SMEs and Circular Economy drivers: empirical evidence from Italy

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The study investigates the determinants of the adoption of circular economy (CE) innovations in Italian manufacturing SMEs by using original data based on 4,042 firms for the 2017-2018 period. Results indicate that firms' innovative efforts, size, export activity, management's environmental awareness as well as the use of the digital innovation policy, *Piano Industria 4.0,* are factors that are positively correlated with the adoption of general CE innovations, showing heterogeneous results across different circular economy practices.

Lo studio indaga i fattori che hanno facilitato l'adozione di innovazioni nelle PMI manifatturiere italiane nel campo dell'economia circolare. Utilizzando dati su 4.042 PMI per il periodo 2017-2018, i risultati indicano che gli sforzi innovativi delle imprese, la dimensione, l'attività di esportazione, la consapevolezza del management della sfida ambientale e l'utilizzo della politica di innovazione digitale, Piano Industria 4.0, sono fattori positivamente correlati con pratiche di economia circolare adottate in impresa, mostrando effetti eterogenei tra le diverse tipologie di innovazione analizzate.

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Introduction

Circular Economy (CE) concerns an industrial system considered restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration and with the progressive use of renewable energy. It also eliminates the use of toxic chemicals that impair reuse and aims to eliminate waste through the superior design of materials, products, systems and, within the latter, business models (Ellen MacArthur Foundation 2013). Thereby, a more circular system may provide several benefits to our society, including environmental and economic effects as well as job opportunities and resource security externalities.

The role of firms is considered crucial in creating conditions for a transition to a circular economy. The present study focuses on a subsample of the latter category concerning small and medium enterprises. The word subsample here used does not simply outline a small fraction of total firms. Indeed, Europe's 25 million small and medium enterprises (SMEs) are the backbone of the EU economy. SMEs employ around 100 million people (*i.e.* two-thirds of European employment), accounting for more than half of Europe's GDP and for 99% of all European enterprises. They play a key role in adding value in all economic sectors (European Commission 2020). Nevertheless, their environmental footprint represents a significant proportion of the total pollution. Recent studies reveal that SMEs consume more than 13% of the total global energy demand, which could be reduced by as much as 30% by adopting cost-effective energy efficiency measures (International Energy Agency 2016). In Europe, SMEs account for approximately 64% of industrial pollution[1] (Constantinos *et al.* 2010). For this reason, this analysis investigates the relation between SMEs and CE strategies to design specific policy incentives supporting the sustainable development of firms.

The research explores this issue by investigating the factors correlated with the adoption of circular economy practices in Italian SMEs using cross-sectional information for the period 2017-2018. The data, extracted from a survey conducted by the CEntre for Research on Circular Economy, Innovation and SMEs (CERCIS[2]) on 4,042 Italian SMEs in the manufacturing sector, represent a novelty in this research field. Indeed, previous studies like the *Flash Eurobarometer 441*[3], mostly used countries' aggregated data (*e.g*. Hoogendoorn *et al*. 2015; Zamfir *et al.* 2017; Yadav *et al.* 2018; Gusmerotti *et al.* 2019; Bassi and Dias 2019; Katz-Gerro and López Sintas 2019; Ghisetti and Montresor 2020). The focus on Italy is crucially important since the literature underlines the high level of heterogeneity between different countries in terms of CE drivers (Zamfir *et al*. 2017; Bassi and Dias 2019; Katz-Gerro and López Sintas 2019).

Using a negative binomial regression model, the analysis indicates that the innovative efforts of firms, size, exporting activity, management's environmental awareness as well as the use of *Piano Industria 4.0* are positive and significant variables. They all represent factors correlated with the adoption of general CE innovations in Italian firms, showing heterogeneous results among different circular economy practices: the small size of enterprises, which strongly characterizes the Italian economy, seems not to be an obstacle to the development of waste markets and, in general, to the adoption of reuse practices which treat waste as new production inputs. The internationalisation of Italian companies is highly correlated only with product design circular innovations and the digital innovation policy, *Piano Industria 4.0*, particularly favored innovation adoption concerning the reduction of raw materials, energy demand and CO_2 emissions in Italian firms.

It is important to bear in mind that, since this is a cross-sectional data study, no direct causal links can be drawn from the results of the estimation strategy. The analysis covers factors that are correlated with CE innovations adoption in Italian SMEs, but the reason for and study of these correlations remain openly questionable.

The study is organized as follows: Section 1 presents a literature review on the relationship between SMEs and the circular economy. It deals with external barriers and internal drivers tracked by the literature background. Finally, it discusses about the transition from *Piano Industria 4.0* to *Piano Transizione 4.0* characterizing the Italian industrial policy framework. Section 2 contains the research methods applied to the data and on the adopted econometric strategy. Results are shown in Section 3; the last section draws the conclusions and some of the policy implications on the issue, by considering the limitations of the proposed analysis.

1. Circular economy and SMEs

EU SMEs and CE

SMEs' business orientation usually differs from larger organisations due to numerous competitors, cash flow issues, lack of financial support and a generally harsher economic environment. SMEs tend to focus more on their economic performance than on their environmental and social performance. (Dey *et al.* 2020). Nevertheless, surveys carried out by the European Commission show how the EU SMEs are becoming increasingly aware of the benefits given

1 The main impacts considered are energy use, CO_2, SO_x, NO_x, PM10, nmVOC, waste and hazardous waste.

2 CERCIS activities are focused on the investigation of firm eco-innovative behaviors, aimed to combine competitiveness with sustainability and to face the challenges set by the European Union Action Plan for the Circular Economy in 2015. The promotion of excellence in education and research (*i.e. Dipartimenti di Eccellenza*) is the responsibility of the Department of Economics and Management at the University of Ferrara and represents, particularly, part of the departmental development program funded by the Italian Ministry of Education, University and Research (MIUR) on a competitive base for the 2018-2022 (https://bit.ly/3Qh03pK).

3 A Survey conducted by the EC in 2016 on European SMEs and Circular Economy in the 28 Member States. Key decision-makers of 10.618 SMEs employing between 1 and 250 persons were interviewed via telephone in their mother tongue (European Commission 2016).

by improvements in resource and energy efficiency strategies. In June 2016, the European Commission published a survey named Flash Eurobarometer 441, carried out in the 28 Member States of the European Union, and concerning European SMEs and the Circular Economy. Key decision-makers of 10.618 SMEs, employing between 1 and 250 persons, were interviewed via telephone in their mother tongue on behalf of the European Commission. Results showed that almost three quarters of the companies (73%) undertook some circular economy-related activities[4], of which 1) minimizing waste by recycling, reusing, or selling it to another company (55%), and 2) re-planning energy use to reduce consumption (38%) were the most common (European Commission 2016). In contrast, a survey led by the FUSION EU co-funded project, based on 300 European firms from three different countries (*i.e.,* France, Belgium, and England), suggested a different perspective on the issue. Its results showed that most managers either never heard about the term 'circular economy', or its meaning was unknown to them. Nevertheless, when participants were given a simpler definition of circular economy focused on aspects like re-use and recovery of waste materials, most of them replied that they were already making efforts to recycle and repair (FUSION 2014).

Drivers of environmental and circular innovation in SMEs

The present study refers to CE innovations as CE practices adopted by SMEs rather than as patents related to recycling and secondary raw materials. Since not all inventions are patentable (especially in the CE context) and most SMEs do not patent at all[5] (Albrizio *et al.* 2017), the analysis is focused on the adoption stage of the CE-related innovations, in agreement with Mazzanti *et al.* (2020). Therefore, this chapter mainly deals with the state of the art of empirical studies investigating the drivers of CE practices in SMEs. Considering the long debate on the drivers of a general eco-innovation (EI), it is worth introducing the differences between an environmental innovation and a standard innovation. According to Rennings (2000), the EIs are characterizes by a so-called double externality. On one side, they produce a positive externality related to knowledge spillover effects. On the other side, they aim to reduce negative externalities related to environmental pollution. This double market failure reduces the firms' incentives to be invested in the EI and introduces the second difference between the EI and standard innovation: the regulatory framework. As stated above, market forces alone cannot provide an optimal social level of EI. Therefore, the role of public intervention in both pushing the offer of greener products and pulling the green demand represents one of the main determinants for the adoption and diffusion of the EI.

Barbieri *et al.* (2016) present a main path analysis to make a literature review on environmental innovation (EI). It systematizes the EI by identifying the main directions in which the literature has developed over time. One of these directions is precisely related to the drivers of environmental innovation. According to the authors, these drivers can be grouped into four clusters:

- *Market-pull*, like former and expected economic performance, demand for green products and consumer preferences;
- *Technology-push*, depending mostly on firm-specific knowledge endowment, increasable through investments in R&D. It also refers to organisational capabilities and innovation;
- *Regulation*, the literature on the "Porter Hypothesis[6]" tries to assess the effects of policy stimulus;
- *Firm-specific factors*, inclusive of all those characteristics like age, size, location or sector, possibly affecting firm innovativeness from an internal point of view.

Specific research on the drivers of circular

4 Re-plan of the way the water is used to minimize usage and maximize re-usage; use of renewable energy; re-plan energy usage to minimize consumption; minimize waste by recycling or reusing waste or selling it to another company; redesign products and services to minimize the use of materials or use recycled materials.

5 For instance, in the sample of 4.454 Italian SMEs, only 1.19% of them has deposited at least one green patent in the 2017-2018 period.

6 According to the famous economist Michael Porter, well-designed and stringent environmental regulation can stimulate innovations which, in turn, increase either the productivity of firms or the product value for end users (Porter and van Der Linde 1995).

economy innovations adopted by SMEs is relatively scarce. It is important to underline that SMEs do not represent the smaller versions of their larger counterparts. In many small firms, the manager is also the company owner and his opinion on the strategic decision of the enterprise is significant. In this sense, some SME managers may have a positive attitude towards the circular economy, while others may not. Furthermore, SME owners or managers may have different risk perceptions. A strong managers' risk aversion can hinder the enactment of the circular economy, even when the benefits associated with its implementation are evaluated (Liu and Bai 2014). For these reasons, the organistional culture represents one of the most important internal drivers for the adoption of sustainable and circular practices by small firms. The concept of sustainability entrepreneurship is based on the idea that the legal context, the ownership-management system, and the management's value and belief system play significant roles in explaining the business decision in favor of environmental-friendly practices (Cambra-Fierro *et al.* 2008; Zamfir *et al.* 2017). According to Font *et al.* (2016), the habits and lifestyles of SME owners affect sustainability activities in the SME themselves. Koe *et al*. (2014) state that the personal commitment of SME managers to pro-environmental attitudes is fundamental for their environmental performance. With regard to the CE realm in particular, Rizos *et al.* (2016) investigates barriers and enabling factors identified in 30 SMEs during the implementation of their circular economy business model. The authors find out that a company culture based on a green mindset on the part of the staff or of the manager is considered a force enabling the transition to a circular economy business. Urbinati *et al.* (2019), investigating managerial practices to adopt circular economy business models, find out that managerial commitment is a necessary condition for the employee-level adoption of a circular economy philosophy, especially for small firms.

Therefore, in the present study, the manager's knowledge of the EU-ETS CO_2 price is used to proxy the management's awareness of environmental topics, considering it as a potential driving force for the adoption of CE practices. The choice behind this proxy is justified by the fact that, during the 2017-2018 period, the price of the EU carbon permits was below € 20 per ton, a level considered to be ineffective in altering the incentives of reducing carbon emissions for European firms. The idea is that managerial knowledge of the early stages of the CO_2 market may proxy managerial awareness of environmental topics.

The size of the firm is obviously another interesting factor when the comparison between SMEs and larger companies is discussed. It may explain the different rates of adoption of circular economy practices by enterprises. In the case of investments in energy efficiency, it has been observed that medium and large companies suffer from a lack of time or of internal skills less than SMEs, due to a more structured organisation of the latter. Moreover, it can be argued that smaller companies have a more agile structure that reduces the obstacles in implementing energy efficiency interventions (Trianni and Cagno 2012). Nevertheless, several arguments suggest a positive correlation between the size of the firm and the rate of adoption of CE activities. First, a presumed lack of resources characterizing SMEs hinders them to respond to stakeholder claims. Second, small firms' investments in sustainable practices may be hard to justify from the viewpoint of scale economics and negligible market shares. Third, due to their size, small firms are less visible to the media and the public and, enjoying a certain degree of anonymity related to secondary stakeholders like environmental consumers, they are less likely to engage in environmental practices. From an empirical point of view, Hoogendoorn *et al.* (2015) calculate that larger firms, in both the number of employees and the turnover, engage more in greener practices. Katz-Gerro and López Sintas (2019) recognize that the patterns reflecting less engagement in CE activities pertain to micro-enterprises with fewer than 10 employees and smaller turnovers. Patterns reflecting engagements of waste minimisation and use of resources optimisation pertain to small companies (10-49 employees) whereas patterns reflecting underway CE activities, or their full engagement pertain to medium-sized enterprises in terms of turnover and employees (50-250). Ghisetti and Montresor (2020) show that the adoption of CE practices is positively correlated with the size and age of the European SMEs.

The export activity of firms is another interesting variable to analyze in relation to CE practices. From regulatory-push and demand-pull perspectives, exporters may be exposed to the possibly more rigorous environmental policy stringency and environmental demand pressure demanded by foreign stakeholders (Newman *et al.* 2018). Moreover, a group of innovation studies investigates the role of external knowledge in triggering environmental innovation in firms. De Marchi (2012) emphasizes that the adoption of environmental innovation necessitates the search for knowledge sources beyond those currently available to the firm while Ghisetti *et al.* (2015) corroborate the importance of external knowledge cooperation, revealing that when firms source external knowledge, it boosts their environmental innovation adoption activity. By trading with foreign partners, firms can expand the volume of their knowledge and have access to new production possibilities.

Whether the variable of firm age can be considered a driver of CE strategies in SMEs is still under debate in the literature. From one point of view, the age of the company might have an effect in terms of established experiences, skills, and relationships that can facilitate the adoption of a circular economy business model (Urbinati *et al*. 2019). Nevertheless, from an empirical point of view Hoogendoorn *et al*. (2015), based on a sample of over 8,000 SMEs, find out that the firm age is consistently unrelated to the environmental practices of SMEs. Bassi and Dias (2019), using data from the Flash Eurobarometer 441, find no statistical significance between the age of the firm and the adoption of CE practices.

The involvement of SMEs in R&D activities investigated in this study is directly linked with the technology-push driver of EI. Macro- and micro-approaches show that innovation is one of the most important facilitating factors for sustainability, as it goes hand in hand with adopting new technologies. Although SMEs are not the best performers in terms of innovation, there is significant financial support for innovation in the European SMEs, aimed to increase their performance in sustainability. From an empirical point of view Bassi and Dias (2019), explaining the adoption of CE practices by the EU SMEs, recognize a significant effect for the percentage of turnover invested in R&D. Garcés-Ayerbe *et al.* (2019), performing a cluster analysis on the Flash Eurobarometer 441, also find out a positive relation between the scope of CE activities and the R&D investments of firms.

From Piano Industria 4.0 to Piano Transizione 4.0

The term Industry 4.0 indicates a trend of industrial automation that integrates new production technologies to create new business models and increases the productivity and production quality of firms (Schwab 2015). In a real-world scenario, Industry 4.0 is configured as a technological mix of robotics, additive manufacturing, sensors, Internet Of Things and programming processes, capable of changing both the company management and the production models (Di Maria *et al.* 2018). These concepts are intrinsically related to the sustainability and efficiency ones discussed in the CE realm. Expectations are therefore for a positive role of Industry 4.0 in fostering the development and diffusion of CE innovations in Italian firms.

The *Piano Industria 4.0* represents the transposition of the European initiative Industry 4.0 into the Italian framework. The policy presented in 2017 defined several tools to incentivize the innovation and the competitiveness of Italian firms such as, for instance, a hyper-amortisation to incentivize companies that invest in new capital goods, tangible or intangible, functional to the technological and digital transformation of production processes. In addition, the policy defines 1) some government aids, in terms of interests and guarantees for bank loans used to invest in new capital goods and 2) some fiscal incentives to help the investment in R&D and the patenting activity of firms (Ministero dello Sviluppo economico 2017). To sum up, this policy tool aims to obtain two dimensions of innovation in firms: technology endowment and development of competences.

In 2020, the policy has been redefined with a major focus on environmental sustainability by explicitly encouraging green investments in the circular economy; this focus is also reflected in the new name *Piano Transizione 4.0* (Enea and Circular Economy Network 2020). The new envisaged facilitating instrument is a form of tax credit which substitutes the hyper-amortisation for expenses incurred in both capital goods and research and development investments related to the ecological transition, and for the digital innovation of enterprises. This tax credit is aimed to support the implementation of projects that include new tangible and intangible assets with high technological content. It is designed to favor technological and digital transformation processes in accordance with the Industry 4.0 model and contributes to achieving, in addition, the following objectives (Ministero dello Sviluppo economico 2020):

- generating an increase in productivity with a lower use of raw materials, materials, and energy, and with lower production of waste;
- reducing industrial processes provoking emissions of pollutants in the air, water, and soil with equal or lower energy intensity or with higher productivity;
- developing alternative uses of materials.

Although the development of this industrial policy towards a more circular economy has been in place only since 2020, there is still reason to expect some effects from the old *Piano Industria 4.0* on the decisions of adopting CE innovations by the Italian SMEs of the sample. Di Maria *et al.* (2018) used a sample of 231 Italian manufacturing SMEs to analyze their investments in the fields of industry 4.0 and circular economy. One in three firms in their sample used a sort of incentive provided by the policy to reach improvements in customer service, in internal efficiency and in environmental sustainability. In particular, the big data-cloud-related technologies are the most relevant ones introduced by these SMEs and concern the ability to measure and monitor the use of production inputs. As a second result, industry 4.0 innovations have enabled the traceability of the supply chain and/or consumption, as well as ultimately leading to a reduction in the amount of materials/inputs used (*e.g.* energy, raw materials).

Considering these results, in the present study a significantly positive relation is expected between the used incentives provided by *Piano Industria 4.0* and the adoption of CE practices, especially those ones aimed to reduce material and energy inputs in the production process.

2. Research Design

Data

The data employed in the analysis have been collected from the *Circular Economy innovation and inventions 2017-2018* survey carried out by the CEntre for Research on Circular Economy, Innovation and SMEs (CERCIS) in collaboration with the company Izi spa. The collection of data was configured as a CAWI (Computer Assisted Web Interview) survey through which a structured questionnaire was administered to manufacturing companies. The sample of responding companies is 4565, stratified on three dimensions: geographical location (macro area, Istat), sector (technological intensity, Eurostat), and size (10-49 employees; 50-249 employees; 250+ employees). The period covered by the national survey is the two-year period 2017-2018 (Mazzanti *et al.* 2021). The questions concerned innovations and investments, adoption of CE practices and internal characteristics of firms, and provided support for multiple potential fields of research in the Italian context.

The objective of the present study is to analyze which characteristics of SMEs facilitate them in the adoption of circular economy practices. Thus, only a fraction of the data provided by the survey is used. After a data-cleaning based on the missing information and on the exclusion of micro (less than 10 employees) and non-manufacturing firms, the sample contains information on 4,042 SMEs. The distribution of firms interviewed at the NUTS 1 and NUTS 2 levels is reported in Table 1. Table 2 shows, instead, the sector of activity of the SMEs involved in the survey.

Table 3 reports the characterisation of the sample of SMEs with reference to the number of employees, the age of the firm, the percentage of the turnover invested in R&D in 2017, the manager's knowledge of the CO_2 price of the EU-ETS, the percentage of firms who benefitted from the *Piano Industria 4.0*, the percentage of exporting companies and whether they adopted at least one CE-related innovation in the 2017-2018 period. Most of the SMEs have between 10 and 49 employees and are mostly located in northern Italy. As for their age, almost half of the firms are over 30 years old; in this case, the proportion of younger firms is higher in the southern and central regions of the country. Almost 70% of SMEs do not invest in R&D and only 5% of them have invested more than 15% of their turnover in innovation. Further, these results likely show different distributions among regions: innovative SMEs seem to be generally more concentrated in the northern regions of the country. In contrast, by looking at the best innovators in terms of the percentage of turnover invested in R&D (more than 15%), there is no significant difference between firms in terms of geographical distribution. The fourth considered variable concerns the knowledge of the manager of the CO_2 price in the EU ETS market during the conduction of the survey. In Table 3, also small differences among regions occur, and the northern ones display the best results. This finding could be explained by the paucity of heavy pollutant industries in southern regions with respect to northern Italy, which translates into a minor number of southern firms regulated by the EU-ETS framework. The last information is whether firms have benefitted from the *Piano Industria 4.0* to introduce technological innovation in the 2017-2018 period. As previously discussed, this form of public intervention represents one of the most important national regulatory tools, aimed to incentivize innovation in Italian firms. Almost 20% of total SMEs have already used it: north-eastern regions show the highest score while the southern regions are at the bottom of the ranking. The disparities between northern and southern Italy can also be traced to the export activity of enterprises. Finally, there is binary information on whether the firm adopted at least one CE-related innovation in the 2017-2018 period: almost 44% of the interviewed SMEs answered positively without large differences among regions.

In the present study, the eco-innovation output of SMEs is proxied by the scope of CE innovations

Table 1. NUTS 1/NUTS 2-level overview of firms

Region	Frequency	Percent
North-West	**1,428**	**35.3%**
Lombardia	1,068	26.4%
Piemonte	301	7.4%
Liguria	51	1.3%
Valle d'Aosta	8	0.2%
North-East	**1,344**	**33.3%**
Emilia-Romagna	559	13.8%
Friuli-Venezia Giulia	127	3.1%
Veneto	581	14.4%
Trentino-Alto Adige	77	1.9%
Centre	**715**	**17.7%**
Toscana	337	8.3%
Marche	223	5.5%
Lazio	94	2.3%
Umbria	61	1.5%
South&Islands	**555**	**13.7%**
Campania	162	4.0%
Puglia	157	3.9%
Sicilia	72	1.8%
Abruzzo	63	1.6%
Sardegna	53	1.3%
Calabria	23	0.6%
Basilicata	16	0.4%
Molise	9	0.2%
TOTAL	**4,042**	**100.0%**

Source: elaboration from CERCIS database

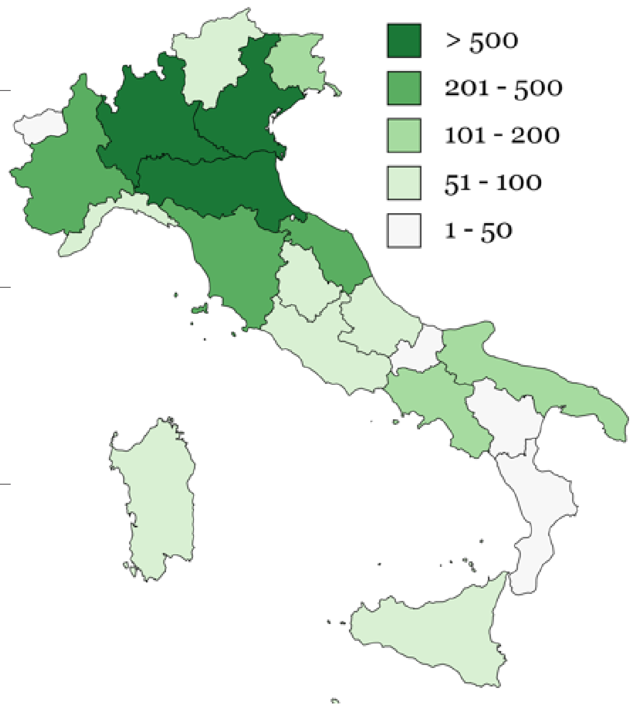

Table 2. Sector of activity of firms

NACE	Description	Frequency	Percentage
10	Food products	364	9.0%
11	Beverages	27	0.7%
12	Tobacco products	1	0.0%
13	Textiles	159	3.9%
14	Wearing apparel	196	4.8%
15	Leather and related products	173	4.3%
16	Wood products and cork, except furniture; articles of straw and plaiting materials	153	3.8%
17	Paper and paper products	78	1.9%
18	Printing and reproduction of recorded media	114	2.8%
19	Coke and refined petroleum products	5	0.1%
20	Chemicals and chemical products	82	2.0%
21	Pharmaceutical products and pharmaceutical preparations	17	0.4%
22	Rubber and plastic products	264	6.5%
23	Non-metallic mineral products	146	3.6%
24	Basic metals	69	1.7%
25	Fabricated metal products, except machinery and equipment	942	23.3%
26	Computer, electronic and optical products	108	2.7%
27	Electrical equipment	166	4.1%
28	Machinery and equipment n.e.c.	471	11.7%
29	Motor vehicles, trailers and semi-trailers	47	1.2%
30	Other transport equipment	49	1.2%
31	Furniture	157	3.9%
32	Other manufacturing	99	2.4%
33	Repair and installation of machinery and equipment	155	3.8%
TOTAL		**4,042**	**100.0%**

Source: elaboration from CERCIS database

adopted by firms. These CE practices are defined in ten categories by the survey. Table 4 shows the categories and the distribution of those firms which have introduced at least one of the CE innovations in their production processes, related to one of the above-mentioned practices. There are some clear differences in the rate of adoption for different categories. More than one in five firms introduced an innovation aimed to reduce the energy use (4) of its activity. Also, innovation aimed to reduce waste (5) and material use (2) appears to be the most popular action in favor of a transition to a CE among SMEs. Group (7) also shows interesting results: the transfer of waste to other companies has the fourth highest proportion of adopters out of the total number of firms. In contrast, the CE innovation related to water efficiency (1), greenhouse gas emissions (10) and product design improvements (8, 9) show the lowest proportion of adoption rates.

Variables

Two sets of variables have been selected from the CERCIS database: the number and typologies of CE activities implemented by SMEs, and the profiling variables. Table 5 gives an overview of them with the related descriptive statistics. The survey does not contain a definition of CE but the firms are asked to report the number of sustainable actions adopted related to the ten categories previously discussed in the 2017-2018 period.

The dependent variables are precisely linked to these data. The study performs two types of

Table 3. Overall characterisation of the sample (%)

	Total sample	North-West	North-East	Centre	South&Islands
Number of employees					
10 to 49 employees	86.0%	83.3%	85.4%	89.5%	90%
50 to 250 employees	12.3%	15.0%	12.2%	9.4%	9.7%
250+ employees	1.7%	1.7%	2.4%	1.2%	0.3%
Years from foundation					
Less than 5 years	4.8%	3.4%	5.2%	6.3%	5.0%
Between 5 and 14 years	19.5%	14.7%	17.8%	25.2%	31.8%
Between 14 and 25 years	18.7%	16.1%	18.5%	20.9%	24.6%
More than 25 years	57.0%	65.8%	58.6%	47.6%	38.6%
Firm's turnover in 2017 invested in R&D (%)					
0%	67.7%	66.1%	65.6%	69.7%	77.6%
From 0.1% to 4.9%	15.7%	18.2%	16.1%	13.7%	9.0%
From 5% to 9.9%	7.0%	7.0%	7.7%	6.6%	4.7%
From 10 to 14.9%	4.7%	4.1%	5.5%	5.1%	3.4%
15% or more	4.9%	4.6%	5.1%	5.0%	5.3%
The manager knows the current price of CO_2	5.2%	5.8%	5.4%	4.4%	4.0%
Adopted at least one CE related innovation in the 2017-2018 period	43.7%	43.2%	44.9%	38.04%	40.5%
The company has introduced technological innovations by exploiting the opportunities of the Piano Industria 4.0 in the 2017-2018 period	21.0%	20.6%	26.3%	16.9%	11.8%
Exporting firm	49.3%	56.6%	50.1%	42.1%	34.0%

Source: elaboration from CERCIS database

Table 4. Distribution of innovative firms among CE innovation categories

Type of CE innovation	Number of innovators	Share of innovators on total firms
1) Reduction of water use	345	8.5%
2) Reduction of material use	735	18.2%
3) Use of renewable energy	543	13.4%
4) Reduction of energy use	943	23.3%
5) Reduction of waste emitted	789	19.5%
6) Reuse of waste	482	11.9%
7) Transfer of waste to other companies	667	16.5%
8) Change in product design to minimize the use of raw materials (including energy)	421	10.4%
9) Change in product design to maximize their recyclability	333	8.2%
10) Reduction of greenhouse gas emissions	319	7.9%

Source: elaboration from CERCIS database

Table 5. Main variable statistics

Variable	N.	Mean	Std. dev.	Min	Max
CE_COUNT	4,042	2.03	3.79	0	35
WATER	4,042	0.10	0.36	0	5
RAWMATERIAL	4,042	0.28	0.96	0	25
RENENERGY	4,042	0.17	0.79	0	30
ENERGY	4,042	0.32	0.81	0	20
WASTE	4,042	0.26	0.94	0	12
REUSEWASTE	4,042	0.17	0.72	0	20
TRANSFERWASTE	4,042	0.24	0.94	0	30
DESIGNINPUT	4,042	0.20	0.86	0	12
DESIGNREC	4,042	0.17	0.89	0	20
REDUCTIONCO2	4,042	0.11	0.50	0	14
GREENMANAGER	4,042	0.05	0.22	0	1
YEARS	4,042	31.89	21.33	1	222
ReD	4,042	0.63	1.11	0	4
SIZE	4,042	1.15	0.41	1	3
INDUSTRIA4	4,042	0.21	0.41	0	1
EXPORT	4,042	0.49	0.50	0	1

Source: elaboration from CERCIS database

regressions, which make different uses of the information on the CE practices provided by the database.

In the first one, CE_COUNT is the dependent count variable, which takes into consideration the total number of CE innovations adopted by firms on the total of ten categories of the survey. It gives a general perspective on the drivers and scopes of the CE practices of the sample. The related equation (1) is:

CE_COUNT (Y) = GREENMANAGER (β1) + YEARS (β2) + SIZE (β3) + ReD (β4) + INDUSTRIA4 (β5) + EXPORT (β6) + Rd + Sd + ε (1)

Where GREENMANAGER is a dummy variable enabling to analyze whether the manager's knowledge of environmental topics (proxied by the knowledge of the CO_2 price) influences the adoption of CE innovations by SMEs. YEARS obviously refers to the years from the foundation and SIZE refers to the number of employees of the firm (small = 10 – 49 / medium = 50 – 250 / big = more than 250). ReD refers to the percentage of turnover invested in ReD in 2017 and INDUSTRIA4 refers to whether the firm benefitted from the *Piano Industria 4.0* in the 2017-2018 period. EXPORT is another dummy variable that indicates whether the firm is an exporting firm. In order to control for geographical and sectoral heterogeneity, this baseline classification is increased by the full set of regional (Rd) and sectoral dummy (Sd) variables.

The second regression model employs a set of dependent variables that reflects the different CE practices. The same regression equation (1) is used by treating each category of CE innovation (Table 4) as an individual dependent variable. Thus, it is possible to analyze the potential differences between different types of CE innovations.

The explanatory variables shown in equation (1) are directly linked to the potential drivers of the adoption of CE innovations in SMEs described in the literature.

The technological input is proxied by the variable ReD, which refers to the percentage of turnover invested in R&D in 2017. There are several variables related to the internal characteristics of firms such as YEARS for years from foundation, SIZE to discriminate between small, medium, and big firms, and the dichotomous variables EXPORT and GREENMANAGER that equates 1 if the interviewed manager of the SME knew the exact CO_2 price in the EU-ETS market. The third type of variable is linked to environmental regulation. The problem in dealing with the regulatory push-pull effect, in this case, is that country-level indicators would entail the loss of much of the heterogeneity due to sub-national measures (Mazzanti *et al.* 2016) while good proxies for more regional-level information are hard to find (Albrizio *et al.* 2017). Thus, the strategy consists in using a combination between the country-level variable INDUSTRIA4 and the full set of regional (NUTS 2 level) dummy variables. The first variable carries information on whether the firm has benefitted from the main industrial policy tool available in Italy to introduce some forms of innovation into its activity; the regional dummy variables are used inasmuch most of the environmental regulations occur at this level of analysis or above (Ghisetti and Montresor 2020). They are therefore able to capture the heterogeneity of regional environmental policies. There is a lack of information related to market characteristics, except for the control variables concerning the sector of activity of SMEs and affiliated region. Ghisetti and Montresor (2020) employed data related to the past economic performance of firms to proxy for market fluctuations, finding no significative effects with the adoption of CE practices. This suggests that the crucial role recognized by the non-academic literature for the market demand and the consumer preferences/habits in driving the CE (Ellen Mac Arthur Foundation 2015), could pass through a more articulated kind of proxy rather than through simply increasing the company's turnover.

Table 6 shows the Spearmen correlation matrix for all the variables, from which no problems of multi-collinearity are expected. Moreover, the VIF calculation, whose results are presented in the regression tables (Section 3), makes it possible to rule out multicollinearity issues.

3. Results

All the different dependent variables employed in the analysis have a count-based nature. When count data are used, instead of binary or multivariate discrete factors that are managed by logit and probit models, the literature suggests using Poisson or Negative Binomial (NBM) models[7] (Cameron and Trivedi 2013). The results were tested using statistical tests such as AIC and BIC calculation to compare the performances of the models, finding a better fit in the case of NBM[8]. Thus, the tables here presented are elaborated using this regression model[9].

The first regression table refers to the firm's ability to extend its portfolio of CE innovations to all the ten CE dimensions indicated by the survey. Table 7 shows the results of the regression.

As shown, all the explanatory variables have a positive significance value (p-value < 0.05) except for years from the foundation. In contrast to Ghisetti and Montresor (2020), the age of the firm did not exhibit significant results in explaining the adoption of CE practices by SMEs. As expected, the manager's knowledge of environmental topics, the use of *Piano Industria 4.0*, exporting activity, the percentage of turnover invested in R&D and the size of the firm are factors correlated to more circular business

Table 6. Spearman correlation matrix

	CE_COUNT	GREEN~ER	YEARS	ReD	SIZE	IND~4	EXPORT
CE_COUNT	1.0000						
GREENMANAGER	-0.0769	1.0000					
YEARS	0.0823	-0.0463	1.0000				
ReD	0.2374	-0.0610	0.0210	1.0000			
SIZE	0.1477	0.0097	0.1742	0.1476	1.0000		
INDUSTRIA4	0.1686	-0.0222	0.0924	0.1745	0.1447	1.0000	
EXPORT	0.1356	-0.0010	0.1983	0.2459	0.2305	0.1462	1.0000

Source: elaboration from CERCIS database

7 Count outcomes are discrete and violate basic assumption of OLS – the outcomes are not continuous. In addition, the residuals may not have a bell-shaped distribution.

8 In general, smaller is better: given two models, the one with the smaller AIC fits the data better than the one with the larger AIC. As with the AIC, a smaller BIC indicates a better-fitting model.

9 The regression results obtained with the Poisson and OLS models are present in the appendix.

Table 7. First model: NBM regression results on CE_COUNT

	Total number of CE innovations adopted in the 2017-2018 period		
	Estimate	**S.E.**	**p-value**
Manager's knowledge of CO_2 price	0.258*	0.134	0.054
Years from foundation	0.002	0.001	0.225
Number of employees (full time equivalent)			
10 to 49 employees (ref.)			
50 to 250 employees	0.167*	0.093	0.072
More than 250 employees	0.474**	0.230	0.040
Firm's turnover in 2016 invested in R&D (%)			
0% (ref.)			
0.1% to 4.9%	0.730***	0.086	< 0.001
5% to 9.9%	0.791***	0.117	< 0.001
10 to 14.9 %	0.860***	0.135	< 0.001
More than 15%	0.869***	0.136	< 0.001
Benefitted from Industria 4.0	0.423***	0.075	< 0.001
Exporting firm	0.122*	0.068	0.072
Sectoral dummy		Y	
Regional dummy		Y	
VIF		2.26	

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01.
Source: elaboration from CERCIS database

Table 8. Second model: NBM regression results for (1), (2), (3), (4), (5)

	Water efficiency (1)	Reduction of material use (2)	Renewable energy (3)	Reduction of energy use (4)	Reduction of waste (5)
Manager's knowledge of CO_2 price	0.301	0.325** (0.162)	0.119	0.337*** (0.128)	0.434*** (0.140)
Years from foundation	0.004* (0.002)	0.001	0.011*** (0.002)	0.001	0.001
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	0.457*** (0.143)	0.409*** (0.113)	0.255* (0.131)	0.154	0.028
More than 250 employees	0.936*** (0.287)	0.470* (0.256)	0.507* (0.278)	0.728*** (0.193)	0.380* (0.230)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.810*** (0.142)	0.865*** (0.109)	0.410*** (0.129)	0.678*** (0.090)	0.921*** (0.099)
5% to 9.9%	0.754*** (0.191)	0.911*** (0.141)	0.473*** (0.168)	0.815*** (0.114)	0.897*** (0.130)
10 to 14.9 %	0.912*** (0.214)	1.080*** (0.160)	0.528*** (0.194)	0.424*** (0.148)	0.911*** (0.153)
More than 15%	0.337	1.354*** (0.153)	0.536*** (0.194)	0.437*** (0.147)	0.961*** (0.147)
Benefitted from Industria 4.0	0.197	0.580*** (0.093)	0.596*** (0.106)	0.494*** (0.076)	0.304*** (0.087)
Exporting firm	-0.138	0.110	0.137	0.026	-0.028
Sectoral dummy			Y		
Regional dummy			Y		
VIF			1.03		

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01. Standard errors are presented in () only for significant estimates.
Source: elaboration from CERCIS database

models. However, the low significance level of some estimators, together whit the heterogeneous nature of circular economy innovation, motivates a more detailed analysis.

To analyse the effects for the specific CE categories we introduce the second type of regression. As stated, the study now considers the scope of the portfolio of CE innovations of firms moving, in this second case, from general to specific groups of CE innovations. The same regression model is performed by taking each category of CE innovations as an individual dependent variable. Tables 8 and 9 show the estimated results of this second regression model.

Firstly, the manager's knowledge of the CO_2 price seems to not have an impact on circular practices related to the introduction of water efficiency measures, renewable energy sources, design improvements to maximize the recyclability of products and the reuse and transfer of waste. While it exhibits the best results in terms of practices related to the reduction of CO_2 emission and, in general, the reduction of inputs into the production processes.

The age of the firm shows significant and positive effects only in the case of the adoption of renewable energy sources and, to a negligible extent, water efficiency measures. Older firms are more prone to change their energy consumption mix towards a more renewable one, but they do not differ from younger firms in other CE types of practices. Nevertheless, the coefficient for this variable is low (0.011), indicating a relatively small correlation evidence for what concerns renewable energy adoption.

The size of firms, proxied by the number of full-time employees, shows some interesting effects. The associated variable exhibits significant, positive, and linear effects only in relation to water efficiency, reduction of input material, renewable energy, and reduction of CO_2 emission. Moreover, only firms with more than 250 employees seem to exploit their scale benefits in the realms of material and energy use, and new designs of products to maximize

Table 9. Second model: NBM regression results for (6), (7), (8), (9), (10)

	Reuse of waste (6)	Transfer of waste to other companies (7)	Product design to minimize inputs (8)	Product design to maximize recyclability (9)	Reduction of CO_2 emission (10)
Manager's knowledge of CO_2 price	0.004	-0.028	0.433* (0.241)	-0.313	0.603*** (0.232)
Years from foundation	< 0.001	0.003	0.001	< 0.001	0.004
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	-0.105	0.136	0.107	0.416	0.363** (0.176)
More than 250 employees	0.513	0.311	-0.111	0.528* (0.311)	1.031*** (0.350)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.625*** (0.142)	0.330*** (0.123)	1.201*** (0.160)	0.925*** (0.195)	0.876*** (0.172)
5% to 9.9%	0.767*** (0.188)	0.176	1.322*** (0.208)	1.019*** (0.246)	1.097*** (0.212)
10 to 14.9 %	0.626*** (0.224)	0.342* (0.195)	1.585*** (0.231)	1.693*** (0.276)	0.966*** (0.255)
More than 15%	0.718*** (0.216)	0.384*** (0.193)	1.797*** (0.225)	1.236*** (0.289)	0.828*** (0.261)
Benefitted from Industria 4.0	0.300*** (0.123)	0.250** (0.106)	0.262*** (0.143)	0.548*** (0.167)	0.504*** (0.145)
Exporting Firm	0.177	0.031	0.502*** (0.139)	0.404*** (0.159)	-0.081
Sectoral dummy			Y		
Regional dummy			Y		
VIF			2.26		

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01. Standard errors are represented in brackets only for significant estimates.
Source: elaboration from CERCIS database

recyclability. The firm dimension does not play a role in explaining the adoption of practices concerning improvements in product design to minimize inputs and reuse or transfer of waste.

As expected, the technological variable represented by the percentage of turnover invested in R&D in 2017 has positive and significant effects on all the CE practices. Effects that appear to be highly heterogenous. In particular, the innovative efforts of firms are strongly and linearly correlated with a higher scope of CE innovations in the cases of product design to minimize inputs, the introduction of renewable energy and reduction of material use, and waste produced.

Finally, the use of incentives provided by the *Piano Industria 4.0* in the 2017-2018 period, seems to have positive and significant effects for all the typologies of CE innovations, except for improvements in water efficiency measures. The variable shows the highest results for the reduction of material and energy, adoption of renewable electricity, and improvements in product design practices. As shown, when passing from general to specific typologies of CE innovations, the explanatory variables exhibit heterogeneous effects.

Conclusion

Despite the recent efforts of the European community aimed to drive our economies towards a more circular framework, there are still too few studies trying to empirically assess the drivers behind this transition. This is especially true in the case of small and medium enterprises, which represent the backbone of the European economy in terms of employment and the environmental footprint of the continent.

The present study tried to fill this gap by providing two original elements to this research field. The first element was the use of a national database containing information on 4,042 SMEs, provided by the research institute CERCIS. This aspect is particularly important for the analysis of drivers for CE innovation since, as highlighted in the literature, the country of origin (and the related legal context, environmental culture, and social aspects) represents one of the main variables explaining the adoption of CE innovations by SMEs (Rizos *et al.* 2016; Zamfir *et al.* 2017; Katz-Gerro and López Sintas 2019; Bassi and Dias 2019). The second original element of the present study was directly related to the different CE practices presented in the survey, ranging from the reduction of different inputs into production processes to choices related to the management and the reduction of waste and CO_2 emissions, to the redesign of products to minimize the use of materials and maximize their recyclability.

It is important to bear in mind that, since this is a cross-sectional data study, no direct causal links can be drawn from the results of the estimation strategy. The analysis covers factors that are correlated with CE innovations adoption in Italian SMEs, but the reason for and study of these correlations remain openly questionable.

The independent variables of the analysis, based on the discussed literature review, partly followed the expectations showing several interesting points in terms of policy implications. In the case of Italian SMEs, the size of the firm did not follow a linear relation with the scope of the portfolio of CE innovations. In all the ten CE dimensions analysed, medium firms (50-250 employees) were able to exploit their scale benefits in the case of water efficiency, renewable energy and reduction of material used and CO_2 emissions. While it is significant that no size effect is traceable in the adoption of practices related to the reuse or transfer of waste. This may suggest that the small size of enterprises, which strongly characterizes the Italian economy, is not an obstacle to the development of waste markets and, in general, to the adoption of reuse practices which treat waste as new production inputs.

Environmentally conscious managers seemed to be more engaged in introducing CE innovations on the reduction of production inputs like raw materials, energy, and water, and on the reduction of waste and CO_2 emitted. Nevertheless, this element had no effects in cases of renewable energy, reuse, or transfer of waste to other companies or for activities related to the redesign of products to maximize recyclability. In this case, it is necessary to highlight *the big elephant in the room*. Of course, a variable able to measure the management's environmental awareness is hard to find and, therefore, the use of the managerial knowledge of the CO_2 price may represent a distorted proxy. This choice is partly justified by the fact that, during the survey period, the price of the EU carbon permits was below €

20 per ton, a level considered to be ineffective in altering the incentives of reducing carbon emissions for European firms. The idea is that managerial knowledge of the early stages of the CO_2 market may proxy the managerial commitment to environmental topics. This, of course, may not be the case for all the firms interviewed.

For the discussion on whether the age of the firm could be considered a positive determinant for the adoption of CE innovations, the results disagree with Ghisetti and Montresor (2020) and suggest that age did not play a central role in Italian firms. In the analysis presented, the years from the foundation of a firm favored only CE practices related to the introduction of renewable energy sources and water efficiency measures, with very low coefficients.

Innovative efforts of SMEs, proxied by the percentage of turnover invested in R&D in 2017 were found to be, as expected, strong and positive predictors of the adoption of CE innovations, especially in the case of new circular design for products able to reduce material demand and increase recyclability.

The internationalisation of Italian companies is also highly correlated with product design innovations, but not with other types of CE practices.

Finally, the analysis of the effects of the main industrial policy tool of the Italian legislation, aimed to introduce innovations in SMEs of the peninsula, gave interesting results. The use of the incentives of the *Piano Industria 4.0* had strong and positive effects on all the CE dimensions, except for water efficiency innovations. In particular, the use of this industrial policy tool had the best results in the cases of reduction of raw materials and energy inputs into the production processes and reduction of CO_2 emission. In accordance with Di Maria *et al.* (2018), the most relevant technologies introduced by these SMEs seemed to concern the ability to measure and monitor the use of production inputs by using big data/cloud-related technologies. Industry 4.0 innovations have allowed the traceability of the supply chain and/or consumption and ultimately led to a reduction of the number of materials/inputs used.

Nevertheless, there are still several limitations in the presented analysis. First, the study does not consider indicators related to the market characteristics and consumer preferences, indicated in the literature as determinants for the adoption of CE innovations in SMEs. It would be interesting to compare the information given by the used data with regional information on consumer preferences towards the circular economy. Second, apart from the use of *Piano Industria 4.0*, there is no information on the other regulatory push-pull effects of the Italian regions. The definition of a regional indicator of environmental stringency surely represents an interesting point for future research.

Appendix

Table 7A. First model: OLS regression results on CE_COUNT

	Total number of CE innovations adopted in the 2017-2018 period		
	Estimate	**S.E.**	**p-value**
Manager's knowledge of CO_2 price	0.567**	0.259	0.028
Years from foundation	0.006**	0.002	0.017
Number of employees (full time equivalent)			
10 to 49 employees (ref.)			
50 to 250 employees	0.492***	0.093	0.007
More than 250 employees	1.726***	0.230	< 0.001
Firm's turnover in 2016 invested in R&D (%)			
0% (ref.)			
0.1% to 4.9%	1.582***	0.170	< 0.001
5% to 9.9%	1.745***	0.233	< 0.001
10 to 14.9 %	2.093***	0.274	< 0.001
More than 15%	2.162***	0.268	< 0.001
Benefitted from Industria 4.0	0.950***	0.146	< 0.001
Exporting firm	0.142	0.128	0.267
Sectoral dummy		Y	
Regional dummy		Y	
VIF		2.26	

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01.
Source: elaboration from CERCIS database

Table 7B. First model: Poisson regression results on CE_COUNT

	Total number of CE innovations adopted in the 2017-2018 period		
	Estimate	**S.E.**	**p-value**
Manager's knowledge of CO_2 price	0.176***	0.042	< 0.001
Years from foundation	0.002	0.001	< 0.001
Number of employees (full time equivalent)			
10 to 49 employees (ref.)			
50 to 250 employees	0.176***	0.030	< 0.001
More than 250 employees	0.395***	0.060	< 0.001
Firm's turnover in 2016 invested in R&D (%)			
0% (ref.)			
0.1% to 4.9%	0.724***	0.030	< 0.001
5% to 9.9%	0.788***	0.038	< 0.001
10 to 14.9 %	0.880***	0.043	< 0.001
More than 15%	0.929***	0.042	< 0.001
Benefitted from Industria 4.0	0.375***	0.025	< 0.001
Exporting firm	0.102***	0.026	< 0.001
Sectoral dummy		Y	
Regional dummy		Y	
VIF		2.26	

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01.
Source: elaboration from CERCIS database

Table 8A. Second model: OLS regression results for (1), (2), (3), (4), (5)

	Water efficiency (1)	Reduction of material use (2)	Renewable energy (3)	Reduction of energy use (4)	Reduction of waste (5)
Manager's knowledge of CO_2 price	0.053** (0.026)	0.082	0.031	0.147*** (0.057)	0.165*** (0.050)
Years from foundation	0.001** (0.001)	0.001	0.002*** (0.001)	0.001	0.001
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	0.068*** (0.017)	0.181*** (0.048)	0.059	0.071* (0.040)	0.007
More than 250 employees	0.166*** (0.044)	0.197* (0.119)	0.192* (0.099)	0.496*** (0.099)	0.163* (0.088)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.094*** (0.016)	0.240*** (0.045)	0.068*** (0.037)	0.246*** (0.037)	0.265*** (0.033)
5% to 9.9%	0.078*** (0.023)	0.247*** (0.061)	0.077	0.331*** (0.051)	0.252*** (0.045)
10 to 14.9 %	0.100*** (0.027)	0.413*** (0.072)	0.103* (0.060)	0.114* (0.060)	0.259*** (0.053)
More than 15%	0.027	0.471*** (0.071)	0.122** (0.059)	0.128** (0.058)	0.292*** (0.052)
Benefitted from Industria 4.0	0.026* (0.014)	0.212*** (0.038)	0.123*** (0.032)	0.193*** (0.032)	0.097*** (0.028)
Exporting firm	-0.017	0.021	0.017	-0.004	-0.014
Sectoral dummy			Y		
Regional dummy			Y		
VIF			1.03		

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01. Standard errors are presented in () only for significant estimates.
Source: elaboration from CERCIS database

Table 8B. Second model: Poisson regression results for (1), (2), (3), (4), (5)

	Water efficiency (1)	Reduction of material use (2)	Renewable energy (3)	Reduction of energy use (4)	Reduction of waste (5)
Manager's knowledge of CO_2 price	0.285	0.209** (0.111)	0.124	0.309*** (0.010)	0.409*** (0.109)
Years from foundation	0.004** (0.002)	0.001	0.010*** (0.001)	0.002	0.001
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	0.485*** (0.132)	0.438*** (0.077)	0.254** (0.106)	0.160** (0.078)	0.028
More than 250 employees	0.980*** (0.248)	0.303* (0.161)	0.518*** (0.201)	0.673*** (0.136)	0.380* (0.230)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.811*** (0.132)	0.838*** (0.082)	0.388*** (0.107)	0.675*** (0.074)	0.916*** (0.083)
5% to 9.9%	0.755*** (0.174)	0.868*** (0.103)	0.449*** (0.139)	0.824*** (0.090)	0.893*** (0.107)
10 to 14.9 %	0.898*** (0.195)	1.158*** (0.108)	0.547*** (0.157)	0.407*** (0.124)	0.920*** (0.123)
More than 15%	0.374	1.320*** (0.104)	0.650*** (0.153)	0.441*** (0.122)	0.995*** (0.118)
Benefitted from Industria 4.0	0.197* (0117)	0.559*** (0.093)	0.611*** (0.087)	0.479*** (0.062)	0.302*** (0.071)
Exporting firm	-0.153	0.136* (0.72)	0.110	0.016	-0.036
Sectoral dummy			Y		
Regional dummy			Y		
VIF			1.03		

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01. Standard errors are presented in () only for significant estimates.
Source: elaboration from CERCIS database

Table 9A. Second model: OLS regression results for (6), (7), (8), (9), (10)

	Reuse of waste (6)	Transfer of waste to other companies (7)	Product design to minimize inputs (8)	Product design to maximize recyclability (9)	Reduction of CO_2 emission (10)
Manager's knowledge of CO_2 price	0.001	-0.005	0.083	-0.090	0.100*** (0.036)
Years from foundation	< 0.001	0.001	0.001	0.001	0.001
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	-0.015	0.001	0.035	0.412	0.363** (0.176)
More than 250 employees	0.196** (0.197)	0.091	0.051	-0.114	1.031*** (0.350)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.111*** (0.034)	0.090** (0.044)	0.230*** (0.040)	0.131*** (0.042)	0.105*** (0.024)
5% to 9.9%	0.142*** (0.046)	0.365	0.247*** (0.055)	0.200*** (0.058)	0.133** (0.032)
10 to 14.9 %	0.109** (0.055)	0.107	0.337*** (0.065)	0.436*** (0.068)	0.114*** (0.038)
More than 15%	0.165*** (0.054)	0.150** (0.070)	0.490*** (0.063)	0.237*** (0.066)	0.081** (0.037)
Benefitted from Industria 4.0	0.051* (0.029)	0.047	0.043	0.093*** (0.036)	0.066*** (0.020)
Exporting Firm	0.025	-0.002	0.078*** (0.030)	0.051	-0.011
Sectoral dummy			Y		
Regional dummy			Y		
VIF			2.26		

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01. Standard errors are represented in brackets only for significant estimates.
Source: elaboration from CERCIS database

Table 9B. Second model: Poisson regression results for (6), (7), (8), (9), (10)

	Reuse of waste (6)	Transfer of waste to other companies (7)	Product design to minimize inputs (8)	Product design to maximize recyclability (9)	Reduction of CO_2 emission (10)
Manager's knowledge of CO_2 price	-0.038	-0.082	0.273** (0.126)	-0.516* (0.186)	0.544*** (0.232)
Years from foundation	< 0.001	0.004*** (0.001)	0.001	0.004** (0.002)	0.004**
Number of employees (full time equivalent)					
10 to 49 employees (ref.)					
50 to 250 employees	-0.101	-0.020	0.123	0.106	0.323** (0.130)
More than 250 employees	0.568*** (0.205)	0.207	-0.006	-0.614** (0.298)	0.990*** (0.208)
Firm's turnover in 2016 invested in R&D (%)					
0% (ref.)					
0.1% to 4.9%	0.611*** (0.105)	0.347*** (0.090)	1.166*** (0.099)	0.925*** (0.195)	0.904*** (0.131)
5% to 9.9%	0.771*** (0.133)	0.164	1.212*** (0.120)	1.019*** (0.246)	1.052*** (0.158)
10 to 14.9 %	0.581*** (0.158)	0.406* (0.138)	1.388*** (0.127)	1.693*** (0.276)	0.955*** (0.187)
More than 15%	0.857*** (0.148)	0.534*** (0.131)	1.748*** (0.118)	1.236*** (0.289)	0.814*** (0.215)
Benefitted from Industria 4.0	0.263*** (0.089)	0.172** (0.077)	0.143* (0.079)	0.442*** (0.088)	0.444*** (0.108)
Exporting Firm	0.178** (0.089)	0.002	0.485*** (0.090)	0.384*** (0.093)	-0.106
Sectoral dummy			Y		
Regional dummy			Y		
VIF			2.26		

*p-value < 0.10, **p-value < 0.05, ***p-value < 0.01. Standard errors are represented in brackets only for significant estimates.
Source: elaboration from CERCIS database

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