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Greening the future: analyzing green entrepreneurial orientation, green knowledge management and digital transformation for sustainable innovation and circular economy

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Abstract

Purpose – Green innovation, digitization and sustainability have attracted considerable attention in recent years due to their transformative potential in organizations. This study, grounded in the resource-based view, explores the intricate relationship among green entrepreneurial orientations, sustainability-oriented innovation, and the circular economy, employing green knowledge management as a pivotal mechanism.

Design/methodology/approach – The proposed model and hypotheses were tested using Partial Least Squares (PLS) structural equation modeling (SEM) with a sample of 274 valid questionnaires collected from manufacturing firms in Saudi Arabia.

Findings – Results unveil positive relationships between green entrepreneurial orientations and sustainability-oriented innovation, as well as the circular economy, along with a positive mediation of green knowledge management in these relationships. In addition, these relationships exhibit heightened strength with increased levels of digital transformation.

Originality/value – The contributions of this research extend to both theoretical and practical realms, offering valuable insights for startups and traditional businesses as they explore the landscape of green innovation and digitization.

Keywords Entrepreneurship, Knowledge management, Digital transformation, Innovation, Circular economy, Sustainability

Paper type Research paper

1. Introduction

Climate change poses a challenging threat to the delicate balance of natural resources, exerting unprecedented pressures on ecosystems globally (Dwivedi *et al.*, 2022). The

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increasing frequency and intensity of extreme weather events, along with the upward trajectory of temperatures and changing patterns, have profound implications for biodiversity, water availability, and productivity (Mperejekumana *et al.*, 2024). In this context, the necessity to embrace sustainable practices becomes imperative in mitigating the adverse impacts of climate change on natural resources (Opoku-Mensah *et al.*, 2024). Sustainability, rooted in fundamental principles of responsible resource utilization, preservation, and regeneration, emerges as a potent strategy to confront these challenges (Aftab *et al.*, 2023). By integrating sustainable practices into resource management, businesses can enhance resilience and minimize vulnerability to disruptions induced by climate change. The promotion of sustainable and efficient management, coupled with conservation initiatives, contributes significantly to the preservation of vital ecosystems and fosters long-term environmental stability (Broccardo *et al.*, 2023; Yong *et al.*, 2020).

In the face of global challenges posed by climate change and resource reduction, sustainability-oriented innovation emerges as a crucial driver for transformative change in contemporary business settings (Adams *et al.*, 2016; Popa *et al.*, 2017). This highlights the dynamic intersection of sustainability and innovation indicating how businesses can harness creative and technological capabilities to foster environmental responsibility and resilience (Bamel *et al.*, 2022; Broccardo *et al.*, 2023). Nevertheless, sustainability-oriented innovation goes beyond traditional notions of product development, emphasizing a holistic approach that considers the entire life cycle, from raw material extraction to end-of-life disposal, thereby minimizing environmental impacts (Ortiz-Avram *et al.*, 2023). Thus, sustainability-oriented innovation, linking environmental responsibility and creative advancement, characterizes a strategic approach that seeks to harmonize business practices with environmental essentials. This transformative paradigm emphasizes the development of products, processes, and systems that meet present needs while also protecting the well-being of future generations. By integrating sustainability principles into innovation processes, businesses can drive positive economic, social, and environmental outcomes, paving the way for a more resilient and responsible global society (Ghobakhloo *et al.*, 2023; Popa *et al.*, 2022).

The perspective of the circular economy has gained importance as a transformative framework that reimagines traditional linear production and consumption models, offering a holistic approach to resource management and environmental sustainability (Fratini *et al.*, 2019). Rooted in the principles of reducing, reusing, and recycling, the circular economy aims to distinguish economic growth from resource diminution by fostering closed-loop systems (Abbasi *et al.*, 2024). Hence, it is a reframing approach to resource management and production that emphasizes sustainability and aims to minimize waste by keeping materials and products in use for as long as possible. Unlike the traditional linear economy, which follows a "take, make, dispose" model, the circular economy promotes a closed-loop system where resources are reused, renewed, remanufactured, and recycled (Zhang *et al.*, 2024). This approach is crucial for both environmental conservation and economic growth. By extending the lifecycle of products, reducing waste, and optimizing resource use, the circular economy mitigates environmental degradation, decreases reliance on determinate resources, and curtails greenhouse gas emissions (Durán-Romero *et al.*, 2020). Moreover, it fosters innovation, job creation, and resilient economic systems. Embracing the circular economy contributes to environmental sustainability and also catalyzes long-term economic prosperity and resilience in the face of global challenges (Del Giudice *et al.*, 2021; Provin *et al.*, 2021; Taneja *et al.*, 2023).

In the pursuit of a more sustainability-oriented innovation and circular economy, several gaps persist, necessitating comprehensive research and strategic interventions. Despite a growing body of studies, there is a notable lack of studies that integrate green entrepreneurial orientation as a direct influencer towards sustainability-oriented innovation and circular economy (e.g. Makhloufi, 2023). In addition, this study requires a critical mechanism that explains the relationship between green entrepreneurial orientation and sustainability-oriented innovation and circular economy. Hence, this study introduces green knowledge management as an indirect influencer within the context of sustainable business practices. Importantly, this study also introduces digital transformation as a moderation of the relationship between green entrepreneurial orientation and sustainability-oriented innovation and circular economy as well as between green entrepreneurial orientation, green knowledge management and sustainability-oriented innovation and circular economy.

This study, therefore, makes a vital contribution to the pursuit of sustainability-oriented innovation and the circular economy by addressing significant gaps in the existing research literature. While the importance of green entrepreneurial orientation in promoting sustainable practices is recognized, there is a scarcity of studies integrating green entrepreneurial orientation as a direct influencer specifically targeting sustainability-oriented innovation and the circular economy. This research establishes green entrepreneurial orientation's direct impact and introduces a critical mechanism by incorporating green knowledge management as an indirect influencer, explaining the intricate relationship between green entrepreneurial orientation and sustainable business practices. Moreover, the study innovatively considers digital transformation as a moderating factor, shedding light on its role in influencing the connection between green entrepreneurial orientation, green knowledge management, and the realization of sustainability-oriented innovation and circular economy goals. This approach to the problem contributes valuable insights for businesses seeking to navigate the complexities of sustainable innovation and the trend of the circular economy.

2. Theoretical framework and hypotheses

2.1 Green entrepreneurial orientation and sustainability-oriented innovation

Green entrepreneurial orientation refers to the strategic orientation of a business toward environmentally sustainable practices and eco-friendly innovation (Shehzad *et al.*, 2023). It encompasses a mindset and set of behaviors that prioritize environmental responsibility and social consciousness within entrepreneurial activities. A business with a strong green entrepreneurial orientation is proactive in identifying and capitalizing on opportunities that align with ecological sustainability (Allal-Chérif *et al.*, 2023). This orientation involves a commitment to reducing environmental impact, promoting resource efficiency, and integrating eco-friendly practices across various facets of business operations, including product development, supply chain management, and marketing (Ameer and Khan, 2023). In essence, green entrepreneurial orientation signifies a conscious effort to balance economic objectives with environmental stewardship, reflecting a commitment to sustainable business practices and a consideration of the long-term ecological implications of entrepreneurial activities (Algarni *et al.*, 2022).

Thus, the relationship between green entrepreneurial orientation and sustainability-oriented innovation has garnered significant attention in the literature, reflecting the increasing importance of environmentally responsible business practices. Studies have highlighted the pivotal role of green entrepreneurial orientation as a driver for sustainable innovation within organizations. For instance, Shepherd and Patzelt (2011) emphasized that a strong green entrepreneurial orientation facilitates the integration of environmental considerations into entrepreneurial processes, fostering a proactive approach toward sustainable practices. Similarly, other studies have highlighted the positive influence of green entrepreneurial orientation on the identification and exploitation of opportunities for sustainability-oriented innovations (Frare and Beuren, 2022). These connections are crucial for firms seeking both to enhance their environmental performance and remain competitive. However, the literature also acknowledges potential challenges and complexities associated with integrating green principles into entrepreneurial activities. Some scholars have pointed to the need for a shading understanding, emphasizing that successful green entrepreneurship involves navigating potential tensions between economic objectives and environmental goals (Hällerstrand *et al.*, 2023; Makhloufi, 2023). Despite these challenges, the dominant consensus in the previous literature suggests a positive and cooperative link between green entrepreneurial orientation and sustainability-oriented innovation, underlining the strategic imperative for businesses to adopt environmentally conscious practices within their entrepreneurial endeavors to remain competitive and avoid being disrupted. Therefore, the following hypothesis is proposed:

H1. There is a positive relationship between green entrepreneurial orientation and sustainability-oriented innovation.

2.2 Green entrepreneurial orientation and circular economy

The integration of green entrepreneurial orientation and the circular economy is imperative in fostering a sustainable and resilient business landscape (Mondal *et al.*, 2023a). Green entrepreneurial orientation underlines the proactive environmental commitment of entrepreneurs, emphasizing the incorporation of eco-friendly practices and sustainable strategies (Takacs *et al.*, 2022; Shaik *et al.*, 2023). When coupled with the circular economy, businesses operating with a strong green entrepreneurial orientation minimize their environmental footprint and actively contribute to the creation of a regenerative and resource-efficient economy. This incorporation is crucial as it aligns entrepreneurial efforts with global sustainability goals, driving innovation in product design, supply chain management, and waste reduction (Gallego *et al.*, 2010; Khan *et al.*, 2022). By adopting circular principles, businesses enhance resource productivity, reduce waste generation, and promote a more holistic approach to consumption. Ultimately, the interaction between green entrepreneurial orientation and the circular economy is essential for building a business ecosystem that mitigates environmental impact and thrives in a world increasingly focused on sustainable development (Kennedy and Linnenluecke, 2022).

In particular, the linking of green entrepreneurial orientation and the circular economy signifies a promising avenue for fostering sustainable business practices. Green entrepreneurial orientation, characterized by a proactive commitment to environmental responsibility, aligns with the principles of the circular economy, emphasizing resource efficiency and waste reduction. Recent literature, such as the work by Mondal *et al.* (2023b), suggests a positive association between green entrepreneurial orientation and the adoption of circular economy practices, mainly in the context of institutional pressures. However, it is essential to note that challenges persist in the practical implementation of circular models. Issues such as resource constraints, global supply chain complexities, and the need for supportive policies and regulations pose significant hurdles for businesses aiming to transition effectively (Wang *et al.*, 2023a). Moreover, market dynamics and consumer awareness play pivotal roles in determining the success of circular initiatives, highlighting the importance of education and advocacy in achieving widespread acceptance. A comprehensive and refinement approach, considering these attentions, is essential for realizing the full potential of the interaction between green entrepreneurial orientation and the circular economy (Mondal *et al.*, 2023a). Consequently, the subsequent hypothesis is formulated:

H2. There is a positive relationship between green entrepreneurial orientation and the circular economy.

2.3 The role of green knowledge management

Green knowledge management plays a pivotal role in shaping the involved link amid green entrepreneurial orientation, sustainability-oriented innovation, and the circular economy.

At its core, green knowledge management incorporates the organized acquisition, creation, dissemination, and utilization of environmentally conscious knowledge within a structural context (Abbas and Khan, 2023; Papa *et al.*, 2020). As businesses increasingly acknowledge the imperative to integrate ecological considerations into their operations, green knowledge management emerges as a key mechanism for harnessing and leveraging green knowledge. This requires fostering a culture of sustainability, encouraging cross-functional collaboration, and facilitating the seamless flow of information related to environmentally friendly practices (Al Halbusi *et al.*, 2023b; Broccardo *et al.*, 2023). Green knowledge management acts as the essential factor that enables businesses to develop a heightened environmental consciousness and encourages a dynamic environment where the principles of green entrepreneurial orientation can thrive (Abdelfattah *et al.*, 2023).

The complex relationship between green entrepreneurial orientation and green knowledge management sets the stage for the emergence of sustainability-oriented innovation, representing a strategic approach wherein businesses leverage green knowledge to drive the development of novel, sustainable products, processes, and services. Green knowledge management acts as the channel through which the insights and lessons acquired from environmental experiences are transformed into innovative solutions addressing ecological challenges (Audretsch *et al.*, 2023). By fostering a culture of continuous learning and knowledge sharing, green knowledge management empowers businesses to direct the complex landscape of sustainable innovation, thereby facilitating the integration of eco-friendly practices into their products and services (Sahoo *et al.*, 2023). Collaborative cooperation among green entrepreneurial orientation, green knowledge management, and sustainability-oriented innovation generally enables businesses to adapt to evolving environmental dynamics, positioning them as innovators in the pursuit of sustainable development (Abbas and Khan, 2023).

In the context of the circular economy, green knowledge management emerges as a crucial driver in the transition towards a reformative and curative economic model. The circular economy emphasizes waste reduction and the promotion of resource efficiency by designing products with a development approach, where materials are reused, recycled, or repurposed (Shehzad *et al.*, 2023). Green knowledge management plays a pivotal role in facilitating the dissemination of knowledge related to circular practices and principles, ensuring that businesses are well-equipped to embrace the transformative shift towards circularity (Al Halbusi *et al.*, 2023b). Through the knowledge-sharing mechanisms embedded in green knowledge management, firms can analytically integrate circular economy principles into their business models, supply chains, and production processes, thereby contributing to the creation of a more sustainable and resilient economic ecosystem (Polas *et al.*, 2023). In summary, the complex network of relationships among green entrepreneurial orientation, green knowledge management, sustainability-oriented innovation, and the circular economy reveals an inclusive framework for fostering environmental consciousness within business landscapes (Abbas and Sağsan, 2019). Based upon that, the following hypotheses are suggested:

H3. Green knowledge management mediates the relationship between green entrepreneurial orientation and both sustainability-oriented innovation and the circular economy.

2.4 The moderating role of digital transformation

Digital transformation, the strategic use of digital technologies to redefine and enhance business processes, functions, and customer experiences, serves as a powerful augmenting force in the elaborate relationship between green entrepreneurial orientation, green knowledge management, sustainability-oriented innovation, and the circular economy

(Chen *et al.*, 2024). At its essence, digital transformation acts as a substance, amplifying the capabilities of businesses to navigate the complex landscape of environmental sustainability by integrating cutting-edge technologies and data-driven strategies into their operations (Saarikko *et al.*, 2020; Shaik *et al.*, 2023; Soto-Acosta, 2020, 2024). As businesses increasingly recognize the urgency of addressing environmental concerns, the interaction between digital transformation and green entrepreneurial orientation becomes evident. Digital technologies provide the tools and platforms necessary for businesses to analyze, interpret, and respond to environmental challenges with agility and precision, enabling them to embed eco-centric practices into their entrepreneurial endeavors (Papa *et al.*, 2018). The incorporation of digital capabilities and green entrepreneurial orientation facilitated by the digitization of processes empowers businesses to make informed, sustainable decisions, fostering a culture of environmental consciousness at the core of entrepreneurial activities (Holzmann and Gregori, 2023; Trigo *et al.*, 2010).

Sustainability-oriented innovation experiences a significant boost through the integration of digital transformation into business contexts. Digital technologies such as artificial intelligence, the Internet of Things (IoT), and big data analytics enable businesses to identify, analyze, and implement sustainable innovations at a unique scale and speed (Bähr and Fliaster, 2023; Shaik *et al.*, 2023; Soto-Acosta, 2020, 2024). These technologies facilitate the collection and interpretation of vast amounts of environmental data, empowering businesses to identify opportunities for sustainable innovation and optimize their processes in real-time. Digital transformation, as a key driver of Sustainability-oriented innovation, accelerates the development of eco-friendly products and services by streamlining research and development processes, fostering collaboration, and enhancing the efficiency of innovation channels (Wang *et al.*, 2023c). The marriage of digital transformation and sustainability-oriented innovation ensures that businesses are approachable to environmental challenges and are at the forefront of driving positive environmental change through technological advancement (Avelar *et al.*, 2024). Regarding the circular economy gains drive and feasibility through the transformative influence of digital transformation. Digital technologies play a pivotal role in optimizing resource management, enhancing supply chain visibility, and facilitating the seamless integration of circular principles into organizational practices (Wang *et al.*, 2023b). IoT devices enable real-time tracking of resources and products throughout their lifecycle, facilitating efficient recycling and repurposing. Blockchain technology, a digital ledger system, can enhance transparency and traceability within supply chains, ensuring the authenticity and sustainability of materials (Feroz *et al.*, 2023; Soto-Acosta, 2020). Digital platforms also contribute to the sharing and circularity of resources through mechanisms such as online marketplaces for reused or repurposed goods. In essence, digital transformation acts as a technological backbone for the circular economy, enabling businesses to transition towards a more regenerative and restorative model by leveraging data-driven insights and smart technologies (Li *et al.*, 2023).

In the realm of green knowledge management, digital transformation serves as a transformative enabler, revolutionizing the acquisition, dissemination, and utilization of green knowledge (Sahoo *et al.*, 2023). The digitization of knowledge repositories, collaborative platforms, and data analytics within green knowledge management frameworks enhances the accessibility and efficiency of green information, facilitating seamless knowledge flow across organizational boundaries (Shehzad *et al.*, 2024; Colomo-Palacios *et al.*, 2011; Soto-Acosta *et al.*, 2010). By leveraging digital tools, organizations can capture real-time insights into environmentally sustainable practices, ensuring that the latest green knowledge is readily available to inform decision-making processes. Furthermore, digital transformation improves the collaborative aspects of green knowledge management, promoting cross-functional engagement and knowledge-sharing on digital platforms (Javeed and Akram, 2024), thereby fostering a dynamic ecosystem where green insights are preserved and actively contribute to the development of innovative sustainable solutions (Sahoo, 2024). Thus, in line with these arguments we posit the following hypotheses:

H4a. Digital transformation moderates the relationship between green entrepreneurial orientation and sustainability-oriented innovation and the circular economy, such that these relationships are stronger when digital transformation is high.

H4b. Digital transformation moderates the relationship between green entrepreneurial orientation and green knowledge management, strengthening this relationship when digital transformation is high.

H4c. Digital transformation moderates the relationship between green knowledge management and sustainability-oriented innovation and the circular economy, such that these relationships are stronger when digital transformation is high.

The set of relationships is illustrated in Figure 1.

3. Methodology

3.1 Data collection and sample

The data was gathered within the Kingdom of Saudi Arabia, recognized as one of the globe's major economies. Nevertheless, carbon emissions are most prevalent in Saudi Arabia's manufacturing sector. The Saudi government places significant emphasis on environmental concerns and has enacted a set of laws and regulations aimed at minimizing environmental impact. Furthermore, there is a commitment to sustainable development, with the government encouraging businesses to incorporate sustainable practices into their operations to foster high-quality economic growth. This approach aligns with the overarching Saudi Vision 2030.

Before sending the ultimate survey, we precisely crafted a questionnaire based on insights from prior studies to enhance comprehension. We sought input from professors and doctoral students in pertinent fields for refinement. Following a pilot test involving 20 participants, comprising senior and middle managers from 10 different firms, we further enhanced the final survey. Subsequently, a telephone inquiry was undertaken as a preliminary step before the formal survey was initiated.

Thus, we contact the firms via phone and email to get their permission to participate. To improve our response rate, we also sent an email to each company, including a survey invitation letter explaining the background and purpose of our research. In particular, the data were collected from firms in the manufacturing sector. Our survey was distributed to

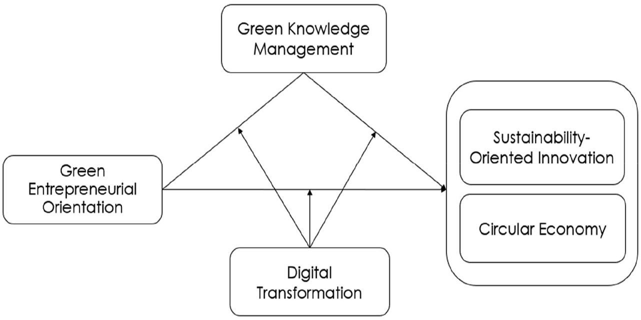


Figure 1. Research model

Source(s): Authors own creation

each firm and was addressed to senior managers and middle managers, such as purchasing managers, marketing managers, and financial managers since they have a good understanding of the entire organization and can provide appropriate key information about the knowledge process and stakeholder management. The questionnaire is issued from August 2023 to January 2024. We received 300 results. Twenty-six incomplete samples were deleted, and 274 firms were used for our testing.

3.2 Measures

Regarding the measurement of variables, green entrepreneurial orientation was assessed using seven items adapted from Zhang *et al.* (2023). Green knowledge management was measured across various dimensions, including knowledge acquisition (5 items), knowledge storage (5 items), knowledge sharing (6 items), knowledge application (5 items), and knowledge creation (5 items), all adapted from Yu *et al.* (2022). Digital transformation was evaluated through two dimensions: digital strategy (3 items) and digital capability (4 items), as suggested by Khin and Ho (2018) and Proksch *et al.* (2021). Sustainability-oriented innovation was measured through several indicators, such as capability (4 items), evaluation (6 items), products and services (5 items), operations (4 items), strategy (4 items), partnerships (4 items), economic (3 items), social (4 items), and demand (4 items), all drawn from Baxter and Chipulu (2023). The assessment of the circular economy, consisting of 10 items, was adapted from Zeng *et al.* (2017).

When evaluating latent constructs, the choice between reflective and formative indicators holds significant importance (Sarstedt *et al.*, 2019). Reflective measures are suitable for indicators that are highly correlated and interchangeable, linked to a specific latent construct. In contrast, formative measures involve less correlated, interchangeable indicators, rendering traditional reliability and validity criteria inappropriate (Sarstedt *et al.*, 2019). In our study, we incorporated both reflective and formative variables, encompassing first-order constructs representing key aspects of the target and second-order constructs. In the case of Reflective-Formative, Type II, the choice of formative constructs is crucial, as neglecting dimensions could lead to a shift in the conceptual domain (e.g. Sarstedt *et al.*, 2019). All items in the second part were anchored on a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5), as shown in Table 1.

4. Data analysis and results

To evaluate the hypotheses in this study, we utilized the Partial Least Squares (PLS) Structural Equation Modeling (SEM) technique (Ringle *et al.*, 2015). This advanced and rigorous analytical approach is well-suited for intricate causal analyses involving both first- and second-order constructs, without necessitating strict assumptions about the underlying components (Hair *et al.*, 2017). The PLS analysis involved the creation of 5,000 subsamples for

Table 1. Common method variance assessment via full collinearity estimate criteria

Variables	VIF
Green entrepreneurial orientation	2.11
Green knowledge management	1.10
Digital transformation	1.13
Sustainability-oriented innovation	1.55
Circular economy	2.41

Note(s): VIF = Variance Inflation Factor
Source(s): Authors own creation

generating bootstrap *t*-statistics with (n-1) degrees of freedom to assess the statistical significance of the path coefficients, where n represents the number of subsamples.

4.1 Nonresponse and common method biases

Given that all variables, both independent and dependent, were obtained through the same survey instrument, the potential for nonresponse bias (NRB) and common method bias (CMB) arises. To address these concerns, we employed a dual-faceted approach involving procedural and statistical methods, as recommended by Podsakoff *et al.* (2003, 2012). In the procedural approach, we incorporated multiple measuring scales into the survey instrument and explicitly communicated to participants that their responses were neither right nor wrong, emphasizing the importance of anonymity.

To address potential statistical biases, we employed three distinct approaches. Firstly, we conducted a bias test to scrutinize any differences in characteristics between participating and non-participating firms. The results indicated no statistically significant variations in fundamental features such as operational tenure, employee count, and asset size among the firms, rendering the presence of non-response bias insignificant (Armstrong and Overton, 1977). Secondly, we applied Harman's single-factor analysis, which revealed no dominant factor. The first factor explained only 25% of the total variance, falling below the critical threshold of 50%. Additionally, seven factors with eigenvalues above 1 collectively accounted for 68% of the total variance. Thirdly, we conducted a comprehensive collinearity test using VIFs, following the recommendations of Kock (2015). This analysis allowed us to assess both vertical and lateral collinearity. According to the criteria outlined by Kock and Lynn (2012), a VIF exceeding 3.3 might indicate problematic collinearity. However, as illustrated in Table 1, our study did not exhibit any issues related to CMB, affirming the robustness and integrity of our findings. Therefore, we can conclude that neither NRB nor CMB are serious threats in our study.

4.2 Confirmatory factor analysis

In the evaluation of our measurement model, attention was directed towards item reliability, internal consistency reliability, convergent validity, and discriminant validity. As presented in Table 2, the factor loadings for these indicators did not reveal any significant issues, with most items surpassing the recommended threshold of 0.707 (Hair *et al.*, 2017). To assess internal consistency, composite reliability (CR) was employed, with a focus on meeting the 0.70 cut-off criteria. The results of the CR analysis indicated a high level of internal consistency for the constructs, thereby supporting the reliability of the latent variable measurements. This outcome reinforces the overall robustness of the measurement model. Convergent validity was confirmed through the average variance extracted (AVE), which exceeded the recommended threshold of 0.50 (see Table 2). This indicates that the variance in each construct is effectively captured by its respective indicators.

Discriminant validity was rigorously examined using Fornell and Lacker's method, along with the heterotrait-monotrait ratio (HTMT). As displayed in Table 3, Fornell and Lacker's method demonstrated that the AVE for each construct exceeded the shared variance with other latent variables. To enhance this assessment, Henseler *et al.* (2015) recommended the utilization of the HTMT of correlations, a more robust method grounded in a multitrait-multimethod matrix. In Table 4, all HTMT values remained below 0.90, providing strong evidence for the discriminant validity of each variable pair. Additionally, all HTMT values significantly deviated from 1, and the 95% confidence intervals (CI) excluded 1, further reinforcing the robust discriminant validity of each variable pair (Henseler *et al.*, 2015).

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ *t*-value	*p*-value
Green entrepreneurial orientation		Our company attaches great importance to green development, such as green R&D and green innovation	Reflective	0.762	0.821	0.655	n.a
		When facing uncertainty, we usually take a proactive attitude to seize potential green opportunities		0.755			
		Compared with competitors, we usually take the lead in green activity		0.885			
		Our company tends to be the first mover to launch green products, services or technologies		0.795			
		We usually have an advantage over our competitors when it comes to dealing with them		0.862			
		Our company develops new products and processes that consider environmental issues		0.755			
		Our company is engaged in reducing the environmental impact of products and processes		0.811			
Knowledge acquisition		My organization regularly acquires information about environment-friendly products and processes/services from external stakeholders (e.g. customers and suppliers)	Reflective	0.868	0.833	0.698	n.a
		My organization regularly acquires information about environment-friendly products and processes/services from internal stakeholders (e.g. management and staff)		0.788			
		My organization regularly arranges training sessions for employees to develop their knowledge about environment-friendly products and processes/services		0.856			
		We have a well-developed information system through which employees can acquire the required information		0.863			
		My organization encourages and supports the employees to acquire knowledge about environment-friendly products and processes/services		0.798			

(*continued*)

Table 2. Measurement model: 1st-order constructs, 2nd-order constructs, items wording loading/ weight, CR/VIF, AVE/ *t*-value *p*-value

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ *t*-value	*p*-value
Knowledge storage		My organization has sufficient information about environment-friendly products and processes/ services	Reflective	0.852	0.864	0.611	n.a
		We have an excellent information system to manage information regarding environment-friendly products and processes/services		0.874			
		It is easy to retrieve information about a specific problem from our information system		0.779			
		We have comprehensive information about our competitors and the impact of their operations on the natural environment		0.836			
		Even if any person leaves, our information system keeps their best knowledge		0.855			
Knowledge sharing		People within our organization regularly interact with each other to discuss different environmental developments and share knowledge	Reflective	0.817	0.878	0.684	n.a
		We have a well-organized system through which we can share knowledge and learn from each other		0.859			
		We are provided with the latest equipment and technology to obtain and share knowledge		0.842			
		My organization recognizes and rewards the employees for sharing innovative ideas and information to improve the process for the protection of the natural environment		0.855			
		My organization regularly share the latest environmental knowledge and market trends with its employees through e-mail, training sessions, and workshops		0.791			
		We regularly share information and knowledge related to the natural environment with our customers, suppliers, and other stakeholders		0.871			

Table 2. (*continued*)

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ *t*-value	*p*-value
Knowledge application		My organization fully comply with environmental regulations in its operations	Reflective	0.785	0.847	0.634	n.a
		My organization ensures the application of acquired knowledge to produce environment-friendly products and services		0.896			
		We use the knowledge obtained from our experiences and mistakes to improve our environmental performance		0.877			
		We use the acquired knowledge to develop our environment-friendly business strategies		0.799			
		We have strong commitments to implementing environment-friendly strategies		0.787			
Knowledge creation		My organization uses existing information to create environment-friendly products and services		0.871	0.778	0.561	n.a
		The management encourages debates and discussions to create new knowledge		0.894			
		Employees proposing new ideas, knowledge, and solutions are highly appreciated and rewarded by the management		0.879			
		We used to collaborate with other firms to create environment-friendly products or processes/services		0.859			
		We regularly evaluate new ideas for further refinement		0.875			
	Green Knowledge Management	*Knowledge Acquisition*	Formative	0.318	1.461	3.491	0.000
		Knowledge Storage		0.322	1.486	3.896	0.000
		Knowledge Sharing		0.321	1.264	4.200	0.000
		Knowledge Application		0.322	1.491	2.175	0.000
		Knowledge Creation		0.247	1.315	2.574	0.001
Digital strategy		We investigate the newest trends and future scenarios in digitalization to stay competitive	Reflective	0.881	0.887	0.612	n.a
		Digital projects have a high priority within our business		0.874			
		We constantly update and refine our digital strategy		0.859			
Digital capability		Acquiring important digital technologies	Reflective	0.78	0.784	0.645	n.a
		Identifying new digital opportunities		0.852			
		Responding to digital transformation		0.859			
		Mastering state-of-the-art digital technologies		0.791			
	Digital Transformation	*Digital Strategy*	Formative	0.411	1.65	3.21	0.000
		Digital Capability		0.387	1.85	2.88	0.000

(*continued*)

Table 2.

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ t-value	p-value
Capability		Understanding the capability of your organization–We have the capabilities required to fully understand the future pollution effects of our new products	Reflective	0.787	0.852	0.701	
		Understanding the capability of your organization–We have the capabilities required to fully understand the future materials life cycle of our new products		0.784			
		Understanding the capability of your organization–We have the capabilities required to fully understand the future carbon footprint of our products and services in use		0.863			
		Understanding the capability of your organization–We conduct environmental research and development (R&D)		0.851			
Evaluation		Sustainability evaluation that your organization carries out–We evaluate the future pollution effects of our new products in use	Reflective	0.817	0.867	0.714	
		Sustainability evaluation that your organization carries out–We evaluate the future materials life cycle of our products and services in use		0.854			
		Sustainability evaluation that your organization carries out–We evaluate the future carbon footprint of our products and services in use		0.778			
		Sustainability evaluation that your organization carries out–We evaluate the current pollution contribution of our day-to-day operation		0.844			
		Sustainability evaluation that your organization carries out–We evaluate the current materials life cycle of our day-to-day operations					
		Sustainability evaluation that your organization carries out–We evaluate the current carbon footprint of our day-to-day operations					

Table 2. (*continued*)

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/weight	CR/VIF	AVE/t-value	p-value
Products and services		The sustainability performance of your new products and services–Our new products and services will produce zero pollution	Reflective	0.789	0.789	0.687	
		The sustainability performance of your new products and services–The materials life cycle of our new products and services will be a closed loop with no landfill		0.884			
		The sustainability performance of your new products and services–Our new products and services will have a zero or negative carbon footprint		0.832			
		The sustainability performance of your new products and services–Our new products and services are sustainable		0.852			
		The sustainability performance of your new products and services–Our new products and services will be socially beneficial		0.795			
Operations		The sustainability performance of your organization's operations–Our day-to-day operations produce zero pollution	Reflective	0.881	0.844	0.581	
		The sustainability performance of your organization's operations–The materials life cycle of our day-to-day operations is a closed loop; there is no landfill		0.874			
		The sustainability performance of your organization's operations–Our day-to-day operations have a zero or negative carbon footprint		0.795			
		The sustainability performance of your organization's operations–Our day-to-day operations are sustainable		0.834			
		Increase in energy saved due to conservation and efficiency improvements		0.782			
Strategy		Your sustainability strategy–We strive to meet exceptionally high environmental goals	Reflective	0.818	0.817	0.641	
		Your sustainability strategy–Our top management are fully committed to sustainability		0.833			
		Your sustainability strategy–Our sustainability strategy is proactive, and goes well beyond current regulations		0.831			
		Your sustainability strategy–Our sustainability strategy is radical, and aims higher than others in our industry		0.844			

(*continued*)

Table 2.

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ *t*-value	*p*-value
Partnerships		Organizational partnerships for sustainability-Our innovations could not be delivered by our organization alone	Reflective	0.841	0.811	0.661	
		Organizational partnerships for sustainability-We collaborate with a wide range of external actors and stakeholders		0.762			
		Organizational partnerships for sustainability-Our sustainability goals are informed by a wide range of external views		0.866			
		Organizational partnerships for sustainability-We are willing to make new partnerships in order to meet our sustainability goals					
Economic		Economic sustainability–My organization will produce economically beneficial products and services	Reflective	0.837	0.825	0.656	
		Economic sustainability–Our innovation decisions include finance as a central consideration (e.g. costs, revenues)		0.813			
		Economic sustainability–My organization is economically excellent		0.756			
Social		Social dimensions of sustainability-My organization has excellent health and safety	Reflective	0.753	0.878	0.587	
		Social dimensions of sustainability -My organization has excellent working conditions		0.871			
		Social dimensions of sustainability–My organization has excellent stakeholder and social dialogue		0.794			
		Social dimensions of sustainability–My organization improves the education and training of its workers		0.766			
Demand		Demand patterns-We are considering how our new products and services might change demand patterns	Reflective	0.774	0.894	0.614	
		Demand patterns-We are considering how our new products and services could be delivered through new business models		0.854			
		Demand patterns-We are considering how our new products and services could be delivered through new service systems		0.787			
		Demand patterns-We are considering the future effect of new regulatory systems		0.859			
		Capability		0.167	1.39	3.49	0.000
		Evaluation		0.322	1.52	3.89	0.000

Table 2. (*continued*)

1st-order constructs	2nd-order constructs	Items and wording	Scale	Loading/ weight	CR/ VIF	AVE/ *t*-value	*p*-value
		Products and Services		0.193	2.27	2.21	0.000
		Operations		0.277	2.55	2.17	0.000
		Strategy		0.435	2.06	3.57	0.000
		Partnerships		0.138	2.08	2.49	0.000
		Economic		0.296	2.11	3.89	0.000
		Social		0.428	2.51	4.20	0.000
		Demand		0.177	1.35	2.17	0.000
Circular economy		The firm is devoted to reducing the unit product manual input	Reflective	0.758	0.875	0.598	
		The firm is devoted to reducing the consumption of raw materials and energy		0.844			
		The firm initiatively enhances the energy efficiency of production equipment		0.743			
		Product packaging materials are used repeatedly		0.841			
		Equipment cleaning materials are used repeatedly		0.844			
		Leftover material is used repeatedly to manufacture other products		0.745			
		Waste produced in the manufacturing process is recycled					
		Waste products from consumers is recycled					
		Recycling waste and garbage is reprocessed					
		Waste and garbage is used after reprocessing to manufacture new products					

Note(s): CR= Composite Reliability, AVE = Average Variance Extracted
Source(s): Authors own creation

Table 2.

Constructs	Mean	SD	1	2	3	4	5
1. Green entrepreneurial orientation	3.411	0.551	*0.781*				
2. Green knowledge management	3.427	0.531	0.611	*0.745*			
3. Digital transformation	4.141	0.626	0.432	0.589	*0.834*		
4. Sustainability-oriented innovation	3.134	0.536	0.134	0.166	0.483	*0.811*	
5. Circular economy	4.56	0.556	0.337	0.587	0.472	0.305	*0.722*

Note(s): S.D. = Standard Deviation. Italic values on the diagonal in the correlation matrix are square roots of AVE (variance shared between the constructs and their respective measures). Off-diagonal elements below the diagonal are correlations among the constructs, where values between 0.13 and 0.16 are significant at $p < 0.05$, and values above 0.16 are significant at $p < 0.01$ (two-tailed test)
Source(s): Authors own creation

Table 3. Descriptive statistics, correlation matrix, and discriminant validity via Fornell and Larcker

4.3 Results

Table 5 presents the findings related to hypothesis H1, indicating a positive association between green entrepreneurial orientation and sustainability-oriented innovation ($\beta = 0.415$, $t = 3.368$, $p < 0.000$). Similarly, hypothesis H2 revealed a positive relationship between green entrepreneurial orientation and circular economy ($\beta = 0.354$, $t = 3.147$, $p < 0.000$). Thus, both H1 and H2 hypotheses find support.

Consistent with our hypothesis H3, the positive impact of green entrepreneurial orientation, sustainability-oriented innovation, and circular economy is mediated by green knowledge management. Using a bootstrapping method with 5,000 subsamples, a notable indirect impact of green entrepreneurial orientation on sustainability-oriented innovation and circular economy through green knowledge management is identified (indirect effect = 0.268, t = 2.85, p < 0.000, Table 5). With the 95% confidence interval excluding 0 (lower limit = 0.023, upper limit = 0.158), we confirm the existence of mediation (Preacher and Hayes, 2008). This underscores the significant mediating role of green knowledge management in the relationship between green entrepreneurial orientation, sustainability-oriented innovation, and circular economy, offering robust support for hypothesis H3.

Aligned with the primary objectives, the moderation analysis investigated whether digital transformation moderates the associations between green entrepreneurial orientation and sustainability-oriented innovation and circular economy. Additionally, interactions involving green entrepreneurial orientation, green knowledge management, and sustainability-oriented innovation along with circular economy were explored. The findings for these interactions are outlined below:

Constructs	1	2	3	4	5
1. Green entrepreneurial orientation					
2. Green knowledge management	0.452				
3. Digital transformation	0.381	0.662			
4. Sustainability-oriented innovation	0.534	0.644	0.522		
5. Circular economy	0.185	0.263	0.391	0.561	

Note(s): HTMT should be lower than 0.85
Source(s): Authors own creation

Table 4.
Discriminant validity via HTMT

Hypothesis	Direct effect	Std Beta	Std error	t-value	p-value	Bias and corrected bootstrap 95% CI BCI 95% LL	BCI 95% UL	Decision
H-1	Green Entrepreneurial Orientation → Sustainability-oriented Innovation	0.415	0.087	3.368	0.000	0.112	0.366	Supported
H-2	Green Entrepreneurial Orientation → Circular Economy	0.354	0.078	3.147	0.000	0.214	0.551	Supported
Structural path analysis: indirect effect								
H-3	GEO → GKM → S-OI and CE	0.268	0.087	2.85	0.000	0.023	0.158	Supported

Note(s): n = 350. Bootstrap sample size = 5,000. SE = standard error; LL = lower limit; CI = confidence interval; UL = upper limit 95% bias-correlated CI
Kyes: GEO = Green Entrepreneurial Orientation, GKM = Green Knowledge Management, S-OI= Sustainability-Oriented Innovation And CE= Circular Economy
Source(s): Authors own creation

Table 5.
Structural path analysis: direct and indirect effects

As shown in Table 6, the initial interaction between green entrepreneurial orientation, sustainability-oriented innovation, and circular economy yielded significant results, with coefficients ($\beta = 0.187$, $t = 2.23$, $p < 0.000$) and ($\beta = 0.153$, $t = 2.20$, $p < 0.000$). Consequently, hypothesis H4a receives support. Regarding the second interaction specified in hypothesis H4b, involving green entrepreneurial orientation and green knowledge management concerning sustainability-oriented innovation and circular economy, the analysis revealed a noteworthy interaction, with coefficients ($\beta = 0.198$, $t = 4.73$, $p < 0.000$) and ($\beta = 0.151$, $t = 2.87$, $p < 0.001$), respectively. The third interaction examining the relationship between green knowledge management and digital transformation affecting sustainability-oriented innovation and circular economy demonstrated a positive interaction, with coefficients ($\beta = 0.15$, $t = 2.87$, $p < 0.001$) and ($\beta = 0.177$, $t = 3.52$, $p < 0.000$). Thus, hypothesis H4c is confirmed.

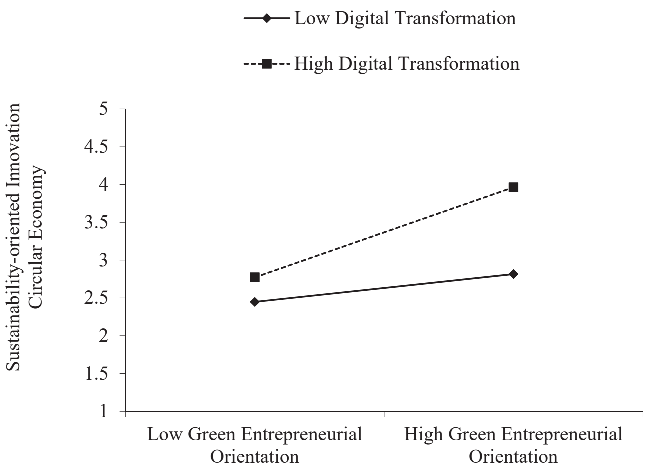
Generally, discerning the nuances of how a moderation analysis diverges for high and low interaction can be challenging. Dawson (2014) proposed addressing this issue by supplementing the analysis with an interaction plot. Therefore, this study incorporated interaction plots for all interactions to assess the slope gradients.

In Figure 2, the line labeled 'high digital transformation' for the first interaction exhibits a steeper gradient compared to 'low digital transformation,' suggesting that a higher digital transformation accentuates the positive relationship between green entrepreneurial orientation, sustainability-oriented innovation, and circular economy. The second interaction involves green entrepreneurial orientation, digital transformation, and green knowledge management. The interaction plot (Figure 3) illustrates that the positive

Hypothesis	Structural path analysis: interaction effect	Std Beta	Std error	t-value	p-value	Bias and corrected bootstrap 95% CI BCI 95% LL	BCI 95% UL	Decision
H-4a	Green Entrepreneurial Orientation × Digital Transformation → Sustainability-oriented Innovation and Circular Economy	0.187 0.153	0.076 0.084	2.23 2.20	0.000 0.000	0.010 0.014	0.274 0.283	Supported
H-4b	Green Entrepreneurial Orientation × Digital Transformation → Green Knowledge Management	0.198	0.078	4.73	0.000	0.047	0.347	Supported
H-4c	Green Knowledge Management × Digital Transformation → Sustainability-oriented Innovation Circular Economy	0.151 0.177	0.054 0.067	2.87 3.52	0.001 0.000	0.069 0.121	0.259 0.287	Supported

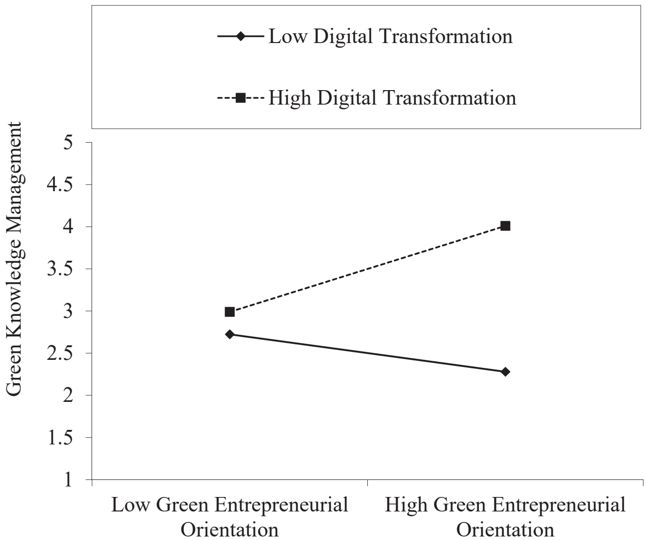
Note(s): n = 350. Bootstrap sample size = 5,000. SE = standard error; LL = lower limit; CI = confidence interval; UL = upper limit 95% bias-correlated CI
Kyes: GEO = Green Entrepreneurial Orientation, GKM = Green Knowledge Management, S-OI= Sustainability-Oriented Innovation And CE= Circular Economy
Source(s): Authors own creation

Table 6. Structural path analysis: interaction effects



Source(s): Authors own creation

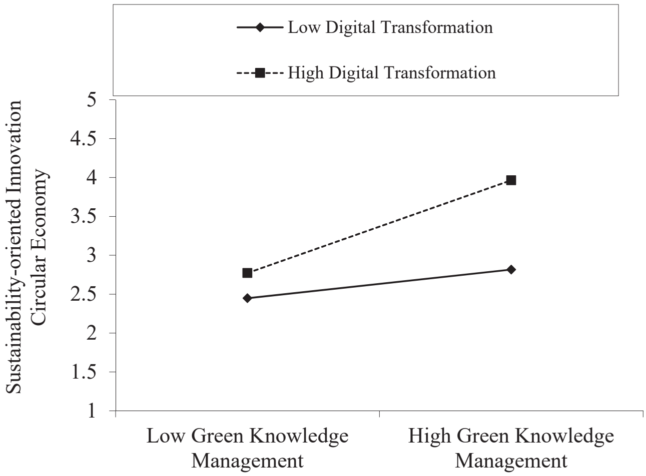
Figure 2.
Interaction plot of green entrepreneurial orientation and digital transformation on the sustainability-oriented innovation and circular economy



Source(s): Authors own creation

Figure 3.
Interaction plot of green entrepreneurial orientation and digital transformation on the green knowledge management

relationship among these variables is accentuated when digital transformation is higher. Figure 4 illustrates the interaction between green knowledge management and digital transformation concerning sustainability-oriented innovation and circular economy. As evident from the interaction plot, a high digital transformation value enhances the positive relationship between green knowledge management and sustainability-oriented innovation and circular economy.



Source(s): Authors own creation

Figure 4. Interaction plot of green knowledge management and digital transformation on the sustainability-oriented innovation and circular economy

5. Discussion and practical implications

This research delves into the complex relationships among green entrepreneurial orientation, sustainability-oriented innovation, and the circular economy, with a particular focus on the pivotal role of green knowledge management. The study envisions a transformative trajectory towards a resilient and ecologically harmonious future. The primary objective is to explore the interplay between green entrepreneurial orientations, sustainability-oriented innovation, and the circular economy, with green knowledge management serving as a crucial mechanism. Additionally, the research introduces digital transformation as a conditional variable shaping these relationships.

The key findings reveal a robust positive relationship among green entrepreneurial orientations, sustainability-oriented innovation, and the circular economy. These results align with existing research that highlights the positive influence of green entrepreneurial orientation on identifying and capitalizing on opportunities for sustainability-oriented innovations and circular economy practices (e.g. Frare and Beuren, 2022; Mondal *et al.*, 2023b; Shepherd and Patzelt, 2011). Moreover, this relationship is positively mediated by the role of green knowledge management, ensuring businesses are well-prepared for the transformative shift towards circularity (Al Halbusi *et al.*, 2023b; Polas *et al.*, 2023). The study further demonstrates that these relationships are strengthened when digital transformation is high. These findings hold implications for both theoretical understanding and practical applications.

The research contributes valuable insights into the intricate relationships between technology, sustainability, and green business practices (Saarikko *et al.*, 2020; Shaik *et al.*, 2023). The positive mediation effect of green knowledge management underscores its strategic importance in fostering sustainable innovation within the circular economy (Al Halbusi *et al.*, 2023b). Additionally, the amplification of these relationships in the presence of higher levels of digital transformation highlights the transformative potential of advanced technological strategies in enhancing the interaction between green entrepreneurial orientations and sustainability-oriented innovation (Soto-Acosta, 2020, 2024). Overall, this study significantly advances our comprehension of the complex mechanisms driving environmentally conscious entrepreneurship and innovation, facilitating informed decision-making and strategic planning towards a more sustainable future.

The comprehensive analysis of green entrepreneurial orientations, green knowledge management, sustainability-oriented innovation, circular economy, and digitalization strategy in this research underscores the importance of consistent elements crucial for policymakers and practitioners navigating the complex landscape of sustainable business practices (Meseguer-Martinez *et al.*, 2021). For policymakers, the amalgamation of these factors prompts a reevaluation and restructuring of existing frameworks to support mechanisms for green entrepreneurship. Insights from the study suggest the necessity for adaptive policies that incentivize environmentally sensible business endeavors, foster knowledge sharing focused on green practices, and promote an ecosystem conducive to sustainability-oriented innovation within the circular economy (Al Halbusi *et al.*, 2022, 2023a; Falahat *et al.*, 2022). Policymakers are encouraged to formulate strategies acknowledging the role of digitalization in shaping the green business landscape and actively incorporating it to amplify the impact of sustainable initiatives. By aligning policy initiatives with the dynamics of green entrepreneurial orientations, policymakers can initiate a transformative wave, steering economies towards a more sustainable course.

On the practical front, practitioners stand to gain a roadmap for navigating the intersection of green entrepreneurship, knowledge management, sustainability-oriented innovation, circular economy practices, and digitalization strategies. The research underscores the strategic importance of integrating green knowledge management into organizational structures, advocating for its role as a corner stone in steering businesses towards sustainability. Practitioners are encouraged to adopt a holistic approach to sustainability-oriented innovation, leveraging insights from circular economy principles and aligning them with digitalization strategies to propel their organizations to the forefront of green business practices. The study highlights the imperative for organizations to embrace a digitalization strategy that not only enhances operational efficiency but also acts as a catalyst for the seamless integration of environmentally conscious practices (Soto-Acosta, 2020, 2024). By understanding and leveraging the intricate relationships between these elements, practitioners can strategically position their organizations for long-term success in a global landscape increasingly defined by sustainability imperatives and technological advancements (Bähr and Fliaster, 2023; Soto-Acosta and Meroño-Cerdan, 2009). In essence, this research serves as a practical guide for both policymakers and practitioners, offering a nuanced understanding of the multifaceted dimensions of sustainable business in a new era where environmental responsibility and economic prosperity must harmonize.

6. Limitations and future research

While this research significantly advances our understanding of the relationships between green entrepreneurial orientations, sustainability-oriented innovation, the circular economy, and the mediating role of green knowledge management, it is vital to acknowledge certain limitations inherent in the study. Firstly, the focus on Saudi manufacturing firms may limit the generalizability of the findings to other industries or regions with different economic, cultural, or regulatory contexts. The scope of the study also centers on the manufacturing sector, potentially excluding nuances specific to service-oriented industries. Secondly, the reliance on cross-sectional data from a single point in time may restrict the ability to establish action or capture dynamic changes over time. Thirdly, the study primarily relies on self-reported data, introducing the possibility of response bias or subjectivity in participants' perceptions. Future research endeavors could consider longitudinal designs, encompassing a broader spectrum of industries, geographical locations, and sources, to enhance the external validity and generalizability of the findings. Exploring variations in the impact of digital transformation across diverse contexts and industries would provide a more accurate understanding of its conditional effects on the relationships under examination. Researchers are encouraged to explore deeper into the specific mechanisms through which digital transformation influences the interplay of green entrepreneurial orientations, sustainability-oriented innovation, and circular economy practices. Additionally, investigating the moderating role of contextual factors, such as regulatory environments or organizational cultures, could enrich our understanding of the complex dynamics involved.

One crucial avenue for exploration is the integration of emerging technologies as influential factors in the nexus of green entrepreneurial orientations, sustainability-oriented innovation, and circular economy practices. For instance, future research could delve into the impact of blockchain technology on sustainable business practices. Furthermore, the adaptation of artificial intelligence (AI) permits careful examination as a potential driver of sustainability-oriented innovation, particularly in improving resource allocation and energy efficiency. Furthermore, variables related to corporate governance structures, industry-specific regulations, and organizational cultures could be integral in comprehending the nuances of sustainability practices across various sectors. By incorporating these variables into future research designs, scholars can contribute to a more precise and complete understanding of the multifaceted dynamics shaping the intersection of technology, sustainability, and green business practices. Such endeavors will advance academic discourse and provide actionable insights for policymakers and practitioners seeking to navigate the evolving landscape of sustainable entrepreneurship and innovation in the digital era.

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