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RESEARCH ARTICLE OPEN ACCESS

# Exploring External Knowledge Networks for Catalysing Material and Energy Eco-Innovations in Spanish Firms

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**Received:** 4 April 2024 | **Revised:** 23 April 2025 | **Accepted:** 15 July 2025

**Funding:** Authors acknowledge funding from INFESE Project PID2020-112984GB-C21 funded by the Ministry of Science and Innovation of Spain and GRIPICO Group funded by the University Complutense of Madrid.

**Keywords:** collaborations | eco-innovation | external knowledge networks | qualitative comparative analysis (QCA)

## ABSTRACT

Several studies have suggested that collaborations between partners could be a key factor in obtaining eco-innovation results. However, there is still an unresolved question regarding the combinations of external knowledge networks that could stimulate eco-innovation. Using qualitative comparative analysis (QCA) on a sample of Spanish firms in 2020, we found evidence that collaborations between different partners could affect eco-innovation and that those partnerships differ depending on the green goal (material or energy). This leads to three main results: (1) For material, six possible paths of collaboration were found, while for energy, we found five paths. (2) Only one common path has been found for both goals: the absence of collaboration with Customers, Competitors and Universities and Research Centres, simultaneously. (3) Among all possible paths, one partner was most repeated: Universities and Research Centres, appearing in four out of six paths for material and two out of five for energy eco-innovation.

**JEL Classification:** L14, L20, O31, O33, Q50

## 1 | Introduction

The European Union (EU) recognises that innovation is essential for achieving its environmental goals, integrating it into environmental strategies to promote sustainable progress. Eco-innovation is a catalyst for encouraging a more environmentally friendly and sustainable economy (European Commission 2011). Specifically, eco-innovations are key to reducing environmental risk, pollution and the consumption of material and energy resources used in production processes (Kemp and Pearson 2008). The development of eco-innovations, and thus, the introduction of eco-friendly products, is particularly relevant in polluting sectors such as the petroleum and the apparel industry, which are the most polluting sectors worldwide (Abbate et al. 2023; Centobelli et al. 2022).

However, the introduction of eco-innovations is not an easy path. Eco-innovations are more complex than general innovations due to the need for specific green knowledge, the presence of green regulation and the challenging coordination at organisational and managerial levels (Bataineh et al. 2024; De Marchi 2012; Díez-Martínez et al. 2023; Higgins and Yarahmadi 2014). Additionally, implementing eco-innovations in isolation entails high risk and significant costs (Andersen 2002; Araújo and Franco 2021). Therefore, collaboration with external sources of knowledge could compensate for the complexity of eco-innovations, stimulating their development (Andersen 2002; Araújo and Franco 2021; Kobarg et al. 2020; Melander and Pazirandeh 2019).

The literature on collaborations and eco-innovation examines the positive effect of individual collaborations with different partners—such as Suppliers, Customers, Competitors, Universities and Research Centres (public and private) and Knowledge Intensive Business Services (KIBS)—on eco-innovation (Cainelli et al. 2015; De Marchi 2012; De Marchi et al. 2022; Horbach 2008; Pereira et al. 2020; Sánchez-Sellero and Bataineh 2022). However, several authors understand eco-innovation as a dynamic process in which different combinations of partners contribute different capabilities, and ultimately, their joint efforts generate strong effects on eco-innovation (De Marchi and Grandinetti 2013; Marzucchi and Montresor 2017; Zhang et al. 2022). Despite its relevance, there is still scarce evidence considering collaborations as a possible set of combinations (networks), which could show different paths to eco-innovation (De Marchi 2012; De Marchi et al. 2022). In addition, these collaborative networks could depend on the green goal pursued in the eco-innovation process—material or energy efficiency (Marzucchi and Montresor 2017).

Based on the above, this paper seeks to answer various calls for studies found in De Marchi et al. (2022) and Araújo and Franco (2021) related to the analysis of collaborations among firms and the role of collaboration patterns concerning the green goal—energy and material—of eco-innovations. To this end, two research questions (RQs) are proposed. The first aims to identify the most suitable external partners for eco-innovation, differentiating by green goal: What combinations of external sources of knowledge encourage material and energy eco-innovations? (RQ1). On the other hand, our second RQ aims to identify differences between the set of partners and green goals: Do these combinations vary when we analyse different green goals? (RQ2).

To address these RQs, we applied an interesting methodology called qualitative comparative analysis (QCA), using a sample from the Spanish Innovation Survey and Statistics on R&D activities for the year 2020. This methodology offers the key advantage of identifying multiple paths involving the interaction of different factors that lead to the same result (Ragin 2009). This technique has been used to test combinations of partners and collaborations by De Marchi et al. (2022) or Díez-Martínez et al. (2023), among others.

Findings reveal six paths of networks for material eco-innovation, and only five configurations appear for energy eco-innovations. Universities and Research Centres and Customers emerge as the most representative partners. Additionally, a common collaboration path is identified in both types of eco-innovation: the simultaneous absence of collaboration with Customers, Competitors and Universities and Research Centres.

Our study contributes to the literature in three ways. First, we develop a framework on collaboration partners and eco-innovation, using a restricted-access dataset developed by the Spanish National Institute of Statistics, which contains more up-to-date data than previous studies on this topic (De Marchi et al. 2022). Second, we add evidence on the different collaboration networks that stimulate eco-innovation using the QCA methodology and differentiating between green goals—material and energy. Finally, we compare collaboration combinations for each type of eco-innovation, identifying a common pathway and offering new insights into the impact of networks on eco-innovation.

The paper is organised as follows. In Section 2, the background that supports our analysis is developed. In Section 3, both the data and methodology used for the analysis are further explained. In Section 4, the main results are interpreted and discussed, and finally, Section 5 provides the conclusions.

## 2 | Literature Background

### 2.1 | External Sources of Knowledge and Eco-Innovation

Firms are pressured to adapt their production processes to more sustainable and efficient outputs. In this scenario, eco-innovation emerges as the main tool for gaining resource efficiency and sustainability.

According to pioneering definitions, eco-innovations are understood as the introduction of new or improved products or processes aimed at reducing environmental impacts, such as minimising the use of material and energy resources (Kemp and Pearson 2008). The introduction of eco-innovations is particularly complex due to several issues: (1) There is a pressing environmental concern that needs an urgent solution (Arranz et al. 2023); (2) eco-innovations entail higher costs, and there are no incentives for investing in eco-innovations (De Marchi et al. 2022); (3) this type of innovation demands specific green knowledge, which is the most risky (Araújo and Franco 2021); and (4) eco-innovations need greater political intervention and regulations (Arranz et al. 2023).

In this process, authors establish that a good strategy for dealing with these complexities is the generation of inter-firm alliances or partnerships, that is, collaborations with Suppliers, Customers, Competitors, Universities and Research Centres and KIBS (De Marchi 2012; De Marchi et al. 2022; Fabrizi et al. 2022; Horbach 2008; Horbach et al. 2012). Collaborations facilitate the introduction of new ideas and resources while also enabling firms to share risk, cost and uncertainty, thereby helping them overcome limitations and eco-innovate (Araújo and Franco 2021; Arranz et al. 2023).

From a theoretical view, the use of collaborations for eco-innovations is supported by three brands of literature: institutional, resource-based and transaction cost theories. The first one postulates that firms are pressured by the regulatory environment,[1] and therefore, they will try to adapt similar practices and structures to gain social legitimacy and improve their chances of survival (DiMaggio and Powell 1983; Meyer and Rowan 1977). This adaptation process to regulations may either facilitate or constrain collaborations. Thus, the success of collaborations often depends on the alignment of expectations and values among partners, as well as the ability to manage multiple and sometimes conflicting institutional logics (Yin and Jamali 2021). Moreover, in situations where the regulatory framework is relevant, as in the field of eco-innovations, firms tend to build partnerships with other market actors to adapt to environmental regulations (Lin and Darnall 2015; Niesten and Jolink 2020). Therefore, the pressure to comply with the regulatory framework for eco-innovations fosters collaborations by allowing firms to pool resources and knowledge (Cainelli and Mazzanti 2013).

On the other hand, resource-based theory highlights how firms can exploit strategic resources to achieve a sustainable competitive advantage (Barney 1991). Firms have heterogeneous resources, which means that they may adopt different strategies depending on their different resource combinations. Therefore, collaborations enable firms to access complementary resources (Dyer and Singh 1998), facilitating the acquisition of knowledge and, in the end, sustainable innovation (Grant and Baden-Fuller 2004; Munodawafa and Johl 2019). Thus, firms could gain a competitive advantage by acquiring knowledge, capabilities, technologies and other external resources through partnerships (Chesbrough 2003; Kobarg et al. 2020; Niesten and Jolink 2020; Yarahmadi and Higgins 2012), which leads to more effective and efficient development of environmentally friendly technologies and practices (Munodawafa and Johl 2019; Singh et al. 2020).

Finally, transaction cost theory examines how firms face costs associated with negotiating, contracting and executing market economic agreements (Williamson 1981). Organisations seek to establish mechanisms that minimise these costs, which depend on the frequency of transactions, their alignment with the organisation, the degree of uncertainty and the degree of resource specificity (Celtekligil 2020). In this sense, eco-innovation has been associated with high transaction costs due to its high level of complexity and uncertainty (Albitar et al. 2023). The use of collaborations could help to reduce uncertainty and costs because both are shared by the different actors involved in the partnership (De Marchi 2012; Niesten and Jolink 2020). In addition, when several actors collaborate, they can develop long-term relationships, which enhances information sharing and mitigates opportunistic practices.

From an empirical view, the literature on eco-innovation drivers has frequently analysed different sources of external knowledge through two aggregate variables—*Breadth* and *Depth*. The concepts of *Breadth* and *Depth* were defined by Laursen and Salter (2006). According to these authors, *Breadth* refers to the number of external sources that firms use in their innovative activities, while *Depth* measures the degree of intensity in the use of external sources of knowledge. Authors have found a positive relationship between eco-innovations and these dimensions (Fernández et al. 2021; Ghisetti et al. 2015; Ketata et al. 2015; Mothe et al. 2018; Torrecillas et al. 2023; Triguero et al. 2018).

This evidence has also been reinforced by studies analysing individual partners (Cainelli et al. 2015; De Marchi 2012; De Marchi and Grandinetti 2013; Yarahmadi and Higgins 2012). Regarding *Suppliers*, authors have postulated that this external partner adds the applied knowledge needed for the development of eco-innovations, offering a great opportunity to share the cost and risk of eco-innovation projects (Araújo and Franco 2021; Cainelli et al. 2015; De Marchi and Grandinetti 2013; Yarahmadi and Higgins 2012). Empirical studies have found a positive relationship between this collaboration and eco-innovations (Cainelli et al. 2012; De Marchi 2012; De Marchi and Grandinetti 2013; Kobarg et al. 2020; Pippel 2015).

Collaborations with *Customers* allow firms to adapt to the green market requirements. In this line, De Marchi et al. (2022) affirmed that Customers are key partners, and Kobarg et al. (2020) found that collaboration with Customers is particularly relevant for product eco-innovations. However, Customers do not appear as frequent collaborators in general eco-innovation studies (Araújo and Franco 2021; Cuerva et al. 2014; De Marchi and Grandinetti 2013).

In addition, collaborations with *Competitors* facilitate the exchange of materials and commodities. It also enables firms to incorporate know-how, expertise and best practices, which may provide a competitive advantage (Kobarg et al. 2020; Yarahmadi and Higgins 2012). This type of collaboration helps firms to solve general problems in areas not related to firms' core businesses (Sánchez-Sellero and Bataineh 2022). However, empirical evidence does not show that collaboration with Competitors is fostering eco-innovations (Cuerva et al. 2014; Kobarg et al. 2020).

Finally, collaborations with *Universities and Research Centres* and *KIBS* facilitate the development of advanced innovations, helping firms overcome limitations related to advanced knowledge at the research frontier. These types of collaborations contribute to generating a higher innovative capability (Martínez-Cháfer et al. 2021) and enable the introduction of more complex forms of eco-innovations (Cainelli et al. 2015). KIBS play a particularly important role in eco-innovations when firms have lower innovation capabilities, as suggested by De Marchi and Grandinetti (2013) and De Marchi et al. (2022). The empirical literature has found such a positive influence of Universities and Research Centres (Arroyave et al. 2020; Cainelli et al. 2012; De Marchi 2012; De Marchi and Grandinetti 2013; Kobarg et al. 2020; Pippel 2015) and KIBS (De Marchi 2012; De Marchi and Grandinetti 2013) on eco-innovation in samples from different countries.

However, it should be noted that the success of collaborations in eco-innovation also depends on organisational aspects, as well as a strategic approach to sustainability (Baumgartner 2009). In this context, organisational innovations facilitate the acquisition of external learning—through different partnerships—and at the same time, they encourage the assimilation of new knowledge, helping, thus, in the development of eco-innovation. Therefore, a good connection with partners in the origin and during the process, organisational support and a green strategy are key to eco-innovation success (Chang and Chen 2013).

## 2.2 | Partnerships of Collaboration in Material and Energy Eco-Innovation

Despite the effort to individually analyse the collaboration with external partners, authors have recognised that the effects of the pattern of collaborations over eco-innovation should be analysed jointly (De Marchi 2012; De Marchi et al. 2022; Díez-Martínez et al. 2023; Melander 2018). They note that different combinations of partners could perform better than the collaboration with one external source of knowledge in isolation. As De Marchi et al. (2022) pointed out, greater heterogeneity in partner combinations or networks can lead to more successful eco-innovation adoption (Zhang et al. 2022).

In this regard, empirical evidence suggests that different collaboration networks increase eco-innovations (De Marchi et al. 2022; Díez-Martínez et al. 2023; Kobarg et al. 2020; Melander 2018). However, few studies have addressed this issue.[2]

On the one hand, the work of Kobarg et al. (2020) analyses mainly the effects of the different types of collaboration individually and jointly. This paper is the first one that introduces partnerships of collaboration to eco-innovate, differentiating by product and process as a supplementary analysis. They noted that configurations involving all partners are a necessary condition but not sufficient for achieving process eco-innovation, and configurations involving Suppliers and Customers are necessary but not sufficient conditions for achieving product eco-innovations. Meanwhile, De Marchi et al. (2022) found three important recipes[3] of partnership for eco-innovate using QCA. The first one is the *science driver*, which means that Universities and Research Centres play a decisive role in the development of ideas that could encourage eco-innovations. The second one is the *upstream research*, in which they have found collaborations with Universities, Research Centres and Suppliers. Finally, the last one is the *supply chain integration*, which includes collaboration with Suppliers and Customers.

Therefore, the study of Kobarg et al. (2020), for a sample of German firms, and De Marchi et al. (2022), analysing Spanish firms, are complementary. The first paper shows that for process eco-innovation, all the combinations of partners are necessary, while for product eco-innovation, necessary conditions are just Suppliers and Customers. The second paper found three sufficient conditions for collaboration that encourage eco-innovation: (1) Universities and Research Centres, (2) Suppliers and Customers and (3) Universities and Research Centres with Suppliers. Both studies underscore the importance of collaboration in eco-innovation, albeit using different methodological approaches and samples, thereby offering a comprehensive perspective on the mechanisms and configurations that drive eco-innovation.

In addition, the study of Díez-Martínez et al. (2023) highlights the positive effects of external information sources and cooperation in fostering innovation with a greater environmental focus.

On the other hand, the green goals pursued in the networks of collaboration and eco-innovation are also critical. This is particularly relevant in certain industries, such as clothing, where the introduction of sustainable materials is replacing conventional ones. In addition, this is also crucial in those sectors which try to reduce energy consumption in the production process, for example, industrial and transportation building sectors (Abbate et al. 2023; Centobelli et al. 2022; Wurlod and Noailly 2018).

In this regard, De Marchi (2012) and De Marchi and Grandinetti (2013) propose that future research should examine external sources of collaboration considering different green strategies. Following this line of research, Marzucchi and Montresor (2017) found that the differences between the eco-innovation modes (energy, material and other green goals) are very relevant. They noted that collaboration affects to a higher extent energy eco-innovation rather than material eco-innovation given the complexities of energy. Finally, Zhang et al. (2022) also differentiate between the green goals considering different energy and emission intensities.

Given the above, it would be valuable to explore the distinct characteristics of material and energy eco-innovation, also known as efficiency eco-innovations (Marzucchi and Montresor 2017).

*Material eco-innovations*—those that reduce the use of materials or substitute them with other materials that are less polluting—are often risky and costly (Marzucchi and Montresor 2017). However, they offer greater flexibility in adapting to green market demands or integrating new environmental knowledge acquired through different value chain actors. Such eco-innovations require adjustments in infrastructure to integrate new materials or reduce reliance on existing ones. Consequently, they frequently encounter technical challenges and high upfront costs, as they necessitate new processes and specialised technologies (Peigné et al. 2024).

*Energy eco-innovations*—those that imply a reduction of the power employed in the production process or the substitution of the energy source—tend to be more radical because they require a complex integration in the production process (e.g., industrial design, engineering mechanism, logistics and organisational management). Furthermore, they are subject to stricter regulations and political and social acceptance (Marzucchi and Montresor 2017; Walton et al. 2020). Therefore, this type of eco-innovation is exceptionally complex, costly and risky, necessitating stronger organisational support (Araújo and Franco 2021; Marzucchi and Montresor 2017; Walton et al. 2020).

Thus, material eco-innovations face greater challenges in terms of technical feasibility and initial development costs (Peigné et al. 2024), while energy eco-innovations, although they are also costly initially, are more policy-dependent (Chang et al. 2018) and offer long-term economic and environmental benefits through lower operating and maintenance costs (Safi et al. 2022). Given these distinctions, the nature of collaborations in eco-innovation is likely to differ between material and energy-focused initiatives.

Regarding value chain actors—*Suppliers and Customers*—both are relevant for the development of eco-innovations (Moreno-Mondejar and Cuerva 2020; Zhang et al. 2022). The collaboration with suppliers affects eco-innovation (Moreno-Mondejar and Cuerva 2020; Segarra-Blasco and Jove-Llopis 2019) and is expected to be relevant for both material and energy eco-innovations. However, knowledge acquired from customers is more likely to contribute to material eco-innovation than to energy-related innovations. In this sense, studies have shown that eco-innovations driven by customer knowledge often focus on reducing material consumption and enhancing product recyclability and biodegradability (Hojnik et al. 2018; Severo et al. 2015). Nevertheless, energy improvements are more exposed to regulatory pressures and industrial standards (Del Río et al. 2015) and are less influenceable by customers (Horbach et al. 2012). Thus, collaboration involving customers is expected to be more common in material eco-innovation than in energy-focused initiatives.

On the other hand, the collaboration with competitors could introduce rivalry among existing competitors, allowing firms to catch up knowledge (Araújo and Franco 2021; Segarra-Blasco and Jove-Llopis 2019) for the development of eco-innovations. As far as we know, there are no studies that have empirically found a link between material and energy eco-innovations considering competitors. However, firms in highly regulated and socially pressured areas, such as energy, often form strategic alliances with competitors to meet regulatory requirements more efficiently (Díaz-García et al. 2015). Therefore, it is expected that there will be more partnerships in collaboration with competitors in energy than in material eco-innovations.

Furthermore, due to the scale, cost and risk involved in both types of eco-innovation, the partnerships referred to as science knowledge—Universities and Research Centres and KIBS—could be decisive for the reduction of material and energy consumption (De Marchi et al. 2022; Marzucchi and Montresor 2017; Zhang et al. 2022). The science partnerships will allow firms to complement cutting-edge knowledge and emerging technologies (Corsino and Torrisi 2023). Then, we could expect various collaboration partnerships in which Universities and Research Centres and KIBS are present for both material and energy eco-innovation. However, the literature on innovation has always given a relevant role to this type of partner when firms aim to develop complex and radical innovations (Bossink 2007; Molina-Morales and Martínez-Cháfer 2016). Therefore, given the higher complexity—including political and social acceptance, as well as regulatory pressure—in energy eco-innovation, we expect that science participation will be higher for energy than for material eco-innovation (Han et al. 2023).

According to the above, mixed collaboration paths will add extra value to the firms in their efforts to eco-innovate (Zhang et al. 2022). In addition, different collaborations facilitate access to emerging technologies and cutting-edge knowledge, which are essential for eco-innovation (Araújo and Franco 2021). Therefore, we propose the following hypotheses:

**H1.** *Different combinations of collaboration could explain the development of material eco-innovations.*

**H2.** *Different combinations of collaboration could explain the development of energy eco-innovations.*

However, although some partnerships could be common in eco-innovating, at the same time, different and specific networks could appear depending on the green goal (energy or material) of the firm. Thus, we propose the following hypothesis:

**H3.** *The collaboration combinations for material and energy eco-innovations are expected to be different.*

The analysis of these combinations as a framework for material and energy eco-innovations is included in Figure 1.

## 3 | Data and Methodology

### 3.1 | Data and Descriptive Analysis

To achieve the aim of this research, we use the Spanish Innovation Survey and Statistics on R&D activities for the year 2020.[4] This survey consists of a subset of Spanish firms and incorporates data on their technological innovation activities, according to the methodology followed by the OECD Guidelines for collecting and interpreting innovation data—the Oslo Manual (OECD 2018). The survey data comprise 35,720 firms. It should be noted that there is a break in the series due to methodological changes introduced in the 2018 version of the Oslo Manual. Additionally, the creation of our eco-innovation variables (see

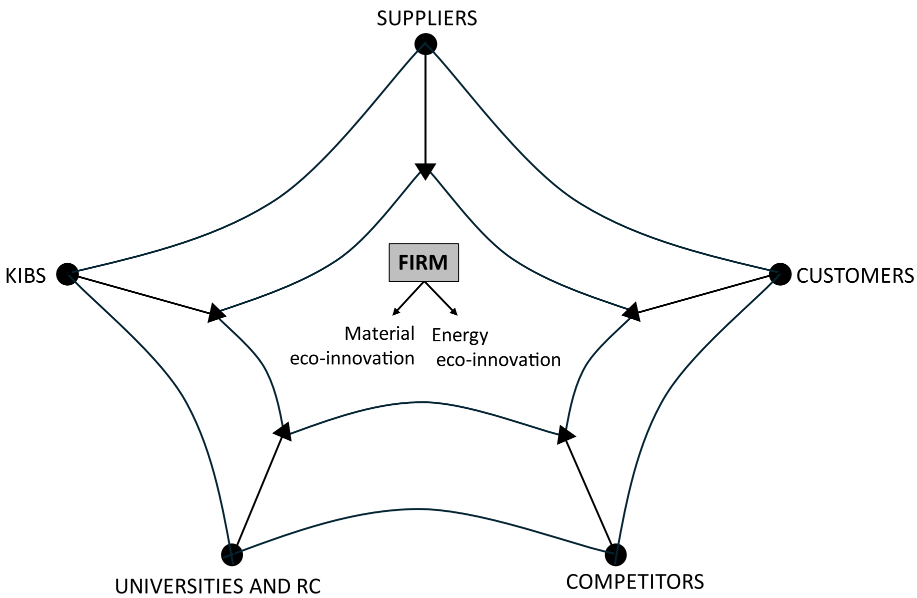


**FIGURE 1** | Research proposal. RC—Research Centres; KIBS—Knowledge Intensive Business Services. *Source:* Own elaboration.

Table A1 from Appendix A) has been possible only from 2020 onwards. Therefore, the data from 2020 are not comparable with those published in previous years. As a result, panel data analysis cannot be conducted.

The section of the survey used to obtain our outcome data (Section D.7.1) relates to the innovations introduced by firms and their environmental impacts. Among the 35,720 firms, we restrict our study to the eco-innovative ones, resulting in a sample of 3518 firms for material eco-innovation and 3986 firms for energy eco-innovation.[5]

Based on this dataset, we construct two outcome variables: material eco-innovation and energy eco-innovation. These outcome variables allow us to identify the conditions under which either material eco-innovation or energy eco-innovation occurs. These conditions, in turn, are identified through the possible relationships with different types of partners: Suppliers, Customers, Competitors, Universities and Research Centres and KIBS. Therefore, these five types of partners constitute the set of predictors for our study, which are obtained from Section D.5.1 of the survey. The definition of variables, the main descriptive statistics and the correlation matrix for all of our variables are shown in Tables A1–A3 from Appendix A.

Related to the sample and considering jointly the number of eco-innovative firms and the type of collaboration carried out, Table 1 shows a synthesis of the data (% of the sample by type of eco-innovation). We observe that the most preferred collaborative agents are KIBS, with 26.52% for material eco-innovation and 25.99% for energy. This is followed by Suppliers (23.91% and 23.98% for material and energy eco-innovations, respectively), Universities and Research Centres (22.00% and 22.83%), Customers (16.63% and 16.78%) and, finally, Competitors (6.25% and 6.02%). In this sense, not all eco-innovative firms collaborate with other external agents, although the vast majority do so. In the case of material eco-innovative firms, 95.31% of the sample engage in collaboration with at least one agent, and in the case of energy eco-innovative firms, 95.61% collaborate with at least one partner.

**TABLE 1** | Number of firms and percentage of the sample by type of eco-innovation and collaboration.

| | Material | | Energy | |
|---|---|---|---|---|
| | **Firms** | **% of the sample** | **Firms** | **% of the sample** |
| Suppliers | 841 | 23.91% | 956 | 23.98% |
| Customers | 585 | 16.63% | 669 | 16.78% |
| Competitors | 220 | 6.25% | 240 | 6.02% |
| Universities and RC | 774 | 22.00% | 910 | 22.83% |
| KIBS | 933 | 26.52% | 1036 | 25.99% |
| | 3353 | 95.31% | 3818 | 95.61% |

Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.

To have a broader view of the most frequently used external agents for collaboration, the percentage of the sample engaged in some form of networking is shown in Figures 2 and 3, for material and energy eco-innovations, respectively. For each type of eco-innovation, the percentage of the sample that has the probability of accomplishing any type of network with one or more external agents has been calculated. The most probable network is to collaborate, at least, with KIBS (21.28% of the sample in the case of material eco-innovations and 20.18% in the case of energy eco-innovations), followed by the collaboration with, at least, Suppliers (19.65% and 18.58%, respectively). Engaging with all agents is the least common practice (2.70% and 2.45%), and the least likely agent for collaboration is Competitors (5.89% in the case of material eco-innovation and 5.52% in energy).

Therefore, this preliminary analysis suggests two main issues. The first one is that collaborating with all potential partners is less attractive than collaborating with a reduced group of the main external stakeholders. The second implication regards the type of collaboration: supply chain partners (Suppliers and Customers) together with the science organisations (Universities and Research Centres and KIBS) are the most preferred, whereas Competitors are the least desirable collaborators. Both implications emphasise that compatibility between partners and the potential joint strategy adopted in the collaboration will determine the successful progress of the partnership, which is in line with De Marchi et al. (2022) and Zhang et al. (2022). The two previous implications, together with the two main RQs proposed in Section 1, are further examined and clarified through the methodology.

## 3.2 | Methodology

The methodology applied is the QCA, which can be interpreted as a middle ground between quantitative and qualitative methodologies (Ragin 2006; Rohwer 2011; Smithson and Verkuilen 2006), and is feasible regardless of sample size, as its use is recommended even with small samples (e.g., 50 observations) (Rihoux and Ragin 2009). QCA is based on two premises: Firstly, changes that occur are often the result of different combinations of factors rather than the influence of any single factor, and secondly, different combinations of factors can produce similar changes (Ragin 1987). Additionally, the method allows us to directly compare various potential interactions (Ragin 2008). However, it should be noted that QCA does not analyse the specific impact, so this analysis does not explore the inferential parametric relationships between our chosen variables (Fernández-Esquinas et al. 2021).

Therefore, because this study explores the existence of complex and contextual patterns that firms adopt to develop eco-innovations in a sample of almost 4000 firms, the use of QCA is appropriate as it allows for the identification of multiple paths that lead to the same result and involves the interaction of different factors (Rihoux and Ragin 2009; Schneider and Wagemann 2012).

QCA uses qualitative procedures systematically and algorithmically and employs Boolean logic to examine the relationship

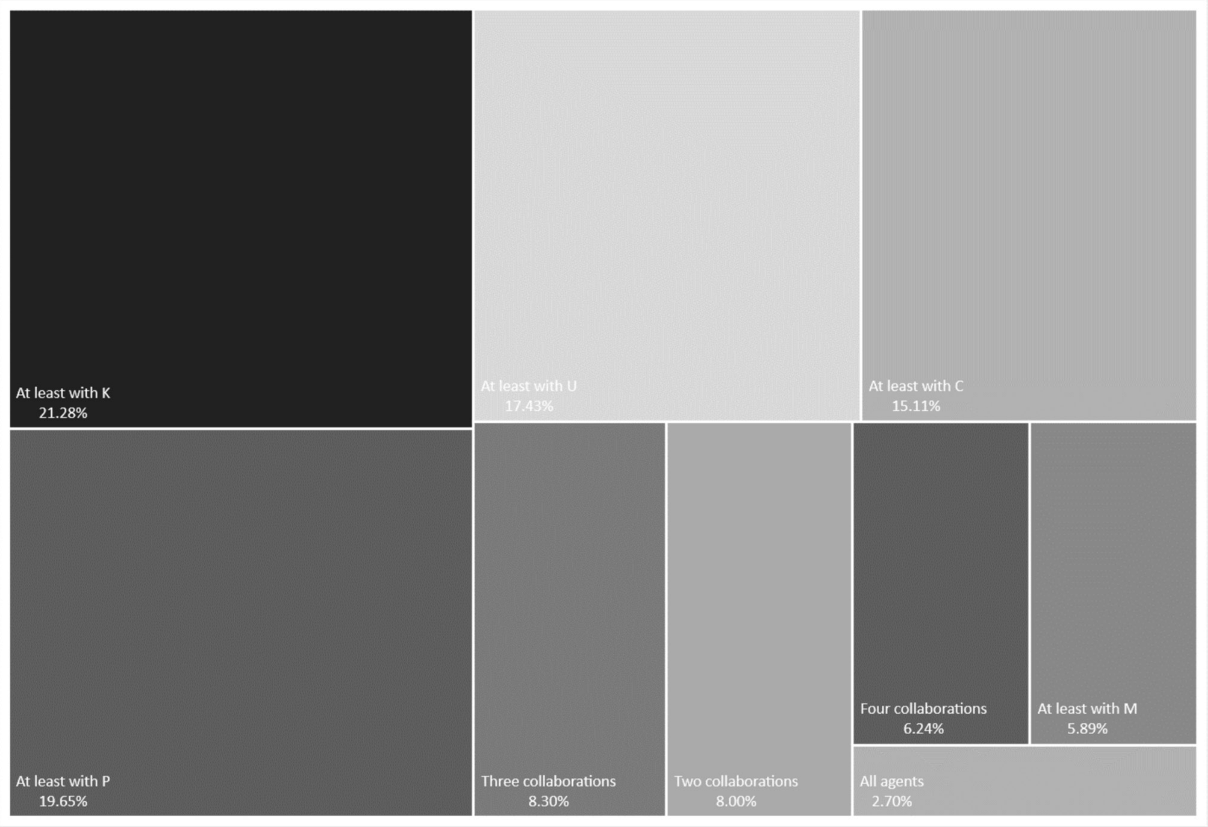


**FIGURE 2** | Collaboration with partners: percentage of the sample that has a likelihood of carrying out each type of collaboration. Material eco-innovation. P—suppliers; C—customers; M—competitors; U—Universities and Research Centres; K—Knowledge Intensive Business Services. *Source:* Own elaboration.

between a particular variable, called the *outcome set*, and all binary combinations (Boolean combinations) of multiple predictors (*set of predictors*) (Longest and Vaisey 2008). In this study, the *outcome set* refers to the different types of eco-innovations (material and energy). Because both variables are dichotomous, the crisp-set case of QCA (Ragin 2008, 2009) is applied. In addition, the *set of predictors* consists of external sources of knowledge (Suppliers, Customers, Competitors, Universities and Research Centres and KIBS).

The logic of the methodology relies on the examination of which *configurations* (combinations of predictors) of external sources of knowledge are most likely to generate the different types of eco-innovations. In this sense, the relationships between the external sources of knowledge and the eco-innovations are assessed using conditional probabilities.[6] Hence, the method studies the idea that different combinations of factors (i.e., predictors acting together) have the potential to produce the outcome (Gerrits and Pagliarin 2020; Ragin 1987, 1999). This implies the existence of complex and contextual patterns, that is, complex causality (Legewie 2013; Rihoux and Ragin 2009). Therefore, QCA does not evaluate the individual relevance of each predictor, but rather how all or some predictors work together—that is, the causal patterns or paths—(Gerrits and Pagliarin 2020; Mahoney 2008). On this basis, it is necessary to identify the necessary and/or sufficient predictors that enable eco-innovation to occur.

Therefore, the *first step* is to conduct a *necessity analysis*. According to Ragin (2009), De Marchi et al. (2022) and Cooper and Glaesser (2016), a predictor is necessary if it is present whenever the outcome occurs. For a predictor to be considered necessary, the consistency score must exceed 0.9 to meet econometric requirements (Schneider et al. 2010). If this threshold is not met, the necessity analysis suggests that a single partner is not necessary for the firm to be eco-innovative. This first step offers a comprehensive analysis overview: If any external source of knowledge is necessary, it will appear in all possible collaborations (Cooper and Glaesser 2016; De Marchi et al. 2022). Conversely, if none of the predictors is necessary, then potential combinations have greater causal power than each partner acting individually (Gerrits and Pagliarin 2020).

The *second step* is the *sufficiency analysis*. This step is the most important for this research because it will determine which combinations are the most relevant for fostering eco-innovations. In this sense, a predictor is considered sufficient if its existence (either its presence or absence) in any potential configuration is relevant to obtaining the outcome (Gerrits and Pagliarin 2020; Legewie 2013). Additionally, not only individual predictors can be sufficient, but also several predictors acting jointly may lead to the outcome (Gerrits and Pagliarin 2020), that is, external knowledge networks drive eco-innovation. In this respect, it should be noted that the possible combinations may include all, none or only some of the external sources of knowledge. The inclusion of an external knowledge source (predictor) in a combination could occur in two ways: its presence (the predictor is required to be included in the configuration, meaning its presence in the configuration is essential to produce the outcome) or its absence (the predictor must not

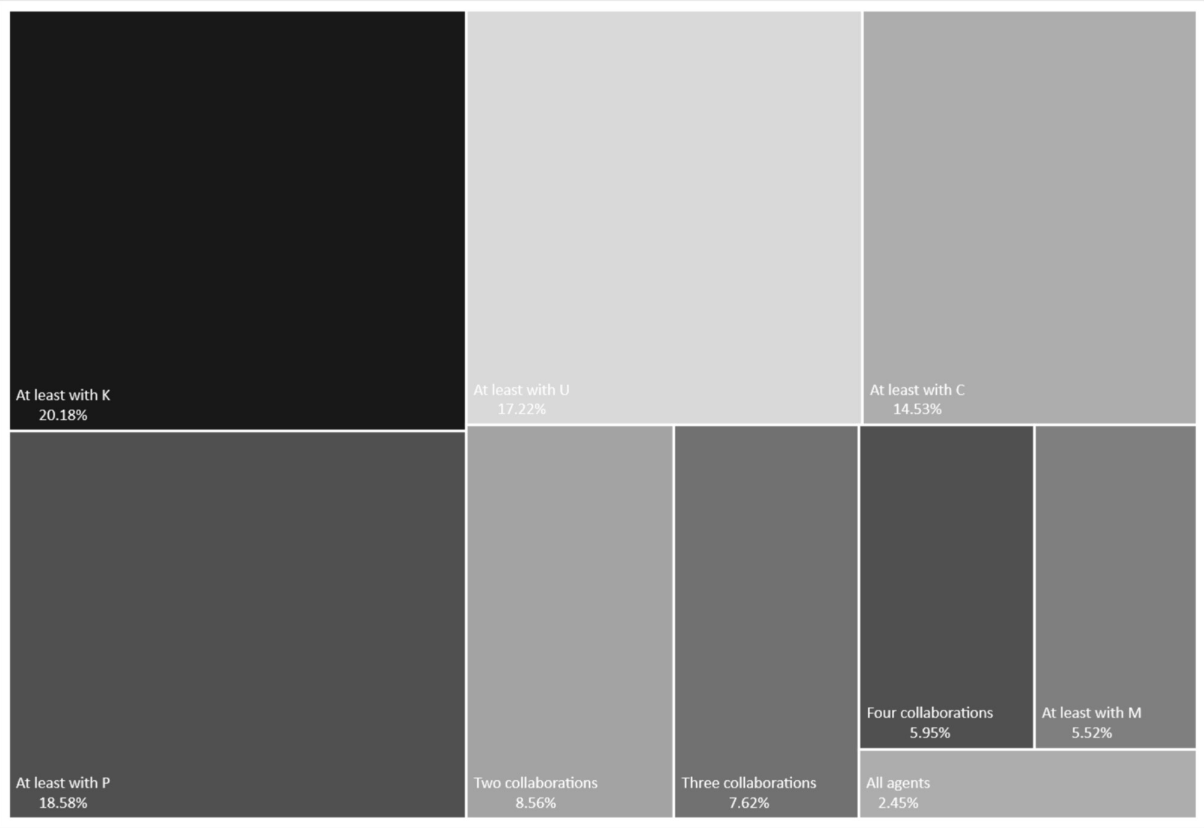


**FIGURE 3** | Collaboration with partners: percentage of the sample that has a likelihood of carrying out each type of collaboration. Energy eco-innovation. P—suppliers; C—customers; M—competitors; U—Universities and Research Centres; K—Knowledge Intensive Business Services. *Source:* Own elaboration.

be included in the configuration) (Ragin 1987, 1999). Finally, if the predictor does not appear in the combination, it would not be significant, so its presence or absence does not affect the outcome.

In addition, in this second step, we define two main measures that display the goodness of fit of the model as a whole: total model coverage and solution consistency. The first one shows the scope of the analysis (cases that could be explained by the configuration) and is similar to $R^2$ in a regression (Ragin 2006). The second one notes the adequacy of the analysis, whose threshold value for Large-*N* samples is 0.750, following specialised literature such as De Marchi et al. (2022) or Ragin (2008).

Therefore, QCA enables us to identify which are the most important external sources of knowledge that generate eco-innovation. Additionally, it allows us to test whether interactions between different partners jointly influence the eco-innovation process. This has been suggested in the works of De Marchi et al. (2022), Ghisetti et al. (2015), Marzucchi and Montresor (2017), Melander (2018), Niesten and Jolink (2020), Rauter et al. (2019), Watson et al. (2018) or Yarahmadi and Higgins (2012).

## 4 | Results and Discussion

This section includes the study of the nature of different collaboration paths for material and energy eco-innovations (necessity and sufficiency analyses). Additionally, the analyses for eco-innovations in general, without differentiating between the types of environmental objectives pursued by firms, are included in Appendix B.

The results of the necessity analysis (first step)[7] are shown in Table 2. This table indicates that none of the individual collaborations can be considered necessary to achieve any of the types of eco-innovations. This is explained by the consistency value of the necessity analysis for each of the predictors, which is below 0.9 and, therefore, does not meet the econometric requirements (Schneider et al. 2010). These results are in line with those obtained by De Marchi et al. (2022), who also argue that a firm can be eco-innovative regardless of whether it collaborates with any of the agents considered. Therefore, because none of the external sources of knowledge is indispensable, collaboration with several partners could be more relevant than collaborating with a single partner.

The necessity analysis shows that although none of the collaborations is strictly necessary, the most relevant partners appear to be Universities and Research Centres, as it holds the highest value, followed by Suppliers and KIBS. As noted in studies that individually examine relationships with science organisations (Universities and Research Centres and KIBS), these contribute to generating more complex forms of eco-innovation, as well as enhancing firms' innovative capabilities (Cainelli et al. 2015; Martínez-Cháfer et al. 2021). Collaboration with Suppliers, as highlighted by Araújo and Franco (2021) or Yarahmadi and Higgins (2012), among others, facilitates risk-sharing in the development of eco-innovations, which tend to be highly complex

(Chang et al. 2018; Peigné et al. 2024). The two least relevant collaborations (see values from Table 2) would be with Customers and Competitors. In the case of Customers, the result aligns with existing literature, indicating that they could be a key partner (De Marchi et al. 2022; Kobarg et al. 2020). However, such results tend to be non-significant when studying this collaboration individually (Araújo and Franco 2021; Cuerva et al. 2014; De Marchi and Grandinetti 2013). Regarding Competitors, while they could serve as potentially useful collaborators in addressing challenges outside the firm's core business, allowing for the exchange of experience and know-how, they are the least important in fostering collaborations due to inherent rivalry. In addition, firms could be reluctant to share sensitive information (Kobarg et al. 2020; Sánchez-Sellero and Bataineh 2022; Yarahmadi and Higgins 2012). Considering the previous appraisal, we could assert that the necessity analysis is consistent with the results of the preliminary study commented on, based on Figures 2 and 3.

On the other hand, Tables 3 and 4 show the results of the sufficiency analysis (second step),[8] indicating the combinations of different collaborations with partners leading to the introduction of material and energy eco-innovations, respectively. A consistency threshold of 0.750 has been established (De Marchi et al. 2022; Ragin 2008).

Regarding *material eco-innovation* results (Table 3), a total model coverage of 0.960 and a solution consistency of 0.950 are observed, which fulfils the requirements established in the literature (De Marchi et al. 2022; Fiss 2011; Ragin 2006, 2008).

Based on these findings, six possible configurations (collaboration paths) are identified for achieving material eco-innovations. These results confirm H1, as different combinations of collaboration partners have been identified to achieve material eco-innovations. This shows that there is no single optimal partnership configuration to attain material eco-innovations, although some configurations hold greater significance than others. Configurations 5 and 1 exhibit the highest level of coverage; therefore, they are preferred configurations, followed at a considerable distance by Configuration 6. Configurations 2–4 are the least relevant based on coverage values (although all our combinations are consistent). The partners included in each of the configurations are explained as follows, ordered by level of coverage.[9]

**TABLE 2** | Necessity analysis.

| | Outcome: Material | Outcome: Energy |
|---|---|---|
| | Consistency score | Consistency score |
| Suppliers | 0.239 | 0.240 |
| Customers | 0.166 | 0.168 |
| Competitors | 0.059 | 0.060 |
| Universities and RC | 0.220 | 0.228 |
| KIBS | 0.265 | 0.260 |

Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.

**TABLE 3** | Sufficiency analysis of material eco-innovation.

| | Configuration | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Suppliers | | | | ■ | ○ | |
| Customers | ○ | ■ | ■ | ■ | | |
| Competitors | ○ | ○ | ■ | | ○ | ○ |
| Universities and RC | ○ | ■ | ■ | ■ | | ■ |
| KIBS | | | | | | |
| Raw coverage | 0.716 | 0.070 | 0.088 | 0.097 | 0.749 | 0.218 |
| Unique coverage | 0.042 | 0.007 | 0.003 | 0.005 | 0.059 | 0.034 |
| Consistency | 0.950 | 0.953 | 0.963 | 0.950 | 0.950 | 0.952 |
| Total coverage | 0.960 | | | | | |
| Solution consistency | 0.950 | | | | | |

*Note:* ■ indicates the presence of antecedent conditions; ○ indicates absence or negation of antecedent conditions; a blank cell indicates ambiguous condition.
Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.

**TABLE 4** | Sufficiency analysis of energy eco-innovation.

| | Configuration | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Suppliers | | ○ | ○ | | ■ |
| Customers | ○ | | ■ | ■ | |
| Competitors | ○ | ○ | | | ○ |
| Universities and RC | ○ | | ■ | ■ | |
| KIBS | | ○ | | ■ | ■ |
| Raw coverage | 0.708 | 0.659 | 0.029 | 0.087 | 0.125 |
| Unique coverage | 0.094 | 0.064 | 0.003 | 0.027 | 0.052 |
| Consistency | 0.816 | 0.815 | 0.913 | 0.892 | 0.883 |
| Total coverage | | | 0.924 | | |
| Solution consistency | | | 0.830 | | |

*Note:* ■ indicates presence of antecedent conditions; ○ indicates absence or negation of antecedent conditions; a blank cell indicates ambiguous condition. Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.

Regarding the *fifth configuration*, results show that firms should not collaborate with Suppliers and Competitors, simultaneously. This may be explained by the fact that competing firms typically share the same Suppliers. Therefore, if firms do not collaborate with their Competitors, it is also likely that they do not collaborate with their Suppliers because this could imply the transfer of information to a direct competitor and, thus, the loss of some competitive advantage (Kobarg et al. 2020; Sánchez-Sellero and Bataineh 2022; Yarahmadi and Higgins 2012).

In the *first configuration*, three types of collaboration should not be combined simultaneously to achieve success: Customers, Competitors and Universities and Research Centres. Similar to the previous case, if there is no collaboration with Competitors, it could be relevant not to collaborate also with Customers, because rival firms could share the same client base. At the same time, Universities and Research Centres primarily serve to transfer R&D advances to society. This implies both direct and indirect relationships with Customers because demand patterns tend to align with green R&D developments (Araújo and Franco 2021). From this perspective, Universities and Research Centres are linked to Customers, and Customers are associated with Competitors. Thus, firms may opt not to collaborate with any of these three actors simultaneously to avoid disclosing relevant information to direct rivals.

Finally, based on the strategy of *Configuration 6*, for achieving material eco-innovations, firms should collaborate with Universities and Research Centres but avoid collaborating with Competitors. Competing firms may independently choose to collaborate with different public research organisations without the need to share these R&D sources. For rival firms, direct access to public sources of eco-innovation trends is valuable, as it helps improve their competitive advantage. However, sharing this strategic information would be counterproductive, as it would aid competitors in strengthening their market position (Sánchez-Sellero and Bataineh 2022).

Although Combinations 5, 1 and 6 are the most recurrent, it should be noted that *Configurations 2–4* are also options for achieving material eco-innovations, only they are less diffuse. In particular, *Configuration 2* deserves special attention, as it involves collaboration with Customers and Universities and Research Centres and the absence of Competitors. De Marchi et al. (2022) found this same path in a similar study in Spain. Specifically, their results showed that this path was one of the most relevant for achieving eco-innovations. Additionally, *Configuration 4* aligns with results obtained by De Marchi and Grandinetti (2013), De Marchi et al. (2022) and Kobarg et al. (2020), which remark on the collaboration with Universities and Research Centres as well as Suppliers, considering both agents key for eco-innovations (Cainelli et al. 2012).

However, the facts presented for Configurations 2 and 6 contrast with those obtained in *Configuration 3*. This combination implies the simultaneous presence of Competitors, Customers and Universities and Research Centres. This could be interpreted as evidence of the previously discussed relationship between Customers and Universities and Research Centres. When collaboration involves both simultaneously, then the collaboration with Competitors could be in both ways (absence or presence); hence, it would depend on the structure of the partnership agreement and the objectives that the different firms are pursuing with that agreement.

In summary, the presence of Universities and Research Centres is essential, as they appear in almost 70% of the configurations obtained (4 out of 6). This is in line with works such as those by Arroyave et al. (2020) and Pippel (2015). Conversely, the absence of Competitors is a crucial factor, occurring in almost 70% of the configurations (4 out of 6). The next relevant external source of knowledge is the group of Customers, whose presence emerges in 50% of the configurations (3 out of 6). Finally, Suppliers and KIBS seem to be the least relevant, as both their presence and absence are marginal: the presence/absence of Suppliers represents 16.7% of the configurations obtained (1 out of 6), and KIBS neither consistently appears nor is entirely absent in any configuration.

Regarding *energy eco-innovations*, Table 4 shows the possible configurations. In this case, the model shows a total coverage of 0.924 and a consistency solution of 0.830, also satisfying the limits established in the literature (De Marchi et al. 2022; Fiss 2011; Ragin 2006, 2008). Results show five combinations for increasing energy eco-innovations. The findings confirm H2, obtaining different combinations of partners for the generation of energy eco-innovation. In the following lines, we describe each path as previously, ordered by level of coverage.

First, *Configuration 1* coincides with the first path of the material eco-innovation model, showing that not collaborating simultaneously with Customers, Competitors and Universities and Research Centres is one of the recipes for achieving both types of eco-innovations. The next most relevant configuration for energy eco-innovations is *Configuration 2*, which points out that a successful approach for this type of eco-innovations is not to collaborate with Suppliers, Competitors and KIBS simultaneously. In this case, note that this configuration is similar to Configuration 5 in the case of material eco-innovation, but adding the no collaboration with KIBS. The connection between Suppliers and Competitors has been commented on previously; however, concerning KIBS, it should be noted that they are private firms offering external services to firms (from financial services to training in the use of new technologies). In addition, KIBS could be understood as suppliers of external expertise or new capacities. De Marchi et al. (2022) affirm that collaboration with KIBS is more accessible and easier when innovation capabilities are lower, and therefore, firms in this situation tend to rely on KIBS as a knowledge provider. For this reason, the relationships with Suppliers and KIBS would move in the same direction. Furthermore, the last top configuration, *Configuration 5*, shows that collaborating with Suppliers and KIBS, while excluding Competitors, would help firms to carry out energy eco-innovations, once again illustrating the strong relationship between the former two.

Finally, the two last paths are 3 and 4. *Configuration 3* implies the absence of Suppliers and the presence of Customers and Universities and Research Centres. These results contrast with those of De Marchi et al. (2022), who found in two of their paths that collaborating with Suppliers is positive when it acts together with Customers or with Universities and Research Centres. However, it could be argued that the absence of Suppliers is crucial in this path. In addition, *Configuration 4* has these same presences but replaces the absence of Suppliers with the appearance of collaboration with KIBS.

To sum up the relevance of the different sources of knowledge in the case of energy eco-innovations, the absence of Competitors is the most essential pattern. In 60% of the configurations (3 out of 5), the absence of this source emerges, and in any configuration, we obtained its presence. It is followed by the absence of Suppliers in 40% of the configurations (2 out of 5), and only in one configuration do we find its presence. Finally, in third place, we have a tie: the appearance of Customers, Universities and Research Centres and KIBS represents 40% (2 out of 5 for each predictor) of the configurations, while their absence is observed in 20% of the patterns obtained (1 out of 5 for each predictor).

Once the different collaboration strategies of firms have been explained for both material and energy eco-innovations, it is convenient to compare the consistencies of each of the configurations to analyse whether there are significant differences among them. Table 5 shows that none of the consistency tests in the case of material eco-innovation show statistically significant results. Therefore, it could be affirmed that in general terms the consistency of the six paths is similar. However, in the case of energy eco-innovation, six significant results are found, which indicates that there are significant differences in the consistency of the paths obtained; in particular, Paths 1 and 2 are preferable to Configurations 3–5. In general, these results suggest that although the consistencies of material eco-innovation paths vary, all are equally relevant. However, in the case of energy eco-innovation paths, some configurations are preferable to others.

**TABLE 5** | Test of configurations' consistencies.

| | **Material eco-innovation** | | **Energy eco-innovation** | |
|---|---|---|---|---|
| | ***F* statistic** | ***p*** | ***F* statistic** | ***p*** |
| Path 1 vs. Path 2 | 0.060 | 0.812 | 0.090 | 0.761 |
| Path 1 vs. Path 3 | 1.210 | 0.271 | 14.770 | 0.000* |
| Path 1 vs. Path 4 | 0.000 | 0.968 | 20.400 | 0.000* |
| Path 1 vs. Path 5 | 0.100 | 0.753 | 20.280 | 0.000* |
| Path 1 vs. Path 6 | 0.030 | 0.864 | | |
| Path 2 vs. Path 3 | 1.120 | 0.289 | 14.250 | 0.000* |
| Path 2 vs. Path 4 | 0.100 | 0.751 | 20.120 | 0.000* |
| Path 2 vs. Path 5 | 0.080 | 0.771 | 21.140 | 0.000* |
| Path 2 vs. Path 6 | 0.030 | 0.873 | | |
| Path 3 vs. Path 4 | 2.170 | 0.141 | 0.720 | 0.395 |
| Path 3 vs. Path 5 | 1.370 | 0.241 | 1.130 | 0.287 |
| Path 3 vs. Path 6 | 1.220 | 0.269 | | |
| Path 4 vs. Path 5 | 0.000 | 0.989 | 0.360 | 0.548 |
| Path 4 vs. Path 6 | 0.030 | 0.854 | | |
| Path 5 vs. Path 6 | 0.410 | 0.524 | | |

*The value is significant with a confidence level of 99%.
*Source:* Own elaboration.

Finally, considering jointly the results shown in Tables 3–5, and similar to what was demonstrated by De Marchi et al. (2022), there are different combinations of collaboration with different partners that allow firms to develop eco-innovations. The results obtained show that to achieve each of the types of eco-innovations considered (material and energy), the collaboration strategy should be different, except for one combination that would facilitate the eco-innovation of both types. Therefore, H3, which proposes different combinations for material and energy eco-innovations, is partially confirmed.

Results show that some collaboration partners seem to be more important than others. University and Research Centres and Customers are the most relevant agents, appearing in four and three configurations for material eco-innovations, respectively, and in two for energy eco-innovations. Specifically, as noted by De Marchi et al. (2022), Universities and Research Centres play a decisive role, as the 'science driver' is the most representative partner in collaboration paths regardless of the other agents involved. In the case of Customers, studies show that they are becoming more environmentally aware and are willing to pay more for more environmentally friendly products or services (McDonagh and Prothero 2014), highlighting them as key partners in achieving eco-innovations (De Marchi et al. 2022; Kobarg et al. 2020).

In this vein, the presence of each partner in the paths found aligns significantly with the existing literature on individual relationships, with their frequency depending on green goals. First, Suppliers are established as collaborators (Moreno-Mondejar and Cuerva 2020; Segarra-Blasco and Jove-Llopis 2019) in both types of eco-innovations equally, appearing in one of the paths in both cases. Regarding Customers, following Hojnik et al. (2018) and Severo et al. (2015), they are more common in material eco-innovation, appearing in 3 out of 6 paths. Competitors, on the other hand, constitute the only exception to the reviewed literature. While Díaz-García et al. (2015) suggest that this collaborator would be expected to be more frequent in energy than in material eco-innovation, in our study, they appear in one path for material eco-innovation and none for energy eco-innovation. Finally, the participation of scientific organisations is ambiguous. Universities and Research Centres are more common in material eco-innovation (appearing in four paths against two). In contrast, KIBS is more frequent in energy eco-innovation (appearing in one path for energy and none for material), as suggested by the work of Han et al. (2023).

## 5 | Conclusions

Eco-innovation is a key driver in the path towards a greener and more sustainable economy (European Commission 2011). However, the achievement of eco-innovations by firms is not an easy task. In this respect, the literature has noted that collaboration with external sources of knowledge could facilitate their development and improvement (Andersen 2002; Araújo and Franco 2021; Kobarg et al. 2020; Melander and Pazirandeh 2019).

Considering the above, this study focuses on analysing the combination of external knowledge sources (networks) that contribute to firms' material and energy eco-innovations using a sample of Spanish firms in the year 2020. To this end, the QCA methodology is applied.

Specifically, this research provides evidence to test the established hypotheses and answer the two proposed RQs. We have obtained different combinations of partners that boost material and energy eco-innovations (RQ1), corroborating H1 and H2. In this sense, although there are some common patterns among different combinations, we have found differences when analysing material versus energy eco-innovation (RQ2), which allows us to partially support H3 and develop several conclusions.

On the one hand, focusing on *material eco-innovation*, the absence/presence of Competitors appears mainly alongside the absence/presence of Customers and Universities and Research Centres. However, if the firm has to choose between the presence of Customers or Universities and Research Centres, the best option is to collaborate with the latter (*Configuration 6*). In addition, collaboration with Customers appears to align with collaboration with Universities and Research Centres, as they tend to emerge together.

On the other hand, for *energy eco-innovation*, the absence of collaboration with Competitors is the most important strategy, because they do not appear in any configuration, while their absence is observed in 60% of the paths. This strategy could be combined mainly with either the presence or absence of Suppliers and KIBS in the collaboration agreement.

Thirdly, for improving eco-innovations (both energy and material), collaborating with external sources of knowledge implies the absence of three agents: Customers, Competitors and Universities and Research Centres (*Configuration 1* in both the material and energy eco-innovation models). Concerning the role of Universities and Research Centres and Customers, they are key actors because they are the most present in both types of eco-innovation (Universities and Research Centres appear in 6 out of 11 configurations and Customers in 5 out of 11). Regarding Competitors, if the firm is not particularly concerned about this agent, that is, it is indifferent about collaborating with rivals, the presence of both Customers and Universities and Research Centres is essential for obtaining material and energy eco-innovations.

Finally, considering the results obtained, it could be noted that collaborating with a reduced group of external sources of knowledge is preferable to collaborating with only one. In addition, collaborating with all potential partners simultaneously is highly questionable due to the complexities of managing networks and the fact that certain actors may pursue objectives that conflict with the firm's strategy: the more actors involved in the network, the more difficult it becomes to manage. This conclusion is in line with De Marchi et al. (2022) and Zhang et al. (2022), who highlight that the success of the partnership path will depend on the compatibility between partners, a shared strategic vision, and, consequently, the potential collaborative approach, which in turn is directly related to the main organisational aspects of the firm (Baumgartner 2009).

Figure 4 summarises all the information previously analysed, showing the possible preferences that firms would have for collaboration with other actors, considering their main eco-innovation objectives.

These results offer contributions to both theory and practice. Specifically, three key contributions to the theories that support this research can be identified. First, Universities and Research Centres have frequently emerged in the resulting combinations. These partners could help firms achieve legitimacy and fulfil institutional requirements for eco-innovation. Their significant presence supports the view of Institutional Theory suggesting that firms aim for compliance and legitimacy by networking with well-considered and recognised organisations. Second, this study demonstrates that the combination of several external sources of knowledge is crucial for achieving eco-innovations. This implies that firms obtain advantages from synergies and

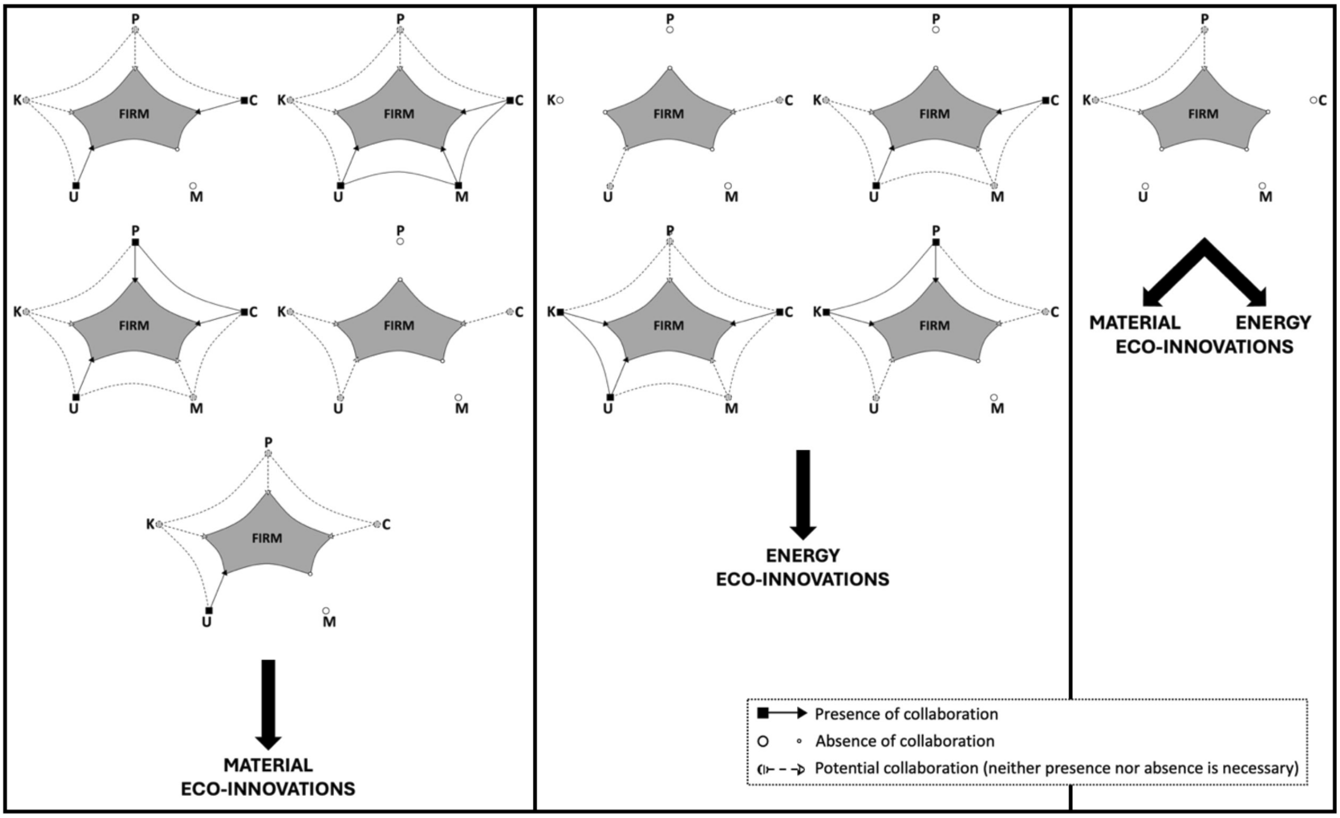


**FIGURE 4** | Main networks. P—suppliers; C—customers; M—competitors; U—Universities and Research Centres; K—Knowledge Intensive Business Services. *Source:* Own elaboration.

complementarities by combining resources and capabilities, thus reinforcing the theoretical background of the resource-based theory on the importance of using a diversified portfolio of resources. Finally, this study finds that competitors generally had a low presence in knowledge networks. Collaborating with competitors naturally leads to increased transaction costs due to the need to create mechanisms to protect critical knowledge. This finding is supported by transaction cost theory, which emphasises the importance of selecting partners who minimise the risks associated with opportunistic behaviour.

In addition, some contributions to practice related to policymakers and managers can be highlighted. First, as previously noted, achieving environmental goals is increasingly important, and, as the literature demonstrates, firms are opening their boundaries to external knowledge to innovate (De Marchi et al. 2022; Laursen and Salter 2006; Triguero et al. 2020). As this work shows, collaboration with other market players is very positive to improve and develop eco-innovations. In this sense, both innovation and environmental policies should be coordinated to consider the potential benefits of collaborating with different actors. However, such policies need to be flexible enough to allow firms to decide whether to collaborate with specific actors, depending on what the main objective of its eco-innovation is and its own business strategy.

On the other hand, firms should consider the type of eco-innovation they aim to achieve before choosing their partners due to the fact that the combination of external knowledge sources is crucial for developing each type of eco-innovation. In this sense, the findings highlight the importance of developing partnership strategies aligned with the type of eco-innovation being pursued. For example, collaboration with universities can provide firms with cutting-edge research and technological breakthroughs, while collaboration with customers can provide valuable information on market demands and sustainability preferences (Dangelico et al. 2017). This suggests that firms should cultivate a network of diverse external knowledge sources to foster a strong innovation ecosystem (De Marchi 2012).

Furthermore, managers should be aware that specific collaborative networks could generate synergies and foster both types of eco-innovations simultaneously. This could help firms optimise their collaborative efforts and resource allocation, thereby improving their overall sustainability performance and competitive advantage (Horbach et al. 2012). This knowledge could guide managers in making informed decisions about building and managing collaborations to effectively exploit external knowledge for eco-innovation.

To conclude, although this work provides important insights into the study of networking between different firms to promote eco-innovation, it has some limitations. The first one is related to the data source: although we have access to recent data, which use is restricted, we were unable to apply panel data. Furthermore, firms are not divided by sector, and although we distinguish between the green goals of the particular eco-innovation carried out by the firm, we cannot differentiate between product, process and organisational innovations. Additionally, there is still work to be done to clarify the appearance of collaborations not only in Spain but also in other countries.

On the other hand, the second limitation is related to the methodology. Using QCA, we explore the different combinations of external sources of knowledge that lead to eco-innovations by Spanish firms. However, this methodology does not allow us to analyse the concrete impact of the predictors on the outcome. Thus, this analysis does not explore the parametric relationships between the independent variables and the dependent ones. In this sense, although we have pointed out that, depending on the type of environmental orientation a firm has, the collaboration paths will differ and certain collaborations may be more effective in fostering eco-innovations within the firm, we are not able to conclude the specific impact (i.e., parametric inference) of each collaboration path on material eco-innovation or energy eco-innovation.

Future lines of research should deal with the previous limitations by analysing potential collaborations that could boost eco-innovations in an environment where sustainability and digital transition are increasingly relevant. In this regard, future research could explore how different combinations of external knowledge networks facilitate the development of sustainable business models and practices, as well as how multipartner collaborations contribute to sustainable innovations in various sectors. Furthermore, as the digital transition offers new opportunities for eco-innovation, investigating the synergies between digital transformation and eco-innovation could provide valuable insights for creating more resilient and adaptive business strategies, as well as examining how digital tools could enhance external knowledge networks. Finally, the application of other methodological techniques to examine different analytical dimensions will be relevant. Among other aspects, investigating the direct impacts of collaboration paths on the reduction of material and/or energy consumption through a more detailed methodological approach could be another significant research avenue.


### Acknowledgements

Authors acknowledge funding from INFESE Project PID2020-112984GB-C21 funded by the Ministry of Science and Innovation of Spain and GRIPICO Group funded by the University Complutense of Madrid.


### Endnotes

[1] The institutional pressure for environmental products has been particularly notable in the apparel industry, as argued by Abbate et al. (2023) or Centobelli et al. (2022).

[2] There are also some studies on general innovation, such as the work of Eggers et al. (2020) or the study of Martínez-Cháfer et al. (2021), which also apply the QCA methodology.

[3] The study finds a total of seven paths, with the three mentioned being the most significant.

[4] The main advantage of using this database is that we have had access to the data from one of the latest surveys, which is restricted in its use. This provides us with an early and unique insight that is highly relevant to the analysis performed.

[5] In the survey, firms add an answer about their level of eco-innovation in reducing the use of materials (material eco-innovative firms) or in reducing energy use (energy eco-innovative firms). For this reason, in this study, we differentiate between the sample of energy eco-innovative firms (11.16% of all firms participating in the survey) and the sample of material eco-innovative firms (9.85% of all firms participating in the survey).

[6] The higher the conditional probability, the higher the empirical correspondence. The closer the value of the probability is to unity, the more consistent the data is with the statement that the corresponding configuration is a relevant configuration for producing the output.

[7] The necessity analysis for eco-innovations in general can be found in Table B1 in Appendix B.

[8] The sufficiency analysis for eco-innovations in general can be found in Table B2 in Appendix B.

[9] To understand each path, it is important to note that each configuration must be interpreted independently of the rest, that is, the firm will choose among those options the best one depending on its own characteristics and circumstances.

[10] The sample consists of 4745 companies. Descriptive statistics for this variable are available on request.

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## Appendix A

**TABLE A1** | Description of the variables.

| Outcome variables | Description | Measurement |
|---|---|---|
| Material eco-innovation | It has been considered whether the company has implemented measures to enhance its material efficiency, including actions such as reducing the use of materials, employing more efficient materials or recycling them. | Binary variable. The variable takes the value 1 if the firm shows that it carries out any of the described activities in a substantial way, and 0 otherwise. |
| Energy eco-innovation | It has been considered whether the company has implemented measures to enhance its energy efficiency, including actions such as using renewable energy or reducing energy use. | Binary variable. The variable takes the value 1 if the firm shows that it carries out any of the described activities in a substantial way, and 0 otherwise. |
| **Predictor variables** | **Description** | **Measurement** |
| Suppliers | Collaboration with suppliers of equipment, materials, components or software. | Binary variable. The variable takes the value 1 if the firm collaborates with at least one external firm, and 0 otherwise. |
| Customers | Collaboration with firms that are its users or customers. | Binary variable. The variable takes the value 1 if the firm collaborates with at least one external firm, and 0 otherwise. |
| Competitors | Collaboration with competitor firms. | Binary variable. The variable takes the value 1 if the firm collaborates with at least one external firm, and 0 otherwise. |
| Universities and Research Centres | Collaboration with Universities or other higher education institutions, public administration, or public research institutes. | Binary variable. The variable takes the value 1 if the firm collaborates with at least one external institution, and 0 otherwise. |
| Knowledge Intensive Business Services (KIBS) | Collaboration with consultants, commercial laboratories or private research institutes. | Binary variable. The variable takes the value 1 if the firm collaborates with at least one external institution, and 0 otherwise. |

*Source:* Own elaboration based on the Spanish Innovation Survey and Statistics on R&D activities in the year 2020 (Sections D.7.1 and D.5.1 of the survey).

**TABLE A2** | Descriptive statistics.

| Variable | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|
| Material | 0.9508 | 0.2163 | 0 | 1 |
| Energy | 0.8270 | 0.3783 | 0 | 1 |
| Suppliers | 0.0674 | 0.2508 | 0 | 1 |
| Customers | 0.0479 | 0.2136 | 0 | 1 |
| Competitors | 0.0159 | 0.1251 | 0 | 1 |
| Universities and RC | 0.0758 | 0.2647 | 0 | 1 |
| KIBS | 0.0797 | 0.2709 | 0 | 1 |

*Source:* Own elaboration.

**TABLE A3** | Correlation matrix.

| | Material | Energy | Suppliers | Customers | Competitors | Univ. and RC | KIBS |
|---|---|---|---|---|---|---|---|
| Material | 1 | | | | | | |
| Energy | 0.4346 | 1 | | | | | |
| Suppliers | 0.0070 | 0.0496 | 1 | | | | |
| Customers | 0.0104 | 0.0495 | 0.4577 | 1 | | | |
| Competitors | −0.0009 | 0.0318 | 0.3014 | 0.3749 | 1 | | |
| Univ. and RC | 0.0059 | 0.0442 | 0.4130 | 0.4657 | 0.3238 | 1 | |
| KIBS | −0.0047 | 0.0490 | 0.5361 | 0.4484 | 0.3005 | 0.4885 | 1 |

*Source:* Own elaboration.

## Appendix B

This appendix contains the results of the necessity and sufficiency analysis for general eco-innovations.[10] Table B1 shows the results of the necessity analysis for eco-innovations in general. Because all consistency scores are below 0.9, no individual collaboration is necessary to achieve eco-innovations. These results are similar to those obtained for material and energy eco-innovations.

Table B2 shows the sufficiency analysis for overall eco-innovations. The total coverage is 0.913 and the solution consistency is 0.806, indicating that the results are significant.

Five possible configurations were found, with Configurations 1 and 2 having the highest level of coverage, followed by Configuration 3 at a considerable distance. However, it should be noted that all five configurations are consistent, although their significance varies.

*Configuration 1* implies the absence of Customers, Competitors and Universities and Research Centres. It is repeated for both types of eco-innovation—material and energy—individually, so confirming that this network is effective when the firm aims to achieve both green goals together.

*Configuration 2* emerges here as a means of achieving general eco-innovations. However, when considering material and energy eco-innovations individually, we can see that it is only a suitable network when the firm seeks to develop energy eco-innovation. The same applies to *Configuration 3*, which only occurs when energy eco-innovation is the outcome.

Regarding *Configuration 4*, it does not appear for either material or energy eco-innovation, although it could be a more specific version of *Configuration 3* for material eco-innovation (Table 3)—the presence of Customers, Competitors and Universities and Research Centres. In this case, a conclusive result for KIBS was not obtained. However, we might interpret that, because its absence appears in Table A5, it would be preferable for companies not to collaborate with this agent rather than to collaborate with it. In any case, this interpretation is subjective and would depend on the specific circumstances of the firm, which is why the presence/absence of the predictor was not conclusive in the specific analysis of material eco-innovation.

Finally, *Configuration 5* does not emerge for either material or energy eco-innovation. Still, it could be interpreted as a more general version of *Configurations 3* and *4* from Table 3 (material eco-innovation). This general configuration implies the presence of Suppliers, Customers, Competitors and Universities and Research Centres, with KIBS being a nonconclusive predictor.

**TABLE B1** | Necessity analysis of general eco-innovations.

| | Outcome: General eco-innovations |
|---|---|
| | **Consistency score** |
| Suppliers | 0.228 |
| Customers | 0.161 |
| Competitors | 0.055 |
| Universities and RC | 0.218 |
| KIBS | 0.252 |

Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.

**TABLE B2** | Sufficiency analysis of general eco-innovations.

| | Configuration | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| Suppliers | | ○ | ■ | | ■ |
| Customers | ○ | | | ■ | ■ |
| Competitors | ○ | ○ | ○ | ■ | ■ |
| Universities and RC | ○ | | | ■ | ■ |
| KIBS | | ○ | ■ | ○ | |
| Raw coverage | 0.720 | 0.669 | 0.119 | 0.006 | 0.028 |
| Unique coverage | 0.094 | 0.072 | 0.090 | 0.003 | 0.024 |
| Consistency | 0.791 | 0.791 | 0.868 | 0.938 | 0.924 |
| Total coverage | | | 0.913 | | |
| Solution consistency | | | 0.806 | | |

*Note:* ■ indicates the presence of antecedent conditions; ○ indicates absence or negation of antecedent conditions; a blank cell indicates ambiguous condition.
Abbreviations: KIBS—Knowledge Intensive Business Services; RC—Research Centres.
*Source:* Own elaboration.