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Building a taxonomy of eco-innovation types in firms. A quantitative perspective

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ABSTRACT

Eco-innovations, or innovations that reduce the environmental impacts of production and consumption activities, are considered crucial for sustainability transitions and a key element of a Circular Economy. Although previous contributions have acknowledged the existence of different types of eco-innovations (e.g., product vs. service or incremental vs. radical), a precise conceptualization of eco-innovation types, which takes into account its multifaceted character, is missing. Yet such a conceptualization is crucial in order to understand how eco-innovations contribute to a sustainable transition, how policy makers can promote different eco-innovation types, and how business practitioners can develop eco-innovations. This article covers this gap in the literature. Its aim is twofold: 1) to develop a quantitative method to categorise different eco-innovation types in a particular setting, taking into account their distinct features and dimensions; 2) to apply this method in a given sector and country, building a taxonomy of eco-innovation types. It draws on a survey of 197 Spanish industrial small and medium size enterprises (SMEs) which developed or adopted an eco-innovation between 2012 and 2013. The statistical analyses reveal the existence of a taxonomy of five eco-innovation types: systemic, externally driven, continuous improvement, radical (technology-push initiated) and eco-efficient. They differ in their techno-economic configurations, contribution to environmental sustainability and corporate goals and required changes in the firms. Specific policy and managerial implications are deducted.

1. Introduction

Eco-innovations, or innovations that reduce the environmental impacts of production and consumption activities, whether intended or not (OECD, 2009, p. 3), are considered crucial in sustainable transitions. They contribute to the Circular Economy at the macro, meso and micro levels (Pauliuk, 2018; Kirchherr et al., 2017). Eco-innovations are an enabler at the macro / system level with their main focus on resource, material and energy flows in economic systems. At the meso level, eco-innovations serve to close the (mainly product and process focused) loop, including resource use efficiency, reuse, recycle and innovations in business models, value creation and capture. Finally, at the micro level, eco-innovations are related to efficiency, pollution/waste reduction and design and they are focused on products and processes (De Jesus and Mendonça, 2018, p.3010).

Notwithstanding, not all eco-innovations contribute in an equal manner to a Circular Economy (Franco, 2017). Different types of eco-innovations and eco-innovators have often been mentioned: e.g. large vs. small eco-innovators (De Marchi, 2012; Del Rio et al., 2017; Kammerer, 2009; Kesidou and Demirel, 2012; Rave et al., 2011; Walz, 2011), new and old ones (Del Rio et al., 2017; Horbach, 2008; Rave et al., 2011; Veugelers, 2012; Wagner, 2007), process, product, organizational and marketing eco-innovations (Belin et al., 2011; Frondel et al., 2008; Rave et al., 2011; Rehfeld et al., 2007; Rennings et al., 2006; Veugelers, 2012) and new-to-the-firm and new-to-the-market eco-innovations (Del Rio et al., 2017; Rave et al., 2011). Many papers refer to the abstract and generic dichotomy of “radical” vs. “incremental” eco-innovations, a reflection of the general innovation literature. Such distinction takes into account the environmental impacts of the innovation and the level of rupture with existing products and processes.

These categorizations are necessary to understand the concept of eco-innovation, but they are rather simplistic. As shown by Carrillo-Hermosilla et al. (2010) and Kiefer et al. (2017), in addition to environmental impacts, eco-innovations have many aspects or dimensions which could contribute to their classification in different “types”. There is a broad agreement in the literature that different eco-innovations are needed in different timeframes, given the barriers to those eco-innovations and the changes in existing production processes that they require. In other words, different types of

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Table 1
Describing the dimensions of eco-innovation in Carrillo-Hermosilla et al. (2010).
Source: Carrillo-Hermosilla et al. (2010).

Dimension	Description
Design	From an environmental perspective, there are two different design rationales to eco-innovations: redesigning human-made systems to reduce their environmental impacts, versus the search for minimization of those impacts. When these two perspectives are combined with the degree of compatibility/rupture of eco-innovations with the established techno-economic system, three different approaches can be proposed to identify the role and impacts of eco-innovations: ● Component addition: "end-of-pipe" solutions minimize negative externalities on the environment, leaving existing processes unchanged. ● Sub-system change: eco-efficient solutions and the optimisation of sub-systems lead to a reduction of negative environmental impacts. ● System change: This involves the redesign of systems towards eco-effective solutions, reducing the environmental impacts on the ecosystem and society at large.
User	All innovations target certain markets. Apart from economic demands, eco-innovations also cover sustainability issues. Firms can learn about both by engaging with current and potential users: ● User development: firms need to identify which (current and potential) users may provide inputs for the innovation process. ● User acceptance: firms need to understand and anticipate the demands of their users if they want their (sustainable) solutions to be successful.
Product-service	A "product-service system" provides value to customers through a "function" combining products and services targeted at specific needs. These systems are embedded in business models and comprise sustainability aspects. The more radical an eco-innovation is, the greater the change in the underlying "product-service system", including production, delivery, consumption and disposal activities within a network. ● Changes in a product-service deliverable imply changes in the underlying "product-service system" and, thus, in the value delivered to the customer, influencing the customer's perception of its relationship with the firm. ● Changes in the product-service process imply changes in the process of how and with whom the product/service is provided and, thus, in the value delivered.
Governance	The more radical and systemic the eco-innovations are, the higher is the likelihood that stakeholders beyond the boundaries of the firm will be involved. The growing importance of knowledge-related cooperation has recently been stressed. Firm governance is required in order to overcome potential obstacles and to renew and maintain cooperative relationships with all stakeholders. Firm governance can also fulfill social expectations of firm behavior.

eco-innovations contribute differently to sustainable transitions and the Circular Economy (Carrillo-Hermosilla et al., 2009; Garcia-Granero et al., 2018). Thus, if different eco-innovation types have a (complementary) role to play in this context, their systematic identification, structured within a taxonomy, is a key step in order to assess the barriers to their adoption and, ultimately, to apply targeted policies which promote them. Furthermore, our results may guide firms to identify the most appropriate eco-innovations for them, taking into account their corporate goals and the requirements and challenges involved in their development or adoption.

Therefore, potential eco-innovation practitioners and policy makers would benefit from the provision of such a method and the resulting taxonomy of eco-innovation types in a given sector/country. Unfortunately, and to the best of our knowledge, neither a widely accepted taxonomy of eco-innovations nor a quantitative method to derive such a taxonomy in a given setting exists. Previous studies resort to different characteristics and aspects when referring to eco-innovations, resulting in many different concepts and understandings (Kiefer et al., 2017). Systematic consolidation has not been undertaken in the past, and a common view is missing. Furthermore, due to the sheer number of identifiable characteristics, the concept of eco-innovation is unmanageably complex and, as a consequence, many studies end up with simple characterizations, such as radical vs. incremental.

Indeed, recent academic literature stresses the need for a better understanding of eco-innovation. As argued by Xavier et al. (2017), "the understanding of the characteristics and particularities of the eco-innovation process is crucial to manage it more efficiently" (op.cit., p.2). Our empirical advancement of the framework is in line with this call. Therefore, this paper tries to cover this gap in the literature. Its aim of this paper is twofold: 1) to develop a quantitative method to categorise different eco-innovation types in a particular setting, taking into account their distinct features and dimensions; 2) to apply this method in a given sector and country, building a taxonomy of eco-innovation types.

This article builds on the novel methodological contribution by Carrillo-Hermosilla et al. (2010) and Kiefer et al. (2017) who provide a model consisting of several dimensions and subdimensions, accounting for the numerous individual characteristics of eco-innovations. We elaborate a method which allows the application of the proposed model to the industrial sector of a national economy, leading to the identification of "real world" eco-innovation types that have been developed in such a context. Based on a survey of 197 Spanish industrial small and medium size enterprises (SMEs) which developed or adopted an eco-innovation between the years 2012 and 2013, the statistical analyses reveal the existence of five eco-innovation types. These results show that none of the previous eco-innovation types are fully represented in our taxonomy, a clear indicator for existing overlaps, fuzziness and knowledge gaps in the field. Furthermore, this study generates additional insights for each eco-innovation type, some of which are completely novel and not backed-up by previous research.

Therefore, this paper contributes to the literature on several fronts. On the one hand, it develops a methodology to categorise different eco-innovation types which can be applied to any sector/country. On the other hand, it contributes to the debate on an eco-innovation taxonomy by providing quantitative evidence in a given sector and country. In the specific case of this article, the application of the methodology leads to the identification of 5 eco-innovation types, going beyond theoretical classification of eco-innovations and case-study anecdotal evidence. Finally, it also represents an important intermediate step in the research on barriers to eco-innovation, which are likely to differ for distinct eco-innovation types. In turn, this research is deemed policy-relevant, as different eco-innovation types are likely to require different support measures.

Accordingly, the paper is structured as follows. The next section provides the theoretical framework. The methodology is described in Section 3. The results of the analysis are provided in Section 4 and discussed in Section 5. Section 6 concludes.

2. Theoretical framework

Our research is rooted on the theoretical framework based on four dimensions of eco-innovation proposed in Carrillo-Hermosilla et al. (2010) (see Table 1). This was chosen for two reasons: 1) its impact on the literature, having accumulated 560 citations in Google Scholar and being renowned as a "Highly Cited Paper" (top 1% of its academic field) according to the ISI Web of Science and; 2) its theoretical guidance and suitability for the purposes of this article.

In short, 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 is about external cooperation in networks. Eco-innovations have characteristics in all these dimensions. Therefore, jointly addressing them is a promising avenue for a better understanding of the phenomenon.

Kiefer et al. (2017) advanced the original framework of Carrillo-

Table 2
Describing the subdimensions of eco-innovation in Kiefer et al. (2017).
Source: Kiefer et al. (2017).

Dimension	Subdimensions	Conclusion
Design	• Environmental impacts from the input side • Business model and firm processes / eco-effectiveness • Savings / eco-efficiency • Environmental impacts from the output side • Reduction of toxicity of the product or service	The design dimension is made up of 5 factors that refer to impacts on the input composition of the product or service, impact on the firm's processes, impact on (direct) savings, various types of emissions and toxicity. The different factors relate to a different extent to aspects of environmental impact and competitiveness.
User	Involvement and anticipation of the acceptance of • internal clients/users • external clients/users • intermediaries	Both the different types of potential and actual eco-innovation users and the different models of interaction are important in eco-innovation.
Product-Service	• Radical deviation from current business bases • Relations with suppliers • Incremental advances within existing business models • New products / services	Changes in the product-service deliverable and product-service process stress the "revenue side" of the competitive advantage of firms. Successful eco-innovations must provide higher value for existing customers and/or attract new customers. The changes encompass the value chain and its actors.
Governance	• Scientific-academic cooperation • Cooperation with universities and research centers • Cooperation with competitors and industrial organizations • Cooperation with clients • Cooperation with NGOs • Cooperation with regulators • Frequency of cooperation with suppliers • Importance of cooperation with suppliers	Eco-innovations are often the outcome of cooperative efforts between different stakeholders. The relevance of cooperation depends on the stakeholder group and its end goal.

Hermosilla et al. (2010) and performed quantitative analyses to reveal the general characteristics of eco-innovations. They found out that, within the aforementioned 4 dimensions, eco-innovations are characterized by 20 "subdimensions" that represent their character traits and can be used to comprehensively describe the phenomenon. A brief description of the subdimensions is provided in Table 2 (see Kiefer et al., 2017 for further details).

Although Kiefer et al. (2017) identified the set of characteristics and subdimensions of eco-innovation, the authors did not use them to derive different eco-innovation types in a particular sectoral and national context. Thus, a taxonomy of eco-innovations is still missing. This is precisely the research gap covered in this paper, which necessarily draws on the theoretical framework developed in the aforementioned two articles. Based on the idea that eco-innovations with similar character traits belong to the same eco-innovation type, a cluster analysis with those subdimensions of eco-innovation is carried out in this paper.

3. Materials and methods

The qualitative aspects that the article aims to quantify are not present in any publicly available dataset and, thus, a survey which directly focuses on those aspects is needed. Quantitative analyses are carried out with self-collected primary data from a set of eco-innovative Spanish industrial SMEs.

3.1. Target universe and data gathering

This study is targeted at Spanish industrial SMEs for the following reasons[1]. The industrial sector is very relevant in the transition towards sustainable production and consumption patterns (OECD, 2009). It has a high weight in the economy and relatively high environmental impacts and it is an innovative and eco-innovative sector (Andersen, 2008; Machiba, 2010).

An increasing number of studies on eco-innovation have recently focused on SMEs (Bocken et al., 2014; Coad et al., 2016; Cuerva et al., 2013; Klewitz et al., 2012; Klewitz and Hansen, 2013; Marin et al., 2014; Triguero et al., 2015, 2013). Their importance for eco-innovations is considerable, given that 99% of European firms are SMEs (Bocken et al., 2014; EU, 2012)), and given their mayor role in employment creation (2/3 of employment in the private sector is generated by SMEs (Bocken et al., 2014; Brammer et al., 2012; EU, 2012)) and their substantial contribution to national income (Ayyagari et al., 2007; Bocken et al., 2014) and environmental impacts. Therefore, since they are an important part of the problem, they could also be part of the solution if they developed or adopted eco-innovations. Indeed, SMEs are highly relevant in eco-innovation development, adoption and diffusion due to some unique characteristics, such as high flexibility, lean structures, informal communication patterns and local economic and social embeddedness (De Jesus et al., 2017; Keskin et al., 2013; Mazzanti and Zoboli, 2005), although the difficulties of SMEs to eco-innovate have also been stressed by several authors (De Marchi, 2012; del Río, 2005). SMEs have developed eco-innovations that have proved very important in the sustainable transformation of industries and societies (Hansen and Klewitz, 2012; Klewitz et al., 2012; Sáez-Martínez et al., 2016). Nevertheless, the literature on eco-innovations in SMEs is still tiny (De Jesus et al., 2017).

Spain was chosen due to its specific features with respect to North European countries, where eco-innovation studies have been carried out (e.g., Germany and U.K.): a weaker national innovation system, lower rigor in applying ecological regulations and a lower willingness of consumers to pay a "green" price premium (Del Río et al., 2015).

There were 2821 industrial SMEs in Spain in 2014, according to the Iberian Balance Sheet Analysis System (SABI). E-mail questionnaires were sent to staff responsible for innovation in May and June 2014. 638 persons accessed the survey and 430 completed it. 197 firms had developed or adopted an eco-innovation between 2012 and 2013. The response rate (29%) is deemed satisfactory compared to similar studies (Horbach et al., 2012; Kesidou and Demirel, 2012). Annex I provides details on the final sample.

[1] This article uses the official definition of SMEs by the European Commission in terms of number of employees (European Commission, 2017): SMEs have between 50 and 250 employees.

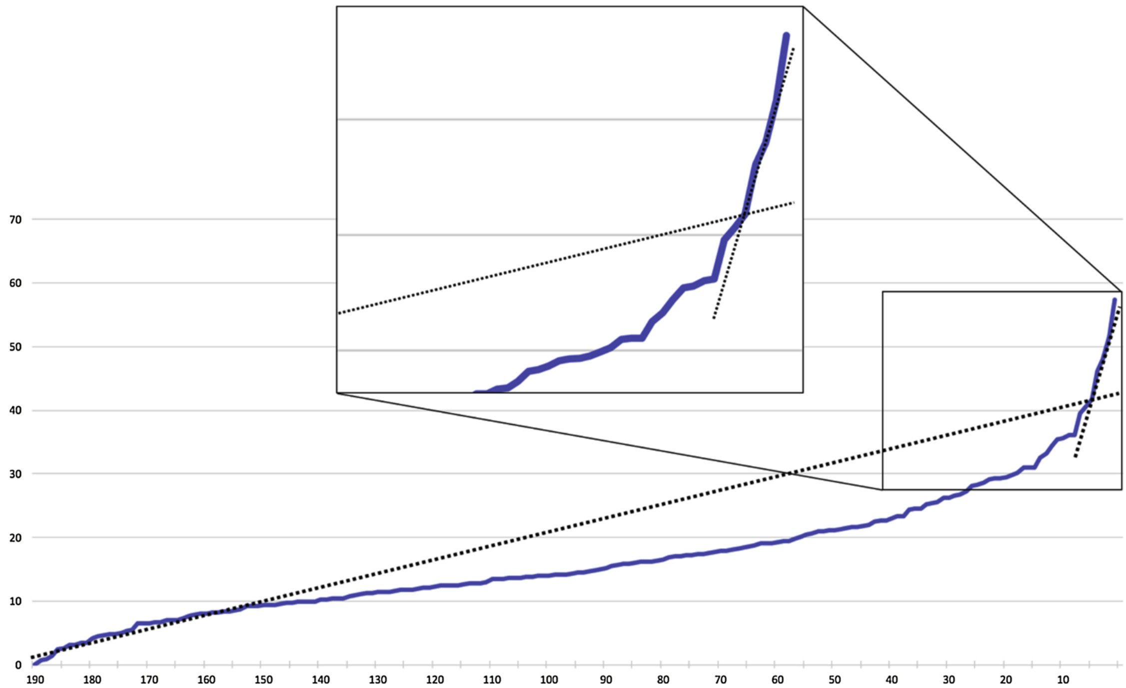

Fig. 1. The conglomeration coefficient as a function of the number of clusters.
Source: own elaboration.

3.2. Statistical techniques

The data collected on observed eco-innovations have been quantified on the 20 subdimensions found in Kiefer et al. (2017) using Factor Analyses based on the solution of Principal Components Analysis (PCA). Cluster Analysis (CA), which groups similar observations according to similarities/dissimilarities, was performed in order to reveal the different types of eco-innovations. As usual, two steps were followed (Castellacci and Lie, 2017; Hair et al., 2010, 1998). In a first step, a hierarchical CA was carried out in order to identify the optimum amount of clusters. The "between-groups linkage" technique was applied, as it maximizes the distance between different clusters. Variables were standardized with the measure "Z-Score" in order to account for different scale effects (Hair et al., 2010, 1998). Then, the agglomeration schedule and the dendrogram were studied. The inflection points were assessed in order to determine the optimum amount of clusters. A second CA was carried out in order to test and confirm those results. The "Ward Method", which maximizes the variance between different clusters (Hair et al., 2010, 1998), was chosen for this purpose. Once the optimum amount of clusters was identified, each case was allocated with the help of a k-means CA, which creates k clusters and allocates the n cases accordingly. This is done by minimizing the Squared Euclidian Distance between the observation and the central mean value of the cluster (center or centroid / k-mean) (Hartigan and Wong, 1979; Likas et al., 2011; Wagstaff et al., 2001). After similar eco-innovations were grouped together using two-step CA, leading to several eco-innovation types, the differences in the resulting eco-innovation types were assessed with analyses of variance (ANOVA). Similar methods have recently been followed in the context of eco-innovation (Castellacci and Lie, 2017; Sáez-Martínez et al., 2016)[2]. However, to our best knowledge, this study is the first attempt to quantitatively explore the existence of different eco-innovation types.

[2] For example, both Castellacci and Lie (2017) and Sáez-Martínez et al. (2016) use similar methodologies, combining factor and cluster analyses in order to identify dimensions/groups and build a taxonomy. Castellacci and Lie (2017) detect the dimensions of green innovation in South Korea and Sáez-Martinez et al. (2016) elaborate a taxonomy of technological trajectories in SMEs in Spain.

4. Results

Eco-innovations with similar characteristics are grouped under the same eco-innovation type. The CA is carried out with the sub-dimensions of eco-innovation (its main characteristics). This allows us to discover the different eco-innovation types that exist according to our data, from which a taxonomy of eco-innovation is derived.

Specifically, turning points are identified after 8, 5 and 3 clusters with the "between-groups linkage" technique. After 8 clusters, the coefficient increases considerably from an average value of 0.196 to 3.394. After 5 clusters, the increase is 4.339 and, after 3 clusters, it is 3.641. The agglomeration coefficient and the corresponding number of clusters are shown in a line graph (Fig. 1).

The turning point can be observed as a change in "direction" of the line (also known as the "elbow"). It is displayed at the intersection of the two direction lines. The suitability of the selection of the 5 clusters is checked visually. This solution maximizes the distance between the different clusters.

In addition, the agglomeration schedule and dendrogram are studied using the "Ward Method". Possible solutions would be the creation of 10, 8, 5, 3 and 2 clusters. Both the "between-groups linkage" and Ward Method confirm that the solution of 5 clusters is appropriate.

In the matrix of final cluster centroids, central values are obtained for each factor and variable (Table 3). The final cluster centroids represent standardized values and, thus, they cannot be attributed a specific meaning in terms of the variables themselves. They are interpreted in relative terms and with respect to average values.

An analysis of the variance (one-way ANOVA) is carried out in order to confirm that the cluster centroid values (average values of factors and variables) actually differ across the 5 clusters. The analysis of the variance requires a normal distribution and uniformity of variance (Field, 2013; Hair et al., 2010).

The results of the Kolmogorov-Smirnov and Shapiro-Wilk normality tests suggest that the data have a non-normal distribution. The variance

Table 3
Final cluster centroids in the subdimensions.
Source: own elaboration.

Subdimensions of eco-innovation	Cluster centroids				
	1	2	3	4	5
Purely ecological characteristics (composition of inputs and downcycling)	.413	−.918	−.964	.331	−.156
Business processes and model / eco-effectiveness	.523	−1.007	−1.221	.427	−.203
Savings / eco-efficiency	−.344	−.152	−.463	.188	.241
Environmental impacts from the output side (probably EOP)	.427	−.307	−.614	−.024	.020
Reduction of toxicity of the product or service	.411	−.738	−.402	.232	−.244
Involvement and anticipation of the acceptance of external clients/users	.403	−1.223	−1.381	.688	−.432
Involvement and anticipation of the acceptance of internal clients/users	.587	−.867	−.990	.274	−.139
Involvement and anticipation of the acceptance of intermediaries	.577	−.206	−.481	.337	−.904
Radical deviation from current business bases	.584	−.990	−1.508	.664	−.630
Relations with suppliers	.771	−.791	−1.260	.286	−.312
Incremental advances within existing business models	.547	−.833	−1.399	.630	−.709
New products / services	.629	−.857	−1.385	.647	−.797
Scientific-academic cooperation	.384	−.613	−.705	.211	−.173
Cooperation with universities and research centers	.247	−1.215	.114	.369	−.439
Cooperation with competitors and industrial organizations	.246	−1.399	.138	.051	.261
Cooperation with clients	.547	−.976	−.984	.398	−.408
Cooperation with NGOs	−.322	1.626	−.095	−.102	−.257
Cooperation with regulators	−.429	1.322	−.046	−.143	.094
Frequency of cooperation with suppliers	1.482	−.548	−.594	−.442	.077
Importance of cooperation with suppliers	1.482	−.445	−.512	−.495	.078

homogeneity (Levene) test identifies whether the variances in the distribution of the 5 clusters are significantly different. The results show that the variance is not homogenous for several variables[3]. Therefore, instead of an analysis of the variance, robust analyses of the equality of averages and, particularly, the Welch and Brown-Forsythe tests have been applied (Field, 2013; Hair et al., 2010). The significance in both tests is always given, which confirms the existence of a significant difference between the centroid values among the clusters. Therefore, five clusters referring to five eco-innovation types have been identified. In the next step, the 5 eco-innovation types resulting from the CA are analyzed and interpreted.

4.1. Systemic eco-innovations

The results of the CA show that the eco-innovations in cluster 1 have above-average scores in all subdimensions of the design dimension and in all user subdimensions, including acceptance of external and internal clients and intermediaries. They also score high on the characteristics of changes in the product/service process with a significant deviation from current sales and traditional markets, towards new models of cooperation with suppliers and also to incremental advances in the established product-service system (within existing business models). Similarly, the score in the subdimension of new products and services is one of the highest among all clusters. Regarding the subdimensions of governance, high scores in scientific-academic cooperation, cooperation with suppliers, interactions with competitors and industry associations and collaboration with clients can be observed. We conclude that there are 37″ systemic eco-innovations".

4.2. Externally driven eco-innovations

Cluster 2 is characterized by below-average scores in all the design subdimensions, including changes in the composition of product or service inputs, organizational/productive processes and business models, sustainability from the output side (EOP) and lower toxicity. This type of eco-innovation has scores which are below the average in both the user (acceptance) and product-service subdimensions. None of the characteristics on the value proposition stand out. Cooperation with NGOs and regulators clearly needs to be emphasized, as they show the highest scores of all the eco-innovation types. There are 20 eco-innovations under this "externally driven” eco-innovation category.

4.3. Continuous improvement eco-innovations

The eco-innovations in cluster 3 resemble those in cluster 2, with scores well below the average in all subdimensions of design, user and product-service. In terms of cooperation and the governance dimension, their score is below the average in most subdimensions. There are 20″ continuous improvement eco-innovations".

4.4. Radical and tech-push initiated eco-innovations

Cluster 4 has high scores in the design subdimensions of purely ecological characteristics and rupture with current business models, and scores above average in the subdimensions of external and internal clients and intermediaries. With respect to the subdimensions of product-service, the radical deviation from the current bases of business, new products and services and incremental changes have high scores. Cooperation with research centers, universities and consultants rank high, whereas cooperation with clients is relatively less important. There are 76 “radical and technology-push initiated” eco-innovations.

4.5. Eco-efficient eco-innovations

The eco-innovations in cluster 5 are characterized by high scores in the subdimension of savings / eco-efficiency, and cooperation with competitors and industrial organizations. The scores in the other subdimensions are relatively low. 37 “eco-efficient eco-innovations” have been observed.

[3] Business processes and model / eco-effectiveness; Savings / eco-efficiency; Environmental impacts from the output side (probably EOP); Reduction of toxicity of the product or service; Involvement and anticipation of the acceptance of internal clients/users; Incremental advances within existing business models; New products / services; Scientific-academic cooperation; Cooperation with universities and research centers; Cooperation with competitors and industrial organizations; Cooperation with clients; Cooperation with NGOs; Frequency of cooperation with suppliers; Importance of cooperation with suppliers.

5. Discussion

A taxonomy of five eco-innovation types has been identified, taking into account their underlying structure with respect to different dimensions and aspects. Each type is characterized by a singular configuration. Some resemble previously established eco-innovation types, such as systemic (Carrillo-Hermosilla et al., 2010) or eco-efficient (McDonough and Braungart, 2010) eco-innovations. However, none of the previous eco-innovation types are fully represented in our taxonomy.

Systemic eco-innovations represent a rupture with previous business processes and models (eco-effectiveness) and lead to considerable environmental improvements. They entail the introduction of new products and services, deviate very significantly from the previous business bases and focus on new markets and customers, confirming the main characteristics of systemic eco-innovations which have been proposed by previous contributions (e.g., Braungart et al., 2007; Carrillo-Hermosilla et al., 2010). They have a clear focus on the market, which is why they emerge under demand-pull regimes, although technology-push also plays a role in this context.

The absorption of already disseminated research results is preferred over engaging in actual research activities. This can be a consequence of the limited resource and competence availability in SMEs. Systemic eco-innovations involve intensive interactions with clients and intermediaries during their development or adoption. This result covers a gap in the eco-innovation literature because the role of users has not been much addressed in the past (De Jesús and Mendonça, 2018, p.3013). Cooperation is critical for this type of eco-innovation, as shown by other authors (De Jesus et al., 2017; Wagner and Llerena, 2011). Scientific cooperation is as important as cooperation with competitors.

In contrast, *externally-driven eco-innovations* arise in the context of interactions with regulators and NGOs. They involve either a reaction to or an anticipation of external pressures, including regulations or environmental demands from society. This highlights the importance of the two subdimensions of governance (cooperation with NGOs and regulators). It could have been expected that these eco-innovations are of the EOP type. However, the results suggest that this is not the case. This eco-innovation type does not have a direct equivalence in the previous literature.

Similarly, *continuous improvement* efforts in firms lead to a specific eco-innovation type. The value proposition of the firm does not change significantly and there isn't a significant rupture with established processes. Clients, intermediaries or other actors in the firm's network are not significantly involved in the development or adoption of these eco-innovations. They arise as "normal" innovations, are not particularly novel and do not lead to substantial reductions in environmental impacts. They emerge in isolation and without any noteworthy interactions.

Radical and technology-push initiated eco-innovations are characterized by substantial reductions in environmental impacts, disruptive technological innovation and radical changes in current business bases. Although these features are similar to systemic eco-innovations, there are also clear differences. Whereas systemic eco-innovations have a strong market focus (demand-pull), radical eco-innovations are rather supply-push. External cooperation is restricted to universities and research centers and, thus, both science and knowledge-related. Cooperation with clients, usually considered a feature of a market-pull approach (Nemet, 2009), is less relevant than for systemic eco-innovations. The results confirm the role of science-push approaches to innovation that entail high degrees of novelty, innovativeness and low compatibility with established systems, along with high sustainability gains (Nemet, 2009).

Finally, *eco-efficient eco-innovations* are focused on input savings and firm-internal efficiency. This is in line with the eco-innovation literature, since eco-efficiency is usually conceptualized as savings in (natural) resources and energy per unit of output (Csutora, 2011). These eco-innovations are not motivated by sustainability concerns, but by competitiveness. This is in line with De Jesus and Mendonça, (2018) who show that SMEs perceive eco-innovations as a tool to increase efficiency and competitiveness. Although this eco-innovation type shows high scores in cooperation with competitors and other business-related industrial organizations, neither upstream nor downstream cooperation with other actors plays a role.

Although our taxonomy of 5 eco-innovation types includes previously defined eco-innovation types, it is broader than existing classifications. Importantly, a dichotomous or multi-step linear eco-innovation classification does not arise, probably due to the multifaceted nature of the phenomenon and its many character traits, some of which are incorporated in opposite ways in different eco-innovation types.

This study suggests some relevant managerial and policy implications. Regarding the former, firms may develop or adopt a given eco-innovation type depending on their corporate objectives and the specific requirements of the eco-innovation. These objectives include improving their competitive advantage by increasing revenues (better and new products and access to new markets) or reducing costs, improving their environmental image or, simply, complying with regulation without undertaking major changes in the firm's production processes. Managers may be interested in the creation of new product or service categories, the opening of completely new market segments, or the satisfaction of previously unmet demands. They may also be interested to serve existing market segments differently. Systemic or radical technology-push initiated eco-innovations may achieve this purpose. They also support environmentally proactive strategies in firms. Competitive advantage through technology leadership may be pursued by radical technology-push initiated eco-innovations, whereas operational efficiency, cost reductions and price leadership may be reached via eco-efficient or continuous improvement eco-innovations. Obviously, firms may pursue different goals simultaneously and, thus, a combination of eco-innovations in order to serve them could make sense. This may entail developing or adopting eco-innovations in different timeframes.

Different eco-innovations bring different types of requirements for the firms. Recent research has highlighted the role of managers (and their risk-averse or risk-loving attitude) in strategic decision-making processes (Horbach and Jacob, 2018; Forsman, 2009). Adequate tools for risk-averse individuals may be continuous improvement and eco-efficient eco-innovations. These are drop-in eco-innovations which do not change the value proposition of the firm, do not involve a significant rupture with the established business and industrial processes and systems and, thus, do not entail major changes in the firm. In contrast, explorative business and innovation approaches may be pursued by systemic and radical eco-innovations, which have a low degree of compatibility with established systems. These entail considerable upfront investments which pose considerable financial challenges for firms. Furthermore, some eco-innovations require strong cooperation between the firm and key stakeholders. This is certainly the case with systemic eco-innovations (cooperation with market actors, especially suppliers) and radical eco-innovations (cooperation with knowledge-related institutions). Eco-efficient eco-innovations strongly benefit from information flows with competitors.

Externally-driven eco-innovations deserve a special mention. They are merely adopted in order to comply with environmental regulations or to meet environmental demands from the local community. Nevertheless, identifying those regulations and relevant eco-innovations to comply with them can be challenging for some SMEs, which have scarce internal resources compared to larger firms (De Marchi, 2012). Therefore, public decision-makers may find it useful to provide this information to SMEs in order to enhance compliance and/or reduce compliance costs.

In general, environmental regulation (whether in the form of command-and-control or market-based instruments) provides a general incentive to encourage the development and uptake of all the eco-innovation types. However, since eco-innovations have different requirements, targeted interventions are more relevant for some eco-innovations than for others. Given their long-maturity periods, and major changes in the firm, appropriate policy framework conditions (long-term targets, regulatory stability and regulatory stringency) are particularly suitable for systemic and radical eco-innovations (del Río et al., 2010). In addition, given their high up-front investments, financial support in the form of soft loans or grants may also be recommendable. Support for cooperation with other market actors or knowledge-based institutions is critical for these eco-innovations and are probably also relevant for others (eco-efficient ones). Given the special features of SMEs in terms of low availability of resources and capabilities, information provision on best eco-innovation practices may be particularly suitable for these firms. Table 4 summarises this discussion.

Overall, the five eco-innovation types are likely to be relevant across different time frames for the Circular Economy and the sustainability transition. While some can easily be dropped-in in the short-term because they are part of business-as-usual corporate practices and do not require major changes in the existing firms or the institutional environment around them (continuous improvement and eco-efficient eco-innovations), others need a longer maturation period since many types of changes are required (systemic and radical and technology-push initiated eco-innovations). A trade-off between environmental benefits and switching costs can be observed. On the other hand, our results suggest that some eco-innovations are environmentally-motivated, whereas the environmental improvements are rather a side-effect of business as usual practices for others. Therefore, in line with Kemp and Foxon (2007), environmental motivation cannot be the single or main criterion to identify eco-innovations. Finally, the different eco-innovation types show distinct combinations of demand-pull and supply-push influences. This is also reflected in the different relevance of cooperation with clients (demand-pull) or with research centers and universities (supply-push).

6. Conclusion

This paper has developed a quantitative method to categorize different eco-innovation types, which takes into account their different features and dimensions. As a result of its application, a taxonomy of eco-innovations in a given sector and country has emerged. The empirical results show that Spanish SMEs in the industrial sector eco-innovate in multiple ways, combining different aspects and dimensions[4]. Five eco-innovation types have been undertaken by those firms: systemic, externally driven, continuous improvement, radical and technology-push initiated and eco-efficient eco-innovations. However, there isn't a common pattern of high scores for each eco-innovation type in all dimensions and aspects. On the contrary, those five types combine high scores in some dimensions/aspects with low scores in others.

Systemic and radical technology-driven eco-innovations are both characterized by a high degree of novelty and rupture with respect to existing production processes and business models in the firm as well as considerable environmental benefits. However, whereas the latter arise as a result of scientific and technological research, systemic eco-innovations emerge with a clear focus on the market and create a completely new competitive base. They arise from a wide network of cooperation and entail deep changes in this network.

Externally driven eco-innovations emerge as a response to external pressures from society or legislation. In contrast, continuous-improvement eco-innovations arise from within the SMEs as a result of day-to-day business activities and are fully compatible with established processes. They represent small advances with respect to existing processes, products and business models in the firms. Similarly, eco-efficient eco-innovations, which are motivated by cost-reduction concerns (input savings), increase the efficiency of products, services or processes, leading to environmental benefits.

These results have several policy and managerial implications. Although the literature has put the emphasis on radical and systemic eco-innovations, which have the greatest potential to contribute to sustainable transitions, policy makers and firms should be aware that this transition also requires the understanding of the contribution of other types of eco-innovations. Eco-innovations which are developed and diffuse in different time scales are needed. Some would be more incremental, such as "end-of-pipe" solutions or eco-efficiency, and can be adopted immediately, whereas systemic changes require joint efforts and more time for their successful implementation. Thus, dual approaches both in policy and management should be explored in order to encourage incremental improvements in the short-term, while simultaneously promoting more radical systemic changes in the long-term.

On the other hand, firms may develop or adopt a given eco-innovation type depending on their corporate objectives and the challenges that the eco-innovation implies. Systemic and radical eco-innovations are most useful to enhance the competitive advantage of firms by opening new market segments and facilitating technology leadership, but they entail major changes in the firm and require strong cooperation links with key stakeholders. In contrast, operational efficiency and cost reductions may be reached via eco-efficient or continuous improvement eco-innovations. These drop-in eco-innovations arise from normal day-to-day operations. If the company is only interested in complying with regulation or meeting the environmental demands of the local community, then externally-driven eco-innovations are the appropriate choice, although they neither create economic value nor improve the competitive position of companies. Since firms are likely to pursue different goals simultaneously, developing or adopting different types of eco-innovations in different timeframes could make sense.

The uptake of all eco-innovation types in industrial SMEs would be favoured by three types of cross-cutting policy measures: environmental regulation, financial support and information provision to these firms, given their scarcity of internal resources. However, since eco-innovations face different challenges, targeted interventions can be recommended. In particular, systemic eco-innovations benefit from appropriate policy framework conditions and support for cooperation with other market actors or knowledge-based institutions. The impulse from science and technological research is crucial for radical eco-innovations and, thus, promoting scientific and technological research in universities and public research centers or facilitating scientific and technological exchanges in public-private partnerships would be useful to encourage these eco-innovations.

The method developed in this paper needs to be applied to other countries and sectors in order to claim that this taxonomy is generalizable, although the method to identify eco-innovation taxonomies certainly is. Therefore, further research should be devoted to its application to other national and sectoral settings. On the other hand, despite careful questionnaire design, biases due to subjective responses to the survey can never be ruled out in self-reported data.

[4] For example, different degrees of environmental improvements and time frames of these improvements, demand-pull vs. technology-push influences, environmental vs. competitiveness motivations, breadth and depth of cooperation, degree of changes required in supply chains, business models and competitiveness bases and compatibility/rupture with existing technologies (processes and systems), infrastructures and institutions.

Table 4
Main managerial and policy implications.
Source: Own elaboration. * Long-term targets, regulatory stability and regulatory stringency.

	SYSTEMIC	EXTERNALLY DRIVEN	ECOEFFICIENT	CONTINUOUS IMPROVEMENT	RADICAL
OBJECTIVES Why would a company be interested in developing or adopting this eco-innovation type?					
Better corporate image	√	(√)			√
Access to new markets, new products	√				√
Cost reductions			√	√	
Only compliance with regulation		√			
CHALLENGES What are the requirements for the company to get involved in this eco-innovation type?					
Intensive cooperation with key actors	√ suppliers, industry associations, competitors, scientific institutions		√ Competitors, suppliers		√ Knowledge-related cooperation (research centers and universities)
Radical changes in the firm	√	(drop-in innovation)	(drop-in innovation)	(drop-in innovation)	√
Internal financing	√				√
Responding to external pressures		√			
POLICY IMPLICATIONS What are the most relevant policy interventions to encourage the uptake of this eco-innovation type?					
Appropriate framework conditions*	√				√
Instruments	-Environmental regulation. -Support for cooperation, public-private partnership. -Financial support -Information provision on markets. -Public procurement	-Environmental regulation. -Information provision to SMEs (on regulation and eco-innovations to comply with it)	-Environmental regulation. -Support for cooperation between companies. -Information provision on best practices to SMEs.	-Environmental regulation. -Eco-innovation training programs. -Information provision to SMEs on best practices.	-Environmental regulation. -Support for cooperation with universities and research centers. -Financial support. -R&D support. -Public procurement.

Unfortunately, hard data were not available for our research purposes and, thus, a survey had to be carried out.

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Annex 1 Overview of the sample: eco-innovators (firms) and eco-innovations

Observed eco-innovators (firms)		
Industry Sector (CNAE 2009) (% of firms, Top-10 sectors)	Manufacturing of plastic products	7.1
	Manufacturing of components, parts and accessories for motor vehicles	6.6
	Manufacturing of other general purpose machinery	5.1
	Manufacturing of concrete, cement and plaster elements	4.1
	Manufacturing of metal components for construction	4.1
	Manufacturing of other metal products	4.1
	Manufacturing of basic chemicals, nitrogen compounds, fertilizers, plastics and synthetic rubber in primary forms	3.6
	Graphic arts and related services	3.1
	Manufacturing of soaps, detergents and other cleaning and polishing products	3.1
	Manufacturing of bakery and pastry products	3.1
Focus market (in %)	Business-to-business	65.0
	Business-to-consumer	4.6
	Both focus	27.9
Foreign activity by imports and exports (in %)	Exports and imports	71.6
	Exports	13.7
	Imports	4.6
	Only domestic activity	10.2
Age of firms (in years)	30 (average value)	
Size of firms (in number of employees)	107 (average value)	
Legal form (in %)	("Public limited companies")	59.9
	Spanish Sociedad Limitada ("Limited liability companies")	39.6
	Cooperatives	0.5
Reported eco-innovations		
Novelty of the eco-innovation in the firms (in %)	New in the developing/adopting firm	53.8
	Not new in the developing/adopting firm	39.1
Novelty of the eco-innovation in the primary sectors of operation of the firms (in %)	New in the primary sector of operation of the firm	12.7
	Not new in the sector of operation of the firm	61.4
Source process leading to the eco-innovation (in %)	Internal development	42.1
	Development with external cooperation	21.8
	External sources and internal adoption	9.6
	Alliances with other firms and joint development	8.6
	Internal development as the result of continuous improvement processes (not a dedicated innovation process)	11.2
Techno-economic and environmental configuration (in %)	End-of-pipe / component addition	14.7
	Change in product/process (partial improvements)	42.1
	Considerable changes and avoidance of environmental damage	31.5

Source: own elaboration.

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