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RESEARCH ARTICLE

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Eco-innovation for circular economy and sustainability performance: Insights and evidence from manufacturing firms

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Abstract

Despite progress in the literature in understanding the relationships between barriers, drivers, and features of eco-innovations (EIs) to promote the circular economy (CE) and improve companies' sustainability results, the evidence remains limited and diffuse. To address this gap, we investigate the effect of barriers, sources of information, and features of innovations and EIs on manufacturing companies' CE and sustainability performance. This longitudinal study used official Colombian government data from 3144 manufacturing companies (2015–2020), considering partial least squares structural equation modeling. Our results reveal that developing or adopting (eco-) innovations with incremental features could cause a blockage in implementing high-level CE and in improving their overall sustainability performance. Similarly, radical (eco-) innovations need more evidence to clarify their impacts on CE and sustainability. Finally, we show that the improvement in environmental and CE performance attributed to (eco-) innovations has a significant and positive impact on the company's economics.

KEYWORDS
circular economy, eco-innovation, structural equation modeling, sustainability, sustainability performance

1 | INTRODUCTION

Eco-innovation (EI) has been recognized as a central driver of change in the transition from the linear model of production and consumption "take, make, and dispose" to a circular one towards sustainable development (Carrillo-Hermosilla et al., 2009; Jaca et al., 2018). The implementation of a circular economy (CE) implies the development and adoption of (eco-) innovations in the economic system to mitigate the negative impact of production and consumption activities, including environmental degradation, biodiversity loss, source scarcity, dependence on fossil fuel energy, water, air, and soil pollution (de Jesus & Mendonça, 2018; Geissdoerfer et al., 2017; Kiefer et al., 2021). In this sense, knowledge about the contribution of EIs to the CE has a fundamental role in achieving a sustainable transition (Ghisellini et al., 2016;

Abbreviations: CB-SEM, covariance-based SEM; CE, circular economy; CECO, circular and economic performance; CENP, circular and environmental performance; DANE, National Administrative Department of Statistics; DCV, dynamic capability view; ECO, economic performance; EI, eco-innovation; ENP, environmental performance; EPI, environmental performance index; IMP, innovation and market performance; OECD, Organization for Economic Co-operation and Development; PBV, practice-based view; PLS-SEM, partial least squares-based SEM; RBV, resource-based view; SEM, structural equation model; SME, small and medium-sized enterprise; SOP, social performance.

Kirchherr et al., 2017; Prieto-Sandoval et al., 2018; Ul-Durar et al., 2023).

The literature has suggested that EIs are determinants of a CE from processes based on change, cooperation, learning, and systemic integration of diverse actors (de Jesus & Mendonça, 2018; Kiefer et al., 2021; Prieto-Sandoval et al., 2018; Ul-Durar et al., 2023). Likewise, the implementation of the CE seems to depend largely on the nature and characteristics of (eco-) innovations for the creation, transformation, and diversification of systems, organizations, business models, practices, processes, products, and services towards others that can incorporate circular and sustainable principles (de Jesus et al., 2018; Geissdoerfer et al., 2018, 2020; Scarpellini et al., 2020). In this context, CE is defined as an economic system that represents a paradigm shift in the way society interrelates with nature and aims to minimize resource input and waste, emissions, and energy leakage by cycling, extending, intensifying, and dematerializing material and energy loops through design, digitalization, servitization, sharing solutions, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling, where (eco-) innovations are fundamental to this end (Geissdoerfer et al., 2018, 2020; Prieto-Sandoval et al., 2018). In line with the above, EIs are understood as innovations that reduce the environmental impact of production and consumption activities and improve environmental outcomes (whether intentional or unintentional) and their features and typologies contribute differently to sustainable transitions and the CE of cities, regions, governments, eco-industrial parks, firms, and consumers (Carrillo-Hermosilla et al., 2009, 2010; García-Granero et al., 2018; Kiefer et al., 2021; Prieto-Sandoval et al., 2018).

From a company level, scholars have recently focused on studying the relationship of (eco-) innovation on the implementation of the CE and the implications for performance as a key aspect of the management, economics, and organization literature that also brings challenges (Chowdhury et al., 2022; Dey et al., 2020; Kiefer et al., 2021; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Rodríguez-Espíndola et al., 2022). Studies have included (1) literature reviews on the connections and interactions of EI and CE, covering partial results on performance (de Jesus et al., 2018; Prieto-Sandoval et al., 2018); (2) CE theoretical frameworks on the practice-performance relationship pointing to the need to clarify linkages associated with EIs (Mora-Contreras, Torres-Guevara, et al., 2023); (3) research on drivers and barriers in the development of a CE based on EIs highlighting limited understanding in the field (de Jesus & Mendonça, 2018; Hartley et al., 2022; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Schultz & Reinhardt, 2022; Stumpf et al., 2021); (4) likewise, previous work on the role of resources, competencies, and dynamic capabilities as determinants of different types of EIs towards a CE calls for extending existing frameworks and revealing new causal relationships (Del Río, Carrillo-Hermosilla, et al., 2016; Del Río, Peñasco, & Romero-Jordán, 2016; Kiefer, Del Río, & Carrillo-hermosilla, 2019). Moreover, the heterogeneity of the literature on EI, CE, and performance suggests that the implications of EI on CE outcomes and sustainability performance, as well as the factors that influence this connection, remain to be understood and clarified (Kiefer et al., 2021; Mora-Contreras, Torres-Guevara, et al., 2023; Ul-Durar et al., 2023). For instance, Kiefer et al. (2021) suggest that it is necessary to advance in deeper analyses of the linkages or, specifically, causal relationships between EI features (e.g., origin, type, and degree of novelty or radicality) and CE to achieve sustainable transitions, according to their study in Spanish manufacturing firms. Bag et al. (2022) point to a lack of understanding of the relationships between EI and capability building to help CE improve firm outcomes in the manufacturing context. Similarly, Ul-Durar et al. (2023) recommend that the current understanding of drivers and factors of EIs and the consequences of the CE are limited. The above challenges and perspectives represent a gap that requires further research.

A new gap emerges as empirical evidence on the effect of the CE on sustainability performance, considering the linkages with EIs remains blurred (Mora-Contreras, Ormazabal, et al., 2023; Saha et al., 2021; Scarpellini et al., 2020; Triguero et al., 2023). In this regard, contradictory results have been found on the impact of the CE implementation on the companies' sustainability performance (Dey et al., 2020; Mora-Contreras, Torres-Guevara, et al., 2023; Saha et al., 2021). For instance, Cheng et al. (2021) found no significant effects of CE on sustainability performance in UK manufacturing firms, while other authors found relevant links on the economic and environmental performance of companies in the same sector in China and Indonesia (Susanty et al., 2020; Zhu et al., 2011). Even Mora-Contreras, Ormazabal, et al. (2023) and Saha et al. (2021) found negative impacts of the CE outcomes on sustainability performance in manufacturing firms in Bangladesh, Vietnam, India, and Colombia, suggesting that the contributions of EI features on microlevel CE outcomes still require further development and testing in different industries and contexts (Kiefer et al., 2017, 2021; Kiefer, Del Río, & Carrillo-hermosilla, 2019). As a result, several interdisciplinary studies have examined the effects of barriers, drivers, and features of EIs on manufacturing firms' CE and sustainability performance to advance their understanding by highlighting their theoretical and practical relevance (Dey et al., 2020; Kiefer et al., 2021; Schultz & Reinhardt, 2022). However, some limitations in this regard include the low number of studies providing empirical evidence of emerging relationships, research with limited sample sizes of firms, the narrow diversity of timescales in different geographies, and the specificity of sectors (Kiefer et al., 2021; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Schultz & Reinhardt, 2022).

The gaps are relevant and significant because understanding the relationships between EIs, CE, and the internal and external factors influencing these linkages could help improve firms' sustainability outcomes (Dey et al., 2020; Prieto-Sandoval et al., 2018). Advancing an understanding of which EI features contribute more or less to CE implementation may benefit business practice and the development of effective policies toward sustainable transitions in diverse geographic contexts (de Jesus et al., 2018). It is also relevant to improve current knowledge on which EIs enable (or block) meaningful circular and sustainable outcomes to promote (or discourage) the adoption of different management strategies and policies.

We bridge these gaps by investigating the effect of barriers, sources of information, and features of innovations and EIs on the CE and the sustainability performance of manufacturing companies in an understudied emerging economy considering 6 years. Through a quantitative study, we conducted a longitudinal analysis of Colombian manufacturing firms using secondary data of the National Administrative Department of Statistics (acronym DANE in Spanish) from the Technological Development and Innovation Survey for 6 years (official information from the Colombian government, 2015 to 2020). The most recent information is right at the beginning of the COVID-19 pandemic, which allows us to avoid considering outlier years and to control for the years established in the study. To achieve the main objective, we employed partial least squares structural equation modeling (PLS-SEM) using the STATA 15.0 for Windows.

The selection of Colombian manufacturing companies can be justified concerning the challenges identified in the national CE strategy (Colombian Government, 2019; Mora-Contreras, Ormazabal, et al., 2023). In this regard, it is indicated that the Colombian industry, despite having a significant share of the national value added (10.9%), has relatively little involvement in global value chains, which limits the acquisition of technologies and investment in research to strengthen technological innovation and productivity (Colombian Government, 2019). On the one hand, this lag in technological innovation is considered one of the most significant challenges to progress on the Sustainable Development Goals. On the other hand, for the period 2000–2018, the productivity of the Colombian economy fell by 1.2%, according to the national CE strategy. Moreover, Colombia, considered the first Latin American country to establish a national CE strategy, recently ranked 87th out of 180 countries in the 2022 Environmental Performance Index (EPI) according to its results on climate change, environmental health, and ecosystem vitality. This suggests that the Colombian industry needs to improve its sustainability performance results through innovation, EI, and CE (Mora-Contreras, Ormazabal, et al., 2023).

As main contributions of this article, we present (1) a response to the call for more studies (de Jesus et al., 2018; Kiefer et al., 2021; Schultz & Reinhardt, 2022), especially quantitative ones with a longitudinal perspective to reveal new effects of barriers, sources of information, and features of innovations and EIs on firms' CE and sustainability performance, highlighting key opportunities and challenges to improve practice and research (Chiappetta Jabbour et al., 2020; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Roxas, 2022); (2) an alternative look and further key evidence on the contributions of previous studies to expand the frontier of knowledge in a field where the relationships of EIs and CE are still not entirely clear (de Jesus & Mendonça, 2018; Kiefer et al., 2021; Schultz & Reinhardt, 2022); and (3) empirical evidence in Colombia as a little explored but relevant geographical context due to its important advances at the macro level in the implementation of the CE and its involvement as a member of the OECD (Organization for Economic Co-operation and Development) in the framework of the promotion and adoption of better public policies based on international standards around sustainability (Mora-Contreras, Ormazabal, et al., 2023).

This paper is structured as follows. Section 2 presents the research model and hypotheses development. Section 3 describes the material and methods. Section 4 shows the results. Section 5 presents the discussion, and Section 6 concludes the study.

2 | RESEARCH MODEL AND HYPOTHESIS DEVELOPMENT

This study proposes a research model to study the effects of the main objective. We develop the model by selecting articles on EIs, CE, and firm performance (i.e., on the relationships of the aspects included in our research objective at the micro level, without neglecting external factors such as the links between economic growth and EIs at the macro level). We also draw on a novel CE theoretical framework (Mora-Contreras, Torres-Guevara, et al., 2023) built on a foundation of relevant studies in the area (e.g., Dey et al., 2020; Kristoffersen et al., 2021; Saha et al., 2021; Scarpellini et al., 2020) and two theoretical lenses, such as the dynamic capability view (DCV) (Teece, 2014; Teece et al., 1997) and the practice-based view theory (PBV) (Bromiley & Rau, 2014). The literature has highlighted the suitability of both theoretical lenses in explaining linkages and influences on performance (Bag, Gupta, & Kumar, 2021; Hazarika & Zhang, 2019; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Mora-Contreras, Ormazabal, et al., 2023).

On the one hand, DCV is an extension of the resource-based view (RBV) (Barney, 1991; Barney, 2001), which postulates that a firm can attain a competitive advantage by integrating, building, and reconfiguring its internal and external competencies to respond to shifts in the business environment (Teece et al., 1997; Zollo & Winter, 2002). Previous studies suggest that developing dynamic capabilities is a key determinant of innovations and EIs to improve performance (Bag et al., 2022; Del Río, Carrillo-Hermosilla, et al., 2016; Hazarika & Zhang, 2019; Patwa et al., 2021; Scarpellini et al., 2020; Ul-Durar et al., 2023). In this regard, the DCV provides an effective means of analyzing the determinants of EIs by considering the endowment of resources (tangible or intangible assets), competencies (resources resulting from activities that are performed repetitively), and dynamic capabilities (intentional creation, extension and modification of the resource and competence base) to reveal the conditioning of firms' ability to eco-innovate (Cainelli et al., 2015; Hazarika & Zhang, 2019; Kabongo & Boiral, 2017; Kiefer, Del Río, & Carrillo-hermosilla, 2019).

On the other hand, the PBV is an extended version of the RBV that explains firm performance based on interacting and interchangeable practices (Bag, Gupta, & Kumar, 2021; Bromiley & Rau, 2014; Mora-Contreras, Torres-Guevara, et al., 2023). According to the PBV, firms within an industry exhibit variation in their performance due to the business practices they adopt (Bromiley & Rau, 2014; Khan et al., 2021; Mora-Contreras, Ormazabal, et al., 2023). The literature suggests that practices impact performance based on five aspects (Bromiley & Rau, 2014; Khan et al., 2021; Mora-Contreras, Ormazabal, et al., 2023): (1) the use of specific practices, (2) the details of how those practices are used, (3) the interaction of those practices with other practices in the firm, (4) the behavior of competitors, and

(5) the sustainability performance as a dependent variable and practices in the firms' supply chain as independent variables when studying their effects.

From the novel CE framework (Mora-Contreras, Torres-Guevara, et al., 2023), the theoretical foundations of the DCV and PBV, and influential literature (Dey et al., 2020; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Scarpellini et al., 2020), this study designed a research model. In this model, barriers, sources of information, and other internal and external factors have implications on the features of innovations and EIs. Moreover, their implementation results in consequences on CE, sustainability, and market and innovation performance, and ultimately, the different types of performance enunciated impact economic and circular performance (see Figure 1). The definition of the constructs is presented in Table 1.

Regarding the research model's scope, components, and relationships, previous studies have suggested that the determinants of the features of EIs and the CE can act as barriers or drivers. For instance, economic, technological, and institutional dimensions, among others, can foster or block EIs and the CE. Moreover, the categories should not be understood as mutually exclusive (de Jesus & Mendonça, 2018; Kiefer, Del Río, & Carrillo-hermosilla, 2019). In this sense, our approach is based on descriptions or items defined by other authors on the characteristics of the determinants when they act as sources or barriers (as appropriate in the model) without ignoring that these could even act in a role opposite to that initially established (Chiappetta Jabbour et al., 2020; de Jesus & Mendonça, 2018; Schultz & Reinhardt, 2022).

We recommend that the proposed research model integrates the barriers, sources of information, other internal and external factors, features of (eco-) innovations, and performance aspects that are relevant in the literature but contained within a broader diversity of all of them (de Jesus & Mendonça, 2018; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Schultz & Reinhardt, 2022). For instance, the works of de Jesus and Mendonça (2018) and Schultz and Reinhardt (2022) include two major typologies of barriers and drivers, the "softer" and the "harder" ones, where the social and cultural dimension is also considered. Moreover, Kiefer, Del Río, and Carrillo-hermosilla (2019) separated internal and external factors to delve into the former based on resources, competencies, and dynamic capabilities that, according to the literature, were grouped into six categories (i.e., physical, reputational/cooperational, motivational/organizational, financial, human intellectual and technological). Our model establishes a simplified representation of such diversity but considers relevant and necessary components and relationships in the literature (Chiappetta Jabbour et al., 2020; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Schultz & Reinhardt, 2022).

Finally, we identified the need to address additional limitations of the microlevel models in terms of considering other external factors. The macrolevel literature recognized key links between EIs and a country's economic growth (Ahmad et al., 2021; Te Tu et al., 2023). These findings encourage us to clarify their relationship independently following the challenges and limitations posed by Schultz and Reinhardt (2022) and the absence of constructs sufficiently solid to argue that economic growth can be contained within an economic barrier

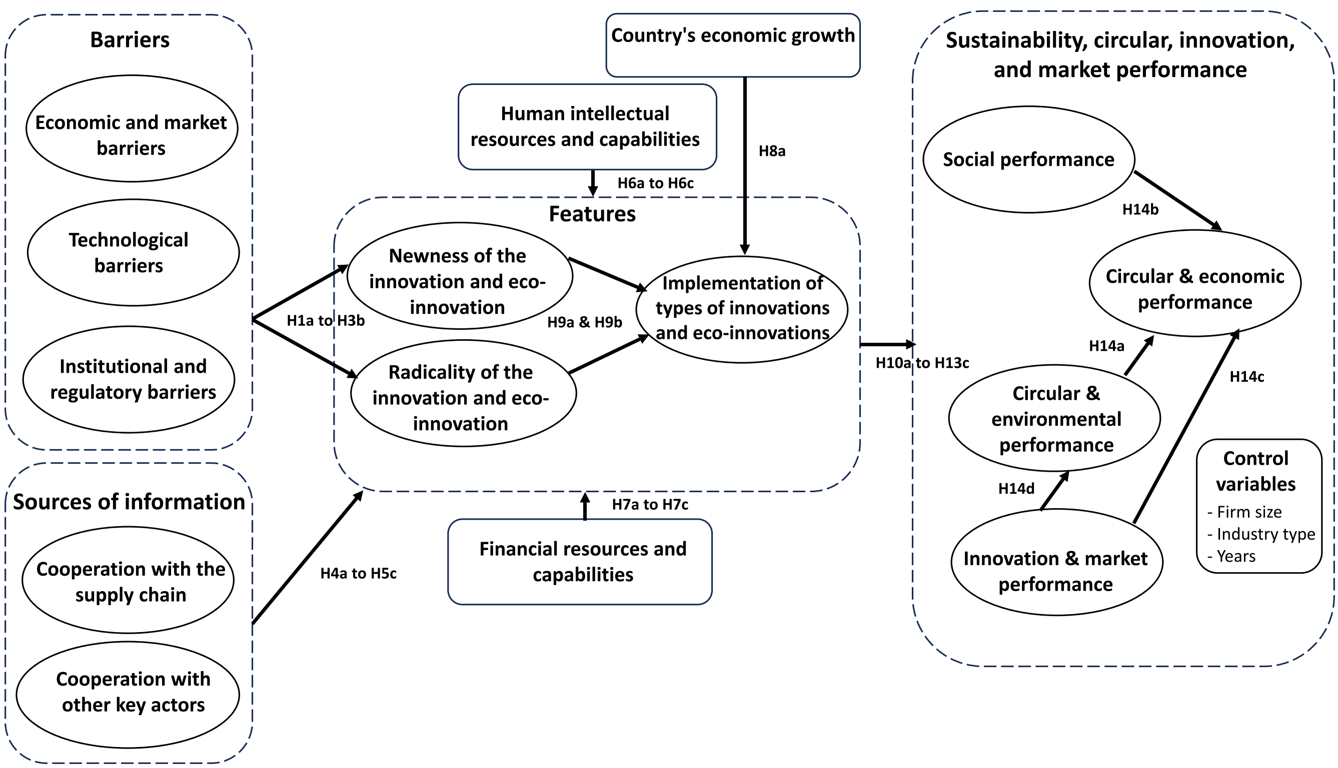

FIGURE 1 Research model.

TABLE 1 Definition of constructs.

Constructs	Definitions	Authors
Circular economy (CE)	Economic system that represents a paradigm change in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy, and materials loops, and facilitate sustainable development where innovation and EI are central and considered key to this paradigm shift.	Del Río et al. (2021); Kiefer, Carrillo-Hermosilla, and Del Río (2019); Ormazabal et al. (2018); Prieto-Sandoval et al. (2018); Scarpellini et al. (2020)
Eco-innovation (EI)	Innovations that reduce the environmental impact of production and consumption activities and improve environmental outcomes, regardless of whether the motivation for their development or adoption is environmental.	Carrillo-Hermosilla et al. (2009, 2010); Kiefer et al. (2021)
EI features	Characteristics or types of EIs including the following dimensions: targets (i.e., products, processes, marketing methods, organizations, and institutions); scope of change (i.e., system component, subsystem, or societal system), mechanisms of change (modification, redesign, alternatives, and creation), and degree of change (i.e., incremental, radical, or disruptive). It is considered newness when it is the first time that a company applies an EI, while radicality is when it is the first time that an EI is implemented in a sector of activity. Four dimensions are also included: design, user, product-service, and governance. Finally, it relates to a taxonomy of five EI types: (1) continuous improvement, (2) eco-efficient, (3) externally driven, (4) radical and tech-push, and (5) systemic.	Carrillo-Hermosilla et al. (2009, 2010); Kiefer et al. (2021); Kiefer, Carrillo-Hermosilla, and Del Río (2019); OECD (2010); Tukker and Ekins (2019)
Barriers, drivers, and factors in the adoption of CE practices through EIs	Barriers that obstruct, slow down, or derail transitions toward a CE, while drivers include factors that enable, accelerate, or encourage change toward a CE. Both elements can be grouped into four typologies considering internal and external factors: (1) economic/financial/market (market structures, prices of raw materials, demand-side trends, transaction costs, and infrastructure), (2) technological (technology, technical support, and training, and technical solutions), (3) institutional/regulatory (initiatives, governmental action, and institutional incentive structures), and (4) social/cultural (mindsets, mental models, peoples' sensitivity, and awareness). Moreover, the following resources, competencies, and dynamic capabilities are determinants (drivers or barriers): (1) physical, (2) reputational and cooperation, (3) motivational and organizational, (4) financial, (5) human intellectual, and (6) technological.	de Jesus and Mendonça (2018); Gong et al. (2020); Kiefer, Del Río, and Carrillo-hermosilla (2019); Schultz and Reinhardt (2022)
Sources of information	The sources of information and the results of cooperative efforts between the different stakeholders that play a crucial role in the development and adoption of EI. For instance, the information provided in the supply chain (customers and suppliers) and by other external sources such as universities, associations, and other companies. The governance dimension describes the stakeholders involved and their behavior within the value network.	Carrillo-Hermosilla et al. (2010); Chistov et al. (2023); Horbach et al. (2012); Kiefer et al. (2017); Kiefer, Carrillo-Hermosilla, and Del Río (2019)
Sustainability performance	The aggregate negative or positive bottom line of economic, environmental, and social impacts of an entity against a defined baseline.	Büyüközkan and Karabulut (2018, p. 253)
Economic performance (ECO)	The company's ability to minimize the cost associated with the acquisition of resources, materials, and different components; production processes; remanufacturing and recycling processes; waste disposal; water use and discharge; energy consumption; waste treatment; defective components/materials; stock maintenance; transportation; reduction of costs related to fines for	Agrawal and Singh (2019); Dey et al. (2020); Khan et al. (2021); Mora-Contreras, Ormazabal, et al. (2023); Mora-Contreras, Torres-Guevara, et al. (2023); Zhu et al. (2011)

(Continues)

TABLE 1 (Continued)

Constructs	Definitions	Authors
	environmental accidents; and market share growth and profit increase.	
Environmental performance (ENP)	The capacity of companies to reduce resource consumption, waste generation, and emissions; packaging; and energy consumption; increase the use of recycled resources and waste that is processed with the other methods of reuse and remanufacturing; use of alternative energies; compliance to environmental regulations; and minimize the use of toxic, noxious, harmful, damaging, or contaminated chemicals and materials.	Agrawal and Singh (2019); Green et al. (2012); Khan et al. (2021); Mora-Contreras, Torres-Guevara, et al. (2023); Zhu et al. (2011)
Social performance (SOP)	A company's ability to engage employee commitment, continuous learning, and personal development; health and safety precautions; respect national legislation; green jobs creation; fair hiring practices of gender, people with disabilities or distance to the labor market; welfare, and improvement of the local community economy; development of educational activities in schools and community; carbon offsetting; and support of social projects and pro-bono services; among others.	Dey et al. (2020); Kazancoglu et al. (2018); Mora-Contreras, Ormazabal, et al. (2023); Mora-Contreras, Torres-Guevara, et al. (2023); Walker, Opferkuch, et al. (2021); Walker, Vermeulen, et al. (2021)
Circular economy performance	The ability of an economic system to reduce, reuse, recycle, and recover resources and leakage; to extend, intensify, and dematerialize material and energy loops; to maintain products in use; to regenerate natural systems; to achieve economic prosperity by gradually decoupling the consumption of finite resources; and to create benefits for all of society at the macrolevels, mesolevels, and microlevels. Likewise, CE performance intersects with sustainability performance, but they are not synonymous.	Geissdoerfer et al. (2017, 2020); Jain et al. (2020); Kirchherr et al. (2017); Kravchenko et al. (2019); Panchal et al. (2021); Prieto-Sandoval et al. (2018); Zhu et al. (2011)
Innovation and market performance (IMP)	The capacity of companies to achieve innovation and market outcomes concerning improving the quality of products and services, leading to more differentiated products and services, winning new customers and markets, reacting promptly to market opportunities, and thus maintaining its market power or improving its market position.	Ahuja and Katila (2001); Gök & Peker (2016); Hogan and Coote (2014); Homburg and Jensen (2007)

(or driver) to CE and EI in the organizational management literature (Chiappetta Jabbour et al., 2020).

The following sections address the literature on the effects of barriers (2.1), sources of information (2.2), resources and capabilities, and economic growth (2.3) on the features of EIs. Then, the effect of newness and radicality on implementing the types of (eco-) innovations is presented in subsection 2.4 (according to Kiefer et al. [2021], it is considered newness when it is the first time that a company applies an EI, while radicality is when it is the first time that an EI is implemented in a sector of activity). Lastly, the impact of features on performance and across performance types is considered (2.5).

2.1 | Effect of barriers on the features of (eco-) innovations in the context of the CE

Governments have recognized the importance of implementing CE by developing national strategies, promoting institutional frameworks and guidelines to mitigate environmental risks, and encouraging the adoption of environmental technologies (Chiappetta Jabbour et al., 2020; Colombian Government, 2019). In this regard, initiatives, opportunities, and challenges for adopting CE practices at the microlevel have been present for several years (Ormazabal et al., 2018). In this paper, we consider economic/market, technological, and institutional/regulatory barriers to CE; the role of sources of information and cooperation; and other internal and external factors that can also act as drivers or barriers to EI features as determinants of the CE (Araújo & Franco, 2021; de Jesus & Mendonça, 2018; Salim et al., 2019). Furthermore, to clarify the complexity of the relationships between factors and EIs, we suggest that the same factor may act as a driver for one EI and, at the same time, it may be a barrier for another. This may depend, for instance, on the type of EI analyzed, as previous literature has shown (e.g., continuous improvement, eco-efficient, externally driven, radical, and tech-push, and systemic) (Hazarika & Zhang, 2019; Kiefer, Del Río, & Carrillo-hermosilla, 2019).

The literature has suggested that within the economic (financial or market) dimension, lack of financial capabilities, high upfront investment cost for new technologies, high economic uncertainty, low primary (raw) material prices, asymmetric information, lack of transparency (e.g., greenwashing and imitation), and uncertainty about (eco-) innovation performance and returns represent a challenge for CE and the nature of EIs (Amoozad Mahdiraji et al., 2023; Awan & Sroufe, 2022; Chiappetta Jabbour et al., 2020; de Jesus & Mendonça, 2018; Schultz & Reinhardt, 2022; Takacs et al., 2022). For instance, the findings of a case study on circular business model innovation in a small and medium-sized enterprise (SME) in the United States highlighted relevant obstacles (Awan & Sroufe, 2022). Pricing mechanisms and the offer of new services, including the price of virgin materials, could represent a crucial disadvantage for companies and make it difficult for them to maintain viable business models (Awan & Sroufe, 2022). Reviews also indicated that enterprises are often unable to access data on products in use due to market barriers and high investment costs, but managing to overcome these barriers to accessing the technological aspect of innovations (e.g., the Internet of Things) can contribute to the radicality of EIs to alter their business models and achieve improvements in terms of circularity and sustainability (Alcayaga et al., 2019; Awan et al., 2021; Manavalan & Jayakrishna, 2019). Mishra et al. (2022) also suggested that a lack of certainty about the demand for (eco-) innovative products is a market barrier to adopting CE practices. Still, it should not be limited to a single specific factor.

López Pérez et al. (2023) indicated that while multinationals have the financial resources to innovate, SMEs have scarce resources that, depending on the context, could pose barriers to EIs features towards CE. Schultz and Reinhardt (2022) found economic and market barriers associated with the low profitability of EI in the European polyurethane industry. Other studies in the manufacturing context recommend that developing radical innovations and digitization of practices using various data transmission techniques involves adopting a range of relevant technologies in the supply chain (e.g., blockchain), which may require considerable investment (Mathivathanan et al., 2021). Nevertheless, these economic barriers could be overcome with several strategies by institutions to provide financial support for initiatives and investments for industry digitization around CE and sustainable outcomes (Awan et al., 2021). On the other hand, there are alternative perspectives to the above relationships. For instance, Kiefer, Del Río, and Carrillo-hermosilla (2019) implied that the higher the financial capital of firms, the lower the likelihood of engaging in systemic/radical EI. Past trajectories could act as barriers to more radical and systemic EIs due to lock-in to past success. These results suggest that financial capital can both hinder and drive the development of EIs for a CE. Based on these arguments, we propose the following hypotheses:

> **H1a.** The economic/market barriers of the CE have a significant and negative impact on the newness of the innovations and EIs.

> **H1b.** The economic/market barriers of the CE have a significant and negative impact on the radicality of the innovations and EIs.

Having the right technology is an initial requirement for a CE, but this need is not always met, which hinders its implementation (Chiappetta Jabbour et al., 2020; Manavalan & Jayakrishna, 2019; Shahbazi et al., 2016). Chiappetta Jabbour et al. (2020) found significant negative effects of technological barriers on adopting CE principles in the Brazilian industrial sector (e.g., lack of clarity on how to integrate CE in product development). Lack of information and technical and technological knowledge to implement eco-innovative strategies have also been identified as technological barriers (de Jesus et al., 2019; Kiefer, Del Río, & Carrillo-hermosilla, 2019). Shahbazi et al. (2016) also recognized the lack of knowledge to adopt CE practices in Swedish manufacturing firms as a technological barrier in medium and large firms. Similarly, studies recognized significant challenges for firms in meeting the technological and scientific research needs for the development and adoption of radical and technology-push EIs, as they are characterized by a high degree of technological novelty, a break with existing solutions, and considerable environmental benefits (Kiefer, Carrillo-Hermosilla, & Del Río, 2019; Kiefer, Del Río, & Carrillo-hermosilla, 2019). Moreover, some authors discuss other technological aspects, considering imitation and patents. While the protection of intellectual property rights through patents is related to EIs, there are technologies that are more difficult to patent than others (e.g., incremental ones) (de Marchi & Grandinetti, 2013; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Sáez-Martínez et al., 2016). Furthermore, it poses challenges that not all key technologies are patented (de Marchi & Grandinetti, 2013; Kiefer, Del Río, & Carrillo-hermosilla, 2019). Based on the above studies, we develop the following hypotheses:

> **H2a.** The technological barriers of the CE have a significant and negative impact on the newness of the innovations and EIs.

> **H2b.** The technological barriers of the CE have a significant and negative impact on the radicality of the innovations and EIs.

Studies indicate that the institutional and regulatory dimension, despite its role as a CE driver, is also one of the most important aspects limiting the development and adoption of EIs for a transition to circularity (de Jesus & Mendonça, 2018; García-Quevedo et al., 2020; Schultz & Reinhardt, 2022). For instance, García-Quevedo et al. (2020) indicated that the complexity of laws and regulations represents one of the most important barriers for European SMEs. Guldmann and Huulgaard (2020) suggested that difficulties and lack of funding opportunities hinder the development and implementation of the CE in the context of Danish companies of different sizes and industries. Likewise, the political discourse highlighted challenges for adopting CE practices, considering the need for dedicated public policies and new forms of cooperation between business and public actors (de Jesus & Mendonça, 2018). Based on these arguments, we propose the following hypotheses:

H3a. The institutional/regulatory barriers of the CE have a significant and negative impact on the newness of the innovations and EIs.

H3b. The institutional/regulatory barriers of the CE have a significant and negative impact on the radicality of the innovations and EIs.

2.2 | Effect of the sources of information on the features of (eco-) innovations

Research has shown that several EIs need sources of information and cooperation with different intensities considering stakeholders such as associations, universities, consumers, suppliers, other companies, and governments (Araújo & Franco, 2021; de Jesus Pacheco et al., 2017; Del Río, Peñasco, & Romero-Jordán, 2016; Horbach et al., 2012, 2013; Kiefer, Del Río, & Carrillo-hermosilla, 2019). For instance, systemic EIs necessarily involve changes in the supply chain that lead firms to cooperate intensively with other stakeholders (Chistov et al., 2023; Del Río, Peñasco, & Romero-Jordán, 2016; Kiefer, Del Río, & Carrillo-hermosilla, 2019). Similarly, Cainelli et al. (2012) and Kiefer, Del Río, and Carrillo-hermosilla (2019) suggest that networking and cooperation with universities are key to achieving radical EIs. In the case of SMEs, there could be a greater reliance on information sources from research institutes, agencies, and universities to enhance organizational learning and facilitate the adoption of EIs and sustainable and circular practices (de Jesus Pacheco et al., 2017; López Pérez et al., 2023). Moreover, EIs are often characterized by relatively new technologies, which require more external sources of information than innovation in general (Horbach et al., 2013; Kiefer, Del Río, & Carrillo-hermosilla, 2019). In this sense, a company's cooperation with its supply chain and other key actors could contribute differently to EIs (Araújo & Franco, 2021). Based on these arguments, we propose the following hypotheses:

H4a. The sources of information and cooperation with the company's supply chain have a significant and positive impact on the newness of the innovations and EIs.

H4b. The sources of information and cooperation with the company's supply chain have a significant and positive impact on the radicality of the innovations and EIs.

H4c. The sources of information and cooperation with the company's supply chain have a significant and positive impact on implementing the types of innovations and EIs.

H5a. The sources of information and cooperation with other external key actors have a significant and positive impact on the newness of the innovations and EIs.

H5b. The sources of information and cooperation with other external key actors have a significant and positive impact on the radicality of the innovations and EIs.

H5c. The sources of information and cooperation with other external key actors have a significant and positive impact on implementing the types of innovations and EIs.

2.3 | Effect of human and financial resources and capabilities, and economic growth on the features of (eco-) innovations

The literature postulates that a firm's resources, competencies, and capabilities are relevant for the development and adoption of EI, but their importance differs according to the features of EI (Del Río, Carrillo-Hermosilla, et al., 2016; Del Río, Peñasco, & Romero-Jordán, 2016; Kiefer, Del Río, & Carrillo-hermosilla, 2019). For instance, eco-innovative practices rely on human intellect resources, capabilities, and competencies (e.g., participation in research and development activities and active knowledge management as a dynamic capability) that can translate into higher innovative performance (a special case of radical and disruptive innovations) (Castellacci & Lie, 2017; López-Nicolás & Meroño-Cerdán, 2011; Yang et al., 2014). Similarly, resources, competencies, and financial capabilities are seen as determinants of EIs depending on internal and external funding, resource availability, and profitability (Hazarika & Zhang, 2019; Kiefer, Del Río, & Carrillo-hermosilla, 2019), as well as other internal and external factors. Based on the above studies, we develop the following hypotheses:

H6a. Human intellectual resources and capabilities have a significant and positive impact on the newness of innovations and EIs.

H6b. Human intellectual resources and capabilities have a significant and positive impact on the radicality of innovations and EIs.

H6c. Human intellectual resources and capabilities have a significant and positive impact on implementing the types of innovations and EIs.

H7a. Financial resources and capabilities have a significant and positive impact on the newness of innovations and EIs.

H7b. Financial resources and capabilities have a significant and positive impact on the radicality of innovations and EIs.

H7c. Financial resources and capabilities have a significant and positive impact on implementing the types of innovations and EIs.

Regarding external factors, studies have found a positive correlation between EI and economic growth (Te Tu et al., 2023). Effective public policies could provide innovation funding to develop appropriate technologies that can ensure complementarity between higher economic growth and lower environmental degradation, although, in practice, this may not necessarily be fulfilled (Ahmad et al., 2021). Moreover, the certainty of national initiatives to try to accelerate economic growth rates to reach respective income thresholds (in particular contexts) beyond which economic growth does not adversely affect the environment necessarily involves EIs (Carrillo-Hermosilla et al., 2009, 2010). However, in the literature, there are perspectives with partial agreements. An inverted U-shaped can be proposed between the availability of financial resources and (eco-) innovation (Kiefer, Del Río, & Carrillo-hermosilla, 2019) and between economic growth and the ecological footprint (Ahmad et al., 2021). Based on the above studies, we develop the following hypothesis:

H8a. A country's economic growth has a significant and positive impact on implementing the types of innovations and EIs.

2.4 | Effect of newness and radicality on the implementation of types of (eco-) innovations

EI features, such as the degree of change (e.g., incremental or radical), involve the implementation of different EI typologies (de Jesus & Mendonça, 2018; Kiefer et al., 2017; Kiefer, Carrillo-Hermosilla, & Del Río, 2019; Wang et al., 2022; Xavier et al., 2017). For instance, radical EIs have implications for the implementation or introduction of alternatives or completely new organizational methods, products, processes, or marketing procedures with different contributions to the sustainability or the CE of a company (Armstrong et al., 2015; Kiefer et al., 2021; Kiefer, Carrillo-Hermosilla, & Del Río, 2019; Ul-Durar et al., 2023; Xavier et al., 2017). In this sense, there are interactions between different features of EI that affect the implementation or introduction. Based on these arguments, we propose the following hypotheses:

H9a. The newness of innovations and EIs has a significant and positive impact on implementing the types of innovations and EIs.

H9b. The radicality of innovations and EIs has a significant and positive impact on implementing the types of innovations and EIs.

2.5 | Effect of the features of (eco-) innovations and different types of performance

According to the literature, EI features are significantly associated with CE outcomes, economic (ECO), environmental (ENP), social (SOP), and innovation and market performance (IMP) (Cheng et al., 2014; Horbach et al., 2012; Lee & Min, 2015; Mora-Contreras, Torres-Guevara, et al., 2023; Pujari, 2006). On the one hand, Kiefer et al. (2021) supported the idea that EI is central to achieving CE, but EI features mediate this relationship. For instance, only one type of EI was found to support high-level CE (i.e., systemic EIs) in the case of Spanish manufacturing firms. On the other hand, Hizarci-Payne et al. (2021) found that EI typologies drive firm performance (i.e., ECO, ENP, SOP, and IMP) mainly manufacturing from developing and developed countries. Still, there are significant variations in the correlation between EI and different types of performance, and the magnitude is stronger in developing countries compared to developed ones (Hizarci-Payne et al., 2021). Other studies showed positive links of EI on emissions, energy and resource consumption reduction, recycling, return on investment, market share, sales, waste utilization, and personnel involved in science, technology, and innovation activities (Cheng et al., 2014; Lee & Min, 2015; López-Nicolás & Meroño-Cerdán, 2011; Mora-Contreras, Torres-Guevara, et al., 2023; Pujari, 2006). Fernando et al. (2021) also found that adopting the EIs appears to help improve circular product outcomes and the performance of Malaysian manufacturing firms. The research highlights that circular EIs are key to promoting business competitiveness in the industry (Fernando et al., 2021). Finally, positive effects were found between different types of firm performance (Khan et al., 2021; Salim et al., 2019; Sarfraz et al., 2021). In this regard, Khan et al. (2021) found positive and statistically significant effects of ENP on ECO and Sarfraz et al. (2021) of ECO, ENP, and SOP on organizational performance. Based on the above studies, we develop the following hypotheses:

H10a. The newness of innovations and EIs has a significant and positive impact on circular and ECO.

H10b. The radicality of innovations and EIs has a significant and positive impact on circular and ECO.

H10c. Implementing the types of innovations and EIs has a significant and positive impact on circular and ECO.

H11a. The newness of innovations and EIs has a significant and positive impact on circular and ENP.

H11b. The radicality of innovations and EIs has a significant and positive impact on circular and ENP.

H11c. Implementing the types of innovations and EIs has a significant and positive impact on circular and ENP.

H12a. The newness of innovations and EIs has a significant and positive impact on SOP.

H12b. The radicality of innovations and EIs has a significant and positive impact on SOP.

H12c. Implementing the types of innovations and EIs has a significant and positive impact on SOP.

H13a. The newness of innovations and EIs has a significant and positive impact on IMP.

H13b. The radicality of innovations and EIs has a significant and positive impact on IMP.

H13c. Implementing the types of innovations and EIs has a significant and positive impact on IMP.

H14a. Circular and ENP have a significant and positive impact on circular and ECO.

H14b. SOP has a significant and positive impact on circular and ECO.

H14c. IMP has a significant and positive impact on circular and ECO.

H14d. IMP has a significant and positive impact on circular and ENP.

3 | MATERIAL AND METHODS

This quantitative study used secondary data sources from the DANE through the Technological Development and Innovation Survey between 2015 and 2020 in Colombia. To the best of our knowledge, there is no longitudinal study available that investigates the effects and presents the dynamics of barriers, sources of information, and other internal and external factors of CE and EI on the characteristics of innovations and EIs, as well as their consequences on the different types of firm performance in an emerging economy such as Colombia. Considering the diversity and complexity of the manufacturing sector's relationships concerning CE and EI, the above aspects justify the relevance and pertinence of the methodological approach.

In this quantitative study, we followed an approach similar to that of other research with similar objectives (Bag, Wood, et al., 2020; Chiappetta Jabbour et al., 2020; Lopes de Sousa Jabbour et al., 2022; Mora-Contreras, Ormazabal, et al., 2023; Pinheiro et al., 2022; Yang et al., 2019). The data and the Technological Development and Innovation Survey are available on the official DANE website (https://microdatos.dane.gov.co/index.php/catalog/Ind-Microdatos). The content of this survey considers the methodological guidelines outlined by the OECD, particularly the Oslo Manual, and by the Ibero-American Network of Science and Technology Indicators—RICYT, as well as the revision of concepts and methods to guarantee conditions of international comparability in the variables that affect the impact on the economy of governments (DANE, 2021). In this regard, the review of international benchmarks of the Technological Development and Innovation Survey included, for instance, the Community Innovation Survey (CIS, European Community), the Survey of Innovation and Business Strategy (SIBS, Canada), the Community Innovation Survey (CIS, France), the Business Innovation Survey (Uruguay), the National Survey on Innovation and Technological Behavior (acronym ENIT in Spanish, Argentina), the Management and Organization Practices Survey (MOPS, the United States), and the Japanese National Innovation Survey (J-NIS, Japan).

The Technological Development and Innovation survey was selected to make statistical inferences and generalize the effect of barriers, sources, and features of innovations and EIs on Colombian manufacturing firms' CE and sustainability performance. An important advantage of using the survey is that its content includes key variables to respond to our research objective. Furthermore, it has comparability conditions of innovations and EIs concerning other countries.

In this study, three steps were necessary to use the DANE survey information in line with other works (Fernando et al., 2019; J. Li et al., 2015; Y. Li et al., 2019; Mora-Contreras, Ormazabal, et al., 2023; Yang et al., 2019):

Step 1: Conceptual framework.

The first step consisted of developing the research model based on previous literature on EIs, CE, and firm performance, a theoretical framework of CE (Mora-Contreras, Torres-Guevara, et al., 2023), and the DCV and PBV lenses. To obtain relevant academic literature on the relationships and effects of the above concepts, a search process was conducted in Scopus and Web of Science considering the following aspects: (1) studies on CE barriers considering EIs, (2) research that included CE and EIs at the microlevel and the study of other external factors related to EIs (e.g., economic growth) at the macrolevel, and (3) articles that investigated the causal relationships between barriers, sources of information, EIs features, and performance. As a result, constructs and measurement variables were identified that allowed us to quantify the concepts involved in this study.

Step 2: Relevance of secondary source data and variable measures.

In the second step, to ensure the use of the data, a thorough review of all the variables in the Technological Development and Innovation Survey was conducted based on validated measures from previous research. In other words, whether there is correspondence between the constructs and indicators in the literature and the variables (de Jesus & Mendonça, 2018; Lopes de Sousa Jabbour et al., 2022; Kiefer et al., 2021; Yang et al., 2019), and whether they also help to answer the main objective of this research (see Section 3.2 for more details). Therefore, only the survey variables that met the aforementioned requirements were included.

Step 3: Analysis methods.

In the last step, we argue the reasons for choosing a particular method of data analysis (Lopes de Sousa Jabbour et al., 2022). Given the nature of the secondary source data (e.g., Likert-scale, binary, and discrete non-binary variables) and the structure and complexity of our research model (e.g., several unobserved variables), SEM is the most appropriate method. The two approaches commonly used in empirical research are PLS-SEM and covariance-based SEM (CB-SEM). In this work, we chose to use PLS-SEM because it is a relevant method for estimating complex models (for details of our reasons, see Section 3.2). In this case, the nature of our model makes the application of CB-SEM less appropriate due to the diversity of constructs, variables, and indicators. Moreover, the explanation and prediction objective, the exploratory nature of the research, and the degree of development of the field of study are other essential aspects that make PLS-SEM a suitable tool instead of CB-SEM, as suggested by other studies with similar purposes (Lopes de Sousa Jabbour et al., 2022; Gupta et al., 2022). Therefore, PLS-SEM was used to determine the effects of barriers, sources of information, and features of innovations and EIs on manufacturing firms' CE and sustainability performance. The STATA 15.0 for Windows was used for this purpose. The procedures used to test the established research model are detailed below.

3.1 | Sampling and data

We focus on a specific target universe (i.e., one economic sector and country and different firm sizes), as other studies in the same field have done (e.g., Dey et al., 2020; Kiefer et al., 2021; Pinheiro et al., 2022). Specifically, Colombian manufacturing companies have been selected. The focus on the industrial sector is justified because it is one of the most polluting and resource-intensive economic activities (Acerbi & Taisch, 2020; Halstenberg et al., 2017). It is also a sector with a great potential to adopt (eco-) innovations with implications for circularity and sustainability, which makes it a relevant context for EI and CE studies (Kiefer et al., 2021). Moreover, according to the DANE, one of the economic activities that contributes most to the dynamics of value added is the Colombian manufacturing industry, which accounted for more than 11.6% of the country's gross domestic product (GDP) based on the third quarterly report of 2023. Below, we detail the sampling and use of data.

The secondary data source used in this research comes from the DANE survey on technological development and innovation in firms located in Colombia. The sample selection followed similar inclusion criteria as in previous works with similar objectives (e.g., Yang et al., 2019). In this sense, it was based on all Colombian manufacturing companies that completed the Technological Development and Innovation Survey and reported information between 2015 and 2020. The information is collected in biennial periods through the completion of the online survey (DANE, 2021). In this context, the reference periods of the survey correspond to the 2 years immediately before collecting the information, starting on January 1 of the first year and ending on December 31 of the second year (DANE, 2021). The companies identified include all manufacturing subsectors defined based on the DANE typology. These companies include a wide diversity of business models, levels of development and maturity, practices, technologies, forms of production, (eco-) innovations, and typologies of products and services to represent the manufacturing sector. Moreover, all sizes are included, from micro to large companies. The initial sample was 8175 companies. From the 8175 firms, we eliminated 5031 firms that lacked the necessary data for the variables used in our analysis, according to the literature (Yang et al., 2019). The above exclusion is also justified according to the perspective of the DANE (2021), which indicates that the data from the Technological Development and Innovation Survey may not be subject to imputation or adjustment because it is recognized that neither the magnitudes nor the relationship between the innovation and technological development activities carried out by the companies can be generalized by assigning values based on historical or sectoral averages, given the non-linear and underdetermined nature of the technological behavior of the companies. Following the above argumentation and the exclusions, the sample comprised 3144 Colombian manufacturing companies.

We also calculated the minimum sample size needed for our research. The software used for this purpose was G*power, which considered parameters such as the number of predictors of our research model, a power level of 0.95, an effect size f^2 of 0.1, and a significance level of 0.05. Our results indicated that the minimum sample size needed was 262 cases for the above conditions. If the relevance for detecting small effects is considered (e.g., an effect size f^2 of 0.01), the minimum required sample size could amount to 2524 cases considering a power level of 0.95. Manufacturing firms include high degrees of complexity and diversity, so considering small effect sizes could more accurately represent reality and the more subtle differences or associations between variables that might be especially important in business practice. In our case, the final sample size of 3144 companies fulfills both conditions for achieving our objective of investigating the effect of barriers, sources of information, and features of innovations and EIs on the CE and the sustainability performance in such a varied environment. Table 2 shows the demographic characteristics of the firms.

The study sample represents a broad set of companies in terms of subsectors, sizes, and levels of development of novel and radical (eco-) innovations. The majority of firms correspond to other manufacturing activities (19.18%—e.g., manufacture of machinery, electrical equipment, and components); textiles, apparel, footwear, and leather (16.95%); manufacture of chemicals and chemical products (15.62%); food, beverages, and tobacco (12.88%); and manufacture of rubber and plastic products (12.02%). The highest proportion includes small and medium-sized companies (39.1% and 37.8%, respectively). The level of adoption and development of novel and radical (eco-) innovations corresponds to 56.5% and 7.6%, respectively. The above characteristics are relevant to our research objective because they include the complexity of industries around the following aspects: (1) the regulatory, technological, and economic pressures associated with manufacturing subsectors; (2) the varying degrees of human and financial resource development and the level of stakeholder consultation and cooperation associated with the size and subsector of firms (among other factors); and (3) the degree to which firms have developed or adopted (eco-) novel or radical innovations to help understand their performance implications.

TABLE 2 Sample characteristics.

Characteristics	Sample (N)	%
Industry—manufacturing	3144	100
Food, beverages, and tobacco	405	12.88
Manufacture of coke, refined petroleum products, and nuclear fuel	52	1.65
Manufacture of rubber and plastic products	378	12.02
Manufacture of chemicals and chemical products	491	15.62
Manufacture of wood and products of wood and cork; manufacture of paper and paper products; and publishing and printing activities	242	7.7
Manufacture of non-metallic mineral products	167	5.31
Metallurgy and manufacture of metal products	273	8.68
Textiles, apparel, footwear, and leather	533	16.95
Other manufacturing activities	603	19.18
Firm size (number of employees)	3144	100
1–9	97	3.1
10–49	1228	39.1
50–249	1190	37.8
250+	629	20
Novel (eco-) innovations	3144	100
Companies that adopted or developed novel (eco-) innovations	1776	56.5
Companies that did not adopt or develop novel (eco-) innovations	1368	43.5
Radical (eco-) innovations	3144	100
Companies that adopted or developed radical (eco-) innovations	238	7.6
Companies that did not adopt or develop radical (eco-) innovations	2906	92.4

3.2 | Measurements of the model variables

The variables selected and included from the Technological Development and Innovation Survey were based on their correspondence with established measures in the literature, with special attention to validated items from previous studies (Chiappetta Jabbour et al., 2020; de Jesus & Mendonça, 2018; Kiefer et al., 2021; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Mora-Contreras, Torres-Guevara, et al., 2023; Schultz & Reinhardt, 2022; Yang et al., 2019). The preference for including variables related to previously validated measures in the literature improves the rigor of our research in line with other authors (Lopes de Sousa Jabbour et al., 2022). Tables 3 and 4 present the operationalization of constructs on barriers, sources of information, and features of innovations and EIs and performance.

The DANE survey measurement items included Likert scales (three-point and four-point) and binary, discrete, and continuous variables (all defined by them except for the economic growth variable). A 3-point Likert scale was identified for all CE barriers (ECOBARR1-4, TECBARR1-3, and INSTBARR1-3) (1 = none, 2 = medium, 3 = high); a 4-point Likert scale concerning all performance types except SOP (CECO1-4, CENP1-5, and IMP1-4) (1 = negative, 2 = none, 3 = medium, 4 = high); binary variables for all information sources (SOURCEA1-2 and SOURCEB1-3), for one newness variable (NEWNESS1), two radicality variables (RADICAL1–2) and one for financial resources and capabilities variable (FINANCIAL1) (1 = when the situation of newness, radicality, sources of information and cooperation or investment in science, technology and innovation activities has occurred and 0 = when it has not occurred); non-binary discrete variables for human intellectual resources and capabilities (HUMAN1), two newness and radicality variables (NEWNESS2-3 and RADICAL3-4), all variables for the implementation of the types of innovations and EIs and SOP (TYPE1-2 and SOP1-3) (number of people, developments, adoptions or implementations as appropriate); and finally, a continuous variable for the country's economic growth (EXTERNAL1). Only in one case did we create a new variable in addition to those selected in the survey, which corresponded to the country's economic growth with support from the literature (Ahmad et al., 2021; Te Tu et al., 2023). The independent and dependent parts of the variables are explained in more detail below.

The independent part included the selection of variables related to CE barriers, sources of information and cooperation, and other internal and external factors on EIs based on the literature (Chiappetta Jabbour et al., 2020; de Jesus & Mendonça, 2018; Kiefer, Del Río, & Carrillo-hermosilla, 2019; Schultz & Reinhardt, 2022). The mediating variables corresponded to the features of innovations and EIs related to the measures defined in previous work (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2017, 2021; Kiefer, Del Río, & Carrillo-hermosilla, 2019). The dependent part belonged to the variables of the different types of performance (CECO, CENP, SOP, and IMP) (Agrawal & Singh, 2019; Lopes de Sousa Jabbour et al., 2022; Dey et al., 2020; Hizarci-Payne et al., 2021; Mora-Contreras, Ormazabal, et al., 2023; Yang et al., 2019). In this regard, we identified indicators of different types of performance that have been used in previous surveys in the literature (Agrawal & Singh, 2019; Lopes de Sousa Jabbour et al., 2022; Dey et al., 2020; Mora-Contreras, Torres-Guevara, et al., 2023; Saha et al., 2021; Walker, Opferkuch, et al., 2021; Zhu et al., 2010, 2011). We contrasted them with the indicators measured in the Technological Development and Innovation Survey to determine their relevance and appropriateness for inclusion (e.g., labor and repair costs, natural resource and energy consumption, employee education and training, entry into a new geographic market). In other words, we ensured that the variables included in the Technological Development and Innovation Survey had theoretical constructs that justified their presence and that there were conceptual coincidences with the CE, EI, and performance (see Table 4) (Bag, Yadav, et al., 2020, 2021; Büyüközkan & Karabulut, 2018; Carrillo-Hermosilla et al., 2010; Saha et al., 2021; Yadav et al., 2020; Zhu et al., 2011). Regarding the control variables, we used firm size, industry type, and reporting years in line with other work (Chiappetta Jabbour et al., 2020; Kristoffersen et al., 2021; Mora-Contreras, Ormazabal, et al., 2023).

To perform the analysis and assess the validity and reliability of the research model, we employed PLS-SEM using the STATA 15.0 for

TABLE 3 Operationalization of constructs on barriers, sources of information, features of (eco-) innovations, and other internal and external factors.

Item	Variable	Measurement constructs	Source
Economic and market barriers	ECOBARR1	Limited market information.	Chiappetta Jabbour et al. (2020); de Jesus and Mendonça (2018); López Pérez et al. (2023); Mishra et al. (2022); Schultz and Reinhardt (2022); Takacs et al. (2022)
	ECOBARR2	Uncertainty in the demand for (eco-) innovative services or goods.	
	ECOBARR3	Low profitability of (eco-) innovation.	
	ECOBARR4	Ease of imitation by others.	
Technological barriers	TECBARR1	Limited information on available technology.	Chiappetta Jabbour et al. (2020); de Jesus and Mendonça (2018); de Marchi and Grandinetti (2013); Kiefer, Del Río, and Carrillo-hermosilla (2019); Kirchherr et al. (2018); Schultz and Reinhardt (2022); Shahbazi et al. (2016)
	TECBARR2	Uncertainty about successful execution and technical support.	
	TECBARR3	Insufficient capacity of the intellectual property system to protect (eco-) innovation.	
Institutional and regulatory barriers	INSTBARR1	Difficulty in complying with regulations and technical standards.	de Jesus and Mendonça (2018); García-Quevedo et al. (2020); Schultz and Reinhardt (2022)
	INSTBARR2	Limited information on public support instruments.	
	INSTBARR3	Limited possibilities of cooperation with other companies or (public) institutions.	
Sources of information–cooperation with the supply chain	SOURCEA1	Sources of information and cooperation with customers for developing or adopting (eco-) innovations.	Cainelli et al. (2012); de Jesus Pacheco et al. (2017); Del Río, Peñasco, and Romero-Jordán (2016); Horbach et al. (2013); Kiefer et al. (2017);Kiefer, Del Río, and Carrillo-hermosilla (2019); López Pérez et al. (2023)
	SOURCEA2	Sources of information and cooperation with suppliers for developing or adopting (eco-) innovations.	
Sources of information–cooperation with other key actors	SOURCEB1	Sources of information and cooperation with associations for developing or adopting (eco-) innovations.	
	SOURCEB2	Sources of information and cooperation with companies in other sectors for the development or adoption of (eco-) innovations.	
	SOURCEB3	Sources of information and cooperation with universities for developing or adopting innovations.	
Human intellectual resources and capabilities	HUMAN1	Number of employees participating in scientific, technological, and innovation activities.	Castellacci and Lie (2017); Kiefer, Del Río, and Carrillo-hermosilla (2019); López-Nicolás and Meroño-Cerdán (2011); Yang et al. (2014)
Financial resources and capabilities	FINANCIAL1	Investment in scientific, technological, and innovation activities to implement several types of innovations.	Kiefer, Del Río, and Carrillo-hermosilla (2019); López Pérez et al. (2023)
Country's economic growth	EXTERNAL1	GDP (gross domestic product) represents the country's economic growth.	Ahmad et al. (2021); Te Tu et al. (2023)
Newness of innovations and EIs	NEWNESS1	The first time that (eco-) innovations developed or adopted around products or services have been applied in the firm.	Carrillo-Hermosilla et al. (2010); Kiefer et al. (2017, 2021); Kiefer, Del Río, and Carrillo-hermosilla (2019)
	NEWNESS2	The number of (eco-) innovations developed or adopted around new products or services that have been applied in the firm.	
	NEWNESS3	The number of (eco-) innovations developed or adopted around improved products or services that have been applied in the firm.	
Radicality of innovations and EIs	RADICAL1	The first time that (eco-) innovations developed or adopted around new products or services have been applied in the economic sector.	Carrillo-Hermosilla et al. (2010); Kiefer et al. (2017, 2021); Kiefer, Del Río, and Carrillo-hermosilla (2019)
	RADICAL2	The first time that (eco-) innovations developed or adopted around improved products or services have been applied in the economic sector.	
	RADICAL3	The number of (eco-) innovations developed or adopted around new products or services that have been applied in the economic sector.	

(Continues)

TABLE 3 (Continued)

Item	Variable	Measurement constructs	Source
	RADICAL4	The number of (eco-) innovations developed or adopted around improved products or services that have been applied in the economic sector.	
The implementation of the types of innovations and EIs	TYPE1	Number of implementations of new or significantly improved processes, methods of service provision, distribution, delivery, or logistics systems at the firm.	Kiefer et al. (2017, 2021); Kiefer, Del Río, and Carrillo-hermosilla (2019); OECD (2010)
	TYPE2	Number of implementations of new organizational methods in the firm's internal operations, knowledge management system, workplace organization, or in the firm's external relationship management.	

TABLE 4 Operationalization of constructs on performance.

Item	Variable	Measurement constructs	Source
Circular and economic performance (CECO)	CECO1	Reduced labor costs.	Dey et al. (2020); Hizarci-Payne et al. (2021); Kaddoura et al. (2019); Kazancoglu et al. (2018); Mora-Contreras, Torres-Guevara, et al. (2023); Saha et al. (2021); You et al. (2019)
	CECO2	Reduced transportation costs.	
	CECO3	Reduced maintenance and repair costs.	
	CECO4	Decreased tax payments.	
Circular and environmental performance (CENP)	CENP1	Reduced consumption of raw materials.	Agrawal and Singh (2019); Lopes de Sousa Jabbour et al. (2022); Dey et al. (2020); Green et al. (2012); Hizarci-Payne et al. (2021); Khan et al. (2021); Mora-Contreras, Ormazabal, et al. (2023); Mora-Contreras, Torres-Guevara, et al. (2023); Zhu et al. (2010, 2011)
	CENP2	Reduced energy consumption.	
	CENP3	Reduced water consumption.	
	CENP4	Improved compliance with environmental regulations, rules, and standards.	
	CENP5	Increased waste utilization.	
Social performance (SOP)	SOP1	Number of women employed in scientific, technological, and (eco-) innovation activities.	Agrawal and Singh (2019; Dey et al. (2020); Mora-Contreras, Torres-Guevara, et al. (2023); Walker, Opferkuch, et al. (2021)
	SOP2	Number of men employed in scientific, technological, and (eco-) innovation activities.	
	SOP3	Number of employees who received education and training in scientific, technological, and (eco-) innovation activities.	
Innovation and market performance (IMP)	IMP1	Improved quality of services or goods.	Ahuja and Katila (2001); Gök and Peker (2016); Hizarci-Payne et al. (2021); Hogan and Coote (2014); Homburg and Jensen (2007)
	IMP2	Expanded range of services or goods.	
	IMP3	Maintained geographic market share.	
	IMP4	Entered a new geographic market.	

Note: The activities considered in the SOP variables do not necessarily include circular ones; hence, a separation is made, unlike CECO and CENP where clear overlaps exist.

Windows, following the recommendations of other studies (Bag, Wood, et al., 2020;Benitez et al., 2020; Kristoffersen et al., 2021). As mentioned above, the literature has suggested that researchers should clarify their reasons for choosing a particular method when analyzing their data (Lopes de Sousa Jabbour et al., 2022). First, we chose the PLS-SEM approach because it is commonly used in organizational and operations management studies to answer similar objectives (Bag, Wood, et al., 2020). Moreover, PLS-SEM is considered an appropriate method for exploratory theory building rather than theory testing (e.g., using CB-SEM) (Kristoffersen et al., 2021). Second, our research model can be considered complex, as it contains many unobserved and observed variables, constructs, and indicators that make PLS-SEM more appropriate. Third, the STATA 15.0 software allowed us to execute the secondary data and to model and test the proposed hypotheses with importance. Furthermore, in terms of bootstrapping, we included a resampling number of 10,000 for the relevance of the estimates. Fourth, PLS-SEM is relevant for studying relationships between variables when the field of study is still in the exploration stage. In summary, our process of data analysis and presentation of results follows recent and well-documented guidelines (Bag, Wood, et al., 2020; Lopes de Sousa Jabbour et al., 2022; Hair et al., 2021).

Finally, the literature has suggested that not necessarily large firms and SMEs experience the same barriers and need for sources of information for CE and EIs, so it is relevant to extend the results to these particularities briefly (de Jesus Pacheco et al., 2017; Del Río, Peñasco, & Romero-Jordán, 2016; Kiefer, Del Río, & Carrillo-hermosilla, 2019; López Pérez et al., 2023). To this end, we perform an extra step complementary to the study's overall results (which includes SMEs and large firms, i.e., the sample defined in subsection 3.1). Using the same research model outlined above, we briefly clarify the relationships of barriers and sources of information for (eco-) innovations of SMEs specifically. We excluded data from large firms and again ensured the relevance of the measurement and structural model with the same criteria as above (presented at the end of Section 4 of the results).

4 | RESULTS

In this section, we present results that address the objective of investigating the effect of barriers, sources of information, and features of innovations and EIs on the CE and the sustainability performance of manufacturing firms using PLS-SEM. We used key metrics commonly employed in PLS-SEM to inform the assessment of the measurement model, including convergent validity, reliability, and discriminant validity (see Tables 5, 6, and 7) (Lopes de Sousa Jabbour et al., 2022; Hair et al., 2022; Henseler, 2021; Latan & Noonan, 2017). The purpose of the convergent validity assessment is to ensure that each indicator measures what it purports to measure. In this regard, we examined the average variance extracted (AVE) values, which should be greater than 0.5 according to the literature (Lopes de Sousa Jabbour et al., 2022; Kristoffersen et al., 2021). It was confirmed that all AVE values obtained for each indicator exceeded the 0.50 threshold. The reliability assessment is intended to check the consistency of the measurements. We checked reliability in line with similar studies (considering longitudinal analyses) using Dillon-Goldstein rho (Roxas, 2022) and composite reliability. The criterion indicates that the values should be greater than 0.7. Our results show that the reliability assessment was met in all cases for the Dillon-Goldstein rho and, in general, for the composite reliability considering some variables close to the threshold. We evaluated the factor loadings of the items, which should be > 0.6, as recommended in other works (Chiappetta Jabbour et al., 2020; Lopes de Sousa Jabbour et al., 2022; Hair et al., 2022). All loadings were found to meet this threshold (see Table 6).

The final step was to test the discriminant validity. We used the heterotrait–monotrait (HTMT) approach, which is a contemporary method to assess discriminant validity in our PLS-SEM model. This approach is more effective than traditional approaches, such as the Fornell-Larcker criterion (Lopes de Sousa Jabbour et al., 2022). The rule indicates that the HTMT should be below the thresholds of 0.85 (more stringent) or 0.9 (more tolerant) for all model constructs (Kristoffersen et al., 2021). According to the data in Table 7, discriminant validity was met.

After reviewing the measurement model, we evaluated the structural model. We reviewed the quality of our model using the coefficient of determination (R^2), predictive relevance (Q^2), and variance inflation factor (VIF). Table 8 presents the results obtained from the evaluation of the structural model. We obtained good R^2 and adjusted R^2 values, ranging between 0.095–0.560 and 0.093–0.559 from small to large categories. The expected magnitude of the R^2 values depends on the phenomenon under research (Benitez et al., 2020; Kristoffersen et al., 2021). In this regard, the literature suggests that the phenomena studied in this case are not yet well understood, so a lower R^2 value is acceptable (Chiappetta Jabbour et al., 2020; Lopes de Sousa Jabbour et al., 2022). Likewise, the predictive relevance (Q^2) of the resulting model was good. Values greater than 0 indicate predictive relevance; values less than 0 indicate insufficient relevance (Hair et al., 2022; Kristoffersen et al., 2021). Our results ranged from 0.015 to 0.453, indicating satisfactory predictive relevance. We also obtained satisfactory VIF values for each predictor in the model being less than 3.3, suggesting no vertical or lateral collinearity between the independent and dependent variables (Lopes de Sousa Jabbour et al., 2022; Kalnins, 2018).

TABLE 5 Convergent validity.

Item	Average variance extracted (AVE)	Dillon–Goldstein rho (ρ)	Composite reliability
Economic and market barriers	0.573	0.843	0.770
Technological barriers	0.613	0.824	0.710
Institutional and regulatory barriers	0.607	0.822	0.833
Sources—Cooperation with the supply chain	0.715	0.834	0.605
Sources—Cooperation with other key actors	0.508	0.752	0.635
Newness of innovations and EIs	0.536	0.775	0.568
Radicality of innovations and EIs	0.549	0.829	0.738
The implementation of the types of innovations and EIs	0.679	0.808	0.550
Circular and economic performance (CECO)	0.558	0.834	0.744
Circular and environmental performance (CENP)	0.571	0.868	0.816
Social performance (SOP)	0.606	0.807	0.814
Innovation and market performance (IMP)	0.555	0.833	0.743

TABLE 6 Variable factor loadings.

Item	Variable	Factor loading
Economic and market barriers	ECOBARR1	0.750
	ECOBARR2	0.817
	ECOBARR3	0.716
	ECOBARR4	0.745
Technological barriers	TECBARR1	0.744
	TECBARR2	0.787
	TECBARR3	0.811
Institutional and regulatory barriers	INSTBARR1	0.834
	INSTBARR2	0.796
	INSTBARR3	0.700
Sources of information—Cooperation with the supply chain	SOURCEA1	0.847
	SOURCEA2	0.844
Sources of information—Cooperation with other key actors	SOURCEB1	0.647
	SOURCEB2	0.644
	SOURCEB3	0.865
Newness of innovations and EIs	NEWNESS1	0.694
	NEWNESS2	0.688
	NEWNESS3	0.809
Radicality of innovations and EIs	RADICAL1	0.679
	RADICAL2	0.726
	RADICAL3	0.755
	RADICAL4	0.795
The implementation of the types of innovations and EIs	TYPE1	0.860
	TYPE2	0.787
Circular and economic performance (CECO)	CECO1	0.717
	CECO2	0.782
	CECO3	0.815
	CECO4	0.667
Circular and environmental performance (CENP)	CENP1	0.745
	CENP2	0.801
	CENP3	0.808
	CENP4	0.690
	CENP5	0.728
Social performance (SOP)	SOP1	0.882
	SOP2	0.891
	SOP3	0.645
Innovation and market performance (IMP)	IMP1	0.775
	IMP2	0.756
	IMP3	0.770
	IMP4	0.675

To test the hypotheses, this study used 5% *p*-value as a cut-off for acceptance, evaluated the estimated parameter coefficients, and considered 95% bias-corrected and accelerated confidence intervals (see Table 9). Specifically, the effects of economic/market, technological, and institutional barriers on the newness and radicality of (eco-) innovations had beta (β) values (standardized regression coefficients) with signs opposite to expected or were not significant (*p*-values < 0.05), except for the relationship technological barriers → newness, which was compatible and significant. This means that only hypothesis H2a was supported. Considering the relationships of supply chain information sources and other key stakeholders on newness, radicality, and the implementation of the types of (eco-) innovation turned out to be significant and with positive beta (β) values, except the link sources of information—supply chain → types, which was not significant. Therefore, hypotheses H4a, H4b, H5a, H5b and H5c were supported.

The effects of human intellectual resources and capabilities on newness, radicality, and the implementation of the types of (eco-) innovation were significant and with positive beta (β) values. Therefore, hypotheses H6a, H6b, and H6c were supported. Moreover, we found that the effect between financial resources and capabilities and the country's economic growth on the features of innovations and EIs were significant and with positive beta (β) values, except for the financial → radicality relationship. Therefore, hypotheses H7a, H7b, and H8a were supported. The effect of newness and radicality on implementing the types of (eco-) innovations was also only significant and had positive beta (β) values for the case of radicality. Considering the above, only hypothesis H9b was supported.

The impact of the features of (eco-) innovations on the different types of performance was significant and with positive beta (β) values, except for the following relationships: newness → CECO, radicality → CECO, newness → CENP, and radicality → CENP. In this sense, hypotheses H10c, H11c, H12a, H12b, H12c, H13a, H12b, and H13c were supported. The effects of the different performance types on each other were significant, with positive beta (β) values, except for the SOP → circular and ECO relationship. Thus, hypotheses H14a, H14c, and H14d were supported.

Finally, the literature has suggested that barriers and sources of information for CE and (eco-) innovations are particular to SMEs (de Jesus Pacheco et al., 2017; Del Río, Peñasco, & Romero-Jordán, 2016; Kiefer, Del Río, & Carrillo-hermosilla, 2019; López Pérez et al., 2023). In this regard, we employed the same model as above. Still, this time, we excluded data from large firms and ensured the relevance of the measurement and structural model with the same criteria as above. Specifically, we found three differences concerning the previous results regarding barriers and sources of information: (1) the effect of technological barriers on newness was not significant, (2) the relationship sources of information—supply chain → radicality was not significant, and (3) the effect of sources of information—supply chain → types was significant and with a positive beta (β) value.

5 | DISCUSSION

This study investigated the effect of barriers, sources of information, and features of innovations and EIs on the CE and the sustainability performance of manufacturing companies using DCV and PBV. The DCV and PBV were used to strengthen the theory of the research

TABLE 7 Heterotrait–monotrait ratio (HTMT).

Item	1	2	3	4	5	6	7	8	9	10	11	12
Newness of innovations and EIs	***(0.85)***	-	-	-	-	-	-	-	-	-	-	-
Radicality of innovations and EIs	0.459	***(0.85)***	-	-	-	-	-	-	-	-	-	-
The implementation of the types of innovations and EIs	0.385	0.544	***(0.85)***	-	-	-	-	-	-	-	-	-
Innovation and market performance (IMP)	0.318	0.289	0.207	***(0.85)***	-	-	-	-	-	-	-	-
Circular and economic performance (CECO)	0.109	0.187	0.268	0.511	***(0.85)***	-	-	-	-	-	-	-
Social performance (SOP)	0.428	0.475	0.535	0.226	0.179	***(0.85)***	-	-	-	-	-	-
Circular and environmental performance (CENP)	0.149	0.215	0.284	0.565	0.790	0.182	***(0.85)***	-	-	-	-	-
Economic and market barriers	0.142	0.158	0.064	0.192	0.187	0.028	0.191	***(0.85)***	-	-	-	-
Technological barriers	0.079	0.098	0.044	0.177	0.218	0.037	0.220	0.755	***(0.85)***	-	-	-
Institutional and regulatory barriers	0.060	0.072	0.031	0.143	0.198	0.050	0.219	0.785	0.826	***(0.85)***	-	-
Sources—Cooperation with the supply chain	0.305	0.274	0.217	0.377	0.242	0.199	0.244	0.271	0.248	0.141	***(0.85)***	-
Sources—Cooperation with other key actors	0.367	0.420	0.382	0.283	0.273	0.382	0.272	0.177	0.137	0.236	0.675	***(0.85)***

TABLE 8 Structural model assessment.

Construct	R^2	Adj. R^2	Q^2	VIF
Economic and market barriers	-	-	-	1.475
Technological barriers	-	-	-	1.332
Institutional and regulatory barriers	-	-	-	1.381
Sources—Cooperation with the supply chain	-	-	-	1.227
Sources—Cooperation with other key actors	-	-	-	1.141
Newness of innovations and EIs	0.178	0.177	0.074	1.162
Radicality of innovations and EIs	0.522	0.521	0.453	1.130
The implementation of the types of innovations and EIs	0.259	0.257	0.083	1.151
Circular and economic performance (CECO)	0.560	0.559	0.015	1.433
Circular and environmental performance (CENP)	0.215	0.214	0.019	1.756
Social performance (SOP)	0.309	0.308	0.177	1.576
Innovation and market performance (IMP)	0.095	0.093	0.016	1.423

models and clarify the complexity of the corresponding capabilities that foster firms' CE-related activities and (eco-) innovations and variations in performance. The findings consider the debate of effects in six folds.

Firstly, it was found that most of the barriers to CE were not significant or did not really act as obstacles to the newness and radicality of (eco-) innovations in manufacturing firms (see Table 9). In this sense, only technological barriers resulted as limiting factors to the newness of innovations and EIs considering limited information on available technology (TECBARR1, 0.744), uncertainty in technical aspects (TECBARR2, 0.787), and insufficient capacity of the intellectual property system (TECBARR3, 0.811). Our results are consistent with the study of Chiappetta Jabbour et al. (2020) who found negative effects of technological barriers (e.g., technical and technological uncertainty) for the development of products based on CE principles in Brazilian industries. This research makes an additional contribution to the literature with an alternative look at the links of technological barriers and the features of (eco-) innovations in the Latin American manufacturing context. Based on our findings, we recommend industry to adopt a cooperative and stakeholder-oriented approach in EI and CE to achieve greater integration of resources and development of key capabilities from an ecosystemic perspective that facilitates leadership and reduces the technological constraints previously revealed (Kiefer, Del Río, & Carrillo-hermosilla, 2019; Ul-Durar et al., 2023).

Considering economic barriers, we found that they did not represent an obstacle to newness and radicality but rather acted as drivers. In this sense, the literature has recommended that the economic/

TABLE 9 Hypotheses testing results.

Hypothesis	Path	Coefficient (β)	*p*-values	Bias corrected 95% confidence interval	Inference
H1a	Economic/market barriers → Newness	0.135	0.000***	[0.100, 0.168]	Not supported
H1b	Economic/market barriers → Radicality	0.089	0.002**	[0.050, 0.123]	Not supported
H2a	Technological barriers → Newness	−0.048	0.034**	[−0.081, −0.015]	Supported
H2b	Technological barriers → Radicality	−0.018	0.527	[−0.046, 0.009]	Not supported
H3a	Institutional/regulatory → Newness	−0.027	0.179	[−0.053, 0.008]	Not supported
H3b	Institutional/regulatory → Radicality	−0.034	0.091*	[−0.052, −0.004]	Not supported
H4a	Sources of information—supply chain → Newness	0.149	0.000***	[0.100, 0.184]	Supported
H4b	Sources of information—supply chain → Radicality	0.038	0.003**	[0.009, 0.061]	Supported
H4c	Sources of information—supply chain → Types	0.017	0.263	[−0.028, 0.075]	Not supported
H5a	Sources of information—external → Newness	0.139	0.000***	[0.069, 0.253]	Supported
H5b	Sources of information—external → Radicality	0.147	0.000***	[0.081, 0.231]	Supported
H5c	Sources of information—external → Types	0.090	0.029**	[−0.064, 0.322]	Supported
H6a	Human intellectual → Newness	0.189	0.000***	[0.117, 0.252]	Supported
H6b	Human intellectual → Radicality	0.222	0.000***	[0.163, 0.276]	Supported
H6c	Human intellectual → Types	0.167	0.000***	[0.102, 0.258]	Supported
H7a	Financial → Newness	0.084	0.000***	[0.043, 0.135]	Supported
H7b	Financial → Radicality	−0.021	0.312	[−0.070, 0.021]	Not supported
H7c	Financial → Types	0.090	0.000***	[0.024, 0.173]	Supported
H8a	Country's economic growth → Types	0.075	0.000***	[0.047, 0.117]	Supported
H9a	Newness → Types	0.051	0.109	[0.004, 0.122]	Not supported
H9b	Radicality → Types	0.329	0.012**	[0.060, 0.515]	Supported
H10a	Newness → CECO	−0.041	0.000***	[−0.056, −0.025]	Not supported
H10b	Radicality → CECO	0.007	0.571	[−0.015, 0.029]	Not supported
H10c	Types → CECO	0.026	0.012**	[0.009, 0.045]	Supported
H11a	Newness → CENP	−0.027	0.037**	[−0.045, −0.009]	Not supported
H11b	Radicality → CENP	−0.001	0.942	[−0.040, 0.045]	Not supported
H11c	Types → CENP	0.122	0.000***	[0.103, 0.152]	Supported
H12a	Newness → SOP	0.131	0.000***	[0.078, 0.181]	Supported
H12b	Radicality → SOP	0.098	0.002**	[0.049, 0.166]	Supported
H12c	Types → SOP	0.177	0.000***	[0.119, 0.252]	Supported
H13a	Newness → IMP	0.235	0.000***	[0.213, 0.290]	Supported
H13b	Radicality → IMP	0.040	0.024**	[0.002, 0.077]	Supported
H13c	Types → IMP	0.052	0.018**	[0.024, 0.088]	Supported
H14a	CENP → CECO	0.711	0.000***	[0.694, 0.726]	Supported
H14b	SOP → CECO	0.013	0.219	[−0.005, 0.030]	Not supported
H14c	IMP → CECO	0.071	0.000***	[0.054, 0.089]	Supported
H14d	IMP → CENP	0.415	0.000***	[0.393, 0.434]	Supported

***$p < 0.001$, **$p < 0.05$, and *$p < 0.10$.

market dimension can act as a driver or barrier depending on the particular local conditionalities of the industries (de Jesus & Mendonça, 2018; Schultz & Reinhardt, 2022). Moreover, challenging economic/market conditions (e.g., rising and volatile costs and pressures on resources) can motivate manufacturing firms to seek solutions to improve their economic situation and stability (de Jesus & Mendonça, 2018). In this regard, industries should consider that, in order to overcome economic barriers, it is necessary not to simply address this dimension in isolation (Schultz & Reinhardt, 2022). We suggest that the intensive interaction of industries with market actors and the knowledge-related scientific-academic and governance base could be determinant in adopting a multidimensional and integrative perspective to effectively address barriers to the CE implementation (e.g., facilitating the absorption of research results that help to reduce the uncertainty of industries in economic, socio-cultural, institutional and technological terms of the CE).

Secondly, it was revealed that almost all sources of information and cooperation within and outside the firm's supply chain are important in driving the features of (eco-) innovations. At the supply chain level, it was evident that collaborations with customers and suppliers were essential for developing and adopting (eco-) innovations (SOURCEA1, 0.847; SOURCEA2, 0.844). Likewise, collaboration with universities (SOURCEB3, 0.865), associations (SOURCEB1, 0.647), and companies from other sectors (SOURCEB2, 0.644) proved to be a relevant factor in facilitating (eco-) innovations. These results are consistent with other research that indicated that cooperation among actors and information flows from knowledge institutions were crucial drivers of EI in the case of the manufacturing industry (Cainelli et al., 2012; Del Río, Peñasco. For instance, Cainelli et al. (2012) showed that cooperation with universities was one of the most important drivers of EIs for firms in Italy. However, our findings partially agreed with those of Kiefer, Del Rio and Carrillo-hermosilla (2019), who indicated that cooperation reduced the likelihood of developing/adopting all types of EIs concerning the baseline EI. In our case, we found that sources of supply chain information and cooperation do not affect the implementation of (eco-) innovation types.

Thirdly, we found that human intellectual resources and capabilities, a country's economic growth, and financial resources and capabilities enabled the features of (eco-) innovations (newness, radicality, and types), except financial resources and capabilities on radicality. Our findings suggested that the allocation of suitable employees participating in scientific, technological, and innovation activities was a driver for the adoption of novel and radical (eco-) innovations as well as for the implementation of different types of (eco-) innovations in line with other work (Castellacci & Lie, 2017; López-Nicolás & Meroño-Cerdán, 2011; Yang et al., 2014). For instance, Castellacci and Lie (2017) found a positive association between internal research and development capabilities of manufacturing firms and EIs aimed at reducing waste and carbon emissions.

Considering financial resources and capabilities, our findings confirmed their relevance as drivers for certain features of (eco-) innovations (e.g., novelty and implementation of types of EIs), in line with previous research that revealed positive effects of financial sources on specific categories of EIs (Kiefer, Del Río, & Carrillo-hermosilla, 2019). However, this paper makes an important contribution by revealing that this type of investment did not affect the radicality feature of (eco-) innovations, which contrasts with the findings unveiled by Kiefer, Del Río, and Carrillo-hermosilla (2019) in Spanish manufacturing industries. A possible explanation for these findings in light of the data corresponds to the fact that the companies in the sample mainly developed novel rather than radical (eco-) innovations. This probably translates into the need to obtain more information about the industries developing radical EIs to further clarify this association. Investments have favored the development or adoption of innovations of a more incremental nature probably because of the degree of innovation maturity of manufacturing firms, for this case, according to the political, socioeconomic, and geographic conditions in which the research is conducted. Moreover, we find a positive relationship between a country's economic growth and (eco-) innovations, which offers an alternative look at macro elements from the firm's perspective. In this regard, Te Tu et al. (2023) also found a positive association of EI and economic growth considering the role of energy consumption in Saudi Arabia, specifically at the macrolevel, which highlights the contribution of our study by including a multilevel view on EI (micro, meso, and macro).

Fourthly, we found that only the feature of radicality was supportive in the implementation of different typologies of (eco-) innovations (RADICAL1, 0.679; RADICAL2, 0.726; RADICAL3, 0.755; RADICAL4, 0.795). Manufacturing companies that have developed EIs that are new in the economic sector where they operate are important in promoting the implementation of the different EI typologies. In this regard, Kiefer, Carrillo-Hermosilla, and Del Río (2019) pointed out that radical EIs promoted the implementation or introduction of (eco-) innovation types related to new organizational methods, marketing procedures, processes, or products. In this sense, we provide further evidence of how the characteristics of (eco-) innovations were related to implementing different EI typologies (de Jesus & Mendonça, 2018).

Fifthly, we observed the effect of the characteristics of (eco-) innovations on CECO, CENP, SOP, and IMP. Our findings indicated that newness had a negative impact on CECO and CENP, and the effect of radicality was not significant on CECO and CENP while implementing types of (eco-) innovations improved both performance groups. Likewise, all the features of the (eco-) innovations improved SOP and IMP. Our results agree with the study of Mora-Contreras, Ormazabal, et al. (2023), who reveal the challenges in the Colombian manufacturing sector to create sustainable value considering CE and EIs. In this sense, industrial companies did not improve their economic, environmental, and circular performance through novelty (eco-) innovations, while radical (eco-) innovations being developed or adopted by a minority of companies could have been expected to have gaps in this relationship. In light of these results, our arguments supported the idea that incremental changes could be inhibitors or obstacles of change towards disruptive and eco-effective CE and EI solutions (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2021; Könnölä & Unruh, 2007). The latter is desirable to achieve systemic changes in companies on the way to value creation by decoupling resource consumption and sustainability.

We recommend that industries aiming to develop systemic EIs supporting high-level CE adoption and improved sustainability performance should overcome technological barriers by recognizing interactions and interdependencies with other barriers (e.g., socio-cultural, political, institutional, among others) (de Jesus & Mendonça, 2018) to move towards holistic problem-solving approaches. Firms should be aware that without the support of the government and other key ecosystem stakeholders, they are unlikely to be able to achieve systemic EIs (de Jesus et al., 2019; de Jesus & Mendonça, 2018). Furthermore, the integration of digitalization, EI, and CE has significant potential that academics and practitioners should explore to develop new circular and smart business models that are expected to promote sustainability performance (Awan et al., 2021). On the other hand, our results agreed with Hizarci-Payne et al. (2021) on the positive effect of EI typologies on CECO, CENP, SOP, and IMP but partially supported the findings of other works on the particular improvements of (eco-) innovations on certain economic, environmental, and circular aspects (Cheng et al., 2014; Lee & Min, 2015; López-Nicolás & Meroño-Cerdán, 2011; Pujari, 2006).

Furthermore, our research uncovered the effects of the different types of performance. We found that CENP significantly improved CECO. IMP also contributed positively to CENP and CECO, while SOP did not affect CECO. Our findings suggest that CENP improvement through (eco-) innovations largely boosted CECO around reducing firms' management and operating costs. IMP improved the economic, environmental, and circular performance of Colombian manufacturing firms in terms of costs, reduced resource consumption, and increased waste utilization. Still, SOP remains a challenge for CEO improvement. The variables available to assess and elucidate causal relationships around SOP in this study remain limited. At least concerning people employed in (eco-) innovation-related activities and who have received education and training, there is no evidence that they improve CECO. The results followed a similar perspective to Mora-Contreras, Torres-Guevara, et al. (2023) and Sarfraz et al. (2021) on the opportunities for CENP to improve firm performance and the limited social outcomes to enhance other dimensions of firm performance (Mora-Contreras, Ormazabal, et al., 2023; Saha et al., 2021).

Finally, our findings are relevant considering the target universe of the study, but the complexity or heterogeneity of the industries affects the generalizability of the results (i.e. when considering a sample of companies composed of different sizes, diverse business models, maturity levels, practices, technologies, and product and service typologies). While a diversity of firms is highly beneficial to represent the reality of the sector, aspects such as size, the relevance of resources, competencies and capabilities, and each firm's own environmental maturity (e.g., reactive, preventive or proactive) may contribute differently to the determinants and features of EIs and their performance impacts (Del Río, Carrillo-Hermosilla, et al., 2016; Ormazabal & Sarriegi, 2014). Our study includes control variables such as firm size, reporting years, and manufacturing subsectors to mitigate potential biases. Moreover, as the literature has pointed out that CE barriers and sources of information for developing or adopting (eco-) innovations in SMEs differ from large firms, we briefly present particular findings on the effects for SMEs. In this regard, we suggest that manufacturing SMEs are unlikely to succeed in developing or adopting radical EIs by cooperating with their supply chain alone. SMEs have scarce resources to benefit from expert knowledge routinely on CE and EIs, but we provide positive evidence of consultation and cooperation with universities, associations, and companies from other sectors. Future research could pursue the following two perspectives: (1) review the relevance of formulating and including new control variables on the environmental maturity of firms to further clarify how diversity affects EIs, CE, and sustainability performance outcomes (e.g. whether the firm has implemented an environmental management system, has any environmental certification or eco-label, when the information allows it) (Scarpellini et al., 2020) and (2) narrow the scope to a specific manufacturing subsector to understand its particular dynamics and overcome potential biases towards certain business models, technologies, and business practices that are central to other sub-sectors.

5.1 | Managerial implications

The findings of this study can help managers understand the challenges and opportunities of developing or adopting (eco-) innovations to implement a CE and consequently improve the sustainability performance of their companies. We found that the features of the innovations and EIs contribute differently to CE and sustainability performance. For instance, we verified that in the Latin American context, the newness of (eco-) innovations (probably incremental or low-level) is a barrier to high-level CE outcomes and the improvement of sustainability performance as it happens in European firms (Kiefer et al., 2021; Mora-Contreras, Ormazabal, et al., 2023; Mora-Contreras, Torres-Guevara, et al., 2023). In this regard, we recommend that companies, when exploring the adoption of new digital practices and taking advantage of Industry 4.0 opportunities to implement CE, should carefully consider the implications of different EIs over a long time horizon (e.g., identify the EIs that can achieve the most significant cumulative benefits over the long term). Technological (eco-) innovations are usually embedded in long-lasting capital assets, so infrastructural lock-in induced by an incremental EI that targets only partial benefits (e.g., economic benefits in the near term) hinders higher levels of CE (Kiefer et al., 2021) and overall improvement in companies' sustainability performance (Mora-Contreras, Ormazabal, et al., 2023). We also confirm that the development or adoption of radical (eco-) innovations is still nascent to elucidate their effects on the CE and sustainability of firms in the geographical context of the study. In contrast, managers may benefit from implementing the two typologies of (eco-) innovations considered in this study to drive different types of firm performance. Likewise, we find strong evidence that CENP improvement leads to significant positive economic outcomes. Therefore, we argue that the strategic implementation of a CE enabled by higher-level (eco-) innovations can contribute to the economics of firms. Moreover, as mentioned above, these benefits should not be evaluated only on short-term criteria but over longer horizons. On the other hand, we identify the key agents that facilitate the development, adoption, or implementation of (eco-) innovations. In this sense, decision-makers hoping to radically eco-innovate must strengthen their sources of information and cooperation beyond the company's supply chain. Collaboration with universities, associations, and companies from other sectors can be key to achieving EIs of higher levels of change (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2017). Finally, we emphasize that managers should recognize technological barriers while encouraging the development or adoption of systemic rather than incremental EIs to achieve new circular business models that help them create sustainable value by decoupling resource consumption.

5.2 | Implications for policymakers

The relevance of our findings also sheds light for policymakers from the following perspectives. Firstly, we identify that while the negative effect of institutional barriers on the features of (eco-) innovations was not significant, we reveal an essential gap for this dimension to be a critical enabler of implementing a CE to improve sustainability performance. Secondly, we provide evidence that policymakers should leverage to foster systemic EIs and promote firms' cooperation with other key actors and organizations to facilitate the implementation of a CE and move toward sustainability. In this sense, policy initiatives should be specific to the diversity of EIs that favor the implementation of high-level CE that improves sustainability performance (Carrillo-Hermosilla et al., 2010; Kiefer et al., 2017, 2021). In other words, policymaking should avoid encouraging low-level (incremental) (eco-) innovations that may block the implementation of a CE and deteriorate sustainability outcomes. Furthermore, public policymakers should help companies overcome technological barriers to promote the development or adoption of their (eco-) innovations with high levels of change that move companies away from linear business models and lack of sustainable value creation. Finally, in the Colombian context and in similar (or applicable) emerging economies, policymakers should collect valuable information through their technology and innovation surveys on the degree of consideration and implementation of Industry 4.0 technologies by manufacturing companies in a more in-depth or detailed manner. The above insights, in order to discover new relationships that will help improve public policies, focused on promoting smart circular business models or digital practices with the expectation of moving towards sustainability.

6 | CONCLUSIONS

The objective of this study was to investigate the effect of barriers, sources of information, and features of innovations and EIs on the CE and the sustainability performance of manufacturing firms. To this end, we employed a longitudinal quantitative study using official Colombian government secondary data on manufacturing firms between 2015 and 2020. As a result of the development, adoption, or implementation of (eco-) innovations, we provide additional information and evidence on which aspects of the CE and sustainability performance have been affected and with what intensity under an underexplored look at the literature.

This research concludes that manufacturing companies that develop or adopt (eco-) innovations with novelty characteristics (probably low-level or incremental) experience a blockage in implementing high-level CE and fail to improve their overall sustainability performance. Likewise, radical (eco-) innovations are achieved by a reduced number of firms (238, representing 7,6%), which makes it difficult to know their impacts on circularity and sustainability. In contrast, we show that companies that improve CENP can boost their CECO by obtaining added environmental and economic value from reduced resource consumption and increased waste use to lower operating and management costs. These results should motivate companies to cooperate with key agents to facilitate the development of systemic EIs that allow them to create sustainable value through new circular business models. They should also advance in implementing a high-level CE that will help them achieve greater results in SOP beyond employing people in eco-innovative activities and ensure the education and training of their employees.

Practitioners, scholars, and policymakers should work collaboratively to overcome technological and institutional barriers and promote developing, adopting, and implementing the diversity of (eco-) innovations that enable circular and sustainable transitions. In this regard, future studies can expand research on the effects of the features of systemic and radical innovations on the sustainability and CE of firms, considering other barriers, such as social and cultural ones. Moreover, new studies could include additional variables to represent CECO, CENP, and SOP with a broader perspective. Regarding the geographical context, more evidence on the relationships of CE, sustainability performance, and EI in Latin America is still needed. Our results are still the first steps in understanding the issue in the region. We also highlight the need for more longitudinal studies to understand the dynamics and the evolution of the CE and sustainability performance of firms that are enabled by systemic and radical EIs.

Like all articles, this research also has certain limitations. First, the sample is limited to the context of Colombian manufacturing companies. In this sense, the results are relevant considering the target universe but may be difficult to generalize. Future research could be directed to new economic sectors and other Latin American countries to advance toward a possible consensus on certain relationships. Second, the variables and data in our study depended on the information available on the official DANE website. Therefore, we left out EI features and typologies that require further research. However, for selecting and including variables, we used measures validated in the literature based on previous studies to ensure their relevance and pertinence. Third, our type of research was quantitative, so further studies with a qualitative design could be advanced to explore our results in depth. Fourth, our research framework does not cover the effects of barriers, Industry 4.0, and EI features on the particularities of circular business models and their implications on sustainability performance. Therefore, it is recommended to explore such relationships in future research. Finally, due to the nature of our research, we only included Colombian manufacturing firms that reported in all available years of the Technological Development and Innovation Survey (2015–2020) to ensure data consistency and completeness, improve internal validity, make more accurate comparisons, and reduce selection bias. However, several companies may have been created or liquidated during this period, so it is important to use alternative methodological approaches and expand the sample to include companies that did not necessarily report in all years for which information is available.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Rafael

Mora-Contreras and Giovanni Hernández-Salazar. The first draft of the manuscript was written by Rafael Mora-Contreras. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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