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Firms' capabilities management for waste patents in a circular economy

ABSTRACT

Purpose: This study aims to define and measure the capabilities applied by firms to waste-related patents and their relations with the businesses economic performance to support decision-making towards a circular economy (CE).

Methodology: A model of cause-and-effect relationships between firms' waste-related patents and the firm' capabilities was defined within the dynamic capabilities' theoretical framework. Empirical results were obtained by applying partial least squares structural equation modelling to a sample of 2,216 Spanish firms that hold 120,406 patents.

Findings: Findings revealed the importance of the innovation capabilities of firms related to patenting, such as collaborative innovation, persistence in patenting or the capabilities to collaborate with research institutes, as drivers of level of waste patents to improve the businesses economic performance.

Originality: Measuring CE-related patents and the specific capabilities needed for patenting in a circular framework is an understudied topic, and this study opens a specific line of inquiry enhancing the knowledge of CE within the dynamic capabilities' theoretical framework

KEYWORDS: circular economy; waste patents management, collaborative innovation; business performance

1. INTRODUCTION

Despite the initiatives taken by businesses to reduce their environmental impacts, huge amounts of resources are being extracted, and the volume of waste generated by production has increased, which had led to the consequent degradation of ecosystems. Due to this situation, the circular economy (CE) is being promoted as a way to close the flow of materials and resources that is frequently repeated through multiple phases (Yuan *et al.*, 2006). In a CE, waste management is conditioned by the hierarchy of waste with an order of priorities that begins with reduction and continues with the reuse, recycling and recovery of energy until its elimination (Portillo-Tarragona et al., 2017)

The transformation of waste into resources contributes to substituting primary resources for secondary raw materials. A CE offers local alternatives that reduce price and supply risks because the development of local infrastructures is shared between companies (Van Berkel, 2009) through 'cradle to cradle' systems and industrial symbiosis solutions (Daddi *et al.*, 2017; Genovese *et al.*, 2017). In a circular model, the costs of large-scale distribution are optimised, and the environmental impacts of waste decrease (Blomberg and Söderholm, 2011; Fizaine, 2020; International Research Panel, 2019; Sarkis, 2003; Stahel, 2013).

In this scenario, waste reduction and its effective management and recycling require new innovations, and the assumption of risks promotes a transition to a CE (Banaite and Tamosiuniene, 2016; Ghisellini *et al.*, 2016; Sitra, 2016). Thus, a CE will lead to patented innovations that close the material loops and development of circular eco-innovations.

Currently, business eco-innovation, green patents and the CE are, albeit partially, interrelated subjects in the literature (de Jesus *et al.*, 2019; Scarpellini, Valero-

Gil, *et al.*, 2020). However, there is little information on the relations among these three topics of analysis, particularly at a micro level. Some authors assert that eco-innovation contributes differently to the CE because the former is likely driven by diverse factors (Del Río *et al.*, 2017), but the analysis of patenting related to the circular eco-innovation is still under development. In particular, the research at micro level focused on firms' specific capabilities for the CE is still in an incipient stage (Barnabè and Nazir, 2021; Katz Gerro and López Sintas, 2019; Khan *et al.*, 2020; Scarpellini, Marín-Vinuesa, *et al.*, 2020; Scarpellini, Valero-Gil, *et al.*, 2020)

From a CE perspective, firms' resources and capabilities have been partially analysed by academics in the dynamic capabilities' theoretical framework. Some authors focused their studies on exploring capabilities related to organisational changes (Katz Gerro and López Sintas, 2019), enhancing knowledge about how firms address CE opportunities (Khan *et al.*, 2020), defining eco-innovations in a circular model (Scarpellini, Valero-Gil, *et al.*, 2020), or developing specific environmental management accounting procedures (Scarpellini, Marín-Vinuesa, *et al.*, 2020). However, more research is needed on this topic. In fact, the analysis of CE-related patent innovations for waste reduction and recycling is of special interest for companies that are progressively introducing a circular business model (Aranda-Usón *et al.*, 2020). In fact, businesses need to reformulate their specific capabilities in a zero waste scenario that could differ from those capabilities previously applied to eco-innovation or to conventional innovation processes.

Therefore, this study's main objective is to define and measure specific capabilities interrelated with research and development (R&D) resources and waste-related patents (in this study, they are defined as 'waste patents') to support decision-making towards a CE. To the best of our knowledge, no previous studies have explored this line of inquiry, and this paper seeks to fill this gap. In summary, in our study, waste patents are used as an indicator of CE at a micro level in order to define and measure the specific capabilities of firms. In addition, the impact of waste patents on the economic performance of firms is analysed.

To achieve the main research objectives and address the corresponding gap in the literature, a model of the cause-and-effect relationship between firms' waste-related patents and the specific capabilities of companies was defined and measured using partial least squares structural equation modelling (PLS-SEM) and tested in a sample of Spanish companies.

2. BACKGROUND

2.1 Waste patents and the CE

A circular model implies the development of technical innovations related to waste recycling and recovery in both the production process and at the end of a product's life cycle (Coenen *et al.*, 2020), permitiendo crear valor a partir de los residuos . In fact, technological innovations for recycling and waste treatment processes contribute to implementing circular strategies and to decreasing the impacts of material and resource cross-border transfers (Rocchetti *et al.*, 2018). Thus, investment in patents linked to waste recycling and recovery improves the transition to a CE as intangible capital that denotes a company's ability to meet the objectives of a circular model.

Several authors states that patents are a valid indicator for measuring innovation (Chava et al., 2017; Griliches, 1990; Hall et al., 2005; Beaudry and Schiffauerova, 2011). Patents related to recycling and secondary raw materials are used as a proxy indicator for monitoring CE (European Commission, 2018), and previous studies have analysed patent data to explore different waste management and recovery solutions

(Aldieri *et al.*, 2019) achieved through R&D (Vuţă *et al.*, 2018). In fact, these intangible assets can be used to monitor the evolution towards a CE and patents' evolution in the territory due to the transformation of waste into sustainable materials (European Commission, 2015; Malinauskaite and Jouhara, 2019). However, the analysis of waste patents is still in an incipient stage in the business literature, and one of the objectives of this study is to begin to fill this gap. To that end, we propose the first research question:

RQ1) How can waste-related patents be measured in a CE framework?

2.2. Waste patent and performance capabilities

It is not easy to revise the previous literature when analysing the capabilities of firms in terms of the CE since it is a line of inquiry that has not been explored in depth. Thus, the close relationship that the CE has with eco-innovation is considered in our background analysis. Furthermore, in this section, we analyse the main literature focused on the capabilities for patenting eco-innovations and, in particular, the reduced number of studies that have been developed in this topic from a CE perspective. Previous studies focused on eco-innovation capabilities have analysed managerial capabilities (Chang and Chen, 2013; Del Río *et al.*, 2016), managers' key role (Bartlett and Trifilova, 2010; Cameron, 2011; Groves and La Rocca, 2012; Pless and Maak, 2011; Pless, 2007), or the impacts of environmental capabilities on performance (Alvarez Gil *et al.*, 2001; Angell and Klassen, 1999; Hart, 1995; Marín-Vinuesa *et al.*, 2020).

Kesidou & Demirel (2014) demonstrate that the existing capabilities of firms are crucial for generating eco-friendly technologies (Portillo-Tarragona *et al.*, 2018), and environmental R&D investment or internal research activity also facilitates eco-innovation in business (Cruz-Cázares *et al.*, 2013; Ding, 2014; Lee and Min, 2015; Parthasarthy and Hammond, 2002; Triguero *et al.*, 2016). In fact, both aspects have been related to patent registration and ongoing innovation activity (Aragon-Correa and Leyva-de la Hiz, 2016; Doran and Ryan, 2012; Peiró-Signes *et al.*, 2011).

In most of the studies, R&D efforts are considered inputs, rather than outcomes, of innovation (Huang and Cheng, 2015). It is largely accepted that firm-internal R&D activity also guarantees the firm's participation in eco-innovative processes (Cainelli *et al.*, 2015; Cruz-Cázares *et al.*, 2013; Ding, 2014; Lee and Min, 2015; Segarra-Oña *et al.*, 2015; Triguero *et al.*, 2014) and investments in patents (Aragon-Correa and Leyva-de la Hiz, 2016; Segarra-Oña *et al.*, 2015, 2011; Triguero *et al.*, 2016). In addition, continuous engagement in innovation would lead to the regular allocation of resources to these activities (Doran and Ryan, 2014). However, previous contributions only provide fragmented evidence of some of the capabilities for R&D that lead to patented eco-innovation. In fact, specific capabilities applied to green patents are sometimes measured along with resources without a thorough explanation of how they complement one another.

In this topic, the dynamic capability perspective has extended the analysis of the importance of internal resources in generating general and environmental innovations. The dynamic capabilities theoretical framework was proposed in the seminal study by Teece et al. (1997) to analyse a firm's ability to integrate, build, and reconfigure its R&D activity to patenting and then achieve a competitive advantage. In fact, dynamic capabilities capture proactive environmental strategies related to the sustainability of competitive advantages in dynamic environments (Garcés-Ayerbe and Cañón-de-Francia, 2017) and are considered particularly well suited to the study of clean technology (Aragón-Correa and Sharma, 2003) and a CE (Khan *et al.*, 2020).

Regarding the internal knowledge strategy, a remarkable output is the higher internal innovative capabilities of green innovators, as was demonstrated by De Marchi

& Grandinetti (2013). In fact, process innovativeness refers to the capability of a firm to engage in and support new ideas, experimentation, and creativity for the development of new processes (Das and Joshi, 2007; Rodriguez and Wiengarten, 2017).

In summary, capabilities related to eco-innovation are fostering improvements of internal resources to reduce environmental impacts (Lee and Min, 2015) because firms' capabilities of exploring and exploiting new technological opportunities rely on their existing capabilities (Miyazaki, 1995). On this basis, some authors conceptualise eco-innovation as a capability similar to innovation capability (Arranz *et al.*, 2020).

The capability to introduce environmental innovation and environmental management capabilities has been related to green patents in some studies (Delgado-Verde *et al.*, 2014; Fabrizi *et al.*, 2018), and the degree of patent registration is an indicator of technological innovation (Kim and Lee, 2015). However, there is little research about how firms develop their environmental innovativeness capability in a CE; and in the following paragraphs, we analyse different capabilities for patenting in a CE scenario that could be developed by firms.

Technological capabilities have been studied by several authors (Eisenhardt and Martin, 2000; Gabler *et al.*, 2015; Georg *et al.*, 1992; Kemp and Soete, 1992; Obrecht *et al.*, 2021; Teece *et al.*, 1997; Winn and Roome, 1993), and some scholars have highlighted the importance of technological and organisational capabilities in stimulating eco-innovations in firms (Horbach, 2008; Kesidou and Demirel, 2014; Wagner, 2007). In addition, the use of technological capability for the recovery and recycling of resources has highlighted the relevance of these capabilities for closing the material loops (Gitelman *et al.*, 2019).

Huang & Cheng (2015) argue that core technology capabilities may influence the trajectory and speed of innovation, which in turn increases their probability of patenting their innovations. Thus, the capability to develop enhanced patents that cover many patents' codes and involve different technologies shows the best performance in achieving the innovation targets of firms (Kim and Lee, 2015).

It must be taken into account that eco-innovations are generally more complex than other types of innovations because they require scarce knowledge within the firm or even within the industry, entail projects with longer lead times and highly uncertain outcomes, and often require radical or breakthrough changes (Ghisetti and Pontoni, 2015; Rennings, 2000; Rodriguez and Wiengarten, 2017). Previous researches on this topic have demonstrated that stakeholders, suppliers, universities or public research institutions are critical partners that provide knowledge and overcome the complexity and risks of eco-innovation (Bossle *et al.*, 2016; Ghisetti and Pontoni, 2015; Ghisetti and Rennings, 2014; Scarpellini *et al.*, 2012). In fact, green innovators seem to be characterised by more intensive external relationships (Cainelli *et al.*, 2015). Specifically, the results indicate that the knowledge achieved through cooperation with R&D institutes and other suppliers is bundled into process innovativeness capability that is extended through cooperation with research institutions (Rodriguez and Wiengarten, 2017).

The capability to collaborate with external private/public institutions for environmental R&D has been analysed in the eco-innovation literature (Bartlett and Trifilova, 2010; Horbach, 2008; Mylan *et al.*, 2015; Parthasarthy and Hammond, 2002; Portillo-Tarragona *et al.*, 2018; Siebert *et al.*, 2018; Triguero *et al.*, 2013). Ding (2014) highlights the strategic capability of firms to combine external information and knowledge flow with internal knowledge to adapt internal processes accordingly to external circumstances. In this line, different authors argue that the internal R&D base decides the absorptive ability of firms to internalise what has been acquired from external partnership and networking into their innovation capability, and it allows an organisation to align itself with changes in their natural and business environments (Ding, 2014; De Marchi, 2012).

Recently, Cainelli et al. (2020) opened a debate about the role played by R&D in the eco-innovations applied to resource efficiency and the CE after finding that absorptive capacity seems to be irrelevant to sustaining specific typologies of eco-innovation. Collaboration can be considered as a mechanism for the development of the CE as it favours the optimisation of resources (Badhotiya *et al.*, 2021; Kuzma *et al.*, 2021), but it is also an important tool for the value creation from waste (Barnabè and Nazir, 2021). Thus, we explore this line of inquiry in order to analyse the firms' capabilities to collaborate with R&D institutes in a circular scenario because collaborative patenting provides firms with various advantages in terms of market responsiveness, flexible offerings to meet customer demand, the prompt capitalisation of market opportunities, and business synergies. In fact, the number of different inventors involved in eco-innovative activities and patenting has been shown to be an indicator of collaboration in organisations (Petruzzelli *et al.*, 2011; Portillo-Tarragona *et al.*, 2018), and some authors affirm that innovation capability represents the most distinguished collaborative advantage (Ding, 2014). In addition, the number of applicants has also been used in studies of innovation (Kim and Lee, 2015). However, to the best of our knowledge, specific analysis of the collaborative patenting process related to the CE has not been conducted in the existing previous studies.

From a spatial perspective, several authors affirm that broader geographical coverage of a patent could improve its valuation due to the extended protection outside the local market (Caviggioli *et al.*, 2020; EPO, 2018; Tosic, B., Vasilijec, D., Milutinovic, 2012). The geographic coverage of a patent represents its internationalisation, highlights its territorial scope (Caviggioli *et al.*, 2020; Smith and Cordina, 2015) and affects its valuation (Agostini *et al.*, 2015). Therefore, offering a dynamic capability to integrate and combine resources and competencies within the international technology commercialization process is relevant for patenting (Gredel *et al.*, 2012), and firms that conduct either local or distant searches generate an innovative capability (Aaldering *et al.*, 2019; Lopez-Vega *et al.*, 2016).

The protection of a patent for a local market would mean the promotion of innovations in that specific country and the linking of other local requirements for the development of the territory (Marsoof, 2018).

Cainelli et al. (2012) observe that some eco-innovation drivers are fostered by joining local and international factors. Cooperating with local actors is also a relevant driver of patenting (Cainelli *et al.*, 2012), and a large proportion of patents are granted to domestic assignees; therefore, it is likely that innovation patterns are linked with the territory of companies that hold green patents (Kim and Lee, 2015). In addition, the percentage of green patents registered at a national level was used as an indicator by Scarpellini et al. (2019). In a CE context, the promotion of sustainable local development is influenced by local proximity since it helps to reduce costs compared to broader areas (Stahel, 2013). In this way, CE-related innovation would allow establishing a local relationship between innovation and investment and employment (Aranda-Usón *et al.*, 2020; Hysa *et al.*, 2020). Thus, we could argue that the linkage of a company with the territory potentially represents a capability to develop CE-related patents due the local implementation of waste management and recycling activities. However, these aspects of patenting have yet to be specifically analysed in a CE context.

From another perspective, some authors argue that innovation is a cumulative process of skills and capability building that in turn spurs subsequent eco-innovation (Arranz *et al.*, 2020; Chassagnon and Haned, 2015). In fact, the accumulated operating experience in protecting and commercialising uncertain technologies has been considered a relevant factor for patenting (Gredel *et al.*, 2012).

In this line, some eco-innovation studies analyse persistence, such as the role played by human resources-related skills (Aboelmaged, 2018; Antonioli *et al.*, 2013), as a previous innovative capability of companies (Cainelli *et al.*, 2015; Rodriguez and Wiengarten, 2017). In fact, eco-innovation is often built sequentially by product innovation of international leaders through technological appropriation (Scarpellini *et al.*, 2019).

In addition, the coexistence of patented environmental and non-environmental innovations was analysed by Aragon-Correa & Leyva-de la Hiz (2016) who observed internal resources and capabilities overlap for eco-innovation. Thus, we could argue that persistence in eco-innovating could be considered as a capability for firms also in a CE and the potential overlap of capabilities could affect also the CE-related innovations.

In Table I we summarise some of eco-innovation capabilities and the authors that have analysed them in literature. In addition, recent studies focused on the CE related patents and innovation are also classified.

In summary, we can affirm that defining and measuring the specific capabilities of firms for waste patents is understudied in the CE literature. Thus, one of the objectives of this study is to empirically analyse the capabilities applied to R&D activity by firms that hold waste patents. To that end, we propose the second research question, which is as follows:

RQ2) *What are the specific capabilities applied to patenting by firms that hold waste patents?*

Table I. Capabilities related to the eco-innovation and CE patenting and previous literature

Description	*Studies related to eco-innovation or green patents*	*Studies related to CE innovation or waste patents*
Innovation capability	(Arranz et al., 2020; De Marchi and Grandinetti, 2013; Delgado-Verde et al., 2014; Fabrizi et al., 2018; Kim and Lee, 2015; Lee and Min, 2015; Scarpellini et al., 2019)	(Calik and Bardudeen, 2016)
Patents´ scope & Technological capability	(Horbach, 2008; Kesidou and Demirel, 2014; Kim and Lee, 2015; Wagner, 2007)	(Gitelman et al., 2019)
R&D collaboration	(Bartlett and Trifilova, 2010; Bossle et al., 2016; Cainelli et al., 2015; De Marchi, 2012; Ding, 2014; Ghisetti and Pontoni, 2015; Ghisetti and Rennings, 2014; Horbach, 2008; Mylan et al., 2015; Parthasarthy and Hammond, 2002; Portillo-Tarragona et al., 2018; Scarpellini et al., 2012; Triguero et al., 2013)	(Cainelli et al., 2020)
Collaborative application & invention	(Ding, 2014; Petruzzelli et al., 2011; Portillo-Tarragona et al., 2018)	
Territorial linkage International range	(Agostini et al., 2015; Cainelli et al., 2012; Kim and Lee, 2015; Scarpellini et al., 2019)	(Aranda-Usón et al., 2020; Hysa et al., 2020)
Innovation persistence	(Arranz et al., 2020; Cainelli et al., 2015; Chassagnon and Haned, 2015; Kim and Lee, 2015; Rodriguez and Wiengarten, 2017; Scarpellini et al., 2019)	

The nexus of the CE and sustainable business performance is evidence in recent studies (Agrawal *et al.*, 2021; Almagtome *et al.*, 2020; Fonseca *et al.*, 2018) denotes future sustainability that allows optimum utilization of firm' resources (Bag et al., 2021). If we apply a parallelism with eco-innovation within the dynamic capabilities' theoretical framework, we could expect that the specific capabilities of firms will lead to higher levels of waste patents and that they could improve the future profitability of the company. In fact, the environmental benefits derived from waste patents can give a company that is aligned with the CE a competitive advantage that would benefit its economic performance accordingly. Thus, we seek to enhance the empirical knowledge on this topic by studying the relationship between the waste patents owned by companies and their performance. To explore this line of inquiry, we propose the third research question as follows:

RQ3: *What is the influence of the level of waste patents owned by firms and their economic performance?*

3. ANALYSIS AND DATA

3.1. Measurement of the waste patents

Patents have been used by several authors as indicators of innovation (Acs *et al.*, 2002; Chen *et al.*, 2009; Karvonen *et al.*, 2016) and eco-innovation (Amore and Bennedsen, 2016; Brunnermeier and Cohen, 2003; Johnstone *et al.*, 2010; Marín-Vinuesa *et al.*, 2020; Oltra *et al.*, 2010; Scarpellini *et al.*, 2019). Oltra et al. (2010) demonstrated that a patent holder is in a position to set a higher-than-competitive price for the corresponding good or service, which allows them to recover the innovation costs. Moreover, the number of patents is one of the indicators frequently used to measure the results of R&D activity and knowledge transference (Hall, 2010; Hall and Ziedonis, 2001; Konar and Cohen, 2001) and the protection of industrial property (van Dongen *et al.*, 2014).

One of the advantages of using this indicator to measure innovation is that patents can be grouped by different technologies (Lindman and Söderholm, 2016; Rezende *et al.*, 2019) identified by their International Patent Classification (IPC) codes. Thus, due to this and other advantages, in this paper, we use waste-related patents to measure technology innovations aligned with the circular model to answer RQ1.

In our study, waste patents are classified through IPC codes related to innovations for waste management and treatment, the energy valorisation of waste, the use of waste materials and pollution control. We adopt this indicator even though not all innovation materialises in a patent and that depending on the country, the sector or the moment of time that is being considered, the propensity to patent may vary (Griliches, 1990).

Nevertheless, the number of waste patents is considered to be an adequate proxy of circular innovation because it allows one to identify the level of circular innovation of companies in this incipient stage of CE research at the micro level.

For this study, a first bibliographic search was carried out using SCOPUS, crossing the terms of CE and patents in scientific journals until 2020. However, it should be noted that we did not intend to carry out a systematic bibliographic review given the incipient stage of development of the research in this topic, and we opted to deepen the study of the literature starting from the initial general search.

3.2. Sample

The sample includes 2,216 firms located in northeastern Spain, a geographic area with high eco-innovation rates (EOI, 2016). The economic-financial data were collected from the SABI database[1], and the information about the patents held by the firms was obtained through the analysis of the patents registered with the European Patent Office (EPO) and with the Spanish Patent Office.

From an original database of 120,406 patents, we conduct an in-depth process to identify the patents' IPC codes and the main characteristics of each patent. In the first stage, we separate the patents into two groups: waste patents and other nonwaste patents. The group of waste patents includes 1,624 patents (1.35% of total), which are directly related to the recycling and recovery of waste, in line with the proposal of the (European Commission, 2018) that highlights these types of patents as an indicator for monitoring the CE. The waste patents were identified through the IPC codes and are mainly related to waste management, waste treatment, the energy valorisation of waste, the use of waste materials and pollution control. The group of conventional patents (no-waste patents) includes 118,782 patents (98.65% of the total).

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[1] *Sistema de Análisis de Balances Ibéricos* (SABI) [online database]. 2016. Madrid

Within the sample of 2,216 firms, 694 firms (31.32%) hold patents registered in Spain (ES patents) or the European Union (EU), and 1,522 firms (68.68%) do not hold patents. A significant number of firms hold waste patents (134 firms, 19.31%) while 560 firms (80.69%) hold other types of patents. The highest percentage of the sample (80.1%) corresponds to manufacturing firms, followed by firms that operate in the transport and storage sector (13.3%), in the energy sector (3.3%), in water supply and waste management (2.6%), or in mining (0.6%). The Spanish regions selected for this study are Catalonia (60.2% of the sample), Basque Country (22.2%), Aragon (9.9%) and Navarre (7.6%).

Descriptive statistics for the sample of 2,216 firms, and the statistical evidence of the firms that hold or do not hold patents and the firms that hold or do not hold waste patents are provided in Table II.

Table II. Statistic description of the sample

	Total firms		**Firms that hold patents**		**Firms without patents**		**Firms that hold waste patents**		**Firms that hold other patents**	
Legal Structure		firms		firms		firms		firms		firms
Cooperative	2.1%	47	3.3%	23	1.58%	24	6.0%	8	2.7%	15
Public Limited Company	63.1%	1399	66.3%	460	61.70%	939	60.4%	81	67.7%	379
Limited Partnership	0.3%	6	0.7%	5	0.07%	1	2.2%	3	0.4%	2
Limited Company	34.5%	764	29.7%	206	36.66%	558	31.3%	42	29.3%	164
Observations	2216 (100%)		694 (31.32%)		1522 (68.68%)		134 (19.31%)		560 (80.69%)	
Dif. Proportions			*Chi2 Pearson = 23.79; p-value = 0.000*				*Chi2 Pearson = 9.856; p-value = 0.020*			
Sector		firms		firms		firms		firms		firms
Mining	0.6%	13	0.3%	2	0.72%	11	0.0%	0	0.4%	2
Manufacturing	80.1%	1776	90.8%	630	75.30%	1146	84.3%	113	92.3%	517
Energy	3.3%	73	5.3%	37	2.37%	36	11.2%	15	3.9%	22
Water supply	2.6%	58	1.4%	10	3.15%	48	4.5%	6	0.7%	4
Transport and storage	13.4%	296	2.2%	15	18.46%	281	0.0%	0	2.7%	15
Observations	2216 (100%)		694 (31.32%)		1522 (68.68%)		134 (19.31%)		560 (80.69%)	
Dif. Proportions			*Chi2 Pearson = 128.68; p-value = 0.000*				*Chi2 Pearson = 26.162; p-value = 0.000*			
CCAA		firms		firms		firms		firms		firms
Aragon	9.9%	220	12.7%	88	8.67%	132	8.2%	11	13.8%	77
Navarre	7.6%	168	8.9%	62	6.96%	106	9.0%	12	8.9%	50

Basque Country	22.2%	493	22.2%	154	22.27%	339	19.4%	26	22.9%	128
Catalonia	60.2%	1335	56.2%	390	62.09%	945	63.4%	85	54.5%	305
Observations	2216 (100%)		694 (31.32%)		1522 (68.68%)		134 (19.31%)		560 (80.69%)	
Dif. Proportions			*Chi2 Pearson = 12.89; p-value = 0.005*				*Chi2 Pearson = 4.747; p-value = 0.191*			

The percentage of firms that hold patents varies according to firms' legal status, sectors and location. For these variables, the differences found between firms with or without waste patents are statistically significant according to Pearson's $\chi 2$ test. Within the group of 694 firms that hold patents, the percentage of firms that hold waste patents also varies according to firms' legal status, sectors and location.

3.3. Methods and Variables

This study aimed to test if there is a cause-and-effect relationship between the level of waste patents and the economic performance of firms to analyse the capabilities' influence on the level of circularity through waste patents and performance. The CE model defines a specific indicator to identify investments in waste-related patents in a circular model and test if there are significant correlations (cause-effect relationships) between the innovation capabilities of firms related to patenting, such as collaborative innovation, persistence in patenting or the capabilities to collaborate with research institutes, and the level of waste patents.

In the first stage, each specific capabilities of firms that resulted defined within the dynamic capabilities' theoretical framework as a capability linked to CE-related innovations were subjected to an ANOVA analysis that shed some light within of the total sample about the main explanators of the variability of a percentage of firms that hold waste patents, obtaining such a characterisation of these firms. The second stage of the analysis was to execute a PLS-SEM with the constructs and variables identified in the previous stage for those measurements of capabilities applied by firms to waste-related patents and their relationship with the business' performance. Results of this analysis were significant, allowing this study to build the discussion on these two bases: validity analysis for the constructs and path analysis testing the correlation between firms' capabilities related to patenting from a CE perspective, the level of waste patents, and firm' economic performance.

Regarding variables, based on the literature review and the background of this study, we analysed a set of variables defined to measure the capabilities of firms applied to R&D for patenting waste patents (Table III).

Table III. Description of the analysed variables

	Variables
Capabilities	RI = Collaborative inventions (patents with several inventors and the number of inventors) SC = Patents´ scope intensity (percentage of patents that have different IPC codes) RD = Collaborative R&D capability (patents in collaboration with R&D institutes) TL = Territorial linkage (percentage ES patents/total ES+EU patents) IP = Innovation persistence (patents along the time = patents in different five time periods) CP = Collaborative application (percentage of patents with several applicants) TC = Technological capability (patents with various IPCs) IR = International range (EU patents + ES patents)
Waste patents	W1 = Waste patents (total number of waste patents) W2 = Waste patents´ scope intensity (percentage of waste patents with respect to other patents)
Economic performance	EP1 = Return on assets EP2 = Return on equity
Firm size	S1 = Employees (number of employees) S2 = Total Assets (thousand euros) S3 = Total Revenues (thousand euros)
Range of patents	RG = different types of patents (waste patents + green patents+ other patents; green patents + other patents; and only other patents)
Sector	MS = Manufacturing sector

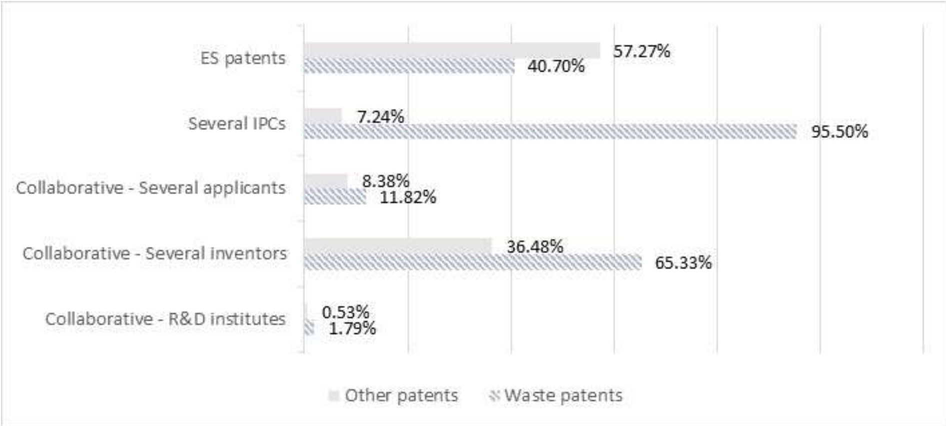
In the first step of our empirical analysis, and to respond to the research question RQ2, we measure the capabilities of those firms that hold waste patents (134 firms) and analyse the main characteristics of their patents in detail.

The innovation persistence measures patents over a time horizon of five periods. The first period is defined as the years before 1986 before Spain entered the EU and the EU Patent Law of 1973 was transposed to Spanish legislation. Periods 2, 3, and 4 defined as 1986-1991, 1992-2000, and 2001-2010, respectively, in concordance with legislative changes introduced to the EU Patent Law. The last period includes the years after 2011 when the green patent classification of the IPC Green Inventory of the United Nations was applied.

The collaborative capability of companies for CE innovation was analysed through the number of patents developed in collaboration with R&D institutes, the volume of patents registered by several inventors and the number of patents with different applicants. Figure 1 summarises the percentage of collaborative patents - waste and other than waste - on the total number of registered patents. The percentage of collaborative waste patents is higher than the percentage of the other collaborative patents in all three variables: in the variable of patents developed in collaboration with R&D institutes (1.79% higher than 0.53%), in the variable of several inventors (65.33% higher than 36.48%), and for patents with several applicants (11.82% higher than 8.38%). These results highlight the capability of firms that hold waste patents of collaborating in patented innovation processes.

The technological capability was analysed through the number of patents with several IPCs, and the territorial linkage of companies was measured using the number of patents registered in Spain. The percentage of patents - waste and other patents - on the total number of registered patents is shown in Figure 1. The percentage of waste patents is higher than the percentage of other patents in the variable of patents with several IPC codes (95.5% higher than 7.2%), but it is lower in the variable of patents registered in Spain (40.7% < 57.3%). In addition, these results observed in Figure 1 show the patents' scope intensity (% of patents with different IPC codes) and the international range capability in the patented-innovation processes.

Figure 1. Analysis of main capabilities of firms related to waste patents



After a preliminary study of firms' capabilities, we performed ANOVA tests to obtain a characterisation of firms that hold waste patents (134 firms of the sample) through the measurement of their capabilities linked to CE-related innovation, thus we compare the capabilities of three firm's groups, those that only hold conventional patents, firms with hold green patents and firms that hold the three types of patents (waste, green and conventional). All these analyses permit us to address research question RQ2.

In a second empirical testings' step, and to test research question RQ3, a PLS-SEM analysis was conducted using the SmartPLS 3.0 statistical software (Ringle *et al.*, 2015). This analysis allows us to test the cause-and-effect relationship between the level of waste patents and firms' economic performance and then analyse the capabilities of firms that influence the level of circularity through waste patents and firms' performance. In addition to the independent variables that measure the capabilities of the company: RI, SC, RD, TL, IP (Table 2), the variables included in the structural model are the following.

- Waste patents (WP) to measure the CE-related innovation of the firms, constructed by two indicators that synthesises patenting intensity and scope. The total number of waste-related patents was measured, and the waste patents' scope intensity in firms was measured through the percentage of waste patents relative to the total number of other patents.

- Economic Performance (EP) generated from two indicators of firm' return: Return on Assets (ROA) and Return on Equity (ROE). Previous studies have used similar constructs for this objective (Hamann, Schiemann, Bellora, & Guenther, 2013; Scarpellini, Valero-Gil, & Portillo-Tarragona, 2016; Caloghirou et al., 2004).

- Control variables. The range of patents (RG) generated from the characterisation of firms, given the ownership of different patents from only conventional patents (other patents) up to green patents in addition to other patents and waste, green and other patents jointly; the firm size (S) measured by number of employees, total revenues and total assets; and the manufacturing sector (MS) as a dichotomous variable (1/0) taking a value of one if firms belong to the manufacturing sector.

4. MAIN RESULTS

4.1. Capabilities of firms with waste patents

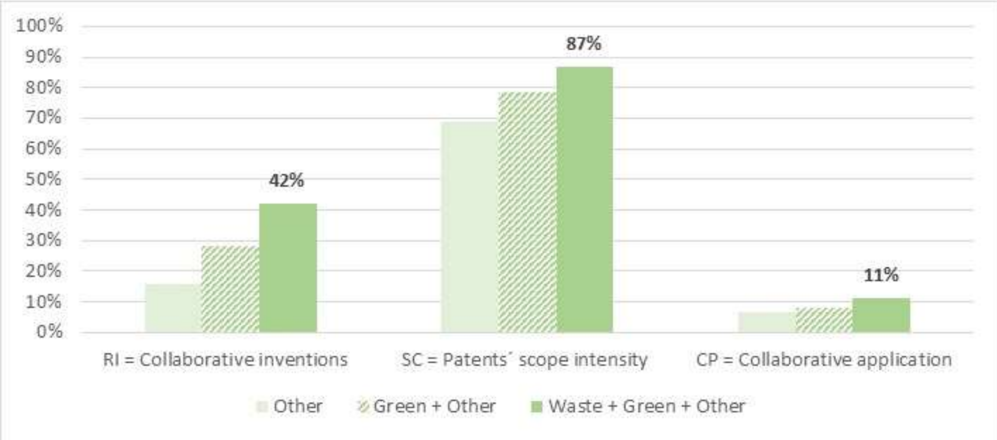
To response research question RQ2, firms that hold waste patents were analysed to define and compare their capability profile with those of firms that hold green and other patents (161 firms) and firms with only other patents (399 firms). It is remarkable that 8 of the 134 firms that hold waste patents also hold green patents but not other types of patents. Results from the ANOVA analyses show for all analysed capabilities, their mean values increase as the range of patents between the different groups of firms increases (Table IV). Research intensity, patents' scope intensity, innovation persistence, collaborative patents, and technological capability are the most relevant capabilities of firms with waste patents. The higher mean value was achieved in this firm group, and the greatest differences with respect to the values reached in other groups were also observed. For collaborative R&D capability, territorial linkage, and the firm' size variable also had higher mean values for the waste patent firms; however, these differences observed are not statistically significant (at the 0.05 level). Figure 2 summarises some of the analysed capabilities of firms that hold waste patents.

Table IV. Capabilities and waste patents. Results from ANOVA

	(1) Firms O (399)	*(2) Firms G-O (161)*	*(3) Firms W-G-O (134)*	F Anova	*p-value*	Bonferroni´ Test
RI = Collaborative inventions	0.16	0.28	0.42	33.77	0.00	+++
SC = Patents´ scope intensity	0.69	0.78	0.87	28.02	0.000	+++
RD = Collaborative R&D capability	0.01	0.01	0.20	0.30	0.742	
TL = Territorial linkage	0.65	0.56	0.61	2.90	0.051	
IP = Innovation persistence	2.54	3.08	3.87	47.95	0.000	1 y 3; 2 y 3
CP = Collaborative application	0.07	0.08	0.11	3.34	0.036	1 y 3
TC = Technological capability	16.83	82.12	633.48	64.75	0.000	1 y 3; 2 y 3
S1 = Employees	219	415	628	11.61	0.000	1 y 3; 1 y 2
S2 = Total Assets	76716.15	228041.87	770847.82	5.93	0.003	1 y 3
S3 = Total Revenues	80028.49	179679.73	308892.32	9.87	0.000	1 y 3
EP1 = Return on Assets	6.24	3.62	4.57	2.25	0.106	
EP2 = Return on Equity	9.37	4.73	-22.09	2.15	0.117	

O = firms with other patents; G-O = firms with green and other patents; W-G-O = firms with waste, green and other patents
+++ differences in the variables between all three groups for each pair of categories

Figure 2 Firms´ capabilities



From another perspective, both the international range and sector are relevant variables that characterise the firms that hold waste patents (Table V). Firms that hold both ES patents and EU patents instead of patents only in a single territorial area (83.6% IR =1, 16.42% IR = 0) also increased as the range of patents between the different groups of firms increased, and the higher mean proportion was reached in the firms with waste patents. The differences found between the three firm groups are statistically significant according to Pearson's χ2 test (at the $p < 0.01$ level). Likewise, the percentage of firms belonging to the manufacturing sector decreased as the range increased, and the lowest mean proportion (83.3% <92.3% <92.5%) was found for the firms with waste patents.

Table V. International range, sector, and waste patents

	Firms O (399)		*Firms G-O (161)*		*Firms W-G-O (134)*	
IR = International range		firms		firms		firms
IR =1	20.80%	83	54.04%	87	83.58%	112
IR =0	79.20%	316	45.96%	74	16.42%	22
Dif. Proportions	*Chi2 Pearson = 173.78; p-value = 0.000*					
MS = Manufacturing sector		firms		firms		firms
MS =1	92.48%	369	91.93%	148	84.33%	113
MS =0	7.52%	30	8.07%	13	15.67%	21
Dif. Proportions	*Chi2 Pearson = 10.196; p-value = 0.006*					

Note (s): O = firms with conventional patents; G-O = firms with green and other patents; W-G-O = firms with waste, green and other patents

4.2. Firm' capabilities- waste' patents -performance

The research question RQ3 was tested from PLS-SEM analysis. First, the reliability and validity of measurement structural model was confirmed (Table VI). For all three constructs (WP, EP, S) statistically significant values of indicators' standardised loadings (greater than 0.7 and neared this value for S1) were observed, and adequate values of composite reliability and average variance extracted (>0.7 and > 0.5, respectively). The discriminant validity criterion was also met: (1) the square root of the AVE was larger than the correlations among constructs, and (2) the Heterotrait–Monotrait ratio (HTMT) between constructs was less than 0.72 in all cases (Table VII).

Table VI. Description of the variables in the path analysis

Variable/Construct (and items)	Variable/Construct description	Mean	standard deviation
Variable: RI	Collaborative inventions	0.24	0.34
Variable: SC	Patents´ scope intensity	0.74	0.26
Variable: RD	Collaborative R&D	0.01	0.10
Variable: TL	Territorial linkage	0.62	0.42
Variable: IP	Innovation persistence	2.91	1.45
Construct: WP	Waste patents	*CR = 0.73;*	*AVE = 0.52*
	WP1 = Waste patents	2.34	10.72
	WP2 = Waste patents´ scope intensity	0.04	0.35
Construct EP	Economic Performance	*CR = 0.74;*	*AVE = 0.59*
	EP1 = Return on assets (ROA)	5.30	14.16
	EP2 = Return on equity (ROE)	2.53	149.43
Construct: S	Firm´ size	*CR = 0.84;*	*AVE = 0.66*
	S1 = Total Assets	239,590.3	1,985,796.3
	S2 = Total Revenues	145,846.8	522,848.3
	S3 = Employees	341.63	874.60
Variable: RG	Range of patents		
	RG = 1/2/3	mode=1	
Variable: MS	Manufacturing sector		
MS	MS = 1/0	mode=1	

Standardised loadings: Waste patents (WP1 = 0.86; WP2 = 0.72), economic performance (EP1 = 0.73; EP2 = 0.81), Firm size (S1 = 0.69; S2 = 0.86; S3 = 0.95).

CR = Composite Reliability; AVE = Average Variance Extracted

Table VII. Discriminant validity of constructs

	WP	EP	S
Fornell-Larcker Criterion			
Waste patentes (WP)	0.720		
Economic performance (EP)	0.017	0.748	
Firm´size (S)	0.047	0.019	0.757
Heterotrait-Monotrait Ratio (HTMT)			
Waste patentes (WP)			
Economic performance (EP)	0.096		
Firm´size (S)	0.155	0.019	

Results from Pearson correlations' analysis indicate weak associations between independent variables, with values ranging from 0.01 to 0.35 (Table VIII). No correlation has a value higher than 0.9, showing the absence of multicollinearity problems between the variables (Hayduk, 1987).

Table VIII. Pearson correlation between the independents variables in the model

	RI	SC	RD	TL	IP	S	RP	M
RI	1.00							
SC	0.18***	1.00						
RD	0.21***	0.04	1.00					
TL	-0.02 ns	-0.23***	0.09*	1.00				
IP	0.01 ns	0.20***	-0.07 ns	-0.09*	1.00			
S	0.24***	0.08*	-0.01 ns	0.11***	0.11**	0.81 ns		
RP	0.30***	0.27***	0.02 ns	-0.06 ns	0.35***	0.19***	1.00	
M	-0.15***	-0.11***	-0.08 ns	0.00 ns	0.07 ns	-0.12***	-0.10***	1.00

*** p<0.01; **p<0.05; * p<0.1; ns= not significant

Results from PLS-SEM analysis show that innovation persistence, collaborative innovation, and patents' scope intensity are the most important variables that explain the firm's level of waste patents with their path coefficients reaching the highest values (β (IP) = 0.23, β (RI) = 0.15, and β (SC) = 0.10). Likewise, the territorial linkage and collaborative R&D were two variables that also drive the explanation of the waste patent level (Table IX). All these variables explain a 10.6% of the total variance of the waste patents' construct. In turn, the cause-and-effect relationship between the level of waste patents and firm's economic performance was also supported by the analysed capabilities in this model (β (EP) = 0.06, p-value < 0.05). Bootstrapping with 5,000 resamples was used to corroborated the significance of the path coefficients (Hair *et al.*, 2014).

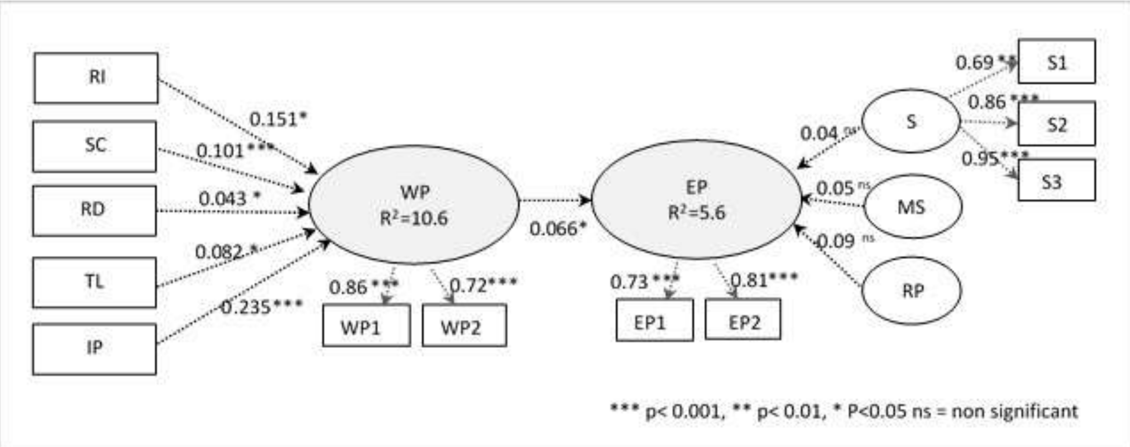
Table IX. The estimation results of the structural equation model

Relations		Path Coefficients		T Statistics	p-value	Percentile Bootstrap 95% Confidence Level	
						Lower	Upper
RI =>	WP	0.151	*	2.372	0.018	0.015	0.254
SC =>	WP	0.101	***	2.760	0.006	0.043	0.157
RD =>	WP	0.043	*	2.125	0.034	0.004	0.085
TL =>	WP	0.082	*	2.366	0.018	0.023	0.093
IP =>	WP	0.235	***	2.888	0.004	0.044	0.285
WP =>	EP	0.066	*	2.042	0.041	0.011	0.131
S =>	EP	0.038	ns	1.075	0.282	-0.042	0.099
RP =>	EP	-0.09	ns	1.889	0.059	-0.213	0.008
MS =>	EP	0.049	ns	0.974	0.331	-0.049	0.205
Variances explained R2		*R2* WP = 10.60; *R2* EP =5.60					
Stone-Geisser's Q2		*Q2* WP = 0.04; *Q2* EP = 0.01					

Note (s): *** p < 0.001; ** p < 0.01; * p < 0.05; ns = not significant

In summary these results show that the research model predicted the level of waste patents and firm' economic performance, providing empirical support to answer research question RQ3. Figure 3 shows the overall model results. Stone-Geisser's cross-validated redundancy Q2 (Geisser, 1974; Stone, 1974) confirms the model's predictive relevance (i.e., Q2 > 0).

Figure 3 Structural model results



4.3 Discussion

In this study, waste patents are considered to be an indicator that demonstrates a company's ability to align itself with the CE's objectives by making investments in environmental intangibles that favour the closing of material loops. However, the use of patents as a proxy of innovation is not without limitations.

Some authors have challenged the use of green patents as reliable indicators of eco-innovation, pointing out that they cannot accurately reflect the output of innovation processes (Rennings *et al.*, 2006). This is because not all innovations can lead to a patent, and many firms use other methods to protect their industrial property, such as industrial secrecy (Archibugi and Pianta, 1996). In fact, in a study related to CE, Cainelli et al. (2020) conduct a quantitative analysis of the adoption stage of CE-related innovations rather than patenting activities. However, despite the problems of using patents as a proxy for innovation stated by some authors, we use waste patents as an indicator of circular innovation in order to analyse the dynamic capabilities that companies apply to manage R&D resources for patenting CE-related innovations and then to improve the company's performance.

In the dynamic capabilities discourse, the analysis of the specific capabilities applied to circular innovation is an interesting topic for researchers because some companies have actively improved manufacturing processes to reuse and remanufacture components over the past few years (Calik and Bardudeen, 2016). However, based on the literature review, we can affirm that this is a new line of inquiry from a CE perspective. Furthermore, this topic is still little explored in eco-innovative processes. Recently, Cainelli et al. (2020) raised a debate about the role played by R&D with respect to eco-innovations applied to resource efficiency and the CE. These authors argue that absorptive capacity seems to be irrelevant to sustaining these specific typologies of eco-innovation. Thus, in our study, we contribute to this debate by demonstrating the relevance of firms' capabilities to collaborate with R&D institutes in a circular scenario.

Other collaborative capabilities that have been analysed in this study are measured through the number of different inventors involved in patenting and the participation of different applicants. Our results also confirm collaboration as a capability of organisations for eco-innovative processes and patenting (Petruzzelli *et al.*, 2011; Portillo-Tarragona *et al.*, 2018). However, unlike previous studies, we analyse the collaborative capability of firms in different stages of the innovation process as a novelty. In our study, collaboration is measured in both the invention phase (through the number of patent inventors) and in the patent exploitation phase (using the number of applicants).

As in the case of collaboration, we corroborate those technical capabilities are relevant for waste patents and circular innovation by confirming the previous results obtained for eco-innovation. We highlight the difference between the patents' scope intensity (measured as the percentage of patents that have different IPC codes) and the ability of companies to achieve a wider technological diversity (measured through patents with different IPC codes) with an expanded approach compared to eco-innovation studies.

From another perspective, as a result of our study, we can argue that persistence in patenting is a relevant capability for firms in circular innovation, in line with innovation and eco-innovation processes (Scarpellini *et al.*, 2019). Furthermore, a linked topic is the overlap of patented environmental and non-environmental innovations observed by Aragon-Correa & Leyva-de la Hiz (2016) when analysing the internal resources and capabilities involved applied to eco-innovation because the potential overlap of capabilities could also affect CE-related innovations.

In this study, the local implications of a CE were used to measure the linkage of firms with the territory using the percentage of patents registered at the national level, which does not have a positive effect on the number of waste patents. Given the results obtained about these capabilities, we could argue that companies that hold national and European patents highlight the international character of innovation and its global application.

4. CONCLUSIONS

This study aimed to fill a gap in the literature by empirically investigating the measurement of waste patents and the specific capabilities that are needed for patenting in a CE model. As the first contribution of our research, we define waste-related patents as an indicator of circular innovation. Our findings demonstrate the statistical validity of measurement of circular innovation based on two variables that synthesize the intensity and scope of waste patents in the firm in response to the first research question (RQ1). In addition to providing new insights into the business literature on the CE, we also enhance the knowledge of eco-innovation and green patents as a broader field of study that includes waste patents.

Previous studies demonstrated the relevance of internal firms' capabilities in generating green patents, but this influence had not been empirically analysed for waste patents from a CE perspective; therefore, this paper fills this gap in the literature within the dynamic capabilities' theoretical framework. The relation between waste patents and firm capabilities has been corroborated for persistence in patenting, collaborative capabilities and research intensity (RQ2). Finally, in response to the RQ3, the positive impact of the level of waste patents on the economic performance of companies has been demonstrated empirically as the first evidence in this research field.

For academics, these results are relevant because they enhance understanding the development of firms' intangible resources in a CE scenario. From the practitioners' perspective, this paper introduces measures that contribute to implementing a CE model in businesses and allows companies to improve their measurement and reporting. Managers can deploy their capabilities to build circular processes through technological innovation and patenting, significantly innovating waste management as one of the main principles of the CE. Policymakers can encourage R&D collaborations between firms and public research institutions to improve the CE and support waste patents as an effective innovation policy for closing the material loop.

Methodological contributions in terms of CE-patents measurement and variables can be applied to different sectors and businesses located in other territories.

Nevertheless, we acknowledge some limitations of this study related to the size, the sectoral aspects and the geographic boundaries of the sample. Future research could implement similar empirical analysis for different sectors and regional contexts to provide an additional perspective and corroborate the achieved results.

5. ACKNOWLEDGMENTS

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