Towards circular economy through innovation: the role of entrepreneurial orientation and human resource management

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Abstract

The development of the circular economy (CE) has become a strategic priority for the EU to achieve the UN's Sustainable Development Goals. While the number of CE-based start-ups is burgeoning, established companies seem to be slower to adopt CE. Incorporating CE principles requires established firms to transform their business processes and activities from a linear to a circular approach, which often requires the introduction of significant and complementary technological and non-technological innovations, as well as significant investments that may hamper the firm's overall performance. Thus, the disruptive nature of CE adoption may make established firms reluctant to embrace this process and underlines the need to identify its drivers and to clarify its potential benefits. Accordingly, we analyze the role of entrepreneurial orientation (EO) in promoting circular human resource management (CHRM), circular product innovation and circular manufacturing. This study is the first to define and measure CHRM and one of the few to apply the concept of EO in the context of CE. Using seemingly unrelated regressions (SUR), we find that EO promotes circular innovation directly and indirectly through CHRM. This factor represents a non-technological innovation which directly impacts on circular product innovation and circular manufacturing, whilst reinforcing the complementarity between non-technological and technological innovation. This research also addresses concerns about potential conflicts in achieving different types of CE performance simultaneously. By analyzing firm performance from a holistic perspective, our study confirms that CE implementation leads to environmental, market and social performance improvements together with the moderating role of technological turbulence.

Keywords: circular economy; entrepreneurial orientation; circular human resource management; technological and non-technological innovation; performance.

1. Introduction

The concept of circular economy (CE) has gained considerable importance over the last decade as a critical solution to address the challenges resulting from overconsumption and environmental degradation (Völker et al., 2020). Thus, in contrast to the traditional linear economy, where materials and resources are used to produce goods and waste is disposed of at the end of the production and consumption cycle, the CE emphasizes retaining the value of materials and resources for as long as possible (Reike et al., 2023). Hence, following the European Union's proposal to foster CE as a means to achieve the Sustainable Development Goals (SDGs), governments and stakeholders are increasingly incentivizing and urging companies in all sectors of the economy to adopt CE (Ahmad et al., 2023).

While circular-based start-ups are bourgeoning, CE adoption by established firms -i.e., the integration of CE principles into their business operations- remains slow (Henry et al., 2020). On the one hand, established firms are reluctant to adopt CE because it not only requires significant investment, but may also potentially disrupt their existing business and operations (Kuhlmann et al., 2022), leading to unclear performance implications (Khan et al., 2022). This concern is exacerbated by the rapid evolution of product and process technologies (Linder and Williander, 2017). On the other hand, established firms often struggle to determine how to make the transition occur (Suchek et al., 2022) because CE adoption requires fundamental changes within the organization (Kuhlmann et al., 2022) and there are many internal barriers to addressing these changes in established organizations (Engzel et al., 2024). To address these concerns, this article aims to explore how to facilitate CE adoption among established firms and its performance implications in different domains.

The adoption of the CE requires the implementation of changes in the firm operations based on the principles of reduce, reuse, and recycle (de Arroyabe et al., 2021). Accordingly, companies need to transform the way they process materials and resources (Frishammar and Parida, 2019), which subsequently requires redesigning their manufacturing processes and, in many cases, their product offering (de Arroyabe et al., 2021). The new circular products and manufacturing processes represent technological innovations which, following Daft's (1978) "dual core model", are usually accompanied by innovations in the non-technological domain or in the firms' management practices or methods. As Damanpour (2014) notes, innovation in administrative processes and systems "*is often a prerequisite for successful introduction of technological innovations*" (p. 1266). Accordingly, recent studies suggest that established firms are more likely to achieve a successful CE adoption when they innovate to incorporate the CE principles into both the technological and the non-technological domains (Ahmad et al., 2023;

Arekrans et al., 2023). Following this line of reasoning, in this study, we analyze CE adoption from an innovation adoption perspective, and use the term "*circular innovation*" to refer to all the changes implemented by firms in their efforts to adopt the CE principles. Drawing on Daft's (1978) "dual core model" and Damanpour's (2014) conceptualization of innovation, "*technological circular innovation*" refers to innovations in the firm's products or manufacturing processes, while *"non-technological circular innovation*" refers to the innovations that occur in the firm's management processes and practices as a result of adopting CE values.

To analyze the adoption of non-technological circular innovation, this study introduces the concept of "*circular human resource management*" (CHRM), which is defined as the management of human resources through practices that incorporate and emphasize CE values. Since management processes determine the principles, procedures, and organizational structures through which employees interact and behave (Santos-Vijande et al., 2012), incorporating CE values into human resource management (HRM) practices is likely to facilitate a firm's transformation toward CE. In this line of reasoning, recent research underlines that employee involvement is essential for firms to adopt environmental practices and adopt eco-innovations (Dragan et al. 2024; Pronti et al., 2023). However, the role of CHRM in CE adoption has not been fully explored in the literature. To the best of our knowledge, the CHRM concept has only been considered previously by Del Giudice et al. (2021), who use data from Italian firms to analyze whether CHRM practices are correlated with circular supply chain performance.

To achieve an in-depth understanding of how to facilitate firms' transformation towards CE, this paper also analyzes the role of firms' entrepreneurial orientation (EO) in facilitating the adoption of technological and non-technological circular innovation, responding to the prevailing need pointed out by Mohapatra et al. (2024) to investigate the role of entrepreneurial orientation in the context of circular value creation. EO is defined as a firm's tendency toward risk-taking, proactiveness, and innovativeness (Miller, 1983). The literature consistently recognizes the usefulness of EO as a key strategic orientation in helping firms to adapt to rapidly evolving competitive environments through innovation (Santos-Vijande et al., 2022; Wales et al., 2023). Therefore, EO enables firms to experiment with new alternatives, to be willing to take risks and to embrace change (Arekrans et al., 2023; Rigtering et al., 2024), which are essential practices for overcoming CE-related challenges and facilitating CE adoption. To our knowledge, with the exception of Khan et al. (2022), EO has not been applied in the context of CE adoption. Khan et al. (2022) conduct interviews and case studies to explore how to configure an EO that is appropriate to the challenges of CE adoption. In contrast, we view EO as a well-defined concept and pioneer a quantitative approach to show how EO guides firms toward CE adoption by simultaneously enabling technological and non-technological circular innovation.

This paper contributes to the literature in several ways. First, the adoption of CE practices among established firms continues to be relatively slow (Khan et al., 2022), and empirical evidence on how to facilitate the transition is still scarce (Reim et al., 2021). Our study adds to the ongoing debate about how firms can overcome barriers to implementing CE practices (Sonar et al., 2023; Engzel et al., 2024) by illustrating the usefulness of EO, answering the call of Mohapatra et al. (2024) while approaching for the first time CE as a technological and non-technological innovation effort (Reike et al., 2023), while most of the articles in this field have focused only on technological innovation (Muldoon et al., 2024).

Second, unlike the dominant approach focusing mainly on the implications of CE adoption for technological innovation (Ferasso et al., 2020), this study highlights the role of the human factor and proposes the use of the CHRM construct to illustrate the adoption of non-technological circular innovation. Singh et al. (2020) demonstrate that green HRM is an antecedent of green product and production process innovation. Although the concept of CE overlaps with the concept of green, the adoption of CE is unique due to its potentially disruptive nature and broader focus than environmentally friendly activities (Kuhlmann et al., 2022). Therefore, by considering CHRM as a driver of circular products and manufacturing, we pinpoint the relevance of HRM in the adoption of potentially disruptive practices and respond to the call for further research on the relationship between human factors and CE adoption (Ahmad, 2023).

Third, we analyze the performance implications of CE adoption by simultaneously examining its impact on environmental, market, and social indicators. Empirical evidence on the benefits of CE adoption remains scarce and fragmented (Mora-Contreras et al., 2022). Previous studies rarely assess the impact of CE adoption on firm performance across these three domains simultaneously (Khan et al., 2021; Magnano et al., 2024; Negri et al., 2021)[1]. Scholars mainly examine the impact of CE on the firms' environmental and economic performance but ignore the social domain. This research gap has been repeatedly pointed out by several recent review articles (Pan et al., 2024; Magnano et al., 2024; Yin et al., 2023; Negri et al., 2021). Although a few studies have analyzed the three domains of performance simultaneously, these studies either focus on (1) how circular marketing practices, green HRM, or circular supply chain

[1] Literature often uses the term "economic performance" instead of "market performance". Due to the selection of measurement items adopted in our study, we prefer the term market performance, which can be considered as one dimension of economic performance.

management affect performance (Le et al., 2022; Obeidat et al., 2023), or (2) mix the concept of CE with the one of eco and green (Alraja et al., 2022).

A comprehensive evaluation of the performance implications of CE allows us to address concerns about potential conflicting effects of CE adoption across different dimensions of performance. For instance, due to its disruptive nature (Kuhlmann et al., 2022), new products designed based on CE-principles may cannibalize the firms' existing products, leading to potential conflicts between environmental and market performances (Iranmanesh et al., 2017). Walker et al. (2022) have also questioned whether CE adoption guarantees positive outcomes across different performance dimensions. For example, although reducing waste and promoting recycling contributes to environmental performance, it may have a negative impact on social performance by harming the health of recycling workers and increasing their workload (Schroeder et al., 2019).

Finally, as uncertainty and rapid change in product and process technologies may hinder the ability of firms to reap the benefits of CE adoption (de Arroyabe et al., 2021), we also analyze the moderating effect of technological turbulence on the relationship between circular product innovation and circular manufacturing and the firm environmental, market, and social performance.

In summary, our study adds value to the existing literature by filling in research gaps and providing substantial insights into ongoing debates. We shed light on how to facilitate established firms to transform towards CE emphasizing the usefulness of EO in line with recent literature calls in the entrepreneurship research domain (Mohapatra et al., 2024). We approach CE as a technological and non-technological innovation, which provides a novel perspective about the real implications of CE adoption in practice that can guide firms strategies (Reike et al., 2023). In response to Ahmand (2023) and Dragan et al. (2024), we demonstrate the pivotal role of the human factor in the CE adoption process through defining and measuring the concept of CHRM. By examining the performance implications of CE adoption in environmental, market, and social indicators simultaneously, we address scholars' concern regarding the lack of a holistic approach when studying the performance impact of CE (Pan et al., 2024; Magnano et al., 2024; Yin et al., 2023; Negri et al., 2021). Our examination of CE's performance impact across three indicators also provides incentives for established firms to engage in CE transformation (Engzell and Kambanou, 2024).

2. Theoretical background

2.1. Entrepreneurial orientation (EO)

EO´s origin can be traced back to the seminal paper by Miller (1983), where he described entrepreneurial firms —EO firms— as risk-taking, proactive, and innovative companies. Risk taking is the willingness to embrace uncertainty and support bold projects and ideas; proactiveness can be defined as the willingness to take an opportunity-seeking perspective that anticipates future trends and demands; and innovativeness reflects a firm's tendency to engage in and support new ideas, novelty, experimentation, and creative processes that may result in new products, services or technological progress. As stated by Wales et al. (2023) "*entrepreneurial orientation (EO) creates new value through a commitment to continues novelty within an organization's product-market offerings*" (Wales et al., 2023, p. 1763). Thus, innovation is at the core of the EO concept (Lumpkin and Dess, 1996) and research has consistently shown that EO enables firms to cope with challenges arising from disruptive innovation (Kraus et al., 2023; Rigtering et al., 2024). Following this line of reasoning, we view EO as an indispensable tool for coping with disruptive changes in nature, such as the transition from a linear economy to a CE (Kuhlmann et al., 2022). Similarly, Suchek et al. (2022) argue that entrepreneurial attitudes and behaviors enable firms to capture new business opportunities arising from the CE and Engzell and Kambanou (2024), highlight the importance of entrepreneurial spirit in the adoption of circular business models. In the same line, Mohapatra et al. (2024) find that entrepreneurial motivation leads to several actions related to business processes that are aimed at circular value creation.

Despite its relevance, the role of an EO in the CE context has been little explored in the literature, with the exception of Khan et al. (2022), who examine how small firms can minimize CE challenges in resource-, process-, and people-related aspects by properly configuring their EO. A related stream of the literature applies the EO concept in the context of sustainability. For example, Andersén (2022) finds a positive relationship between an EO and green product innovation among small Swedish manufacturing firms. Although green and CE concepts are both environmentally friendly concepts, CE adoption is potentially disruptive, requiring fundamental changes in firms' operations, market offerings and manufacturing processes (Kuhlmann et al., 2022), which may not be the case for green adoption. Some scholars attempt to incorporate the element of green or sustainability into the EO construct and propose constructs such as a "green EO" (Ameer and Khan, 2022; Khan et al., 2023) and a "sustainable EO" (Criado-Gomis, 2018). Since innovation is at the heart of EO, we believe that the constructs of green EO and sustainable EO already encompass the relationship we want to examine, i.e., how an EO relates to circular innovation. For this reason, we decide to follow Miller's (1983) definition of EO and exclude studies on green EO and sustainable EO from our literature review.

2.2. Circular innovation

The CE can be described as a restorative system in which waste is eliminated and resource use is minimized as materials are continuously looped back into the system (MacArthur, 2013). The successful implementation of this closed-loop system requires fundamental changes in the firm product design and manufacturing processes as well as in management practices (Ferasso et al., 2020), changes referred to in this study as "circular innovation". As Kirchherr et al. (2017) note, there is currently no consensus regarding the definition of "circular innovation". Some scholars propose using the term "eco-innovation" to refer to changes resulting from the implementation of CE principles. The European Commission (2018) defines "*eco-innovations" as "... all forms of innovation – technological and non-technological – that creates business opportunities and benefits the environment by preventing or reducing their impact, or by optimizing the use of resources*" (p. 1). Thus, although eco-innovation is related to the concept of circular innovation, the two concepts are not identical. Some eco-innovations share common characteristics with circular innovation, such as the support of energy efficiency and the exploitation of renewable resources; however, others do not necessarily implement CE principles despite their favorable effect on the environment (Scarpellini et al., 2020).

To address these potential differences, some researchers have recently begun to use the term "circular eco-innovation" to refer to eco-innovations that aim to circulate resources in loops of reuse, recycling, and renewal (Scarpellini et al., 2020). Since one objective of our study is to investigate the relationship between circular innovation and environmental performance, we prefer to use the term circular innovation instead of eco-innovation or circular eco-innovation. This is because the definition of circular eco-innovation includes the objective of benefiting the environment. Consequently, it becomes a tautology to examine the impact of circular eco-innovation on environmental performance. However, this is not the case for circular innovation. As Blum et al. (2020) observe, there is no guarantee that a circular solution is more sustainable than its linear equivalent. This uncertainty creates an opportunity for us to add value to the CE literature by investigating how circular innovation affects firms' environmental performance.

2.2.1 Technological circular innovation

CE investments in technological innovation are basically implemented in two main areas: (1) product redesign, which includes the use of environmentally friendly materials, extending the product life cycle, or the design of completely new products; and (2) manufacturing process redesign, which encompasses reducing waste, reusing products, and recycling resources and materials for new purposes (de Arroyabe et al., 2021). Product redesign has attracted significant interest from researchers (Kuhlman et al., 2022) as it is seen a critical factor in ensuring that products remain in use indefinitely within a closed and waste-free cycle. The implementation of circular manufacturing processes has also been acknowledged for its positive impact on cost savings and the achievement of competitive advantages (Darmandieu et al., 2022). Although both are considered technological innovations, product and production process innovations are often driven by different factors (Franco and Landini, 2022). Thus, we classify "technological circular innovation" into the categories of "circular product innovation" and "circular manufacturing" to refer to the implementation of CE principles in the redesign of products and manufacturing processes, respectively.

2.2.2 Non-technological circular innovation: circular human resource management (CHRM)

The technological implications of CE adoption have been relatively well established in the literature (Jabbour and Santos, 2008). However, its non-technological counterpart has received much less attention, and particularly, the human factor has been largely ignored (Jabbour et al. 2019). Nevertheless, the relevance of addressing the 'human side' of organizations is undeniable (McGregor, 1960). In the case of CE, the failure to consider the human side has contributed to the perception of adopting CE practices as a complex and challenging endeavor (Jabbour et al., 2019), which hinders the successful implementation of CE.

Thus, to support both technological and non-technological innovation, organizations need to strengthen their human resources and provide them with adequate training (Pronti et al., 2022), knowledge (Erdiaw-Kwasie et al., 2023), and empowerment (Soni et al., 2023). In this sense, the development of dynamic capabilities and organizational learning have been recognized as key variables to advance in the implementation of CE practices (Ahmad et al., 2023), and both are closely related to proactive and collaborative HRM (Nayal et al., 2023). Moreover, recent studies also underline that the success of the CE adoption depends on changing the mindset of all actors in the economic system, which implies that changes in HRM to foster the CE principles are also essential (Jabbour et al., 2019; Suchek et al., 2022). For all these reasons, and in response to the call for more research on the human factor in the CE domain (Ahmad, 2023), we study the role of HRM in CE adoption.

Recent literature mostly uses two terms to study the role of HRM in the development of the CE, namely, *sustainable human resource management* (SHRM); (Nayal et al., 2023) and *green* *human resource management* (GRHM) (Chau et al., 2023; Marrucci et al., 2021). While both terms share a concern for sustainability, they are distinct concepts.

Scholars have yet to reach an agreement on the conceptual definition of SHRM, although it is broadly described as the adoption of HRM practices that enable organizations to achieve economic, environmental and social goals (Wikhamn, 2019). However, most authors in literature have given more weight to the social and economic impact of SHRM than to its environmental impact. Regarding GHRM, Wagner (2011, p. 444) provides a widely cited definition of this concept as "*those parts of sustainable human resource management dealing with the needs that relate to environmental sustainability*." This definition locates GHRM within the broader field of SHRM with research in both fields developing simultaneously (Aust et al., 2020).

Nevertheless, both SHRM and GHRM have limitations in analyzing the role of HRM in CE adoption. For example, CE adoption requires a set of general sustainable skills, but also specific circular skills (Straub et al., 2023). Previous studies on SHRM and GRHM respectively analyze how to develop sustainable or environmentally sustainable skills, but how to develop circular skills among employees remains underexplored (Straub et al., 2023). Moreover, as shown in Table 1, researchers have recently found inconclusive results on the positive contribution of GHRM and SHRM to CE adoption (Jabbour et al., 2015; Marrucci et al., 2021).

Table 1. Recent empirical evidence of the "GHRM/SHRM-CE adoption" relationship.

Reference	Research topic	Methodology	Research context	Key findings
Chau et al. (2023)	The impact of GHRM on CE adoption.	Survey 438 questionnaires textil sector	Pakistan Textil sector	The results show that GHRM has a significant positive impact on CE adoption. Green innovation and big data analytics have a mediating and moderating effect, respectively.
Jabbour et al. (2015)	The impact of GHRM on green/circular product development.	Survey 62 questionnaires	Brazil	The results show that, GHRM does not have a significant effect on green/circular product innovation.
Marrucci et al. (2021)	The impact of GHRM practices on CE adoption and environmental and economic performance.	Survey 819 EMAS (Eco-Management and Audit Scheme) registered organizations.	Organizations extracted from the EMAS Register provided by the European Commission	The results show that GRHM has a positive impact on environmental and economic performance, although not all GHRM practices have an impact on CE adoption. Specifically, attracting, training, appraising, and rewarding are not significant.

Nayal et al. (2023)	The effect of human resource management (SHRM) on the implementation of circular product design strategies	Survey 424 SMEs	Indian B2B manufacturing firms	The results show that SHRM supports circular product design strategies. It is also observed a combined positive effect of circular product design and SHRM on market performance.
Obeidat et al. (2023)	The effect of GHRM and green empowerment on CE, and the effect of CE on performance	Survey 131 questionnaires	Qatar Service Sector	The results confirm the positive relationship between GHRM and green empowerment on CE, and the positive relationship between CE and sustainable performance.

Source: The authors.

This heterogeneity illustrates that not all GHRM and SHRM practices are effective in helping firms transform toward CE. Moreover, the circular concept differs from the green concept because the former is associated with "restorative" and "regenerative" activities (MacArthur, 2013), while the latter is associated with environmentally friendly activities. Compared to green practices, circular practices are a more specific and novel concept, so providing employees with training on green practices may not be sufficient to develop employees' CE skills (Marrucci et al., 2021). Similarly, although sustainability and circularity are sometimes referred to as synonymous terms, in reality they are not (Geissdoerfer et al., 2017). Sustainability focuses on the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development (Brundtland Commission), 1987). CE involves decoupling economic activity from the consumption of finite resources and eliminating waste from the system by design (MacArthur, 2013). The CE entails an effort to promote sustainability and environmental protection, but CE focuses on achieving the maximum circulation of product contents at the end of their useful life, the reintroduction of resources and materials into the production process (Bernon et al., 2018). Furthermore, the timeframes for implementing sustainable and circular systems are different. In the case of the sustainability timeframe, it is more open and long-term, while the circular timeframe is more precise and concrete (Geissdoerfer et al., 2017). For all these reasons, it is necessary to introduce the term CHRM when talking about circular economy, rather than using the common term GHRM.

For these reasons, this paper proposes a new definition of the construct, “circular human resource management (CHRM)”, based on Jabbour et al. (2019), to capture the incorporation of CE principles into HRM practices. We define CHRM as HRM policies and practices that aim to increase the adoption of CE by employees and improve the effective implementation of CE in the organization. CHRM includes hiring employees in line with CE values; identifying, training, and developing employees' CE competencies; developing employees' motivation to adopt CE through appropriate performance appraisals and rewards; and providing opportunities and encouraging employees to participate autonomously in decision making on CE-related issues.

3. Hypothesis Development

3.1. EO and technological circular innovation

As in other types of innovation, firms face high technological uncertainty when developing new circular products (Linder and Williander, 2017). Moreover, using CE principles to design new products often involves incorporating the latest technologies, which are less mature and less stable. However, an EO implies that the firm is constantly conducting bold experiments to develop new technologies that facilitate product and new value creation (Wales et al., 2023). Additionally, EO firms tend to engage in higher levels of information scanning (Barringer and Bluedorn, 1999), sharing, and exploitation (Matsuno et al., 2002) to leverage their innovative processes than non-EO firms. Thus, EO firms are more likely to accumulate greater innovation experience over time and develop relevant competences to cope with technical uncertainty (Covin et al., 2020).

The introduction of new circular products is also associated with high market uncertainty (Linder and Williander, 2017). As the concept of CE is still relatively new, circular product innovation may fail to attract potential customers. There is also the possibility of cannibalization, resulting in tension between the new and existing products (Kuhlmann et al., 2022). Faced with these challenges, EO firms embrace the risks associated with circular innovation and proactively involve their current and potential customers in new product development activities (Zucchella et al., 2022). Co-creating new products with customers improves customer loyalty, prevents cannibalization and leads to an increasing market acceptance of the new circular products, ultimately improving innovation rates (Wang et al., 2020).

EO firms are also more likely to be ready to act when new market opportunities arise due to their proactive and highly forward-looking nature (Dess and Lumpkin, 2005). Although it can be expensive to develop circular products (Demirel and Danisman, 2019), circular product design is self-sustaining and linked to material efficiency (Genovese et al., 2017), which ultimately improves firms' productivity. In addition to enabling cost savings, firms can also benefit from the additional value created by the extended life of circular products (Murray et al., 2017). All of these benefits make circular product innovation attractive to firms and increase their willingness to sacrifice short-term gains in exchange for medium- and long-term benefits, which is particularly attractive to EO firms (Wales et al., 2023). Thus, EO firms often see the transformation of their business activities according to circular principles as an attractive business opportunity (Ghisellini et al., 2016). Based on the above arguments, we propose the following:

H1: Entrepreneurial orientation (EO) is positively associated to circular product innovation.

Despite its potential to reduce costs (Darmandieu et al., 2022) due to greater efficiency in resource use (Ghisellini et al., 2016), implementing CE principles in the manufacturing process can be challenging (de Arroyabe et al., 2021). Employees may resist the new manufacturing processes because they change existing work practices and are likely to disrupt employees' work routines and/or slow their progress. However, EO firms are better positioned to deal with this challenge because these firms have organizational structures and management practices tailored to support adaptation and change (Suchek et al., 2022). Thus, employees in EO firms are likely to view task disruption as temporary, reducing their resistance to change. Another potential challenge associated with circular manufacturing processes is the complexity of setting up these processes. Because circular manufacturing often requires relatively new technologies, not all firms have sufficient knowledge to adopt them. Due to their willingness to proactively seek out and share relevant information (Barringer and Bluedorn, 1999, Matsuno et al., 2002), EO firms are more likely to have leading edge knowledge. If not, they are more likely to search for partners to access relevant technologies (Veleva and Bodkin, 2018). Implementing CE principles in the production process is also costly and technically uncertain, which may make firms hesitant. EO firms are more likely to take risks if they foresee significant benefits in the future. Therefore, we suggest the following:

H2: Entrepreneurial orientation (EO) is positively associated with circular manufacturing.

3.2. EO and non-technological circular innovation: CHRM

The literature agrees that employees are valuable resources in achieving organizational goals (Jabbour et al., 2019). Thus, because employees interact with and behave according to management practices (Santos-Vijande et al., 2012), implementing changes in HRM practices is essential to capture the opportunities created by the CE. In other words, moving toward CE adoption requires implementing appropriate HRM practices aimed at developing employee commitment and competence with CE (Erdiaw-Kwasie et al., 2023; Veleva et al., 2017).

EO firms are likely to interpret CE as an opportunity and, thus, to act upon it (Suchek et al., 2022). Because of their ability to reconfigure resources to create new value (Wales et al., 2023), EO firms are likely to reconfigure human resources so that CE principles are incorporated into their HRM practices—CHRM. Different studies have confirmed that EO firms are more experienced in developing employees´ competences by implementing knowledge creation and sharing systems (Jiang et al., 2019). EO firms also tend to be proactive in providing employees with cutting-edge knowledge through training, which empowers and motivates them in the desired direction (de Angelis, 2021). Nevertheless, incorporating change into HRM practices is challenging. Not only do organizations have to deal with implementation costs, but they also face the risk of employee turnover (Islam et al., 2020). Since EO firms are more willing to take risks for long-term development, we argue that they are more likely to assume the risk of CHRM. Thus, we propose the following:

> **H3:** Entrepreneurial orientation (EO) is positively associated with circular human resource management (CHRM).

3.3. The role of CHRM

According to the literature, a workforce with CE-capabilities would enable firms to identify and pursue CE opportunities (Khan et al., 2021) and implement circular manufacturing (Scarpellini et al., 2020). Marrucci et al. (2022) highlight the relevant role of employees in assimilating the CE knowledge, which is needed to design circular products (Erdiaw-Kwasie et al., 2023) and to reduce costs and improve the implementation of circular manufacturing processes (Darmandieu et al., 2022). On the one hand, a workforce with CE knowledge can better understand customer needs in the CE domain and design new circular products accordingly. On the other hand, employees with better CE knowledge can help firms to select circular practices that fit best with the production processes, and ensure proper implementation (Marrucci et al., 2021).

Although adequate recruitment and training are two ways to improve employees' CE knowledge and skills and constitute key practices for developing circular innovation (Pronti et al., 2023) and implementing circular manufacturing (Beducci et al., 2024), an adequate reward system is also necessary to incentivize employees to adopt CE (Jabbour et al., 2019; Marrucci et al., 2024). Studying the CE adoption in established firms, Kuhlmann et al. (2022) find that circular product and production innovations are more likely to occur when firms empower employees to participate in organizational efforts toward circular practice implementation. Similarly, Singh et al. (2018) also find that empowering employees increases job satisfaction in CE contexts, which in turn enhances CE initiatives. As Dragan et al. (2024) and Veleva et al. (2017) indicate, enhancing employee engagement through proper communication and empowerment is critical to ensure advancement toward circular practice implementation. In the same line, Soni et al. (2023) highlight the relevance of the employees´ empowerment in CE adoption by emphasizing the role of distributed leadership. Given that the implementation of CHRM involves recruiting talent with CE values and providing CE training to enhance employees' CE skills and knowledge, designing appropriate performance appraisals and rewards to encourage CE initiatives, and providing employees with opportunities to autonomously participate in decision making on CE-related issues, we propose the following:

H4a: Circular human resource management (CHRM) has a positive effect on circular product innovation.

H4b: Circular human resource management (CHRM) has a positive effect on circular manufacturing.

While we argue for positive associations between EO and CHRM and between CHRM and technological circular innovation, we also point out that CHRM mediates the relationship between EO and technological circular innovation. In this sense, Liu et al. (2023) recently demonstrate the critical role that HRM systems play in translating a CEO's entrepreneurial orientation into employee innovative behavior.

Examining the technological features of environmentally friendly innovations, Petruzzelli et al. (2011) show that environmental technological innovations tend to be more complex and novel than other types of innovations. Anticipating the need to cope with increasing complexity and novelty, we expect that EO firms are more likely to respond by reconfiguring their resources, due to their tendency to be proactive, to facilitate circular innovation. As Rivera-Torres et al. (2015) show, EO firms often make changes in their organizational design and management practices while implementing pro-environmental practices in their product design and production processes. Sawe et al. (2021) also recommend that entrepreneurial firms focus on people-driven factors to achieve successful CE adoption. Therefore, we propose the following:

H5a: Circular human resource management (CHRM) mediates the relationship between EO and circular product innovation.

H5b: Circular human resource management (CHRM) mediates the relationship between EO and circular manufacturing.

3.4. Technological circular innovation and CE performance: the moderating role of technological turbulence

Compared to technological innovation in a traditional linear model, technological circular innovation emphasizes not only efficiency but also resource value retention (Kirchherr et al., 2017). Thus, going beyond slowing down resource consumption, circular product and circular manufacturing innovation allow resources to be used more than once. For example, by designing new products with as many recyclable materials as possible, firms allow these resources to re-enter a new production cycle at the end of their use. Similarly, waste and residues can have a "second life" if they are integrated into a new production process. Because of the ability of technological circular innovation to create multiple lives for resources, it is deemed an environmentally valuable resource (Singh et al., 2020).

As suggested by the resource-based view, owning a valuable resource enhances firm performance (Barney, 1991). Chan (2005) defines environmental performance as "*meeting and exceeding societal expectation with respect to concerns about the natural environment*" (p. 632). Based on this definition, we argue that circular products and manufacturing processes will meet and exceed societal expectations by complying with environmental protection regulations, pursuing efficiency and creating multiple lives for resources (Kirchherr et al., 2017), thereby reducing negative environmental impacts. This is consistent with Zhang et al.'s (2022) finding that investments in circular innovation positively impact firms' environmental performance. Similarly, Valero-Gil and Scarpellini (2024) prove that firms that successfully register patents related to waste reduction achieve improved environmental performance. Furthermore, a recent meta-study covering more than 13,000 manufacturing firms also confirms that preserving the inherent value of products and materials for reuse leads to improved environmental performance (Pan et al., 2024). Therefore, we propose the following:

H6a: Circular product innovation is positively associated with environmental performance.

H7a: Circular manufacturing is positively associated with environmental performance.

Technological circular innovation also creates market value by delivering value to customers. Circular manufacturing is characterized by resource efficiency, which leads to cost savings and potentially lower prices for customers (Bag et al., 2022). Incorporating CE practices such as waste management and recycling into the manufacturing process can also enhance a company's brand reputation (Mazzucchelli et al., 2022). Circular products are more durable, which is valued by consumers because they can be repaired and upgraded (de Arroyabe et al., 2021). Technological circular innovation can also create value for customers by addressing public concerns. Kim and Hall (2020) find that customers perceive value when dining in restaurants that employ food sustainability and waste reduction practices. This is because customers perceive value through self-gratification from engaging in benevolent activities that also benefit the society. In this line of reasoning, Tsai et al. (2023) find that emotional perceptions increase individuals' willingness to use the service provided by CE-based platforms. Thus, we argue that technological circular innovation creates value for customers and, thus, can be considered a valuable market resource.

Based on the resource-based view (Barney, 1991), we expect that owning circular innovation will improve firms' market performance because firms can use their circular products to develop differentiation strategies and build a strong brand to attract customers who prioritize environmental issues (Mazzucchelli et al., 2022; Reinhardt, 1998). Previous studies have shown that this type of customer is willing to pay a price premium for products designed or manufactured according to environmentally friendly principles (Reinhardt, 1998). Circular product innovation and manufacturing also signal to customers that firms are committed to environmental issues, which is likely to enhance the loyalty of customers who share similar values (Kim and Hall, 2020). In fact, Bataineh et al. (2024) confirm that firms engaging in activities leading to reduction of energy or material use are likely to achieve a competitive advantage over their peers due to improved public image and reputation. Thus, we hypothesize the following:

H6b: Circular product innovation is positively associated with market performance.

H7b: Circular manufacturing is positively associated with market performance.

Technological circular innovation can act as a socially valuable resource to improve a company's social performance in several ways. First, environmental and social issues are often linked together, so that firms´ efforts to address environmental issues often have social consequences (Dey et al., 2020). For example, by integrating waste into the production cycle, firms not only incorporate CE principles but also improve local residents' well-being by eliminating potentially harmful residuals. Using a case study approach, Cullen et al. (2021) illustrate how the initiative to use local apples, which would otherwise have been wasted, as a key ingredient in the beverage manufacturing process benefits the local community by better conserving nature capital and building local social capital. By adopting circular principles in product design and manufacturing processes, firms are also likely to create new jobs (Moreno-Mondéjar et al., 2021). In addition, technological circular innovations often require employee involvement (Dragan et al., 2024), which is likely to increase job satisfaction (Iranmanesh et al., 2017).

Furthermore, the introduction of circular products and the implementation of circular manufacturing processes demonstrate the firm interest in taking a proactive approach to environmental issues, which can be interpreted as a proactive response to stakeholder concerns. As suggested by Shaukat et al. (2016), a proactive approach to stakeholder concerns is likely driven by corporate governance characteristics, which tend to be persistent over time. Thus, we expect that these firms would also respond proactively to societal concerns. Indeed, Dias-Sardinha and Reijnders (2005) found that firms that demonstrate the ability to address environmental issues tend to have better social performance, likely because they proactively seek solutions to meet stakeholders' social expectations. As Zhang et al. (2022) argue, patenting environmentally friendly technologies often helps SMEs improve their corporate image in the eyes of employees and other stakeholders. Therefore, we suggest that:

H6c: Circular product innovation is positively associated with social performance.

H7c: Circular manufacturing is positively associated with social performance.

3.4.1. The moderating role of technological turbulence

Technological turbulence refers to the rate of technological change in products and manufacturing processes over time within an industry (Chavez et al., 2015). As previously explained, firms face high technological uncertainty when developing circular innovations due to the novelty and rapid evolution of circular technologies (de Arroyabe et al., 2021; Linder and Williander, 2017). Rapid technological change in products and breakthroughs in manufacturing processes create unstable environments that may reduce the firm performance, i.e., that may ultimately hinder the ability of firms to reap the benefits associated with CE adoption due to accelerated obsolescence, increased costs, and/or reduced ability to incorporate the new technologies. Breakthroughs in product and manufacturing technologies can also quickly render technological circular innovations obsolete, reducing their positive environmental impact. As social and environmental issues are closely linked, the lower environmental performance of firms can also diminish the social impact of technological circular innovation. Moreover, the increasing uncertainty resulting from high technological turbulence may lead customers to change their preferences frequently.

Faced with demanding customers, companies may find it more difficult to meet and exceed customer expectations. Changing customer preferences also imply a shorter window of opportunity for firms to create value for customers. Thus, we argue that technological turbulence will limit the ability of technological circular innovation to improve firms' market performance. Drawing from the resource-based view, resources can improve firm performance because they are valuable (Barney, 1991). Accordingly, we expect that high technological turbulence will reduce the ability of technological circular innovation to create value in environmental, market, and social performance. Therefore, we hypothesize the negative moderating effect of technological turbulence in the relationship between circular product innovation and circular manufacturing and the three domains of CE performance (environmental, market and social).

> **H8:** Technological turbulence negatively moderates the effect of circular product innovation and circular manufacturing on environmental, market and social performance.

The proposed research model illustrated in Fig. 1 provides an understanding of the causal relationship among EO, CHRM, circular product innovation, circular manufacturing, and firm performance in the environmental, market, and social domains.

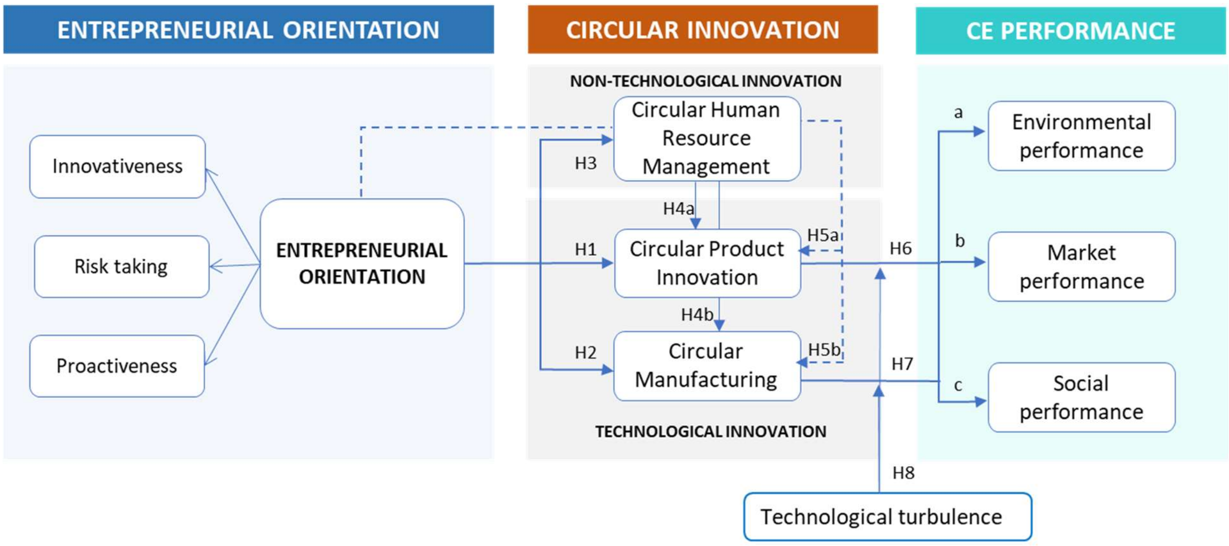

Fig 1. Research model.

4. Data collection and methods

4.1. Sample and data collection

The empirical analysis is based on a cross-sectional database of Spanish firms involved in CE practices and operating in different economic sectors. To this end, we identified a population of

1,357 companies using information published by private associations dedicated to the promotion of circular practices, ministerial reports, news and various sectoral reports developed by consulting firms. Primary information was collected through a survey conducted by a market research company. Qualified respondents were defined as CEOs or senior managers to ensure that they had sufficient knowledge about the strategic direction and CE practices implemented in their companies. After eliminating incomplete responses, the final sample consists of 218 organizations (16.06% response rate).

The description of the sample of companies can be done: a) by sector: plastics and rubber (15.84%), metallurgy and metal products (10.41%), automotive (9.95%), textiles and clothing (9.50%), construction (8.14%), packaging (8.14%), furniture, wood and cork (7. 69%), other non-metallic products (7.69%), chemicals (6.79%), mechanical machinery and equipment (6.33%), food and beverages (4.98%), and electronics and TIC (4.52%); b) by company age: up to 10 years (11. 76%), 10-25 years (25.34%), 26-40 years (38.46%), more than 40 years (24.43%); c) by turnover: up to 300,000 € (7.3%), 300,001 € - 600,000 € (8.7%), 600,001 € - 1,500,000 € (14.7%), 1. 500,000 - 3,000,000 (13.8%), more than 3,000,000 (55.5%); and d) by company size: up to 10 employees (17%), 11-49 employees (39%), 50-249 employees (27.5%), more than 250 employees (16.5%)..

Following Armstrong and Overton (1977), we conducted a nonresponse bias test. After analysis, no significant differences were found between early and late respondents, so the results do not reveal a nonresponse bias problem. In order to avoid common method bias (CMB) in the data, we applied ex-ante remedial procedures in the questionnaire design and tested for the presence of CMB ex-post using the marker variable technique suggested by Lindell and Whitney (2001). In this case, we used an industry-related item ("customers easily switch suppliers") as a marker variable. In all cases, the correlations of the model constructs with the marker variables are not significant, ranging from 0.014 (sig=0.84) to 0.044 (sig=0.56). Finally, we recalculated the construct correlations in the research model, excluding the lowest positive correlation between the constructs and the marker variable. The results show that all correlations are not significant after adjustment. Therefore, it can be concluded that common method bias (CMB) is not a problem in this study.

4.2. Instrument development

We used 7-point multi-item scales to measure the constructs in the conceptual model in Table 2. EO is measured as a second-order reflective construct that includes the three first-order dimensions established by Covin and Slevin (1989): innovativeness (Brettel et al., 2015), risk-taking (Chen et al., 2012), and proactiveness (Chen et al., 2012). The CHRM scale is adapted from Del Giudice et al. (2021) and Jabbour et al. (2019), including for the first time a reference to employee selection, training, compensation, consciousness and active involvement in CE implementation. The scales for measuring circular product innovation and circular manufacturing are adapted from the studies of de Arroyabe et al. (2021), Bag et al. (2022), and Khan et al. (2021). The scales for measuring environmental, market, and social performance were inspired by Jabbour et al. (2020). Finally, technological turbulence was measured using a scale based on Chen et al. (2012). We included firm turnover and firm age as control variables.

4.3. Psychometric properties of the scales

In order to analyze the psychometric properties of the reflective scales we use covariance-based structural equation modelling (CB-SEM) with STATA software. Table 2 summarizes the measurement scales used and the psychometric properties of the scales. Due to the limitations imposed by the size of the sample in relation to the observable variables in the research model, we first tested a CFA model in which the underlying dimensions of EO are allowed to correlate. Once this first model showed a good fit and the adequacy of the scales' properties, we tested a second model in which EO, represented by the mean values of its three underlying dimensions, and the rest of latent variables in the research model are correlated. Former exploratory factor analysis of the scales used in the research model revealed the presence of two distinct factors in the circular product innovation scale, whose configuration is coherent with the two main motivations for circular product design: (1) to narrow resource flows, or (2) to slow down or close resource loops. Circular product innovation involves creating new products or redesigning existing products to be more efficient throughout their life cycle (EMF, 2015). The aim is to develop goods and services that: (1) use fewer resources that are renewable and/or recycled whenever possible, (2) have high quality components that allow their lifecycle to be extended, and (3) are easier to maintain, repair, upgrade and recycle, whether for the original purpose or for other purposes. These initiatives achieve both the so-called *narrowing* of resource flows (or resource efficiency) and the *slowing down or closing* of resource loops (through reduced resource use) (Jensen, 2018). Accordingly, we considered two distinct factors in the second measurement model where EO, and the rest of the constructs in the research model correlate (see Table 2). We then used CFA to test the convergence of the two dimensions of circular product innovation into a second-order factor, in order to use circular product innovation as a single construct in the Seemingly Unrelated Regressions (SUR) model utilized to test the hypothesis. The goodness of fit indexes of this model will support this approach.

The analysis of the psychometric properties of the scales (reliability, convergent and discriminant validity) shows that most of the item loadings are above the threshold of 0.7, and the associated *t*-statistic is statistically significant (Anderson and Gerbing, 1988), which suggests internal consistency. Furthermore, Cronbach's alpha and the composite reliability index (CR) values exceed the recommended threshold value of 0.7, indicating construct reliability. The average variance extracted (AVE) values range between 0.546 and 0.820, which are above the acceptance levels established by Hair et al. (2011) to assess convergent validity.

To determine the discriminant validity, we considered the Fornell-Larcker (1981) criterion and Heterotrait-Monotrait ratio of correlations (HTMT) criterion -Table 3. The results confirm that the square root of the AVE of each construct is greater than the cross-correlations between each construct and other constructs in the model and is not less than 0.50. Additionally, the HTMT values are less than 0.90 for conceptually similar constructs. We also confirmed that multicollinearity is not a problem in our study because the variance inflation factor (VIF) scores range between 1.21 and 4.50, well below the commonly threshold of 5.

Table 2. Results of the measurement models.

Constructs	Measurement items	Factor Loading	CR; AVE; α
Innovativeness (INN)	Our company welcomes innovation proposals.	0.600***	CR=0.887; AVE=0.669; α=0.874
	Management actively pursues innovative ideas.	0.925***	
	Management encourages and supports innovative thinking, experimentation, and creativity.	0.911***	
	Innovation is a fundamental part of our corporate culture.	0.793***	
Risk-Taking (RTK)	We are willing to take risks to take full advantage of potential opportunities.	0.810***	CR=0.888; AVE=0.725; α=0.884
	We are capable of assuming high-risk projects.	0.900***	
	We are prepared to manage audacious risks if necessary.	0.842***	
Proactiveness (PRO)	Our company usually recognizes new market opportunities first.	0.802***	CR=0.909; AVE=0.625; α=0.912
	...usually takes advantage of new opportunities first by developing new products and services.	0.867***	
	...emphasizes first exploiting new opportunities to generate profitable businesses.	0.861***	
	...is ready to anticipate new market growth opportunities.	0.780***	
	...often initiates actions to which competitors respond.	0.735***	
	We create new customer preferences based on the new advantages of our products.	0.682***	
Overall goodness-of-fit index: Satorra–Bentler χ^2 (61)=153.3 *p*< 0.001 CFI=0.955 TLI=0.943 RMSEA=0.080 SRMR=0.048			
	Innovativeness	0.808***	
	Risk- Taking	0.700***	

Entrepreneurial Orientation (EO)	Proactiveness	0.852***	CR=0.831; AVE=0.623; α=0.621
Circular Product Innovation (CPI) – **Narrowing of resource loops (NC)**	We design our products ... ...to minimize consumption and try to use renewable or recyclable resources as much as possible.	0.785***	CR=0.827; AVE=0.546; α=0.824
	...to be easily recyclable (e.g., separation of components, information on chemical contents) and/or biodegradable.	0.794***	
	...to have good durability (i.e., avoiding premature or programmed obsolescence).	0.660***	
	…to use nonpolluting or nontoxic materials.	0.709***	
Circular Product Innovation (CPI) – **Slowing down or closing resource**	...to facilitate repair and maintenance.	0.894***	CR=0.918; AVE=0.736; α=0.886
	...to ensure the availability of spare parts.	0.862***	
	...to be easily upgradable (modular, upgradeable...).	0.803***	
	... to be reusable.	0.871***	
Circular manufacturing (CMF)	We increase efficiency in the use/consumption of materials and energy.	0.862***	CR=0.849; AVE=0.587; α=0.847
	We reduce raw material and energy consumption.	0.777***	
	We reduce our CO_2 footprint.	0.752***	
	We strive to improve the efficiency of our production equipment to become more efficient and less wasteful.	0.660***	
Circular Human Resource Management (CHRM)	When hiring, we make sure that our future employees are aligned with CE values.	0.793***	CR=0.907; AVE=0.661; α=0.907
	We offer CE training to improve the skills and knowledge of our employees.	0.852***	
	Employees receive recognition/rewards for proactive management of CE issues.	0.771***	
	Employees are involved in the implementation of the CE in the company.	0.828***	
	We encourage different work teams to discuss how to best develop CE management.	0.818***	
Environmental Performance (EPF)	The implementation of CE has led to ... ... a reduction in water and solid waste consumption.	0.764***	CR=0.932; AVE=0.774; α=0.902
	...a reduction in the consumption of energy and raw materials during the production process.	0.848***	
	...a reduction in CO_2 emissions from the production.	0.853***	
	...a reduction of environmental impacts.	0.879***	
Market Performance (MPF)	...an improvement in the brand value of our products.	0.879***	CR=0.948; AVE=0.820; α=0.947
	...a better corporate image of our company.	0.940***	
	…increased customer satisfaction.	0.933***	
	...an improvement in customer loyalty.	0.867***	
Social Performance (SPF)	... an improvement in stakeholder wellbeing.	0.720***	CR=0.936; AVE=0.709; α=0.936
	...an improvement in the health and safety of society.	0.801***	
	...a reduction in the company's risk image in the eyes of its target audiences.	0.800***	
	...an improvement in employee health and safety.	0.859***	
	...an improvement in employees' overall satisfaction with their job.	0.938***	
	... improvement in employee engagement with the company.	0.915***	

Technological turbulence (TTB)	It's difficult to foresee the technological evolution of our industry.	0.754***	CR=0.854; AVE=0.663; α=0.851
	The technological environment is uncertain.	0.919***	
	New opportunities arising from technological evolution are unpredictable.	0.758***	
Overall goodness-of-fit index: Satorra–Bentler χ2 (590)=1186.8 p< 0.001 CFI=0.906 TLI=0.900 RMSEA=0.068 SRMR=0.056			
Circular product innovation	**Narrowing of resource loops (NC)**	0.849***	CR=0.753; AVE=0.606; α=0.920
	Slowing down or closing resource loops (SD)	0.871***	
Overall goodness-of-fit index: Satorra–Bentler χ2 (18)=97,2 p< 0.001 CFI=0.937 TLI=0.900 CFI=0.934 NFI=0.918 SRMR=0.009			

Note: *** p<0.01; AVE (*average variance extracted); CR (composite reliability*).

4.4. Seemingly Unrelated Regression (SUR)

In this study, we used a SUR method to test the proposed hypotheses. This model consists of multiple regression equations, so PLS-SEM could be used for its analysis. However, SUR allows simultaneous evaluation of equations and is more effective than SEM in estimating relationships between variables (Chen et al., 2023; Gao et al., 2022). In addition, SUR, also known as multivariate regression or Zellner's method (1962), estimates system parameters taking into account heteroskedasticity and contemporaneous correlation of errors across equations (Bočkus et al., 2023).

Table 3. Discriminant validity.

	Fornell-Larcker & HTMT								
	EO	**CPI_NA**	**CPI_SC**	**CMF**	**CHRM**	**EPF**	**MPF**	**SPW**	**TTB**
EO	**0.788**	0.460	0.315	0.480	0.552	0.359	0.354	0.445	0.054
CPI_NA	0.500	**0.738**	0.772	0.355	0.465	0.495	0.525	0.480	0.070
CPI_SC	0.300	0.704	**0.858**	0.238	0.364	0.409	0.379	0.401	0.063
CMF	0.492	0.381	0.242	**0.765**	0.534	0.639	0.497	0.456	0.070
CHRM	0.572	0.477	0.345	0.536	**0.813**	0.655	0.758	0.784	0.083
EPF	0.377	0.494	0.404	0.656	0.665	**0.837**	0.595	0.784	0.051
MPF	0.368	0.535	0.351	0.486	0.754	0.596	**0.905**	0.744	0.056
SPW	0.455	0.473	0.364	0.410	0.772	0.761	0.687	**0.842**	0.102
TTB	0.032	-0.045	-0.054	-0.064	0.055	0.018	0.068	0.104	**0.814**

Note: Fornell-Larcker: the diagonal elements (bold) are the square root of the variance shared between the constructs and their measures (average variance extracted); off-diagonal: the correlation between constructs; HTMT ratios are above the diagonal; EO: entrepreneurial orientation; CPI_NA: circular product innovation_ narrow resource loops; CPI_SC: circular product innovation_ slow down or close resource loops; CMF: circular manufacturing; CHRM: circular human resource management; EPF: environmental performance; MPF: market performance; SPF: social performance; TT: technological turbulence.

The use of the SUR allows for more efficient estimation by combining information from different equations and mitigating potential endogeneity problems (Autry and Golicic, 2010; Cambra-Fierro et al., 2020). For example, previous studies emphasize that multi-linear systems of equations produce more efficient estimates when the error terms of different regressions are correlated, as in the case of SUR (Autry and Golicic, 2010; Gao et al., 2020). Similarly, "*since some variables are dependent and independent variables in different regressions, this technique allows us to alleviate endogeneity problems that can potentially present in the data*" (Autry and Golicic 2010, p. 95). Thus, although an ordinary least squares (OLS) method could be used to test the hypotheses, the SUR method is particularly useful when the model has more than one dependent variable, as the regressions can be run simultaneously (Cambra-Fierro et al., 2021).

Furthermore, our research model includes several dependent variables that represent the "two sides of the same coin" such as circular product innovation and circular manufacturing (technical innovation) and circular economy performance (environmental, market, and social). In this case, SUR is a suitable method to estimate the parameters of all our proposed model equations simultaneously, as the parameters of each equation take into account the information provided by other equations (Wang et al., 2024). The result is an increase in the efficiency of parameter estimation as additional information is used to describe the system. Accordingly, SUR models have been used in previous studies for similar purposes (Cambra-Fierro et al., 2021; Gao et al., 2020; Gao et al., 2022).

In this case, we developed a six-equation SUR to empirically test the conceptual framework and related hypotheses proposed in Figure 1. In this step, we used the composite variable scores obtained in the CFA estimation for the variables measured with multi-item scales (Chen et al., 2023). The first linear regression analyzes circular product innovation. Second linear regression examines circular manufacturing. Third linear regression examines CHRM. Fourth linear regression explains environmental performance. Fifth linear regression analyzes market performance. Finally, the sixth linear regression explains social performance. In all these cases, we use firm age, number of employees, and sales as control variables. In addition, we included the moderating role of technological turbulence on performance (market, social and environmental). The linear equations in the SUR model are presented below:

$$Circular\ product\ innovation = \beta_{01} + \beta_{11} \cdot EO + \beta_{21} \cdot CHRM + \beta_{31} \cdot Age + \beta_{41} \cdot Number\ of\ employees + \beta_{51} \cdot Turnover + \varepsilon \tag{1}$$

$$Circular\ manufacturing = \beta_{02} + \beta_{12} \cdot EO + \beta_{22} \cdot CHRM + \beta_{32} \cdot Age + \beta_{42} \cdot Number\ of\ employees + \beta_{52} \cdot Turnover + \varepsilon \tag{2}$$

$$CHRM = \beta_{03} + \beta_{13} \cdot EO + \beta_{23} \cdot Age + \beta_{33} \cdot Number\ of\ employees + \beta_{43} \cdot Turnover + \varepsilon \tag{3}$$

$$Environmental\ performance = \beta_{04} + \beta_{14} \cdot Circular\ product\ innovation + \beta_{24} \cdot Circular\ manufacturing + \beta_{34} \cdot Technological\ turbulence + \beta_{44} \cdot Circular\ product\ innovation \cdot Technological\ turbulence + \beta_{54} \cdot Circular\ manufacturing \cdot Technological\ turbulence + \beta_{64} \cdot Age + \beta_{74} \cdot Number\ of\ employees + \beta_{84} \cdot Turnover + \varepsilon \tag{4}$$

$$Market\ performance = \beta_{05} + \beta_{15} \cdot Circular\ product\ innovation + \beta_{25} \cdot Circular\ manufacturing + \beta_{35} \cdot Technological\ turbulence + \beta_{45} \cdot$$

$Circular\ product\ innovation \cdot\ Technological\ turbulence + \beta_{55} \cdot Circular\ manufacturing \cdot Technological\ turbulence + \beta_{65} \cdot Age + \beta_{75} \cdot Number\ of\ employees + \beta_{85} \cdot Turnover + \varepsilon$ (5)

$Social\ performance = \beta_{06} + \beta_{16} \cdot Circular\ product\ innovation + \beta_{26} \cdot Circular\ manufacturing + \beta_{36} \cdot Technological\ turbulence + \beta_{46} \cdot Circular\ product\ innovation \cdot\ Technological\ turbulence + \beta_{56} \cdot Circular\ manufacturing \cdot Technological\ turbulence + \beta_{66} \cdot Age + \beta_{76} \cdot Number\ of\ employees + \beta_{86} \cdot Turnover + \varepsilon$ (6)

Where β is the unknown coefficient and ε is an error term of the model that is independently and equally distributed.

5. Results

We conducted the SUR analysis using STATA v.15.1. The results of the Breusch-Pagan test ($Chi^2(15)$ =345.982; p<0.001) indicate that the error terms are correlated across equations, justifying the use of SUR. Thus, the correlation between the results that was already predicted theoretically due to the causality between the dependent variables and that we now see exists empirically. Therefore, it is appropriate to use the SUR. The main results of the SUR analysis are presented in Table 4.

Table 4. Estimation results.

	Dependent variables					
	CHRM	**Circular product innovation**	**Circular manufacturing**	**Environmental performance**	**Market performance**	**Social performance**
	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6
	R^2=0.258	R^2=0.192	R^2=0.276	R^2=0.412	R^2=0.358	R^2=0.314
	Chi^2=83.37	Chi^2=58.72	Chi^2=98.14	Chi^2=175.24	Chi^2=163.67	Chi^2=163.88
	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01
Independent variables						
EO	0.231***	0.092***	0.084***	--	--	--
CHRM	--	0.203***	0.277***	--	--	--
Circular product innovation	--	--	--	0.351***	0.409***	0.408***
Circular manufacturing	--	--	--	0.661***	0.588***	0.526***
Technological turbulence	--	--	--	-0.016n.s.	0.029n.s.	0.004n.s.
Circular product innovation x Technological turbulence	--	--	--	-0.063n.s.	-0.036n.s.	-0.094**
Circular manufacturing	--	--	--	0.060n.s.	0.104**	0.080*

x Technological turbulence						
Control variables						
Age	0.003n.s	-0.012n.s.	0.002n.s.	-0.016*	0.007n.s.	0.011n.s.
Number of employees	-0.246**	-0.126n.s.	0.123n.s.	-0.067n.s.	-0.216*	0.001n.s.
Turnover	-0.623n.s.	0.001n.s	0.037n.s.	-0.107n.s.	-0.095n.s.	-0.176**
Indirect effects						
EO→CHRM	--	0.047***	0.064***	--	--	--
EO→CHRM → Product innovation	--	--	--	0.016***	0.019**	0.019***
EO→CHRM →Circular manufacturing	--	--	--	0.042***	0.038***	0.034***

Note: ***p<0.01; **p<0.05; *p<0.10; n.s.: non-significant.

The results show that EO (β=0.092; p<0.01) and CHRM (β=0.203; p<0.01) have a significant influence on circular product innovation, thus supporting H1 and H4a. Also, EO (β=0.084; p<0.01) and CHRM (β=0.277; p<0.01) have a significant influence on circular manufacturing thereby confirming H2 and H4b. In addition, EO has a significant effect on CHRM (β=0.231; p<0.01), therefore, H3 is confirmed. The results illustrate that EO exerts a significant indirect effect on circular product innovation (β=0.467; p<0.01) and circular manufacturing (β=0.064; p<0.01) through CHRM, which allows confirming H5a and H5b.

Our results also indicate that circular product innovation (β=0.351; p<0.01) and circular manufacturing (β=0.661; p<0.01) have a positive and significant impact on environmental performance, confirming H6a and H7a. For market performance, the impact of circular product innovation (β=0.409; p<0.01) and circular manufacturing (β=0.588; p<0.01) is positive and significant, confirming H6b and H7b. For social performance, the hypothesized relationships with circular product innovation (β=0.408; p<0.01) and circular manufacturing (β=0.426; p<0.01) are confirmed, supporting H6c and H7c.

In addition, further analyses show an overall indirect effect of EO on performance through CHRM and product innovation/circular manufacturing. On the one hand, in the case of indirect effect through CHRM and product innovation, there is an indirect effect on environmental performance (β=0.016; p<0.01), market performance (β=0.019; p<0.01), and social performance (β=0.019; p<0.05). On the other hand, in the case of indirect effect through CHRM and circular manufacturing, there is an indirect effect on environmental performance (β=0.042; p<0.01), market performance (β=0.038; p<0.01) and social performance (β=0.034;

p<0.05). These results indicate that EO can improve firm performance by promoting circular innovation.

The results for the moderating role of technological turbulence are mixed. We found no significant moderation in the relationship between technological circular innovation and environmental performance. However, technological turbulence does positively moderate the relationship between circular manufacturing and market performance (β=0.104; $p<0.05$). Moreover, technological turbulence negatively moderates the relationship between circular product innovation and social performance (β=-0.094; $p<0.05$), and positively moderates the relationship between circular manufacturing and social performance (β=0.080; $p<0.1$). Overall, the moderation effect of technological turbulence seems to be limited. Four of the six moderating effects considered are either not significant or only marginally significant. The coefficients that are significant at the 95% confidence level suggest a weak negative effect of technological turbulence on the social benefits derived from CE (as suggested in H8) and, contrary to our expectations, a slightly positive effect of technological turbulence on market performance. Thus, technological evolution may also provide customers of new circular products with improved functional benefits, thereby increasing their satisfaction. Therefore, H8 is partially supported.

6. Discussion

6.1. Theoretical and managerial implications

Motivated by the need to accelerate CE adoption in established firms and answering to the call of further research on the drivers and barriers in the CE adoption (Engzel et al., 2024), this study confirms the relevance of EO as a driver of technological and non-technological circular innovation. Our findings contribute to the literature in several ways. First, we advance knowledge about EO by highlighting its potential in managing disruptive change such as CE adoption, (Kuhlmann et al., 2022; Mohapatra et al., 2024), extending the list of CE drivers. Thus, our study provides evidence that EO is a valuable strategic orientation to overcome the potential barriers associated with CE adoption (Sonar et al., 2023). To this end, we view the adoption of CE as a holistic innovation effort across technological and non-technological domains, highlighting the breadth and depth of change required to put CE principles into practice. (Reike et al., 2023). From this perspective, our study confirms that EO contributes to the firm's technological circular innovation, that is, to the development of circular product innovations and the implementation of circular manufacturing processes. Moreover, in addition to determining the effect of CE adoption on technological innovation, we go beyond and examine the effect of CE adoption on non-technological innovation, in line with the suggestion of Ahmad et al. (2023). Specifically, we propose, measure, and validate the construct of CHRM and prove that CHRM is a key mechanism through which EO leads to circular product innovation and circular manufacturing, demonstrating (1) the relevance of EO in transforming HRM to incorporate the values of CE, and (2) the key role of CHRM in the adoption of circular practices in the technological domain. In fact, our results show that the impact of EO on CE adoption is stronger in the case of non-technological innovation and show that EO promotes circular innovation not only directly, but mainly indirectly through CHRM, which is a novel contribution to the EO literature. Furthermore, our results also show that EO in firms directly leads to performance improvements in the environmental, market, and social domains by promoting circular innovation, which allows us to respond to recent calls in the literature for a better understanding of the impact of EO on performance (Wales et al., 2023), especially in the context of environmental concerns (Ameer and Khan, 2022) and circular economy (Mohapatra et al., 2024). Additionally, our work is innovative research into a key knowledge cluster recently identified by Muldoon et al. (2024), referred to entrepreneurship for sustainability and circular economy.

In contrast to most previous studies focusing on certain performance dimensions (Jabbour et al., 2020; Khan et al., 2021), we simultaneously evaluate the impact of circular innovation on environmental, market, and social performance. This allows us to respond to the call to examine how CE practices affect performance from a holistic perspective (Yin et al., 2023), as well as to fill the research gap identified by recent review articles (Pan et al., 2024; Magnano et al., 2024) regarding the lack of studies on the relationship between CE adoption and social performance. To the best of our knowledge, only Le et al. (2022) and Obeidat et al. (2023) have tested and found a positive relationship between CE adoption (not green nor eco) and firm performance across the three domains. However, both studies differ from ours in two important ways. Our study focuses on circular innovation; however, the aforementioned studies examined CE adoption in the context of business models and value creation (Le et al., 2022) or exclusively in the manufacturing process (Obeidat et al., 2023). In addition, both studies treat firm performance as a single construct with items measuring the environmental, economic, and social domains. Instead, we consider economic, market and social variables as three distinct but interrelated variables and analyze their relationships with CE adoption respectively. Given the development of CE is imperative, firms need to have a clear understanding of the performance implications of CE in order to justify their adoption (Bag et al., 2021; Yin et al., 2023). By treating firm performance in environmental, market and social domains as three distinct but interrelated variables, our empirical results reveal that adopting CE not only improves environmental performance but also allows firms to cultivate a better market image and to satisfy demands from different stakeholders. That is, our findings help alleviate concerns about potential conflicts between firm performance in the three domains (Iranmanesh et al., 2017; Kuhlmann et al., 2022; Schroeder et al., 2019; Walker et al., 2022). This provides a full set of incentives for firms to transform towards CE. Finally, despite the prevailing technological turbulence in many markets, which may hinder the benefits of circular innovation, our results overall reinforce the positive impact of circular innovation on firms' environmental, market and social performance in turbulent markets, which reinforces the relevance of understanding how to favor firms' CE adoption.

In addition to contributing to the literature, our findings have several managerial implications. Our results highlight the importance and need for firms to cultivate a strong EO to support the adoption of CE. Adopting CE is not without risk. It requires significant organizational change to capitalize on new market opportunities. In order to unleash the potential of firms to take advantage of emerging CE opportunities, managers are urged to develop their firm's EO as a key tool to facilitate the transformation to CE. To achieve this goal, managers must first develop an adequate understanding of CE in order to anticipate the new opportunities associated with the non-linear economy. Attending CE-related events and workshops and collaborating with knowledgeable partners are promising avenues for knowledge acquisition. In addition, managers need to encourage risk-taking and proactively assess all the requirements for developing circular products and manufacturing processes, which may include actively seeking the necessary technologies and collaborations with partners (Aarikka-Stenroos et al., 2022) to achieve adequate implementation of CE. Managers also need to pay special attention to HRM from a circular perspective, as CHRM is a critical variable for designing new circular products and implementing circular manufacturing. Managers are therefore advised to include CE values in recruitment processes and to provide specific training for employees. Creating a compensation and reward system that recognizes employees' CE initiatives and encourages interaction among interdisciplinary work teams will also encourage the development of business activities based on CE principles. It is also useful to note the heterogeneous effects of technological circular innovation across the three performance domains, which provides managers with options to prioritize CE adoption according to their needs. For firms seeking to improve their environmental performance, implementing CE principles in the production process would be the more effective path. Finally, a workforce with innovative CE knowledge and skills can also enable firms to cope with the increasing demands from a variety of stakeholders. In this respect, our findings have implications for the management of business schools. To the extent that their students may be future employees and managers, strengthening their awareness and knowledge of CE principles and related market opportunities is crucial. Therefore, we recommend that business schools include CE issues in the curriculum. This would help future workers and managers to develop CE competencies, leading to an accelerated transformation towards CE.

6.2. Limitations and path for future research

Despite its contribution and relevance, our research has limitations that provide opportunities for future studies. Our empirical evidence is obtained by analyzing Spanish firms, which may limit the generalizability of the findings. Also, using the SUR method with a larger and more diverse sample in terms of the type of countries analyzed would allow better generalization of the results. Thus, scholars could replicate the study in different national contexts or analyze firms in different countries from a comparative perspective to test the boundary conditions of our research model. In addition to national differences, it would also be interesting to analyze how our proposed model varies across industries. This would require researchers to collect data from a larger sample size, making it possible to explore the differences and similarities across sectors.

We are also aware that EO is unlikely to be the only antecedent of firms' transformation to CE. Recent studies suggest the relevant role of firms' ambidexterity in the pursuit of frugal innovation, which is also closely related to circular practices (López-Sánchez and Santos-Vijande, 2022). In addition to CHRM, future studies should also investigate other non-technological innovations to promote technological circular innovation. Another line of research is to clarify the boundary conditions of the relationships by searching for additional potential moderators and trying to clarify the role of technological turbulence in different contexts. Our study is also limited in terms of the measurement of CE principles. We treat CE as a homogeneous concept without distinguishing its specificity. Although they share the same idea of circularity, the implementation of the 3R, 6R, and 9R principles (de Arroyabe et al., 2021) may require different knowledge and skills. In the future, scholars could use a more fine-grained measure to explore heterogeneity within CE concepts. Finally, our data are cross-sectional, which limits the ability of our analysis to clarify the causality between variables. The single-country nature of the dataset also calls for caution when attempting to generalize the results.

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