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On the contribution of eco-innovation features to a circular economy: A microlevel quantitative approach

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Abstract

The circular economy (CE) and eco-innovation (EI) are two concepts deemed instrumental in achieving a sustainable transition. They have been proposed in the academic literature and by practitioners and have acquired very high public policy relevance, being endorsed by policymakers and ultimately leading to regulations supporting them. It has been argued that both concepts are compatible and interrelated and that EI is instrumental in achieving the CE. However, little is known about how different EI features contribute to the CE at the microlevel. This article tries to cover this gap. Its aim is to assess and quantify the causal relationship between different EI features and the CE with the help of a unique dataset of small- and medium-sized firms in Spain and an econometric analysis. Our results show that only systemic EIs contribute to a global CE, whereas other EI types such as component additions or small changes in existing production processes could even be barriers to high levels of circularity. It is found out that technological novelty is not relevant for reaching the CE. The results support the understanding of how EIs enable a transition to the CE. Care should be taken not to promote incremental EIs that do not only achieve low (or no) circularity but that effectively lock-in the economic system in solutions that entail a barrier to the achievement of high-level circularity.

KEYWORDS
circular economy, eco-innovation, small- and medium-sized firms, Spain, transition

1 | INTRODUCTION

There is currently a considerable concern on the environmental impacts of production and consumption activities, including the depletion of natural resources, biodiversity loss and the pollution of water, soil and air, particularly the emissions of global pollutants leading to climate change. Fundamental changes, or innovations, in the economic system are required to mitigate them. Sustainability has become a main goal in this regard. It has many definitions (around 300, according to Johnstone & Hascic, 2007), but the most commonly cited is the one from the World Commission on Environment and Development (1987), also known as Brundtland report, as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. Sustainability is made up of three dimensions: economic, social and environmental. In fact, Geissdoerfer et al. (2017, p. 766) define it as the 'balanced integration of economic performance, social inclusiveness and environmental resilience, to the benefit of current and future generations'. Hence, a sustainability transition, understood as a process that leads to improvements in those three dimensions, has been deemed desirable (Kitzing, Fitch-Roy, Islam, & Mitchell, 2018). Scholars have recently and increasingly devoted research efforts to sustainability transitions from different perspectives and based on different theoretical frameworks (Grubb, McDowall, & Drummond, 2017). They share the common diagnosis that such a transition is a highly complex issue due to the need for change at different levels, lock-in conditions and triple externality problems (Markard, Raven, & Truffer, 2012; van den Bergh, Truffer, & Kallis, 2011).[1]

Some concepts, which are instrumental in achieving such transition, have been proposed in the academic literature and by practitioners and have acquired very high public policy relevance, being endorsed by policymakers, and ultimately leading to policy roadmaps or regulations supporting them. Two of these are eco-innovation (EI) and the circular economy (CE).

EIs, defined as innovations that lead to lower environmental impacts of production or consumption activities, whether the main motivation for their development or adoption is environmental or not (Carrillo-Hermosilla, Del Río, & Könnölä, 2010; Kemp & Pearson, 2007), have been emphasized as a core driver for change in the transition to sustainability (Carrillo-Hermosilla et al., 2010; Markard et al., 2012).[2] It has long been sensed and is now corroborated that environmental sustainability and firm competitiveness can be achieved simultaneously through EIs (i.e., Boons & McMeekin, 2019; Carrillo-Hermosilla, del Río, & Könnölä, 2009; Fussler & James, 1996). Several contributions have explored eco-innovative firms and their environmental orientation (i.e., del Río, Peñasco, & Romero-Jordán, 2016; González-Benito & González-Benito, 2006) and factors that facilitate (drivers) or hinder (barriers) the uptake of EI in firms (i.e., del Río, Carrillo-Hermosilla, Könnölä, & Bleda, 2016; Horbach, 2016; Peralta et al., 2019; Rothenberg & Zyglidopoulos, 2007; Zubeltzu-Jaka, Erauskin-Tolosa, & Heras-Saizarbitoria, 2018). More recently, the measurement and modelling of EI have received increased attention (i.e., Garcia-Granero, Piedra-Muñoz, & Galdeano-Gomez, 2018; Kiefer, del Río, & Carrillo-Hermosilla, 2019; Xavier, Naveiro, Aoussat, & Reyes, 2017). The relevance of the concept led to EI programmes by international institutions (including the Organisation for Economic Cooperation and Development [OECD], the European Union [EU] and the United Nations). In the EU, its importance was emphasized in the Eco-innovation Action Plan (EcoAP)[3] and the package 'Closing the loop—An EU action plan for the circular economy'.

On the other hand, the CE, which has its roots in different approaches (Industrial Ecology and the Performance Economy, among others), is considered by many authors as a promising concept for the pursuit of global sustainability (Kirchherr et al., 2018; Prieto-Sandoval, Jaca, & Ormazabal, 2018; Smol, Kulczycka, & Avdiushchenko, 2017), although others are more critical in this regard (e.g., Geissdoerfer et al., 2017; Kirchherr, Reike, & Hekkert, 2017). Several definitions of the CE exist (see Kirchherr et al., 2017, for a review), but a main distinguishing feature of the CE concept is 'value retention', that is, keeping resources within the economy by retaining the added value in products for as long as possible, extracting their maximum value and eliminating waste (Smol et al., 2017). Most definitions emphasize the contribution of the CE to sustainability by closing material cycles. For example, Yuan et al. (2006, p. 5) argue that the core of the CE is 'the circular, closed flow of materials and the use of raw materials and energy through multiple phases'. The most renowned definition is probably the one by the Ellen MacArthur Foundation (2013), for which the CE refers to 'an industrial economy that is restorative or regenerative by intention and design' (p. 14). Similarly, Geissdoerfer et al. (2017, p. 759) define the CE as 'a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling'. The European Commission has recently published a generic, sector-agnostic CE categorization system that defines 14 distinct categories of activities substantially contributing to a CE (European Commission, 2020).

A crucial aspect in the CE is its levels. The highest levels of circularity entail maintaining the value of a product or its useful life for as long as possible through product life extension or sharing approaches, whereas intermediate levels refer to the reuse of products in their original use with little enhancement and lower levels of circularity involve recycling product parts and materials as input instead of virgin raw material in new products (Dijksma & Kamp, 2016, p. 23; Ellen MacArthur Foundation, 2013; see Section 2.1).

The concept ranks high in the public policy agenda in many countries. In 2015, the European Commission approved the European Circular Economy Action Plan (COM [2015] 614 final) (Mcdowall, Geng, Huang, & Bartekov, 2017). The approach has also been embraced at the country level. China adopted a Circular Economy Plan in 2008 (Mathews & Tan, 2011; Yuan et al., 2006), and other countries have elaborated or are elaborating circular plans (i.e., Spain; see Spanish Ministry for the Ecological Transition, 2018).[4] Policy think tanks, such as the aforementioned Ellen MacArthur Foundation (2013), embrace the concept from a practitioner's perspective.

Despite the increased attention paid to the CE in recent years, the EI concept has not disappeared, neither in academia nor in current public policy practice, and both still coexist, which raises doubts about the nature of their relationships and connections. As the CE concept builds on fundamental changes in the products, services and general functioning of the economic system, it makes sense to connect it with the EI literature and look at the CE through the prism of an EI perspective. Indeed, innovation and EI are at the heart of any transition to a CE (Cainelli, D'Amato, & Mazzanti, 2020; O'Brien, 2014). Specifically, EI is considered instrumental for achieving the CE (de Jesus, Antunes, Santos, & Mendonça, 2019; de Jesus & Mendonça, 2018; Mazzanti, 2018). The intersection of both concepts has been subject to analyses. However, these are often too general and unsystematic, identifying only broad relationships (Prieto-Sandoval et al., 2018; Vence & Pereira, 2019) or major patterns between both concepts (de Jesus et al., 2019; de Jesus, Antunes, Santos, & Mendonça, 2018), providing anecdotal evidence on the contribution of some EIs to the CE (O'Brien, 2014), stressing only the differences between both

[1]Three main market failures to clean technologies in the form of externalities have been considered in the literature (del Río, 2011): an environmental externality, an innovation externality (spillover effects in innovation) and a diffusion externality (which refers to initial investors not capturing the benefits of learning investments).

[2]See Carrillo-Hermosilla et al. (2010), Kemp and Pearson (2007) and Xavier et al. (2017) for a detailed overview of definitions on the EI.

[3]See https://ec.europa.eu/environment/ecoap/frontpage_en.

[4]Although not explicitly called 'circular economy' plans, Germany's 'Closed Substance Cycle and Waste Management Act' in 1996 and Japan's 'Basic Law for Promoting the Creation of a Recycling-Oriented Society' in 2002 can be considered pioneering initiatives in this regard (Franco, 2017).

concepts (Gente & Pattanaro, 2019), focusing on the connections at the level of indicators (Smol et al., 2017) or analysing the drivers and barriers to the EI that facilitate a CE (de Jesus & Mendonça, 2018; Diaz Lopez, Bastein, & Tukker, 2019). Closely related are studies on the adoption of CE in firms through 'CE innovations' (Guldmann & Huulgaard, 2020), cleaner production practices (Sousa-Zomer, Magalhães, Zancul, Campos, & Cauchick-Miguel, 2018), novel CE-related 'activities' (Aranda-Usón, Portillo-Tarragona, Scarpellini, & Llena-Macarulla, 2020; Gusmerotti, Testa, Corsini, Pretner, & Iraldo, 2019; Katz-Gerro & López Sintas, 2018) and 'practices' (Moktadir et al., 2020), business models (Diaz Lopez et al., 2019; Rizos et al., 2016) or 'circular EIs' (Scarpellini, Valero-Gil, Moneva, & Andreaus, 2020). Despite the differences in wording, these studies also analyse the relationship between EI and CE and provide some insights on the adoption of systemic versus incremental innovations (or EIs) by firms. They generally show that reaching the CE is a gradual process that starts with the adoption of the more incremental EIs.

However, even if one can intuitively argue that EI and CE are closely related, and assume that achieving a CE without EI is unlikely, it remains to be seen in what ways this is so (de Jesus et al., 2018, p. 3000). More specifically, how do different EI features contribute to the CE? Do they all drive the implementation of the CE or are some more relevant than others in this respect? Could a particular EI type even be a barrier to the CE? The aim of this article is to assess the relationship between different EI features and different CE levels. With the help of a unique dataset of small- and medium-sized firms (SMEs) in Spain comprising EI and CE variables, different features of EI are identified and an econometric analysis of the contribution of those features towards a CE at different levels is carried out.

Therefore, our paper complements and adds to the literature in several respects. As suggested by our review of the literature (see the Supporting Information for details on the reviewed papers and how they differ from this one), the relationship between both concepts has not been systematically analysed and some critical aspects of such relationship remain largely unaddressed. In particular, how different features of EI, including different EI types, contribute to different CE levels is a topic that has not been previously investigated. This paper tries to cover this gap.

Our research provides a valuable contribution at the empirical level. It responds to the call for more research, especially quantitative or, as put by de Jesus et al. (2018) for 'more empirical methods for assessing and measuring their mutual influence, in particular regarding the role of EI in implementing a CE' (p. 3014). In this sense, we follow the recommendation of de Jesus et al. (2018), who argue that a deeper analysis of the relation should consider the specific aspects of EI (targets, mechanisms and impacts) and the different levels of the CE (microlevel, mesolevel and macrolevel), and the analysis of the contribution of the EI to the CE requires more empirical analysis (de Jesus et al., 2019). We empirically investigate the relationship between different EI features and different CE levels using regression analysis. It also covers the call for more CE studies at the microlevel (Ghisellini, Cialani, & Ulgiati, 2016; Lieder & Rashid, 2016; Scarpellini, Portillo-Tarragona, Aranda-Usón, & Llena-Macarulla, 2019) and, particularly, regarding its implementation (Franco, 2017; Lieder & Rashid, 2016; Sousa-Zomer, Magalhães, Zancul, Campos, & Cauchick-Miguel, 2018), as contributions on these levels are relatively scarce. In particular, Franco (2017, p. 835) argues that there is a lack of studies examining how feasible the concerted implementation of preparatory strategies for CE implementation (which include eco-design, cleaner production and waste management) 'actually is and to what degree they impact the materialization of the CE at the macro level'.

Our research is complementary to other contributions based on case studies (O'Brien, 2014), literature reviews (de Jesus et al., 2018; de Jesus & Mendonça, 2018; Smol et al., 2017; Vence & Pereira, 2019), a bibliometric analysis (Gente & Pattanaro, 2019), a Delphi approach (de Jesus et al., 2019) or a public cross-sectional dataset (the EU Community Innovation Survey) (Cainelli et al., 2020).

This paper is structured as follows. Section 2 provides the theoretical background on CE, EI and their relationship. Section 3 discusses the methodology. Section 4 provides the results, which are discussed in Section 5. Section 6 concludes the paper.

2 | THEORETICAL BACKGROUND: CONNECTING EI WITH THE CE

Because this paper analyses the relationship between different CE levels and EI features, a discussion on those levels and features and their possible connection is provided.

2.1 | CE levels

The analysis of the CE in a given setting has been approached from two different yet overlapping perspectives, the 'hierarchical' and the 'systemic' (or R framework) approaches. The former has emphasized the different levels of circularity, whereas the latter tries to identify best practices in each level. Both perspectives are combined in any analysis of circularity practices; that is, the hierarchical perspective is used in combination with the systemic perspective as a core principle of the CE (Kirchherr et al., 2017).

Regarding the hierarchical perspective, the CE has often been characterized as a multilevel phenomenon. CE may occur and can be analysed at different levels, including the microlevel (products, companies and consumers), mesolevel (interfirm networks, symbiosis association, (eco-)industrial parks and green supply chain management) and macrolevel (city, province, region or nation) (Kirchherr et al., 2017; Korhonen, Honkasalo, & Seppälä, 2018; Pauliuk, 2018). Circular solutions are understood to replace existing linear solutions at each level with circular solutions/processes, involving different kinds of stakeholders at the corresponding level.

On the other hand, the identification of a hierarchy of activities in the CE has led researchers to focus on those that maximize the extent of circularity. Current linear processes are non-circular and are thus placed at the bottom of the hierarchy. Circular solutions addressing individual products or production processes, that is, the reuse and recycling of material, parts or energy, correspond with circularity at lower levels, as the scope and overall impact are small. Circular solutions addressing sectors (activity-wise or geographical) comprise an ecosystem of actors that repair, refurbish, maintain and redistribute goods at the end of their useful lives with much longer total useful lives compared with linear solutions and correspond to intermediate levels of circularity. The highest levels of circularity can be reached by solutions that change the economic system as a whole and at a global scale, that is, what Dijksma and Kamp (2016, p. 23) call 'full circularity'. This is characterized as the constant reuse of natural and man-made resources that completely reduce negative impacts on the environment (emissions of pollutants and discharge of waste and also the use of virgin resources) (Kirchherr et al., 2018). The 'butterfly figure' from the Ellen MacArthur Foundation, for instance, proposes a hierarchical arrangement of recycling, refurbishment, reuse, maintenance and sharing (Bocken, Olivetti, Cullen, Potting, & Lifset, 2017). The further inside the loops in the figure (activity-wise and geographically), the higher the addressed level of circularity and the more profitable and resource efficient it is (Kalmykova, Sadagopan, & Rosado, 2018). The inner circles (product reuse, remanufacturing and refurbishment) demand less resources and energy and are also more economic compared with the outer circles of conventional recycling of materials as low-grade raw materials (Korhonen, Nuur, Feldmann, & Birkie, 2018).

2.2 | EI features

Different types of EIs have traditionally been distinguished in the literature, including the well-known and useful yet simple classifications of product, process and organizational EIs and radical versus incremental EIs (del Río, Peñasco, & Romero-Jordán, 2016). However, more elaborated classifications of EIs, taking into account their features and dimensions, have recently been proposed. Indeed, a stream of the EI literature has focused on the identification of the dimensions of EI whose combinations may lead to different 'EI types' or 'EI features'. We draw on this literature for the purposes of this paper. Three main (complementary) contributions are Carrillo-Hermosilla et al. (2010), OECD (2009) and Tukker and Ekins (2019). These studies are part of the broader literature on the systems of innovations and societal transitions, which focuses on how EIs must be classified according to whether they 'fit' in the existing system or truly create an upheaval in the system (Diaz Lopez et al., 2019). They provide a more sophisticated discussion on the typology of EIs and lead to a more comprehensive set of EI types than the aforementioned simple classifications.

OECD (2009) proposes that EI activities are analysed along three dimensions: targets (the focus areas of EI: products, processes, marketing methods, organizations and institutions); mechanisms (the ways in which changes are made in the targets: modification, redesign, alternatives and creation); and impacts (incremental, radical or disruptive effects of EI on the environment). Therefore, EI types are defined according to these dimensions.

Partly drawing on OECD (2009), Tukker and Ekins (2019) have analysed a number of concepts that provide such dimensions, characterizing the radicality of change. They suggest two relevant dimensions, that is, the scope of change and the degree of change. The former refers to the scope of the system that is being affected by the innovation, whether a component of the system (e.g., a technology or product), a subsystem (value chain or sectors) or a societal system. The degree of change refers to incremental versus radical change.

Carrillo-Hermosilla et al. (2010) characterize EIs along four dimensions (design, user, product-service and governance). The design dimension refers to environmentally friendly technological change, the user dimension considers sustainability demand and interactions with users in the innovation processes, the product-service dimension represents the market-specific value proposition, matching demand and technological and ecological change, and the governance dimension refers to external cooperation in networks. EIs have characteristics in all these dimensions. This analytical framework has been used in this article, given its theoretical guidance and suitability for its purposes, the fact that it has shown to lead to empirically testable EI types and features (Kiefer, Carrillo-Hermosilla, & del Río, 2019; Kiefer, Carrillo-Hermosilla, del Río, & Callealta Barroso, 2017) and its impact on the literature.[5]

The original framework of Carrillo-Hermosilla et al. (2010) was further refined by Kiefer, Carrillo-Hermosilla, & del Río (2019 and Kiefer, Carrillo-Hermosilla, del Río, & Callealta Barroso (2017). Kiefer, Carrillo-Hermosilla, and del Río (2019) built a precise conceptualization of EI types, which takes into account its multifaceted character. Their statistical analyses revealed the existence of taxonomy of five EI types, which differ in their techno-economic configurations, contribution to environmental sustainability and corporate goals and required changes in the firms: systemic, externally driven, continuous improvement, radical/technology-push initiated and eco-efficient (Table 1). The authors emphasize the importance of systemic innovation in the sustainability transition.

2.3 | Connecting EI features to the CE

Our starting point is that the contribution of the EI to the CE is related to the features of the EI (EI types) and the level of the CE. As suggested by several authors, a 'high-level' CE is preferable to a 'lower level' CE (Reike, Vermeulen, & Witjes, 2018). Different types of EIs contribute to higher CE levels differently and, thus, add differently to sustainability transitions and the CE (Franco, 2017; Kiefer, Carrillo-Hermosilla, & del Río, 2019; Prieto-Sandoval et al., 2018).

Some authors suggest that all EIs can contribute to the CE. Vence and Pereira (2019) claim that all EI types play different roles in the journey towards a CE. De Jesus and Mendonça (2018, p. 81) state that a CE is 'dependent on a broad array of technologies in order for it to gain widespread penetration'.

[5]The article has accumulated 855 citations in Google Scholar and is renowned as a 'Highly Cited Paper' (top 1% of its academic field) according to the Institute for Scientific Information (ISI) Web of Science.

TABLE 1 Description of the different EI types

EI type	Description
Systemic	They have high degrees of novelty, involve a rupture with existing solutions, lead to considerable environmental benefits throughout their life cycle and create a new base for competitiveness.
Externally driven	They are developed or adopted as a result of external pressures from society or legislation.
Continuous improvement	They emerge from within the SME as a result of daily business practices and are fully compatible with existing processes and systems. They entail small improvements with respect to existing solutions.
Radical and tech-push	They are characterized by high degrees of technological novelty, a rupture with existing solutions and considerable environmental benefits. They emerge as a result of a push from science and technology research.
Eco-efficient	They increase the efficiency of products, services or processes, leading to environmental benefits as a result.

[a]Source: Kiefer, Carrillo-Hermosilla, and del Río (2019).
Abbreviations: EI, eco-innovation; SME, small- and medium-sized firm.

In contrast, we hypothesize that not all EIs would contribute equally to a 'high-level' CE. We expect that systemic EIs would be particularly relevant in this regard. The CE requires a systemic shift and, thus, systemic EIs (Kirchherr et al., 2017), instead of incremental twisting of the current system. The review of the literature in de Jesus and Mendonça (2018) shows the importance of a 'systemic' EI approach towards a CE. The CE requires essential changes in current production and consumption patterns (Kirchherr et al., 2018), which is not surprising, as CE is a systems-level and interorganizational approach (Korhonen, Honkasalo, & Seppälä, 2018). De Jesus and Mendonça (2018, p. 84) argue that the CE transition is contingent 'on adopting a systemic approach to EI that encompasses value and supply chains in their entirety and engages all actors involved in such chains'. Thus, future-oriented knowledge on how to direct 'system innovation' to 'circular' practices acquires an increased importance (de Jesus et al., 2019). In particular, the CE should aim for eco-effective (system change) rather than eco-efficient EIs (Ellen MacArthur Foundation, 2013; Kalmykova et al., 2018). Therefore, the following hypothesis is proposed.

Hypothesis 1. Systemic EI contributes to a 'high-level' CE.

In this discussion on the contribution of different EI types to the CE, the classical distinction in the EI literature between incremental and radical EIs is relevant. The former refer to the gradual modification or redesign of organizations, processes and products. Radical EIs entail the introduction of alternatives or completely new organizational methods, products, processes or marketing (de Jesus et al., 2018). We would expect that a 'high-level' CE requires radical EI, in line with Cullen (2017) and others. De Jesus et al. (2018) argue that radical alterations are necessary as the transition to new sustainable ways of living implies the genuine transformation of the status quo. O'Brien (2014, p. 9) comments that 'while the shift towards a CE can be supported by incremental evolutions within the existing systems (such as material-efficient manufacturing or improved recycling technologies), achieving its full potential will require a radical change of the existing production and consumption systems'. Thus, the following hypothesis is put forward.

Hypothesis 2. Radical EIs are a driver to a 'high-level' CE.

However, even if authors stress the need for more radical approaches, incremental EIs are still predominant (de Jesus et al., 2018; Gusmerotti et al., 2019; Katz-Gerro & López Sintas, 2018). On the other hand, it might not only be an issue of which types of EIs contribute more to a 'high-level' CE, but whether some EIs, and particularly incremental EIs, are in fact barriers to achieve such 'high-level' or global CE, locking-in the productive system into a suboptimal CE.

The role of incremental EIs in the CE has not been sufficiently analysed at an empirical level. Some authors argue that a widespread and comprehensive change towards the CE, that is, the entire economy becoming circular, cannot rely only on radical innovations. These radical EIs might be beyond the reach of most companies (especially SMEs) (Lacy & Rutqvist, 2015). Some authors argue that CE-related EIs are adopted by companies in a gradual manner, starting initially from incremental EIs (Aranda-Usón et al., 2020; Garcés-Ayerbe, Rivera-Torres, Suárez-Perales, & Leyva-de la Hiz, 2019). Incremental EIs can easily be dropped-in existing systems (Carrillo-Hermosilla et al., 2010). Gusmerotti et al. (2019, p. 315) claim that 'business models can also progress through incremental innovations aimed at boosting circular principles in their value chains'. Cainelli et al. (2020, p. 3) argue that 'the transition to a greener circular economy consists of various incremental and radical changes that characterize both mature sectors and new emerging ones'.

Several contributions suggest that the adoption of incremental EIs may (indirectly) contribute to the implementation of the CE through their influence on the dynamic (organizational) capabilities of firms, which, in turn, allow them to implement higher level CE practices. For example, Katz-Gerro and López Sintas (2018, p. 494) show that most firms have not implemented CE practices and those who have done so start with the most incremental ones. 'Minimizing waste may be the easiest activity to implement. Hence this activity may provide entrepreneurs and managers with not only the experience necessary to convince themselves of the benefits of implementing CE activities but also the knowledge needed to develop dynamic capabilities for the implementation of additional CE activities'. Similarly, Scarpellini et al. (2020, p. 2) argue that 'firms that have previously demonstrated capabilities related to EI and that can apply them to new innovative circular models could implement CE-related activities more easily', although these authors do not distinguish between different EI features and types. Demirel and Danisman (2019) also stress that EIs can facilitate the implementation of the new organizational routines that are required to introduce CE-related activities and thus circular EI, which will then produce eco-innovative products and processes that can close material loops. Finally, Sousa-Zomer, Magalhães, Zancul, Campos, and Cauchick-Miguel (2018, p. 741) state that 'the adoption of cleaner production practices as part of company culture may act as a facilitator for CE implementation at the micro level (…) perhaps evolving to meso- and macro-levels'. According to Sousa-Zomer, Magalhães, Zancul, and Cauchick-Miguel (2018, p. 4) 'CE principles are introduced either top-down (policymakers take the lead in implementing actions) or bottom-up (organizational innovation). From the bottom-up, transitioning to a CE represents a radical change that requires new ways of thinking and doing business', and these would be facilitated by the adoption of EIs. However, we argue that the CE is more than just about re-engineering existing processes (i.e., incremental change of existing components). It is also about rewiring, that is, changing the architecture of the whole system of supply and demand (de Jesus et al., 2018). Systemic EIs provide relevant contributions to a CE, but some authors doubt this for incremental EIs, because of the need to overcome system lock-in and introduce more fundamental system changes (Könnölä & Unruh, 2007; Unruh, 2000).

More importantly, the proposition that incremental changes may support radical changes towards the CE through their possible effects on the dynamic capabilities of the firm seems a reasonable one but needs stronger empirical evidence. This view does not take into account the well-known fact demonstrated by the literature on innovation and EI that incremental changes may lock-out more radical ones.

Lock-in, and particularly infrastructural lock-in, may also be an important barrier to the CE, together with other barriers. As argued by Guldmann and Huulgaard (2020), investments made in existing manufacturing facilities and value chains make building new CE infrastructures unattractive for existing firms. Indeed, the high upfront investment cost is one of the five main barriers to the uptake of CE practices in firms observed in Kirchherr et al. (2018). Although there might be a role for incremental EIs in the CE, this role might not be neutral but rather a hindering factor. Incremental EIs can actually be a barrier (at least, to a high-level CE) if they prevent the adoption of more systemic EIs, leading to a lock-in in lower levels of circularity. The pioneering literature on the drivers of environmental technological change would support this idea on the discouraging effects of drop-in innovation on more radical technological change (see, e.g., Carrillo-Hermosilla, 2006; del Río, 2005; Faucheux & Nicolaı, 1998; Kemp, 1994). Companies with few resources may be able to afford practices such as reduction of waste, but not more demanding redesigning practices (Bassi & Dias, 2019), locking-in the company into the former practices and discouraging the latter ones for a long time. This may be a problem, because high-level CE activities (such as redesigning practices) are the main approaches in, for example, the EU CE package. Therefore, the following hypothesis is proposed.

Hypothesis 3. Nonsystemic (incremental) EIs are a barrier to a 'high-level' CE.

3 | MATERIALS AND METHODS

Several methodological steps have been followed. First, an extensive literature review was carried out at the intersection of the EI and CE literature. This revealed that the existing contributions in that area are mainly qualitative. The identified research gaps led us to propose some hypotheses and to develop our quantitative model. A search for existing variables and indicators that allow the quantification of the concepts of EI and CE and to quantitatively model their relationships was carried out. Where they existed, suitable variables and indicators were adopted, which was the case for EI features. For CE, we relied on the existing theoretical contributions on CE hierarchies (see Section 2.1), because there is yet no consensus on quantifiable variables and measurement indicators (Aranda-Usón et al., 2020; Kristensen & Mosgaard, 2020). Therefore, this was measured on a quantitative Likert scale, which was created in order to differentiate the existing levels (see Section 3.1 and Table 2). Second, as no publicly available information covered the aspects analysed in this paper, data had to be directly recollected from primary sources. Therefore, a survey was developed and sent to decision makers in SMEs in Spain (see Section 3.2). Third, regression analyses were carried out with the dataset on 197 firm-developed EIs and their impact or contribution to the CE (see Section 3.3). Full details on the procedure are given in the following sections.

3.1 | Definition of variables and indicators

On the one hand, there is an abundant literature on different aspects of EI, including EI features, sources of EI and drivers and barriers to EI (see del Río, Peñasco, & Romero-Jordán, 2016, for a review). We focus on the first aspect for the purposes of this paper. Regarding the features of EIs, their newness, radicality, scope and typology are taken into account (Table 2). For the scope of EI, we draw on the categories considered in the seminal paper by Carrillo-Hermosilla et al. (2010), who distinguish between component-level, subsystem and systemic innovation. For the typologies of EI, we rely on Kiefer, Carrillo-Hermosilla, and del Río (2019), who distinguish between continuous improvement, eco-efficient, externally driven, radical and tech-push and systemic EIs.

On the other hand, previous literature has stressed that CE may occur at different levels (see Section 2). Despite conceptual agreement on 'EI', there is no such a broad agreement on which variables describe EI and, thus, on the impacts of different EIs on CE. Therefore, we recur to a standard measurement indicator on a Likert scale. Because we try to achieve the maximum conceptual closeness to the existing work on CE hierarchies, the scale points refer to the intermediate steps from low to high circularity, in line with the previous literature (see Section 2.1). When working with nonacademic survey participants, caution has to be applied to identify levels of circularity. Besides nonmotivational biases (i.e., unavailability of information to the respondent or overconfidence leading to inflated estimations), motivational biases must also be accounted for

TABLE 2 Variables and indicators

Concept	Variable	Indicator	Description
EI	Newness of the EI	Binary ■ High/not high	Newness is considered when it is the first time the firm implements the EI. It is not high when it has been implemented in the firm before.
	Radicality of the EI	Binary ■ High/not high	Radicality is considered when it is the first time the EI is implemented within a sector of activity. It is not high when it has either been implemented in the sector or firm before.
	Subject/scope of the EI	Ordinal ■ Component-level innovation ■ Subsystem innovation ■ Systemic innovation	Drawing on the literature reviewed in Section 2, different targets, mechanisms and impacts of EI can be identified including how locally versus globally such EI shifts occur (i.e., Carrillo-Hermosilla et al., 2010; Diaz Lopez et al., 2019; OECD, 2009).
	EI type	Nominal (Likert scale) ■ Continuous improvement EI ■ Eco-efficient EI ■ Externally driven EI ■ Radical and tech-push EI ■ Systemic EI	Carrillo-Hermosilla et al. (2010), Kiefer et al. (2017) and Kiefer, Carrillo-Hermosilla, and del Río (2019) propose a specific conceptualization of EI with measurable/quantifiable EI-type indicators.
	Origin of the EI	■ Internal continuous improvement of prior solutions ■ Internal new development ■ Adoption of an eco-innovation developed elsewhere without major changes ■ Adoption of an eco-innovation developed elsewhere with major changes ■ Codevelopment in alliance with other firms	EI may surge as the result of internal continuous improvement or development processes or be adapted from external sources with or without major changes. Also, they may be jointly developed with other firms or agents (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2017).
CE	'Levels of circularity'	Ordinal (Likert scale) ■ None (no impact on increased circularity) ■ Firm-internal ■ Sectoral/regional ■ Global (system-wide circular solution)	The 'levels of circularity' were identified based on the respondents' textual description of the circularity of the CE-related solution that was translated into an ordinal Likert scale variable by the research team (see text).

[a]Source: Own elaboration.

Note: The variable and measurement 'subject/scope of innovation' is based on Carrillo-Hermosilla et al. (2010), and the variable and measurement 'EI type' is based on Kiefer, Carrillo-Hermosilla, and del Río (2019).

Abbreviations: CE, circular economy; EI, eco-innovation.

(i.e., intentional overestimations for a better 'image'). With the aim of reducing such biases to an absolute minimum, and to ensure maximum robustness of the analyses, an open textual question, which asked for a description of circularity ('Please describe the impact that the EI has had'), was included (see Table A1 for details). Then, the research team allocated the responses to the different circularity levels. The advantage of such a procedure is that the respondents do not need to know what levels of circularity exist, mitigating motivational bias. They are only required to describe a specific EI and its contribution to the CE, combating nonmotivational bias.

All variables and their measurement indicators are summarized in Table 2.

3.2 | Survey and data

Data on those specific variables were unavailable from public sources, such as the Community Innovation System (CIS). This is why a dedicated survey that contained these variables and indicators was needed. For each variable, a question was included, and for each indicator, the corresponding answer choices were elaborated. The resulting questionnaire underwent a concept validation process before its distribution. Specifically, it was sent out as a 'pilot test' to 12 academic and business experts in the field. Their feedback on the wording of questions and answer options led us to introduce some minor changes.

We focused on a specific target universe (i.e., a given economic activity, type of firm and country), as done by others in the field of EI or CE research (see, e.g., de Jesus & Mendonça, 2018; Kiefer, Carrillo-Hermosilla, & del Río, 2019). Specifically, industrial SMEs in Spain were chosen, with a target universe of 2821 firms. The focus on the industrial sector is justifiable because it is a heavily polluting and resource-using sector everywhere, and particularly in Spain. It is also an innovative sector with a large potential to adopt environmentally friendly innovations, whether circular or not, which makes it interesting for both EI and CE studies. The focus on SMEs is totally justifiable given their economic importance in the EU in terms of value creation and jobs, their relevance in terms of the pollution caused by these firms and the fact that there are ample opportunities to close cycles in these firms despite the well-known fact that they have fewer capabilities to invest in EIs leading to CE (Scarpellini et al., 2020). According to the latest Annual Report on European SMEs (Muller, 2019), SMEs account for 66.6% of EU-28 employment and about 56.4% of its value added; 99.8% of enterprises in the EU-28 are SMEs.[6] They represent 60% to 70% of the total industrial waste in the EU (Constantinos, 2010). Their reduced size makes it easier to obtain information from these firms on given EIs and CE impacts from survey respondents (Bocken, Farracho, Bosworth, & Kemp, 2014; Demirel & Danisman, 2019; EU, 2012; Sáez-Martínez, Díaz-García, & Gonzalez-Moreno, 2016). We also cover the gap on the missing focus on SMEs in CE studies, which has been mentioned by some researchers (e.g., Ormazabal, Prieto-Sandoval, Puga-Leal, & Jaca, 2018). Within these firms, the survey targeted decision makers involved in decisions to develop or adopt innovations, because it was assumed that they had sufficiently deep insights on the characteristics of the developed or adopted EI and could adequately describe the contribution to an (increased) circularity of the EI-based solution. In order to identify those decision makers, all firms were contacted by phone, and they were asked to identify the senior management member in charge of innovation-related activities or the person who carried out such functions in the firm. This was possible in 2215 cases. Some SMEs, especially smaller ones, only had one management member, that is, the founder. In total, 2206 managers or founders and their direct contact data could be identified. Invitations to participate in the survey were sent to them via email.

The survey was carried out between May and June 2014. A total of 638 answers and 430 complete answers were received. Within this set of firms, 197 firms had developed/adopted an EI and provided information on their contribution to CE. The general response rate of 29% is in line with similar studies on the topic and, thus, deemed acceptable.[7]

The answers were numerical for the EI-related variables. The textual answers for the CE variable were quantified by the research team. The goal was to establish a Likert scale that could be used in the econometric analyses. Every individual textual answer was ranked from low to high circularity. Similar responses were then grouped together in the Likert scale levels as a function of similarity with respect to the levels of circularity. For instance, descriptions such as reuse of parts, substances, waste or energy in subsequent in-house production processes were grouped together because they are related to circularity at the firm level; cooperation initiatives between firms from the same sector were grouped together as they refer to circularity at the sectorial level, and so forth. The allocation was carried out by two of the authors independently. The third author double checked the results. Concordance was reached for 163 cases. For 34 cases, either no classification was possible or the classification by the two researchers did not coincide. It was decided to exclude these cases from the statistical analyses in order to ensure maximum robustness. As a result, the Likert scale provides a measure of the level of circularity (from lower to higher): no circularity, firm-internal, sector/region-wide and global (system-wide) circularity (see Table 3 for details). The collected data are self-reported survey-based data and can thus not be considered to be as objective as e.g. patent data (Mazzanti, Antonioli, Ghisetti, & Nicolli, 2016). However, given the unavailability of the type of data needed for this analysis from other sources, the use of survey data is deemed justifiable (see the recent example of Scarpellini et al., 2020).

TABLE 3 Sample construction

Step	Number
Identified firms in the target universe	2821
Firms reached by telephone	2215
Identified contact persons in these firms and invitations sent	2206
Accessed surveys	638
Completed surveys	430
Firms having realized an activity related to EI/CE	197
Final set of data without missing values	163

[a]Source: Own elaboration.
Abbreviations: CE, circular economy; EI, eco-innovation.

3.3 | Model definition and selection

The overall goal was to quantitatively identify the relationship between CE and EI. For this purpose, regression analyses were carried out between the dependent variable 'level of circularity' and the variables on EI, which were the regressors. Given the variable types and data structure, the multinomial logistic regression (MNLR) was deemed the most suitable type of regression analysis.

Following Castellacci and Lie (2017), the general MNLR model is specified as follows:

$$Pr(Y_i = j) = \exp(\beta_j X_j)/1 + \sum_k \exp(\beta_k X_i), \text{for } j = 2, 3, \ldots, J,$$

$$Pr(Y_i = 1) = 1/1 + \sum_k \exp(\beta_k X_i), \text{for } j = 1,$$

where Y_i represents the j levels of circularity, X_i is the vector of regressors and β_j is the coefficient.

In order to identify the most suitable regression model, three intermediate models were specified. They differed with respect to the inclusion of regressors. The first model (main effects model) included all EI variables as regressors (see Table 2) and quantified their direct or main effects on the dependent

[6]The EU's Annual Report on European SMEs considers nonfinancial business sectors (NFBS) only.
[7]These include articles that have used surveys to companies. The response rate ranged from 39% in Kirchherr et al. (2018) to 2% for Italian manufacturing firms in Gusmerotti et al. (2019). Our response rate is much higher than those that have used surveys to SMEs in Spain: 21% in Aranda-Usón et al. (2020) and 13% in Ormazabal et al. (2018). It is slightly below the response rate of Liu and Bai (2014) for SMEs in China (31%).

TABLE 4 Model specification and selection

	Main effects model	Interaction effects model	Control variables model	Final model
Dependent variable	1 CE levels variable	1 CE levels variable	1 CE levels variable	1 CE levels variable
Regressors	5 EI variables	5 EI variables	5 EI variables	5 EI variables
Control variables			3 control variables - Subsector code of economic activity - Firm size - Firm age	3 control variables - Subsector code of economic activity - Firm size - Firm age
Regressor interaction effects		5^2 (10) two-way interaction effects between the 5 EI regressor variables		1 interaction effect between newness of the EI and the origin of the EI variable
Model fitting information (χ^2 reduction should be significant)	χ^2_R = 94.834 df = 42 p = .000	χ^2_R = 120.859 df = 57 p = .000	χ^2_R = 151.052 df = 111 p = .007	χ^2_R = 175.655 df = 126 p = .002
Goodness of fit (χ^2 should be non-significant)	χ^2_D = 169.115 p = 1.000	χ^2_D = 143.090 p = 1.000	χ^2_D = 219.932 p = 1.000	χ^2_D = 195.329 p = 1.000
Pseudo-R^2	Pseudo-R^2_N = 0.483	Pseudo-R^2_N = 0.574	Pseudo-R^2_N = 0.690	Pseudo-R^2_N = 0.751

[a]Source: Own elaboration.
Abbreviations: CE, circular economy; EI, eco-innovation.

variable. The second model (interaction effects model) contained all EI variables as regressors and additionally included the two-way interaction effects among them.[8] The third model (control variables model) included the main effects of the EI regressor, controlling for the industrial subsector of economic activity, firm age and size.

Both the introduction of the interaction effects and the control variables significantly improved the models compared with the main effects model. Regarding the former, the interaction effect between newness of the EI and origin of the EI proved to be significant. Thus, both the significant interaction effect and the control variables were kept in the final model. According to established textbook criteria, the final model outperforms the other three models significantly (Field, 2013; Wooldridge, 2002, 2016). In addition, it does not include too many variables, as the MNLR is sensitive to relatively low numbers of cases in relation to the number of variables (see Table 4 for full details).

Generally, the MNLR requires a reference category for the dependent variable, against which all other categories are contrasted. As the objective of the article is to assess and quantify the relationship between EI and CE, the reference category in the dependent variable was defined as 'Global (system-wide circular solution)'. Thus, the statistical results can be naturally interpreted as 'contributions to higher levels of circularity'.

[8]Interaction effects occur when the simultaneous effect of two independent variables on the dependent variable is significantly greater than the sum of the individual effects.

4 | RESULTS

4.1 | Descriptive results

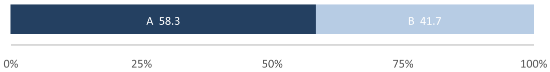
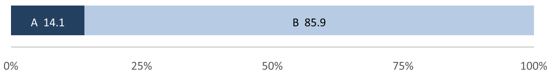
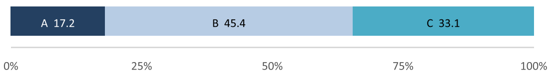
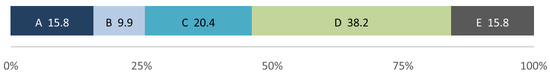
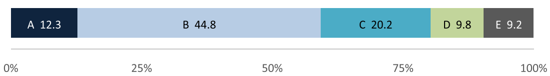
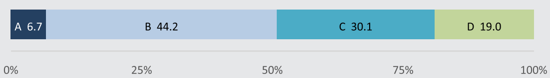
The mean scores of the observed EIs are characterized by rather high degrees of novelty (58.3% self-report high newness) and low degrees of radicalness (85.9%); that is, they are mostly incremental (Table 4). Internal development is the most common innovation process (44.8%), whereas cooperative development involving several stakeholders is the least frequent one (9.2%). Almost half of EIs represent subsystem innovations (45.4%), followed by systemic (33.1%) and component-level ones (17.2%). The EI type is predominantly radical/technology-push EI (38.2%), followed by eco-efficient and systemic EIs (both 15.8%). Concerning the level of circularity, firm-internal circular processes and solutions clearly dominate (44.2%), followed by sectoral and/or regional circularity (30.1%) and global and system-wide circular solutions (19%). Interestingly, some EIs had no impact on any level of increased circularity (6.7%), which is coherent with the idea that CE innovations are a subset of all possible EI innovations (Cainelli et al., 2020; Horbach & Rammer, 2019) (Table 5).

4.2 | Model results

The results of the final MNLR model identify the individual parameter estimates of each regressor, control variable and interaction effect, which indicate the impact on the 'level of circularity' (Table 6).

Regarding the first comparison between 'Global (system-wide circular solution)' and 'None (no impact on increased circularity)', the

TABLE 5 Descriptive results

Concept	Feature (variable)	Mean scores measurement	Mean scores graph
EI	Newness of the EI	▪ (A) High: 58.3% ▪ (B) Not high: 41.7%	
	Radicality of the EI	▪ (A) High: 14.1% ▪ (B) Not high: 85.9%	
	Subject/scope of the EI	▪ (A) Component-level innovation: 17.2% ▪ (B) Subsystem innovation: 45.4% ▪ (C) Systemic innovation: 33.1%	
	EI type	▪ (A) Systemic EI: 15.8% ▪ (B) Externally driven EI: 9.9% ▪ (C) Continuous improvement EI: 20.4% ▪ (D) Radical and tech-push EI: 38.2% ▪ (E) Eco-efficient EI: 15.8%	
	Origin of the EI	▪ (A) Internal continuous improvement of prior solutions: 12.3% ▪ (B) Internal new development: 44.8% ▪ (C) Adoption of an EI developed elsewhere without major changes: 20.2% ▪ (D) Adoption of an EI developed elsewhere with major changes: 9.8% ▪ (E) Co-development in alliance with other firms: 9.2%	
CE	Levels of circularity	▪ (A) None (no impact on increased circularity): 6.7% ▪ (B) Firm-internal: 44.2% ▪ (C) Sectoral/regional: 30.1% ▪ (D) Global (system-wide circular solution): 19.0%	

[a]Source: Own elaboration.
Note: Observations: n = 163. For the variable 'level of circularity', one category obtained no answers. Not all textual answers could unequivocally be assigned to one specific category; such answers were left uncategorized and excluded from the statistical analyses.
Abbreviations: CE, circular economy; EI, eco-innovation.

parameter estimates indicate that no EI feature acts as either a driver or a barrier in a statistically significant way.

Regarding the second contrast between 'Global (system-wide circular solution)' and purely firm-internal circularity, parameter estimates are positive and significant for the subject/scope of the EI, namely, component addition (3.454, p = .084), subsystem change (2.872, p = .131) and system change (3.217, p = .082). Thus, both component addition and eco-efficient changes at the subsystem level would be sufficient to reach firm-internal circularity but not global, system-level circularity, suggesting that Hypothesis 3 cannot be rejected.

In the same vein, eco-effective changes addressing system change are again sufficient to reach firm-internal circularity, but not on a global scale. Although counter-intuitive at first sight, this is deemed a logical result for SMEs, as more radical redesigns of larger parts of systems may simply be out of reach for these firms. These incremental changes, especially by small players, may also lead to global economic systems being locked-in in existing solutions. Therefore, eco-effective changes that affect larger parts of economic systems are a barrier towards higher levels of circularity (and a driver to lower levels). Support for this conclusion is reinforced by the fact that neither wide-scale cooperation nor technological novelty or radicality of the EI is a driving factor of change at global levels. Additionally, externally driven EIs, whereby the SMEs respond to external (environmental) pressure by eco-innovating, are also a driver for increased circularity at the firm level (4.055, p = .081), but not on a more global scale.

Concerning the third contrast between 'Global (system-wide circular solution)' and sectoral/regional circularity, EI types play a significant role. Specifically, as above, externally driven EIs (4.970, p = .046) are a driver at the sectoral/regional level, but not at the global level. On the other hand, systemic EIs are clearly a driver towards the global level, whereas they are a barrier at the lower levels (−2.486, p = .087). This highlights the importance of systemic EIs for reaching the global (system-wide) CE. Additionally, the adoption of EIs developed elsewhere (−4.668, p = .104) and internal continuous improvement processes (−4.888, p = .052) play a positive role at the global level, which suggests the importance of the diffusion of CE solutions on that global scale, once they are developed. The Spanish industrial SMEs do not seem to be able to introduce their systemic EIs in the global market, but they adopt and incrementally adapt such EIs that have been developed elsewhere.

TABLE 6 Relationships between levels of circularity and EI features: Results of the MNLR

EI features	Levels of circularity: None *relative to* global (system-wide)	Firm-internal *relative to* global (system-wide)	Sectoral/regional *relative to* global (system-wide)
Newness of the EI (high vs. not high)	7.996 (0.920)	17.764 (0.637)	1.889 (0.942)
Radicality of the EI (high vs. not high)	−3.681 (0.751)	−0.706 (0.561)	−1.580 (0.300)
Origin of the EI (internal continuous improvement)	−9.256 (0.847)	6.119 (0.799)	−4.888** (0.052)
Origin of the EI (internal new development)	−1.968 (0.972)	12.286 (0.682)	2.989 (0.869)
Origin of the EI (adoption of an EI developed elsewhere without major changes)	−8.493 (0.868)	5.243 (0.827)	−4.668* (0.104)
Origin of the EI (adoption of an EI developed elsewhere with major changes)	3.932 (0.952)	12.490 (0.722)	4.526 (0.860)
Origin of the EI (co-development in alliance with other firms)	11.984 (0.807)	14.147 (0.612)	5.501 (0.704)
Subject/scope of the EI (component addition)	14.244 (0.536)	3.454** (0.084)	8.779 (0.591)
Subject/scope of the EI (subsystem change)	9.781 (0.669)	2.872* (0.131)	17.645 (0.266)
Subject/scope of the EI (system change)	13.102 (0.570)	3.217** (0.082)	18.300 (0.248)
EI type (systemic EI)	−5.884 (0.626)	0.709 (0.557)	−2.486** (.087)
EI type (externally driven EI)	−0.460 (0.973)	4.055** (0.081)	4.970*** (0.046)
EI type (continuous improvement EI)	−2.173 (0.640)	1.207 (0.319)	−0.738 (0.597)
EI type (radical and tech-push EI)	0.652 (0.864)	0.551 (0.612)	−1.299 (0.329)
Interaction effects			
Newness of the EI (high vs. not high) × origin of the EI (internal continuous improvement)	4.006 (0.960)	−18.068 (0.631)	−0.845 (0.960)
Newness of the EI (high vs. not high) × origin of the EI (internal new development)	−6.877 (0.936)	−24.876 (0.551)	−8.839 (0.936)
Newness of the EI (high vs. not high) × origin of the EI (adoption of an EI developed elsewhere without major changes)	−0.631 (0.994)	−15.647 (0.678)	1.475 (0.994)
Newness of the EI (high vs. not high) × origin of the EI (adoption of an EI developed elsewhere with major changes)	−10.647 (0.908)	−23.918 (0.600)	−8.993 (0.908)
Newness of the EI (high vs. not high) × origin of the EI (co-development in alliance with other firms)	−19.685 (0.823)	−19.422 (0.664)	−3.162 (0.823)
Control variables			
Subsector	−9.467 (0.939)	−6.522 (0.915)	−11.751 (0.884)
Firm size	−0.019 (0.290)	−0.002 (0.759)	−0.005 (0.544)
Firm age	−0.007 (0.899)	0.011 (0.508)	−0.004 (0.833)

Note: Empty reference categories are not shown. Standard errors are in parentheses. Number of observations: 163. χ^2_R = 175.655***, df = 126, p = .002. Pseudo-R^2_N = 0.751. The industrial subsector codes were individually included in the regression. Because of space restrictions, only the first code is shown. None of them are significant at the 10%, 5% or 1% level.
Abbreviation: EI, eco-innovation.
*Significant at 15% level.
**Significant at 10% level.
***Significant at 5% level.

Taken together, these results clearly indicate that (only) systemic EIs are sufficient to reach high-level (global and system-wide) circularity and, thus, Hypothesis 1 cannot be rejected. On the other hand, a global diffusion of adequate solutions is crucial for reaching a global CE. In particular, not all contributions towards such a global CE must consist of radical and new in-house developments. For example, adopting adequate external solutions and adapting them to the individual firm is a strong driver to reach a global CE. It is important to note that firms cannot externally be forced to do so. Pressure is translated into lower levels of circularity, being a barrier to higher levels. On the other hand, developing nonadequate (below systemic) solutions does not contribute at all to the CE, which confirms that Hypothesis 3 cannot be rejected. High EI radicality or newness is not related to the CE. Therefore, Hypothesis 2 can be rejected. Finally, firm size, age and industrial subsectors do not play a relevant role.

5 | DISCUSSION

Several insights can be inferred from the results of the MNLR analysis. Generally, and maybe most importantly, EI features do not act as general drivers or barriers to CE but are context (level) specific.

First and foremost, our results show that reaching a global and system-wide CE is contingent on systemic EIs as a transition mechanism. Interestingly, systemic EIs can both be developed in-house by firms and subsequently be introduced in the global economy, or be adopted from external sources and merely be adapted through minor changes. Thus, both the development and diffusion of systemic EIs contribute decisively to the transition towards a global CE.

The Spanish industrial SMEs both develop and adapt systemic EIs but with a clear dominance of the latter, given that they are not always capable of successfully introducing their systemic EIs on a global scale. On the other hand, the firms in the target universe are quite active in developing other kinds of EIs, especially radical and tech-push and continuous improvement-based EIs.

However, sustainable transitions towards a high-level CE explicitly require systemic EIs. We find out that it is not possible to scale below-system-level EIs up to the system level and that only system-wide EIs are deemed an adequate tool to reach global circular solutions. These findings are in line with several contributions in the literature, which stress the role of systemic innovation in attaining the CE (de Jesus et al., 2018; Kirchherr et al., 2017; Prieto-Sandoval et al., 2018; Vence & Pereira, 2019). Below-system-level innovations are not enough to reach high-level circularity. Interestingly, EIs at component or subsystem level do not merely contribute 'less', but are barriers to high-level circularity, which is in line with the findings in the EI literature on the 'lock-in' role of drop-in, incremental innovations (del Río, 2005; del Río & Unruh, 2007; Kemp, 1994; Unruh, 2000; Unruh & Carrillo-Hermosilla, 2006). For Spanish industrial SMEs, even eco-effective change addressing the system level is a barrier to a global CE. As mentioned above, this may be so due to the difficulties they face when trying to introduce their solutions on a global scale, given the problem of infrastructural lock-in (see, e.g., Carrillo-Hermosilla et al., 2010). Our results are also in line with the few analyses that have included the variable 'high investment costs' as a hindering factor to the uptake of CE practices in firms and found that this is indeed a very relevant barrier (e.g., Guldmann & Huulgaard, 2020; Kirchherr et al., 2018), because SMEs may simply be 'too small' from a resource perspective to globally diffuse their EIs. On the other hand, our results are only partially in line with the findings of those authors who stress the role of radical innovations in this context (e.g., Cullen, 2017). Although radicality is not found to be a driver to any level of CE, systemic EIs are. This provides some evidence that the CE depends less on technologically radical, or very novel, solutions and more on solutions that address the functioning of the system. This may very well be reached with existing technology.

Furthermore, our findings are in contrast to Katz-Gerro and López Sintas (2018), who show that the probability of adopting high-level CE practices increases in SMEs that have already adopted the lower level CE practices. Our findings show that both practices are not related. They are also partially in contrast to those who argue that incremental EIs may have a role to play in the CE (see, e.g., Cainelli et al., 2020; Gusmerotti et al., 2019) and that incremental and radical/systemic innovations are complementary in achieving a CE, because this is a gradual process that starts with the adoption of the innovations with the lowest levels of circularity (Aranda-Usón et al., 2020; Garcés-Ayerbe et al., 2019). Our results stress that this is only the case when firms adopt externally developed systemic EIs and adapt them incrementally. Indeed, most CE innovations adopted in our sample are incremental, which is in line with the findings in the literature (Aranda-Usón et al., 2020; Bassi & Dias, 2019; Garcés-Ayerbe et al., 2019; Katz-Gerro & López Sintas, 2018; Ormazabal et al., 2018). However, those authors do not investigate whether the adoption of those incremental EIs represents a barrier to systemic EIs and a higher level of circularity. Therefore, the infrastructural lock-in induced by incremental IE has a clear negative effect on higher CE levels, although further research should explore the extent to which this is offset by the positive effects of the adoption of incremental EIs on the dynamic capabilities of the firm, as proposed by Demirel and Danisman (2019), Katz-Gerro and López Sintas (2018) and Scarpellini et al. (2020) (see the detailed discussion in Section 2).

Finally, our results point out that external pressure does induce an increase in circularity at the company and regional/sectorial level, but not at the global level. Legislators or stakeholders can thus force firms to adopt more sustainable practices, but a global CE cannot be reached that way. This is to be expected, as the legislation to reach a global CE must be globally coordinated or passed by a global policymaker. Both scenarios are unrealistic at present.

5.1 | Implications for theory and practice

The findings of this paper support the idea that EIs are instrumental in achieving the CE but that this relationship is mediated by EI features. They confirm that distinct EI types contribute differently to a 'high-level' CE. Some are drivers and others are barriers, whereas the contribution of others is neutral.

In line with previous studies on the topic, although using other methods, our findings indicate that (only) systemic EIs support a 'high-level' CE. They also show that EIs at lower levels are more likely to be developed or adopted by firms but that they do not contribute to a global CE. We also show that EIs at lower levels can be a barrier to a high-level CE. Spanish SMEs find considerable difficulties to have their systemic EIs penetrate global markets. These results have obvious implications for both private and public decision makers, given the strong path dependencies and lock-ins that we observe in existing sectors (Markard et al., 2012). As argued by O'Brien (2014, p. 6), indeed, the most difficult challenge for the transition to a CE, and the main task of policy, will be to overcome systemic lock-ins, which are the outcome of infrastructural lock-in, unfavourable regulatory frameworks, networks organized around vested interests, risk-averse organizational models or value systems underlying the choices and practices of producers and consumers.

Our results have particular implications for (infrastructural) systemic lock-in. For practitioners willing to develop the highest levels in the CE hierarchy, our results imply that a detailed analysis of the long-term implications for the company of adopting a given EI should be carried out. Given that technological innovations are usually embedded in long-lasting capital assets, any CE innovation being adopted will lock-in the company for years. Thus, care should be taken when adopting a CE innovation, which may look economically optimal from a short-term point of view but suboptimal in a longer term horizon, taking into account a circular transformation. Gusmerotti et al. (2019) have found that at least Italian firms follow this short-term approach to the CE.

On the other hand, the relevance of our results for policymakers is undeniable. For instance, identifying which EIs contribute or constrain the achievement of the CE in companies is an important step towards empowering practitioners, policymakers and researchers to identify effective EI pathways towards the CE and devise solutions that overcome the barriers to those EIs and accelerate their adoption (Kristensen & Mosgaard, 2020). This paper contributes to such identification of the relationship between EI features and CE levels.

For public policymakers, committed to encourage a high-level CE, our findings suggest that policies need to be implemented which encourage systemic EIs. In order to steer the transition towards a global CE, they should try to promote, both, new developments and the adoption of solutions developed elsewhere. Because more incremental EIs lock-out more systemic ones, there is a risk that policy interventions intended to support a CE will in fact promote incremental EIs that lock-in the economy into lower CE levels. Therefore, our findings would lead to very different policy recommendations to those of Katz-Gerro and López Sintas (2018, p. 495), who argue that 'at a policymaking level, governments should encourage SMEs to get involved initially in efficiency improvement activities and, once they have gained experience in their deployment and see the benefits, to encourage them to move on to the next step to transforming their technologies (…) it is easier for people to make a bigger commitment to something (e.g., to the CE) if they have already made a smaller commitment in the same direction (e.g., reducing waste in a linear economy)'. Thus, if, as the literature on EI usually indicates and our results suggest, incremental sustainability improvements tend to be implemented easier than systemic and radical sustainability improvements (Carrillo-Hermosilla et al., 2009; Diaz Lopez et al., 2019) and the former lock-in the latter, then policymakers have a key role to play to avoid such lock-in in lower circularity levels and address systemic change directly.

6 | CONCLUSIONS

Several authors have noted in the past that the analysis of the antecedents of CE implementation at the microlevel remains a largely unexplored topic (Franco, 2017; Ghisellini et al., 2016; Lieder & Rashid, 2016; Sousa-Zomer, Magalhães, Zancul, Campos, & Cauchick-Miguel, 2018), and this is particularly the case with the contribution of EI to the CE. This paper has tried to close this gap in the literature.

CE and EIs are deemed instrumental in achieving a sustainable transition and, thus, have received considerable attention by academics, practitioners and public policymakers. Although concepts are interrelated and some of their connections have been explored, this has been done in a rather generic and unsystematic manner. In particular, the few contributions on the EI–CE links have abstracted from the impact of EI features on CE levels. In addition, most contributions have relied on literature reviews or have been undertaken in a theoretical or quantitative manner. Quantitative analyses have been missing.

This paper has provided an analytical framework on the relationships between different EI features and CE and has carried out an empirical analysis of these relationships. Our findings suggest that the transition towards a CE requires system innovations. Only systemic EIs contribute to a global CE, whereas other EI features (component additions, small changes in existing subsystems such as production processes and especially external pressure-induced EIs) act as barriers. At lower levels, such as sector/region and firm, some EI features contribute to circularity. Surprisingly, upscaling an EI from a lower level to a global circularity level is not possible, and technological novelty is not a driver of the CE. The results support the understanding of how EIs enable a transition to the CE. EIs contribute to CE on different levels by acting as drivers and/or barriers. However, such contributions, particularly to a high-level CE, are limited. Indeed, we may wonder whether we can aspire to have a high-level, global and full CE at all, as it requires the development and global diffusion of adequate innovative solutions. However, global cooperation between all national/supranational policymakers seems highly unfeasible, and no global policymaker with such a mandate exists. Instead, we can probably only aspire to achieve second-best circularity in certain territories, such as the EU. The high-level CE cannot be achieved either with incremental and bottom-up steps, as suggested by our results. Therefore, the challenge for policymakers is to support EIs to reach second-best circularity, primarily by encouraging systemic EIs.

Our results suggest that the CE requires systemic innovations, but the adoption of these will be very slow in the absence of public intervention. The industrial change of the CE will not emerge suddenly and will be the outcome of well-coordinated actions initiated in different parts of the system (Franco, 2017). If policymakers want to contribute to the circularity of the economy, they should prioritize the support of systemic EIs. But they should also be careful not to adopt policy measures that encourage EIs which lead to (suboptimal) short-term environmental benefits at the expense of locking-out EIs that result in higher levels of circularity and greater potential environmental benefits in the long-term. Identifying the types of policy interventions that will be needed to encourage those EI types that lead to a higher CE level without encouraging incremental EIs that lead to such lock-in is a fruitful area for further research. Some instruments may not be supportive in this regard and could even be counterproductive. This might be the case with environmental management systems, which may induce the aforementioned lock-in, as stressed by Könnölä and Unruh (2007). The finding in Ormazabal et al. (2018) that there is no relation between the SMEs that have achieved some environmental certification and the level of implementation of CE may corroborate this idea, but certainly, more research is needed, as Scarpellini et al. (2020) suggest that a positive relationship between (informal) environmental management systems and CE implementation may exist. Indeed, a policy-oriented approach to this topic is needed. Which framework conditions, instruments and design elements within instruments should be applied to encourage the systemic EIs, while simultaneously avoiding the risk of lock-in, should be the focus of future research.

Although related to the previous point, our results have also considerable implications for academics engaged in sustainability transitions and CE transitions. Because policy measures should ascertain the path-dependent character of EI adoption contributing to the CE, policy interventions will need to be based on deep analyses of the drivers and barriers to the adoption of higher level EIs at the microlevel, preferably using the systems of innovation approach. So far, these analyses have been scarce.

Some limitations of this paper suggest other fruitful avenues for future research. The survey was targeted at firms only. Despite the high relevance of firms in the transition towards CE, other types of actors certainly play a role too. On the other hand, the results are representative of the target universe and may be difficult to generalize. Empirical studies in other countries and sectors (subsectors within and sectors beyond the industrial one) or with larger samples are recommendable. The CE transition will probably have different dynamics and timescales in different geographies, with EIs emerging and diffusing differently in different locations. Taking into account the geographical dimension is particularly relevant for changes towards a CE, notably for understanding dynamics of supply and value chains. Second, the evolution to a CE is dependent upon sector specificities. These have been disregarded in this paper, as well as the timing issue involved in the transition to a CE. Finally, this paper has shown the lock-in role played by incremental EIs towards high CE levels, but further research should explore to which extent this is offset by the positive effects of the adoption of incremental EIs on the dynamic capabilities of the firm.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX A

TABLE A1 Survey questions

Concept	Variable	Question in the survey	Measurement scale in the survey
EI	Newness of the EI	Is it the first time that the eco-innovation you developed or adopted has been implemented in your firm?	Binary
	Radicality of the EI	Is it the first time that the eco-innovation you developed or adopted has been implemented in the economic sector your firm operates in?	Binary
	Subject/scope of the EI	How was the environmental benefit mainly obtained?	- A component was added in order to minimize negative environmental impacts without realizing major changes in the products or services (such as installation of filters) - A part of the product or process has been changed without realizing major changes in the products or services themselves (such as partial improvements) - Significant changes in the product or service have been realized and these changes result in alternative products or services when compared with the original ones - Fundamental changes in the products or services with the aim of altogether eliminating the negative environmental impacts - Complete new development of products or services that are environmentally friendly
	EI type	The EI type was identified in a prior study by (Kiefer et al., 2017) who use a detailed survey with that aim	
	Origin of the EI	What was the main origin of this eco-innovation	- Internal continuous improvement of prior solutions - Internal new development - Adoption of an EI developed elsewhere without major changes - Adoption of an EI developed elsewhere with major changes - Codevelopment in alliance with other firms
CE	Levels of circularity	Please shortly describe the eco-innovation and the impact it has generated	Open textual question

Abbreviations: CE, circular economy; EI, eco-innovation.