities affect the implementation of sustainable manufacturing techniques in firms? Innovation activities in this study are used as a proxy for firm capabilities to create and/or adopt new knowledge and use it to respond to market requirements and changes related to sustainability issues. They are expected to impact their decision on the forthcoming steps regarding sustainability in manufacturing.

Orientation toward sustainable manufacturing implementation can be a long-term orientation that implies continuous implementation of sustainable manufacturing techniques or just a short-term activity. In the context of this research, it can be expected that capabilities and resources related to the innovation activities will reflect in firms' decisions to take one of these paths. To fully understand the orientation towards sustainable manufacturing in business practices, the analysis should include several paths for firms to take: refusing to adopt sustainable manufacturing techniques completely; planning to implement sustainable practices in the future despite lacking prior experience; abandoning previously adopted sustainable manufacturing; and continuous commitment to sustainable manufacturing.

Methodology

The empirical part of the paper relies on responses of 1152 manufacturing firms operating in Europe (EU countries, including the UK and Switzerland). Data were obtained through GESIS Data Archive and refer to survey data from Flash Eurobarometer 433 (ZA6771, Innobarometer 2016 – EU business innovation trends. February 2016. TNS Political & Social [Producer]; dataset version 1.0.0. (2016)).

The data collected by this survey refer to the period from 2013 to 2015. Although there are situations that allow the use of old data (Kertschen Jr., et al., 2023), the use of a 10-year-old dataset can be viewed as a limitation to the study. However, this dataset provides a unique source of information on innovation activities and sustainable manufacturing techniques across the EU countries and enables an understanding of the relationship within the wider context, beyond the single economy or market. As

environmental issues transcend national borders, an analysis that includes 29 countries enhances the quality of the findings.

The multinomial probit model is used to analyse relationships between innovation activities (and other firm characteristics) and the implementation of sustainable manufacturing techniques. The multinomial probit regression was performed using the *mprobit* command in Stata. The marginal effects are computed using the *mfx* command.

The dependent variable in the model is a nominal variable that refers to the implementation of sustainable manufacturing. There are four outcomes: no experience with sustainable manufacturing technologies, occasional introduction, intention to introduce them for the first time, and continuous dedication to their use. No experience with sustainable manufacturing techniques is the base outcome in the model.

Relying on the data on sustainable manufacturing techniques in over 1000 establishments in Europe, specifically the EU countries plus the UK (which at the time covered by the survey was part of the EU and therefore is treated as one of the EU countries) and Switzerland, it can hardly be concluded that the trend has largely amplified. Most firms across 29 countries still have no experience with sustainable manufacturing and show no intention to use it. 56.1 per cent of firms in the sample don't use or plan to use sustainable manufacturing techniques. 8.5 per cent of all interviewed firms have used it but will not do so in the future, while 8.3 per cent expressed their intention to adopt some of these techniques in the future. 27.1 per cent are firms that already use sustainable manufacturing and plan to use it in the future.

To sum up, approximately 35 per cent of firms in the sample have at least some experience with sustainable manufacturing techniques. Most of them are dedicated to continuous implementation, while those with experience but who intend to abandon sustainable manufacturing techniques in the future are a minority. However, over half of the interviewed firms are not interested in the adoption of sustainable manufacturing techniques whatsoever. Their aversion towards sustainable manufacturing techniques is not related to bad experiences, as they have not applied any of these techniques in the past. The percentage of firms that plan to abandon the implementation of sustainable manufacturing techniques is still notably lower.

The set of independent variables in the model captures characteristics of innovation activities that make firms more prone to certain decisions regarding the sustainable manufacturing implementation. They include the type of innovation (product, process, organisational and/or marketing innovation), innovation intensity (R&D to turnover and plans to increase R&D investment in the future) and motives for innovation development (market potential, customer requests, increased competition, new solutions offered by suppliers, upcoming regulations and future impact on environmental protection). Together, they depict capabilities and resources developed within the firm that relate to innovativeness.

In addition to those variables, models control for age, turnover, and turnover increase in comparison to the previous year, size, operating as part of the group and

operating in the EU. Although these variables are not in the central focus of the research, they are expected to influence outcomes, considering previous research findings cited in Section 2. They are thus included in the model. A list of dependent and independent variables and their explanation is provided in Table 1.

Table 1: List of variables and descriptive statistics

Variable	Description	Descriptive statistics
Dependent variable		
Implementation of sustainable manufacturing techniques	0 = no experience with SMT	56.1
	1= occasional introduction of sustainable manufacturing techniques	8.5
	2= no experience, but plans to apply it	8.3
	3= continuous use of SMT	27.1
Independent variables		
Product innovation	1 if firm reports introduction of new product and/or service	86.4
Process innovation	1 if firm reports introduction of new process	69.5
Marketing innovation	1 if firm reports introduction marketing innovation	46.7
Organizational innovation	1 if firm reports introduction of organisational innovation	54.7
R&D increase	1 if the firm plans to increase R&D investment in the future	35.3
R&D to turnover	Percentage of turnover in 2015 invested in innovation: 1 if 0%	4.4
	2 if less than 1%	25.0
	3 if between 1 and 5%	49.1
	4 if between 6 and 10%	13.0
	5 if 11% or more	8.4
Market potential	1 if market potential is one of the main reasons for investing in innovation in the next 12 months	46.9
Customer requests	1 if customer requests are one of the main reasons for investing in innovation in the next 12 months	41.9
Increased competition	1 if increased competition is one of the main reasons for investing in innovation in the next 12 months	41.4
New solutions offered by suppliers	1 if new solutions offered by suppliers are one of the main reasons for investing in innovation in the next 12 months	7.8
Upcoming regulations	1 if upcoming regulations are one of the main reasons for investing in innovation in the next 12 months	6.8
Future impact to environmental protection	1 if the company expects its innovation activities in a 5-years period can make a positive impact to environmental protection	19.3
Age	1 if firm was established more than 5 years ago	92.1
Turnover (in logs)	Total turnover in 2015 in logs	
Part of the group	1 if firm is part of the group	34.2
Turnover increase	1 if turnover has risen	51.2
SME	1 if firm has 10 to 249 employees	64.1
Large	1 if firm has more than 250 employees	15.3
EU	1 if firm operations are in EU country	91.2

Descriptive statistics presented in Table 1 show that most firms in the sample have experience with innovation development. As many as 86.4 per cent of firms in the sample report product innovation developed in the past two years. A significant percentage introduced process innovations. Namely, 69.5 per cent of respondents in the sample introduced process innovations. Marketing innovations are introduced in 46.7 per cent of firms, while 54.7 per cent report implementation of organisational innovations. Furthermore, 35.3 per cent of firms in the sample plan to increase their R&D investments in the next twelve months.

Their future innovation activities are, in most cases, driven by market potential (46.9 per cent), customer requests (41.9 per cent) and increased competition (41.4 per cent). Only 6.8 per cent of them plan to innovate in the future to meet upcoming regulatory requirements. It is also worth noting that 19.3 per cent of firms in the sample expect their innovation activities over a 5-year period to make a positive impact on environmental protection.

As for the control variables, 64.1 per cent of firms in the sample are SME and 15.3 per cent are large firms. The rest of them are micro-entrepreneurs. 91.2 per cent are established over five years ago, while 34.2 per cent operate as part of the group. Over half of the respondents report a turnover increase in the last year. Finally, the majority of firms (i.e. 91.2 per cent of the sample) operate in EU countries.

Results and discussion

Table 2 shows the results of the multinomial probit model. The coefficients presented in the table indicate the probability of occasional introduction, no experience but intent to apply, and continuous implementation of sustainable manufacturing techniques, in comparison to the complete absence of their use in the company.

According to the results of the multinomial probit, firms that introduce process and marketing innovation and envisage future impact on environmental protection are more likely to occasionally implement sustainable manufacturing techniques in comparison to those that avoid its implementation completely. At the same time, product innovation and customer requests as drivers of future innovation activity decrease the likelihood of occasional introduction in comparison to the complete absence of sustainable manufacturing techniques.

Analysis also reveals what drives firms with no previous experience with sustainable manufacturing techniques to consider their application in the next period. According to these results, having process innovation, planning R&D increase, and innovating in response to customer requests as well as because of new solutions offered by suppliers are factors that make a firm more likely to introduce sustainable manufacturing techniques in the future rather than remain status quo in that respect. Furthermore, firms that expect to make a positive impact on the environment with

their innovation activities are also more likely to turn to sustainable manufacturing techniques. Being part of the group, on the other hand, decreases the likelihood of sustainable manufacturing techniques implementation in firms with no previous experience.

As for the continuous implementation of sustainable manufacturing techniques, its likelihood in comparison to the complete absence of their implementation is positively associated with process and organisational innovation, an increase in R&D investment, the amount of R&D to turnover, upcoming regulations, and future impact on environmental protection as motives for innovation activities. It is worth noting that upcoming regulations are a significant predictor only in the case of continuous orientation towards sustainable manufacturing as opposed to completely rejecting their implementation.

The results of multinomial probit point to the variables that explain the implementation of sustainable manufacturing techniques. According to these findings, the implementation of sustainable manufacturing techniques depends mainly on innovation activity and R&D, as well as motives that spur innovation activities. Control variables are mostly not significantly related to firms' decisions on sustainable manufacturing techniques. Although a substantial body of literature deals with the uniqueness of SMEs in terms of sustainable practices (as cited in the previous section), according to these findings, firm size only partially matters. More precisely, SMEs are only significantly more likely to report occasional introduction of sustainable manufacturing in comparison to no implementation of these techniques at all.

Table 2: Results of multinomial probit

	Occasional introduction of sustainable manufacturing techniques	No experience, but plans to apply it	Continuous implementation of sustainable manufacturing techniques
Product innovation	-.419 (.204)**	-.258 (.217)	-.060 (.176)
Process innovation	.449 (.175)***	.308 (.170)*	.347 (.135)***
Marketing innovation	.420 (.154)***	.236 (.157)	.184 (.122)
Organizational innovation	-.055 (.154)	.145 (.158)	.220 (.123)*
R&D increase	.115 (.158)	.435 (.154)***	.222 (.123)*
R&D to turnover	-.021 (.082)	.041 (.080)	.207 (.063)***
Market potential	-.149 (.170)	.185 (.177)	.084 (.135)
Customer requests	-.405 (.172)**	.302 (.171)*	.132 (.132)
Increased competition	-.122 (.168)	.196 (.175)	.106 (.136)
New solutions offered by suppliers	-.183 (.303)	.523 (.265)**	.022 (.230)
Upcoming regulations	.098 (.290)	.251 (.316)	.387 (.236)*
Future impact to environmental protection	.338 (.189)*	.476 (.182)***	.449 (.145)***
Age	-.270 (.263)	.300 (.296)	.103 (.230)
Turnover (in logs)	-.018 (.035)	-.008 (.035)	.028 (.029)
Part of the group	-.051 (.167)	-.659 (.186)***	.068 (.131)

	Occasional introduction of sustainable manufacturing techniques	No experience, but plans to apply it	Continuous implementation of sustainable manufacturing techniques
Turnover increase	.034 (.153)	.042 (.155)	.150 (.121)
SME	.357 (.204)*	.265 (.198)	.252 (.164)
Large	.398 (.300)	.557 (.287)*	.984 (.221)***
EU	-.437 (.245)*	-.152 (.277)	-.467 (.206)**
Constant	-.765 (.534)	-2.482 (.584)***	-2.336 (.459)***
Number of observations	1152		
Wald chi2	161.34		
Prob>chi2	0.0000		
Log likelihood	-1174.8429		

The results of the multinomial probit show that upcoming regulations as a reason for future innovation activity do not affect the probability of sustainable manufacturing techniques implementation in comparison to avoiding it completely. Innovation activity, on the other hand, appears to be a significant predictor of orientation towards sustainable manufacturing implementation in manufacturing firms. This is especially relevant for process innovation that makes a difference from turning from no sustainable manufacturing innovation to its implementation, both occasionally and continuously. Its development also encourages firms with no previous experience to consider introducing sustainable manufacturing techniques.

Interestingly, the development of product innovation increases the probability of the occasional introduction of sustainable manufacturing techniques in comparison to the complete absence of their implementation. A significant relationship to other decisions regarding the implementation of sustainable manufacturing techniques is not identified. In addition to process innovation, the probability of continuous implementation of sustainable manufacturing techniques is increased when organisational innovation is developed. Firms that introduce marketing innovations are significantly more likely to understand sustainable manufacturing techniques as an occasional activity that will probably be abandoned in the future.

To explore the magnitude of impact of the independent variables on the probability of each strategy, the marginal effects are used. As already mentioned, innovation activity motivated by upcoming regulations is not a significant predictor of sustainable manufacturing behaviour. Marginal effects in Table 3, therefore, show that upcoming regulations do not have a significant impact on any of the four categories.

The introduction of product innovation significantly decreases the probability of the occasional introduction of sustainable manufacturing techniques by 5.1 per cent. Process innovation decreases the probability of not implementing sustainable manufacturing techniques by 11 per cent and increases the probability of both occasional and continuous implementation of sustainable manufacturing techniques (by 3.4 per cent and 5.9 per cent, respectively). Marketing innovation decreases the likelihood of no sustainable manufacturing techniques by 7.6 per cent and increases the probability

of occasional introduction of sustainable manufacturing techniques by 4 per cent. As for organisational innovations, they increase the probability of continuous effort to implement sustainable manufacturing techniques by 5.2 per cent.

Furthermore, firms that report an increase in R&D are more likely to plan the implementation of sustainable manufacturing techniques in the future and are less likely to refuse their implementation. Firms that plan to increase R&D investment in the future are 7.6 per cent less likely to be among those that refuse sustainable manufacturing and 4.3 per cent more likely to turn to its implementation. Higher R&D to turnover significantly increases the probability of continuous implementation of sustainable manufacturing techniques by 5.2 per cent. It also decreases the likelihood of not implementing sustainable manufacturing techniques at all by 3.8 per cent.

Table 3: Marginal effects

	No SMT	Occasional introduction of SMT	No experience, but plans to apply it	Continuous implementation of SMT
Product innovation	.059 (.045)	-.051 (.030)*	-.022 (.027)	.013 (.040)
Process innovation	-.110 (.033)***	.034 (.017)**	.017 (.017)	.059 (.030)*
Marketing innovation	-.076 (.032)**	.040 (.018)**	.014 (.017)	.022 (.028)
Organizational innovation	-.044 (.032)	-.017 (.018)	.010 (.017)	.052 (.028)*
R&D increase	-.076 (.032)**	-.002 (.018)	.043 (.018)**	.035 (.029)
R&D to turnover	-.038 (.016)**	-.011 (.009)	-.003 (.009)	.052 (.015)***
Market potential	-.017 (.035)	-.024 (.019)	.021 (.019)	.020 (.032)
Customer requests	-.017 (.034)	-.056 (.018)***	.037 (.019)	.037 (.031)
Increased competition	-.024 (.035)	-.021 (.018)	.021 (.020)	.024 (.032)
New solutions offered by suppliers	-.037 (.060)	-.029 (.026)	.079 (.044)*	-.013 (.053)
Upcoming regulations	-.094 (.063)	-.008 (.030)	.013 (.037)	.090 (.061)
Future impact to environmental protection	-.134 (.039)***	.015 (.023)	.035 (.023)	.084 (.036)**
Age	-.012 (.058)	-.047 (.039)	.031 (.023)	.028 (.051)
Turnover (in logs)	-.003 (.007)	-.003 (.004)	-.002 (.004)	.008 (.007)
Part of the group	.027 (.034)	.001 (.019)	-.070 (.016)***	.041 (.031)
Turnover increase	-.031 (.031)	-.002 (.017)	-.001 (.017)	.035 (.028)
SME	-.084 (.041)**	.028 (.021)	.016 (.020)	.040 (.37)
Large	-.243 (.057)***	-.006 (.032)	.016 (.034)	.233 (.060)***
EU	.125 (.055)**	-.034 (.034)	.008 (.028)	-.100 (.054)*

These results without question show the relevance of innovation activities for determining sustainable manufacturing implementation in European firms. The most relevant predictor of sustainable manufacturing strategy is process innovation, which

encourages firms to implement these techniques continuously but also decreases the probability of complete aversion towards sustainable manufacturing. According to the results of the multinomial probit model, continuous focus on sustainable manufacturing is the most likely in firms innovating with process and organisational innovations that report higher R&D intensity.

Further support for this conclusion is the significant and negative association of innovation with the probability of complete avoidance of sustainable manufacturing techniques. As testified by marginal effects, both process and marketing innovation decrease the probability that a firm will refuse to implement sustainable manufacturing in any form. The same is true for firms that increase R&D and have a higher R&D-to-turnover ratio.

Results also show the presence of customer pressure to consider the implementation of sustainable manufacturing, unlike pressure from competitors. Innovating in response to increased competition is not significantly related to the decision on sustainable manufacturing implementation. Firms obviously do not view sustainable manufacturing as a way of outperforming other firms they compete with.

Concluding remarks

Firms, among others, must continually adapt their resources and capabilities to effectively respond to the increasing importance of sustainability issues. Results presented in the paper indicate the importance of innovation and R&D activities for implementing sustainable manufacturing techniques in general and for sticking to their implementation. This makes innovation a driver of sustainability in production and key to a long-term focus that goes beyond regulatory pressure and compliance. Process innovation is the most relevant from the perspective of sustainable manufacturing practices. Furthermore, findings show that R&D matters when it comes to sustainable manufacturing implementation. Higher R&D intensity decreases the probability of avoiding sustainable manufacturing techniques and increases the probability of its continuous implementation.

It is worth pointing out the relationship between marketing innovation and the occasional implementation of sustainable manufacturing techniques. Results show that firms that have developed this type of innovation are more likely to end previously implemented sustainable manufacturing practices. It can be speculated that new marketing activities are related to building an image of a company oriented toward sustainability or green practices, as long-term commitments to sustainable manufacturing are lacking.

To summarise, the research findings demonstrate the importance of innovation activities in fostering long-term sustainability orientation in manufacturing. Capabilities related to innovation activities enable firms to continue providing solutions to the growing environmental issues associated with manufacturing. Considering the

complexity of ecological problems, efforts to build adequate innovation capabilities within firms are becoming important.

This is not just important for managers, but also for policymakers. The insights from this study should encourage them to support firms in developing adequate innovation capabilities. Both innovation and sustainability are recognised in EU policies for improving competitiveness. These research findings can be useful for encouraging them to adequately address growing environmental pressure by helping firms to develop and use resources and capabilities related to innovation. They can be used as an input for designing programs to encourage and support innovation activities at the firm level. This is especially important for firms that still have no experience with sustainable manufacturing but are considering its implementation. Adequate support could be beneficial in helping them adjust and utilise their capabilities to implement sustainable manufacturing techniques in the future.

In addition to the presence of innovation activities in the past, the reasons for future innovation activities are what matter. Whether they will focus continuously on the implementation of sustainable manufacturing techniques strongly depends on taking the future impact on environmental protection into account when innovating. Upcoming regulations as a driver of innovation activities in the next period are not found to be significant.

Interestingly, the increased competition as a reason to innovate does not affect the probability of implementing sustainable manufacturing techniques. There is obviously no pressure from competitors to behave more environmentally friendly. This can be attributed to the low level of implementation of sustainable manufacturing techniques or their irregular, short-term implementation in most firms.

Firms that have introduced sustainable manufacturing techniques in the past but now intend to abandon them represent an interesting group for research. It would be interesting to understand their reasons for that decision. Without empirical evidence, it can only be speculated whether the reasons behind those decisions are poor impact on performance, high costs or even a lack or absence of regulatory pressure. This is an interesting topic for future research.

This research encompasses past innovation activities (innovation type and R&D intensity) and future focus of innovation activities (R&D increase and reasons for innovation activities in the future), and thus contributes to a better understanding of the relationship between innovation activity and sustainable manufacturing. However, the research is not without limitations.

The main limitation refers to the narrow focus of the research. Future studies should expand their focus on factors other than innovation activities and their nature. The literature would benefit from exploring how other resources and capabilities influence firms' decisions regarding the implementation of sustainable manufacturing. Existing research findings show that firms do not approach sustainable manufacturing strategically because of price competition, quality issues and inadequate integration of various

enablers of sustainable manufacturing (Hariyani & Mishra, 2022). Therefore, it would be interesting to include variables referring to those issues to gain better insight.

Furthermore, this study does not include information on the reasons why firms decided to implement sustainable manufacturing principles in the first place, whether it was regulatory pressure or any other reason. For those who decide not to implement or proceed with the implementation of sustainable manufacturing techniques, the exact reasons remain unknown. Therefore, future research can focus more on the reasons why firms decide not to stick with sustainable manufacturing principles.

This study analyses the relationship between innovation capabilities and sustainable manufacturing techniques in a wide set of industries. This can be considered a limitation of the study as it does not account for sector-specific characteristics (related to the innovation activities or sustainability). Future studies should focus on more specific industries to gain a deeper understanding of whether there are any sector-specific relationships.

Declarations/acknowledgement

Funding

This work was made as part of the project "Determinants of Strengthening Technological Capabilities of Different Sectors" at the Institute of Economics, Zagreb and funded within the National Recovery and Resilience Plan 2021-2026 – NextGenerationEU.

Conflicts of interest/Competing interests

There is no conflict of interest/Competing interests

Availability of data and material

The data that support the findings of this study are openly available from GESIS Data Archive (Flash Eurobarometer 433 (ZA6771, Innobarometer 2016 – EU business innovation trends. February 2016. TNS Political & Social [Producer]; dataset version 1.0.0. (2016) https://doi.org/10.4232/1.12635).

Code Availability

The computer program results are shared through the tables in the manuscript.

Authors' Contributions

Not applicable.

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