Transforming organizational readiness into green innovation: The crucial roles of green knowledge management and environmental culture

Abstract

Grounded in the Resource-based view and dynamic capabilities theory, this study investigates the interplay between organizational readiness (OR), green knowledge management (GKM), and environmental organizational culture (EOC) in fostering green innovation (GI). By using data collected from 340 respondents across 159 UAE SMEs, employing a quantitative approach with partial least squares structural equation modelling (PLS-SEM) and moderated mediation analysis. The findings revealed that OR significantly influenced both radical and incremental GI. Additionally, GKM mediates the relationship between OR and both GI types. EOC was found to strengthen the positive effect of GKM on radical GI, but not on incremental GI. Furthermore, the conditional indirect effects show that the mediating effect of GKM on the relationship between OR and radical GI is more pronounced when EOC is high, whereas this effect does not hold for incremental GI. These results provide critical insights for practitioners and policymakers. Organizations are encouraged to enhance readiness, implement robust GKM practices, and foster a strong environmental culture to drive sustainable innovation. This study contributes to the theoretical framework of RBV and dynamic capabilities by elucidating the interconnected roles of OR, GKM, and EOC in driving GI.

1. Introduction

In response to escalating global environmental concerns, organisations increasingly adopt environmentally responsible practices within their operations to achieve sustainable development (Shahzad et al., 2020). Balancing ecological sustainability with economic objectives remains a significant challenge, especially for organisations in developing economies (Shehzad et al., 2023). The manufacturing industry, a major contributor to environmental issues such as global warming and carbon emissions, plays a pivotal role in addressing these challenges (Wang et al., 2023). Green innovation (GI) strategies bridge environmental sustainability and economic objectives, enabling firms to adopt sustainable business practices that protect the environment while fostering economic growth (Abbas & Sağsan, 2019; Shehzad et al., 2024). By integrating GI, organisations can enhance their operations to achieve both environmental and economic goals, addressing the urgent need for sustainable development in resource-dependent and environmentally vulnerable regions (Wang et al., 2020).

Enhancing a company's green innovation (GI) capacity is crucial for lasting success because it allows businesses to reduce environmental impacts, optimise resource use, and create value for stakeholders, including customers and shareholders (Wang & Juo, 2021). GI has two main approaches: radical and incremental. Radical GI involves major advances in environmental technology, leading to new eco-friendly products, processes, or services (Chen et al., 2014; Idrees et al., 2023). Incremental GI entails minor improvements to existing technology, enhancing environmental performance without drastic changes. Both types of GIs are vital for manufacturing firms in developing countries (Chen et al., 2014; Idrees et al., 2023). Radical innovations can offer a competitive edge by establishing a unique green market presence, whereas incremental innovations provide a practical way to improve sustainability with limited resources steadily (Zhang et al., 2022). Embracing both strategies helps firms overcome the challenges of limited resources, technology, and knowledge, fostering long-term growth, enhancing their green image, and expanding market reach (Shehzad et al., 2023). This dual approach is key to addressing social, environmental, and commercial prospects in developing regions (Al-Khatib & Shuhaiber, 2022; Guo et al., 2020). Therefore, this study aims to identify key factors fostering sustainable development through GI in the manufacturing industry, addressing a novel and significant area of study.

First, several studies have been carried out regarding the determinants of GI, which include technological capability (Indrawati et al., 2023), market demand (Wasiq et al., 2023), government regulation (Zou et al., 2024) and leadership (Shehzad et al., 2024). Although RGI and IGI are essential for sustainability, they are different in scope, risk and impact, implying that the mechanisms supported by OR should be different (Shehzad et al., 2024). On the one hand, as disruptive and transformative (Idrees et al., 2023), RGI needs a more visionary OR, ready to embrace high-risk and disruptive technology innovation and lead in organizational change for greater effectiveness in response to environmental challenges. On the other hand, IGI aligns itself with gradual improvements (Chen et al., 2014) and, thus, needs to adopt a more structured OR for better operational efficiency, continuous learning, and incremental improvements in existing processes or products. Moreover, existing research regards an organization's ability to operate as ambidextrous (Wang et al., 2020) and pursue both IGI and RGI to facilitate performance (Shehzad et al., 2024). Given the significance and differences between RGI and IGI, there is no differentiation in current literature regarding the extent to which OR affects these two distinct types of innovation. Most studies analyze green innovation as a single entity (Ullah et al., 2024; Zhang et al., 2020) but neglect to examine the differentiated role of OR for different types of GI. Therefore, there is a need to bridge this research gap regarding the effects of OR on the distinctiveness of GI (RGI and IGI).

Second, the firms use knowledge to develop their competencies for GI (Schneider, 2015), to engage the customers in the organization (Attia & Salama, 2018) and to compete in the marketplace (Mothe et al., 2018). Green knowledge management (GKM) constitutes the basis for the successful innovation of green services and products and the legal compliance of the operations (Mothe et al., 2018). Sahoo et al. (2022) indicate that the GKM systematically manages the environmental knowledge assets to assist the firms in innovating and responding to environmental challenges. Though previous studies have focused on the importance of GKM driving GI outcomes (Abbas & Khan, 2023; Wang et al., 2022), empirical research into how GKM utilizes different mechanisms to facilitate RGI and IGI is still missing. However, the mechanisms behind GKM supporting GI types may differ (Shehzad et al., 2023). RGI needs knowledge management systems that promote disruptive thinking, cross-functionality, and the integration of up-to-date knowledge. At the same time, IGI is obsessed with continuous improvement, operational efficiency and optimization of existing practices. Although various studies have confirmed the positive association between different aspects of OR and GI outcomes (Kassa et al., 2024; Ullah et al., 2024; Zhang et al., 2020) from the perspective of GKM practices (Ghorbani, 2023; Khan et al., 2024; Shehzad et al., 2024), but do not clarify the distinction between RGI and IGI. Idrees et al. (2023) also highlight the importance of building on the potential mechanism through which GKM relates to OR to drive RGI and IGI. Thus, investigating how GKM influences the link between OR and distinct aspects of GI (RGI and IGI) is necessary.

The present research contributes significantly to understanding the individual contributions of the OR, GKM, and environmental organizational culture (EOC) for GI. However, no integrative models encompass their reciprocal interaction, specifically the moderating role of EOC on the mediating role of GKM. Although several works focus on exploring the impact of OR on GI (Zhang et al., 2020), GKM on GI (Abbas & Khan, 2022), or EOC on GI (Sobaih et al., 2024), these studies do not contribute much insight into how all these elements are interconnected. EOC impacts resource allocation and green knowledge in organizations with environmental responsibility and employee engagement in green actions (Wang, 2019; Wang et al., 2022). A robust EOC ensures that OR and GKM align with the firm's strategic objectives, enhancing the effectiveness of GI efforts (Gopalakrishnan & Zhang, 2017; Wang et al., 2020). On the other hand, a weak EOC undermines innovation by establishing resistance to change or innovation (Sobaih et al., 2024). Furthermore, GKM mainly bridges OR with GI; nevertheless, its efficiency is contingent upon EOC as envisaged. A supportive EOC improves the flow of knowledge and facilitates interaction, thus enhancing the impact of GKM on GI (Abbas & Khan, 2023). Although the role of EOC is acknowledged in maintaining the sustainable innovation equilibrium (Wang et al., 2020), the moderation effects of EOC in the investigated relationships between OR, GKM, and GI have not been examined in prior literature. Addressing this research question is important in analyzing the role of cultural factors in enhancing organizational resources and GKM for GI.

Based on the above arguments, this study sought to address the following research questions:

RQ1. Does OR significantly influence GI?
RQ2. Does GKM mediate the relationship between OR and GI?
RQ3. Does EOC moderate the mediating role of GKM in the relationship between OR and GI?

To address these research questions, this study employs a quantitative approach using cross-sectional data from manufacturing firms in the UAE. By exploring the interrelationships between OR, GKM, EOC and GI, this study intends to provide theoretical and practical insights for firms to enhance their GI capabilities and contribute to sustainable development. The subsequent sections of the study are structured as follows: First, the relationships between the constructs of the proposed research model are examined through the lens of RBV and dynamic capability theory. Next, we describe the methodology used to evaluate the proposed model. The empirical data are then analysed to present the findings. Finally, a discussion, implications, limitations, and conclusions are offered.

2. Literature review

2.1. Theoretical underpinnings

Drawing on RBV and dynamic capabilities theory, this study proposes that OR is crucial for GI capability. The RBV (Barney, 1991) and DCT (Eisenhardt & Martin, 2000) reinforce the notion that OR for GI, including radical and incremental GI, is greatly influenced by the interaction of resources and capabilities. According to the RBV, competitive advantage requires possessing valuable, rare, inimitable, and non-substitutable resources (Srivastava et al., 2001). Tangible assets, like eco-efficient technologies and sustainable infrastructure, are among the resources in the case of GI (Kumar et al., 2024); intangible assets, including a strong green organisational culture and environmental knowledge (Raghavendra, 2024); and human capital with experience in sustainable practices (Shehzad et al., 2023). While having these resources is requisite, it is not sufficient to have them since dynamic capabilities are critical to sense, select and reconfigure these resources for responding to the dynamic environment of the GI process (Pathak et al., 2024). Sensing capabilities include identifying emerging opportunities in the green landscape (Smart et al., 2007) and seizing capabilities to acquire and deploy the necessary resources. Usually, significant organisational change management is needed to incorporate GIs into current operations and reconfigure capabilities to do so (Pathak et al., 2024).

Additionally, the practice-based view (PBV) is a useful addition to RBV and DCT by extending the focus beyond resource ownership and capability implementation to the processes by which resources and capabilities are leveraged (Bromiley & Rau, 2014). PBV notes that competitive advantage is found not only in what organizations possess but in how organizational resources and capabilities are performed in ongoing work practices. In the context of GI, this means supporting and encouraging sustainable behaviours, activities, procedures and practices that reflect the ideas of environmental responsibility across an organisation. By promoting the performance of green knowledge, cooperation, and resource utilization, PBV connects resources ownership and capability utilization. Therefore, sustainable competitive advantage through GI only occurs when resources, capability and practice are well coordinated interactively to address the dynamic environment challenges and opportunities.

OR, in the case of GI, comprises how ready the firm is to participate in environmentally sustainable innovation, and GKM characterises the process in which the firm creates, acquires, shares and applies green knowledge. (Kassa et al., 2024; Shehzad et al., 2023) OR for GI offers a foundation of resources, capabilities, and organisational culture that GI initiatives require. However, these resources must be used well and turned into GI. GKM is performing a crucial mediating role in this case. GKM systems are effective only if they ensure that the company's green knowledge (technological know-how, market intelligence, regulatory expertise, and best practice) is systematically acquired, processed, shared, and applied throughout the organisation (Ghorbani, 2023; Rahim et al., 2023)This means that GKM is effective only when combined with positive internal knowledge processes and fully integrated with external stakeholders.

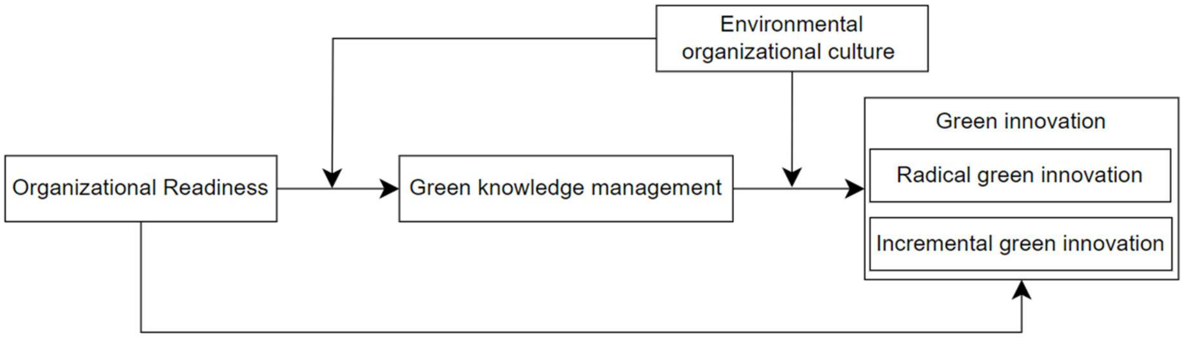

Figure 1. Research model

These resources achieve higher value and inimitability with a strong environmental, and organizational culture (Wang et al., 2020). A strong culture encourages a firm's employees to commit themselves to ecological sustainability and, thus, enhances the effectiveness of their green initiatives and makes it hard for a firm's rivals to imitate their practices (Xiaoyi et al., 2023). The culture also adds value to OR and GKM by ensuring these resources are utilised most appropriately (Abbas & Khan, 2023). A culture that encourages the sharing and applying knowledge is more inclined to use knowledge (Nasir et al., 2024). Second, environmental organisational culture nurtures the formation of dynamic capabilities, the ability to sense, seize and reconfigure resources (Wang et al., 2022). Environmental culture is strong enough to enhance sensation by raising environmental awareness and monitoring proactively (Abdulmuhsin et al., 2024). A supportive culture allows the firm to identify opportunities and threats better and how to exploit new opportunities and adjust to the changing conditions (Zhao et al., 2018). Integrating RBV and DCT offers a robust framework to understand how OR influences GI through GKM, with EOC moderating these relationships.

2.2. Organizational readiness and green innovation

OR for GI refers to the essential characteristics of an enterprise that are needed to successfully implement GI. It includes a company's knowledge, expertise, and ability to manage organizational changes associated with GI (Ullah et al., 2024). The key components of OR are innovation capability and environmental concerns (Zhang et al., 2020). Innovation capability is necessary for GI at the organizational level, involving the capacity to absorb new knowledge and adapt to changes, which is crucial for effectively implementing GI (Tsai & Liao, 2017). This capability enables the management of the complexities of introducing new green processes, products, or managerial practices (Zhang et al., 2020). Environmental concerns are a sufficient condition for employee engagement in GI activities. It reflects the importance placed on environmental issues by the organisation and its members (Hojnik & Ruzzier, 2016). A high level of environmental concern fosters a proactive approach to GI, aligning the organisation's goals with environmental sustainability objectives (Ullah et al., 2024; Wang et al., 2020). Together, innovation capability and environmental concern constitute OR essential for successful GI. Readiness initiates and sustains GI, contributing to long-term corporate sustainability (Zhang et al., 2020).

GI is vital for sustainable development, including radical and incremental approaches to reducing environmental impacts through new or improved products, services, or technologies (Idrees et al., 2023). Previous studies show that terms such as ecological innovation, eco-innovation, environmental innovation, and GI are interchangeable (Shahzad et al., 2020). GI is defined as "hardware or software innovation related to green products or processes, including innovation in technologies involved in energy-saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management" (Chen et al., 2006). Radical GI involves significant technological breakthroughs, substantial investments, and long development periods, leading to transformative environmental benefits and market disruptions (Bouncken & Kraus, 2013). Incremental GI focuses on minor modifications to existing products or processes, enhancing efficiency, reducing resource consumption, and minimising waste (Okuyama, 2017). Both types are driven by regulatory pressures, market demand for eco-friendly products, and technological advancements, contributing to environmental, economic, and social sustainability (Zhang et al., 2022). Despite their benefits, financial, technological, and market barriers can hinder the adoption and implementation of GIs. Overcoming these challenges is essential for maximising their positive impacts on the environment and society (Idrees et al., 2023).

Numerous studies have found a strong positive relationship between OR and RGI (Tian et al., 2023; Xue, 2023). With heightened levels of OR, RGI adoption is more likely, investment in green technologies increases, and RGI initiatives are more successfully implemented (Shehzad et al., 2024). Research has consistently highlighted the importance of specific factors within OR: Leadership commitment and support matters in building innovation culture and offering resources to RGI initiatives (Indrawati et al., 2023). Resources are required to support development, pilot projects and the implementation of new technologies. GI covers product, process, service, managerial and marketing innovation to reduce environmental impacts (Wang et al., 2023). Radical GI capability is significantly affected by organizational factors such as leadership, culture and architecture (Idrees et al., 2023). Contextual and environmental factors affect organizational risk attitude and, therefore, the pursuit of radical innovation. The successful implementation of GI depends on three dimensions which include organizational, technological and environmental readiness (Barforoush et al., 2021).

The literature shows that OR for incremental GI is driven by internal and external factors determining a firm's ability and willingness to pursue green initiatives. Internally, While leadership commitment plays a pivotal role, active leadership support provides a strategic direction, allocates resources, and cultivates environment responsibility culture. Green technologies require adequate financial capital, technological capabilities and qualified personnel (Hafeez et al., 2024; Schrank & Kijkasiwat, 2024). Without these resources, GI efforts may fail. Other critical factors include effective knowledge management systems, which allow organizations to obtain, store and share knowledge on green technologies and practices, improve environmental performance and stimulate innovation (Abbas & Khan, 2022; Ghorbani, 2023). Externally, government policies and regulations are important in providing incentives, like tax breaks and subsidies, or forcing standards that lead to the purchase and use of GI (Gu, 2023). Note that too tight rules can sometimes slow down production. The market pull is strong because customer demand for environmentally friendly products is strong, and firms need to innovate to meet expectations and get ahead of the competition (Chu et al., 2019). In addition, organizations have to adopt green practices to sustain their market position and brand image. Lastly, collaboration within industry networks such as supplier, customer and research institution partnerships increases GI capabilities through knowledge sharing, resource pooling, and joint development projects (Fridgeirsson et al., 2023). These factors together define OR for incremental GI efforts and sustaining them. Therefore, we propose the following hypothesis:

Hypothesis 1a. OR significantly influences firms' radical GI.

Hypothesis 1b. OR significantly influences firms' incremental GI.

2.3. Mediating role of green knowledge management

GKM involves systematically acquiring, sharing, and utilising knowledge related to environmental sustainability within an organisation (Sahoo et al., 2022; Shehzad et al., 2023). It combines traditional knowledge management with ecological goals to enhance environmental performance and support sustainable development (Shehzad et al., 2023). Key aspects of GKM include creating new environmental knowledge through research and collaboration, sharing this knowledge organisation-wide to ensure that all employees are informed about best practices and regulatory requirements, and applying this knowledge to improve processes, products, and services (Abbas & Sağsan, 2019; Khodadadi & Feizi, 2015). Additionally, GKM integrates environmental knowledge into core business operations, strategic planning, and decision-making processes, fostering a culture of continuous learning to stay updated with the latest environmental trends and technologies (Sahoo et al., 2022). The benefits of GKM include improved environmental performance, innovation in developing eco-friendly products and processes, compliance with environmental regulations, enhanced reputation, and competitive advantage. Studies by Chen and Chang (2013) and Wang et al. (2023) underscore its critical role in promoting sustainability across various industries.

An RBV of the firm argues that organizations having unique and valuable resources and capabilities are in a more advantageous position to gain a competitive advantage (Shehzad et al., 2024). Thus, GKM can be an important resource for organizations to exploit knowledge in radical GI to develop and introduce new green technologies and practices (Chen et al., 2014). These organizations possess strong GKM capabilities, which allows them to detect and realize the environmental opportunities for GI and to better respond to the changing environmental conditions and green market demands (Riaz et al., 2024). From the dynamic capabilities perspective, the organizational capabilities to sense, seize, and reconfigure resources are crucial to maintaining a competitive advantage in dynamic environments (Qu et al., 2022). All three of these capabilities require GKM. GKM assists organisations in sensing, seizing and reconfiguring resources and capabilities to adapt to changing environmental conditions and market demands by developing and implementing new green technologies (Sahoo et al., 2022; Shehzad et al., 2023). Several studies provide empirical evidence for the mediating role of GKM in the relationship between OR and radical GI (Ghorbani, 2023). Abbas and Khan (2023) have shown a positive relationship between the level of GI implemented and OR measured in terms of factors such as the availability of resources, technological capabilities, and supportive organizational culture. Moreover, the study has shown a positive relationship between the GKM processes (creating, sharing and utilizing knowledge) and the level of GI (Zairbani & J. P), 2024). Organisations with strong GKM capabilities can better transform their OR into successful radical green initiatives (Riaz et al., 2024). For instance, knowledge-sharing mechanisms have been shown to help organizations develop and implement radical GIs, given their ability to stimulate the sharing of knowledge and expertise between various departments and functions that need to collaborate to gain the organizational benefit of the innovation.

Overall, GKM strengthens organisations' innovation capabilities and addresses environmental concerns, leading to significant improvements in GI. Based on these arguments, we proposed the following hypotheses:

Hypothesis 2a. GKM mediates the relationship between OR and radical GI.

Hypothesis 2b. GKM mediates the relationship between OR and incremental GI.

2.4. The moderating effect of environmental organizational culture

Culture is a shared system of beliefs, attitudes, and values that shapes behaviours within an organisation. Environmental organizational culture refers to the values, beliefs, symbols, and assumptions that shape a firm's green management styles and processes (Roscoe et al., 2019; Wang et al., 2020). It was developed to align with external environmental demands and internal organizational activities over the long term (Shao, 2019; White et al., 2003). Embedded in a firm's operational philosophy and conduct, it critically influences employees' values, beliefs, behaviours, thinking patterns, habits, and styles (Chang & Lu, 2009; Dai et al., 2018). An environmental organizational culture within firms can enhance the impact of green learning orientation on green knowledge acquisition. De Long and Fahey (2000) argued that an effective organizational culture is essential for long-term survival and success, facilitating knowledge acquisition and sharing. Schneider (2015) suggested that organizational culture creates a conducive environment for learning, acquiring, and applying knowledge. Therefore, firms with a strong environmental organizational culture are better positioned to seize opportunities from the external environment and access more green knowledge resources related to products and markets. Consequently, the stronger the environmental organizational culture, the more significant the effect of green learning orientation on green knowledge acquisition.

Moreover, EOC may significantly influence the relationship between GKM and GI. Shahzad et al. (2021) stated that organizational knowledge about sustainable actions maximizes GI by enhancing the capacity to reduce energy and resource waste, increase recycling, and improve pollution control. Gürlek and Tuna (2018) identified green culture as a driving force for GI in the hotel industry. EOC includes firms' intuitions, beliefs, and expectations regarding environmental protection and operational objectives (Khazanchi et al., 2007). This is reflected in firms' attitudes, behaviours, and values (Dubey et al., 2019). As a resource, organisational culture can help firms innovate (De Long & Fahey, 2000). Zhu et al. (2013) proposed that EOC affects competitive advantage through GI. Gopalakrishnan and Zhang (2017) highlighted the moderating role of organizational culture in innovation. Thus, firms with strong EOC are likely to explore green knowledge related to products, customers, markets, and the environment, and integrate it with existing knowledge to enhance radical and incremental GI. This study argues that EOC can enhance the effectiveness of GI when GKM is in place by raising employees' sustainability concerns (Abbas & Khan, 2022). When an organisation leans towards implementing environmental knowledge, EOC will further encourage employees to contribute to GI. Green culture is a boundary condition between GKM and organizational green creation that moderates their relationship. Thus, we propose the following hypotheses:

Hypotheses 3a. The positive effect of GKM on radical GI becomes more positive when EOC is stronger.

Hypotheses 3b. The positive effect of GKM on incremental GI becomes more positive when EOC is stronger.

2.5. Moderated mediating effects

In the above discussion, it is assumed that GKM mediates the relationship between OR and both radical and incremental GIs. This suggests that when an organisation is prepared to adopt eco-friendly practices, managing green knowledge can significantly enhance its innovative capabilities. Additionally, EOC can strengthen the links between GKM and both types of GIs (radical and incremental). Studies have shown that GKM is a significant predictor of organizational GI capabilities and that its effectiveness is amplified by a strong green culture (Abbas & Khan, 2022). When EOC is high, OR is more likely to positively affect both radical and incremental GIs through GKM. This is because a supportive organizational culture enhances the absorption and utilisation of green knowledge, leading to more robust innovation outcomes (Wang et al., 2020). Furthermore, research indicates that green entrepreneurial orientation coupled with supply chain learning can further enhance both radical and incremental innovations. This relationship is moderated by EOC level, which strengthens the mediating role of GKM in the innovation process. Therefore, when EOC is high, the mediating effects of GKM on OR and its impact on radical and incremental GIs are stronger. This underscores the importance of fostering an environmentally conscious organizational culture to maximise the benefits of GKM in driving sustainable innovations. Thus, the following hypothesis is proposed:

H4a. GKM has a stronger mediating effect on OR and radical GI when EOC is high.

H4a. GKM has a stronger mediating effect on OR and incremental GI when EOC is high.

3. Methodology

3.1. Research Design and Procedures

This study uses a deductive approach to test the hypotheses based on the existing theory (Bryman, 2007). It examines how OR (innovation capability and environmental concern) impacts GI both radically and incrementally. Additionally, it proposes GKM as a mediator and EOC as a moderator of these relationships.

As per criteria outlined by UAE Cabinet Resolution No. 22 of 2016, this study focuses on SMEs in the Manufacturing sector of UAE following (Singh et al., 2022). The country of choice for the study of GI is the UAE, with its high–income emerging economy attainment and advancements, which provides a rich environment for investigation. Manufacturing firms have significant social and ecological impacts, with both high resource consumption and environmental footprints (Abbas & Khan, 2022; Shehzad et al., 2023), hence, this study targets manufacturing firms.

The sample includes SMEs as defined by the UAE Cabinet Resolution: It focused on small enterprises with 10 to 100 employees and annual revenues of 50 million AED and medium enterprises with 101 to 250 employees and annual revenues of 250 million AED (Singh et al., 2022). Using the Yellow Pages search engine (https://www.yellowpages.ae/) from January to May 2023, we randomly sampled 273 manufacturing enterprises. These firms' specializations range from food production to machinery fabrication to textile and plastic production; they represent different manufacturing industry sectors. From a pool of 273 selected enterprises, 159 firms agreed to participate, while others were uninterested or declined because of internal policies.

For accurate data and to minimize socially desirable responses, respondents were told that their data would be kept anonymous and that they would be used only for academic purposes. In addition, several validation checks were included in the questionnaire to detect inconsistencies or too-idealized answers. Because managers have strategic decision-making authority and access to critical organizational information (Shehzad et al., 2023), a non-probabilistic convenience sampling approach was used for their selection.

The methodology adopted from the previous research is that this study disseminated a standardized questionnaire to participants at the top, middle, and lower management levels

(Ooi, 2014). In total, 639 questionnaires were distributed, and 387 were returned. After excluding 47 incomplete submissions, 340 valid responses remained, with a response rate of 53.2%. This means that the selected respondents' engagement level is very high. The data collection process included online surveys and self-administration techniques, with every effort to accommodate respondents' schedules and preferences to encourage truthful and thoughtful participation. Table 1 presents an in-depth account of the demographic characteristics of the respondents.

To assess the potential impact of non-response bias, the respondents were categorized into two groups based on the order of questionnaire submission: Early respondents and late respondents. Thus, a t-test was run to compare firm age, firm size, and type of ownership, following the recommendations of Swink and Nair (2007) to compare the first 25 respondents with the last 25. Analysis showed no significant difference between the groups, indicating that non-response bias is not a significant problem in this study.

3.2. Measurements

The research utilised items sourced from prior investigations to ensure the dependability and validity of the measurement tools. All items were evaluated using a five-point Likert scale ranging from "1" (strongly disagree) to "5" (strongly agree).

This study assessed key variables using constructs derived from previous research. Environmental Concern was evaluated using three items adapted from (Zhang et al., 2020), focusing on cultivating a green culture, attention to environmental protection, and incorporating sustainable development**.** Innovation Capability was measured using three items adapted from (Zhang et al., 2020), emphasising creative thinking, managerial support, and resource availability for GI. GKM was assessed using five items from Sahoo et al. (2022) and Shehzad et al. (2023), covering access to environmentally friendly practices, knowledge of competitors' practices, best practice exchange, green information initiatives, and applying knowledge to new challenges. Radical and incremental GI were measured using six items each from the studies of (Chen et al., 2014) and Lennerts et al. (2020). Radial GI focuses on new GIs, investing in modern technologies, radical organizational changes, novel green experiences, new environmental ideas, and green distribution channels. Incremental GI emphasises minor changes in green products, continuous improvements, employee ideas, regular improvement meetings, production line enhancements, and efficient waste recycling. Finally, EOC was measured using six items from Dubey et al. (2017) and Wang et al. (2020), highlighting environmental protection knowledge, cooperation, agreement, change, impact, and vision. Each construct was measured using a structured questionnaire to ensure comprehensive and robust data collection. Moreover, following the prior studies of Abbas and Sağsan (2019) and Shehzad et al. (2023), firm type, ownership form, firm size, and firm age were assessed as contextual factors.

A pretest was performed in light of Hinkin's (1998) suggestions to verify the reliability and validity of the chosen items relative to the UAE context. Questionnaires were filled out by 40 manufacturing firm management-level participants. The pilot study of internal consistencies indicated reliability coefficients of 0.728 to 0.914, thus meeting the standard reliability coefficient of 0.70, as suggested by Hair et al. (2016). Therefore, after completing a pilot survey, the researcher conducted a broader survey for the main study.

3.3. Common method bias

The analysis of common method bias was performed using Harman's single-factor test. The test results showed that the first factor was responsible for 25.206% of the total variance, which is less than the conventional threshold of 50% for substantial common method bias (Podsakoff et al., 2003). It is worth noting that PCA identified multiple factors, with the first six components collectively accounting for 71.781% of the total variance. However, the first component alone contributed only 25.206%, suggesting that the variance was dispersed across various factors rather than being primarily attributed to a single factor. These findings suggest that common method bias is not a significant issue in this study, as no single factor dominates the majority of the variance. This reinforces the reliability of the measurement scales and the soundness of the data collection process.

Table 1. Demographic profile of respondents

Characteristics		Frequency	Percent
Firm type			
	Chemical and Petroleum	50	13.5
	Fertilizer	42	11.3
	Cement	58	15.6
	Textile	57	15.4
	Auto part manufacturing	55	14.8
	Sports goods	54	14.6
	Leather	44	11.9
	Others	11	3.0
Ownership			
	Non-State Owned	172	46.4
	State owned	199	53.6
Organization size (by numbers of employees)			
	<100	86	23.2
	100-200	70	18.9
	201-500	75	20.2
	501-1000	59	15.9
	>1000	81	21.8
Organization age			
	< 5 Years	64	17.3
	6-10 Years	76	20.5
	11-20Years	89	24.0
	21-40years	70	18.9
	>40Years	72	19.4

4. Data analysis

This study applied the Partial Least Squares (PLS) approach with structural equation modelling (SEM) to examine structural relationships in the theoretical model. PLS-SEM, which is known for its predictive capabilities, has been widely adopted in recent studies (Rehman et al., 2021; Shehzad et al., 2023). Guidelines from Cepeda-Carrion et al. (2019) validate this method, which excels in analysing complex relationships among latent variables in large models (Hair et al., 2016) and is ideal for research focused on prediction and variance explanation (Hair et al., 2014) and early stage theoretical development (Chin, 2010). This method is suitable for exploring new phenomena (Richter et al., 2016). SmartPLS 4 was used for PLS-SEM analysis, and SPSS version 25 was used for further analysis. Process macro Model 14 was employed to investigate the moderated mediation relationship, providing insights into the moderating effects on the mediation pathways.

4.1. Measurement model

In this study, we employed a two-step measurement model approach using PLS-SEM and SmartPLS. This approach effectively assesses both first- and second-order constructs within complex models. The first step evaluated the measurement model's reliability and validity, followed by the assessment of the structural model in the second step.

Table 2 displays the measurement model results, which include the first-order constructs of environmental concerns, innovation capability, GKM, radical GI, incremental GI, and environmental organisational culture, as well as the second-order construct of organisational readiness. The reliability and validity of these constructs were assessed using item loadings, VIF, Cronbach's alpha (Cα), Dijkstra–Henseler's rho (rho_a), composite reliability (rho_c), and AVE.

The item loadings ranged from 0.646 to 0.969, indicating acceptable convergent validity. (Hair et al., 2014). VIF values ranged from 1.391 to 2.960, well below the threshold of 3.3, indicating no multicollinearity concerns (O'brien, 2007). Reliability was assessed using Cα (0.733–0.983), rho_a (0.737–1.028), and rho_c (0.838–0.985), all exceeding the recommended threshold of 0.7, indicating high reliability (Nunnally & Bernstein, 1994). AVE values ranged from 0.509 to 0.918, demonstrating sufficient convergent validity, as values above 0.5 suggest that the construct explains more than half of the variance of its indicators (Fornell & Larcker, 1981).

The discriminant validity of the constructs was assessed using the HTMT ratio of correlations. Tables 3 and 4 present the HTMT ratios for the first- and second-order constructs. According to the HTMT criterion, values below 0.85 indicate adequate discriminant validity. (Henseler et al., 2015). Table 3 shows the HTMT ratios for the first-order constructs: environmental concerns, organisational culture, GKM, innovation capability, incremental GI, and radical GI. All HTMT values are well below the 0.85 threshold, demonstrating good discriminant validity among the constructs. Table 4 presents the HTMT ratios for the second-order constructs of environmental, organisational culture, GKM, incremental GI, OR, and radical GI. Again, all HTMT values were below 0.85, indicating strong discriminant validity.

4.2. Predictive relevance

Table 5 summarises the predictive relevance of the constructs examined using PLS-SEM, detailing the coefficient of determination (R^2 and adjusted R^2) and predictive relevance (Q^2) values. For the GKM construct, R^2 was 0.327 and adjusted R^2 was 0.325, with a Q^2 value of 0.161. The IGI construct had an R^2 of 0.311 and an adjusted R^2 of 0.303, with a Q^2 value of

0.175. The RGI construct displayed an R^2 of 0.324 and an adjusted R^2 of 0.316, with a Q^2 value of 0.230. According to Chin (1998), R^2 values of 0.19, 0.33, and 0.67 can be considered weak, moderate, and substantial, respectively. Furthermore, Q^2 values greater than 0 indicate predictive relevance, with values above 0.02, 0.15, and 0.35 considered small, medium, and large predictive relevance, respectively (Hair et al., 2017). The results indicate that all constructs exhibit moderate R^2 and small-to-medium Q^2 values, with RGI demonstrating the highest predictive relevance.

Additionally, several fit indices were used to assess the overall fit of the proposed structural model of the study. The value of the standardised root mean square residual (SRMR) was 0.0625, which means that the model is acceptable since it is below 0.08 (Hair et al., 2017; Henseler et al., 2016). Moreover, the estimate of the d_ULS was 0.902, which also indicated a good fit for the model. The normed fit index (NFI) was 0.844, just a shade beneath the ideal value, though values closer to 0.9 are better (Bentler & Bonett, 1980). Last, the chi-square value was 949.126, which gives us additional information about fit indices but again should be viewed with caution, especially in large sample sizes, because it is sensitive to sample size. (Hu & Bentler, 1999). Altogether, the given indices indicate that the proposed structural model is correctly specified and represents a reasonable fit to the data.

Table 2. Measurement model results

First order constructs	Second order constructs	Items Loading (Range)	VIF (Ranges)	Cα	Rho_a	Rho_c	AVE
Environmental concerns		0.821 - 0.901	1.801 - 2.416	0.817	0.819	0.892	0.733
Innovation capability		0.780 - 0.889	1.751 - 1.994	0.778	0.786	0.871	0.693
	Organizational readiness	0.876 - 0.900	1.502 - 1.607	0.733	0.737	0.882	0.789
Greem knowledge management		0.646 - 0.791	1.391 - 1.613	0.759	0.769	0.838	0.509
Radical green innovation		0.823 - 0.886	1.930 - 2.960	0.880	0.884	0.917	0.735
Incremental green innovation		0.748 - 0.826	1.420 - 2.041	0.799	0.821	0.867	0.619
Environmental organizational culture		0.944 - 0.969	1.876 - 2.235	0.983	1.028	0.985	0.918

Note: VIF: Variance inflation factor rho_a: Dijstra-Henseler's rho; AVE: average variance extracted; Cα, Cronbach's alpha; rho_c: composite reliability

Table 3. Heterotrait-monotrait ratio (for first order constructs)

	EC	EOC	GKM	IC	IGI	RGI
EC						
EOC	0.025					
GKM	0.562	0.050				
IC	0.723	0.019	0.720			
IGI	0.529	0.029	0.571	0.569		
RGI	0.537	0.032	0.533	0.567	0.709	

Note: EC=Environmental concerns; IC=Innovation capability; GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation; EOC=Environmental organizational culture

Table 4. Heterotrait-monotrait ratio (for second order constructs)

	EOC	GKM	IGI	OR	RGI
EOC					
GKM	0.050				
IGI	0.029	0.571			
OR	0.024	0.753	0.642		
RGI	0.032	0.533	0.709	0.646	

Note: OR=Organizational readiness; GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation; EOC=Environmental organizational culture

4.3. Hypotheses results

In this study, following the guidelines of Hair et al. (2019), we used bootstrapping with 5000 iterations to evaluate the hypotheses. The results, summarised in Table 6, include path coefficients (β), standard deviations (STDEV), T-statistics, P values, F-square, confidence intervals (2.5% and 97.5%), and conclusions regarding support for each hypothesis.

First, the analysis reveals that most control effects (Firm type, Ownership, Organisation size, and Organisation age) on RGI and IGI are not statistically significant, as indicated by non-significant T statistics and P values (all $P > 0.05$). Therefore, these relationships were not supported.

Next, for direct effects, Hypothesis 1a is strongly supported. The path from OR to RGI had a significant positive effect ($\beta = 0.387$, $T = 5.608$, $P < 0.001$) with a substantial effect size (F-square = 0.149). The 95% confidence interval (0.255, 0.524) did not include zero. Similarly, the path from OR to IGI showed a significant positive effect ($\beta = 0.374$, $T = 6.953$, $P < 0.001$) with a substantial effect size (F-square = 0.136), and the 95% confidence interval (0.264, 0.476) did not include zero.

Moreover, for Hypothesis 2a, the mediation analysis revealed that GKM partially mediated the relationship between OR and RGI. The direct effect of OR on RGI was significant ($\beta = 0.387$, $T = 5.608$, $P < 0.001$), and the indirect effect through GKM was also significant ($\beta = 0.129$, $T = 3.016$, $P = 0.003$). The total effect of OR on RGI was significant ($\beta = 0.517$, $T = 10.827$, $P < 0.001$). The bias-corrected confidence interval (BCI) for the indirect effect did not include zero, confirming partial mediation (BCI-LL = 0.047, BCI-UL = 0.214). Similarly, for Hypothesis 2b, the relationship between OR and IGI was partially mediated by GKM. The direct effect of OR on IGI was significant ($\beta = 0.374$, $T = 6.953$, $P < 0.001$), and the indirect effect through GKM was significant ($\beta = 0.141$, $T = 3.897$, $P < 0.001$). The total effect of OR on IGI was significant ($\beta = 0.514$, $T = 13.042$, $P < 0.001$). The BCI for the indirect effect did not include zero, confirming partial mediation (BCI-LL = 0.078, BCI-UL = 0.218). These results indicate that GKM partially mediates the effects of OR on both RGI and IGI, highlighting the importance of GKM in leveraging organizational resources for growth.

Moreover, As shown in Table 7, H2a (OR -> GKM -> RGI) and H2b (OR -> GKM -> IGI) are significantly related to both direct and indirect effects, which are in the same direction (i.e. positive). Therefore, there was a complementary mediation between OR, GKM and both aspects of GI (RGI, IGI). The complementary mediation stresses that there may be an omitted mediator in the direct path (Zhao et al., 2010). Yet, it also indicates that the presence of GKM as a mediator in the proposed model of the study is plausible (Zhao et al., 2010). Thus, H2a and H2b hypotheses about the mediation of GKM were also supported.

For the moderating effects, Hypothesis 3a shows a significant positive interaction between EOC and GKM on RGI (β = 0.138, T = 2.173, P = 0.030), with a small effect size (F-square = 0.028). The 95% confidence interval (0.008, 0.251) did not include zero. However, the interaction effect on IGI was not supported (β = 0.062, T = 1.240, P = 0.215), with a minimal effect size (F-square = 0.006), and the 95% confidence interval (-0.040, 0.155) included zero.

Table 5. Predictive relevance

	Coefficient of determination		Predictive relevance		
	R-square	R-square adjusted	SSO	SSE	Q^2 (=1-SSE/SSO)
GKM	0.327	0.325	1700.000	1425.525	0.161
IGI	0.311	0.303	1360.000	1121.642	0.175
RGI	0.324	0.316	1360.000	1047.557	0.230

Note: GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation

Table 6. Hypotheses results

Hypotheses	Relationship	β	STDEV	T statistics	P values	F-square	2.5%	97.5%	Conclusion
Control effects									
+Ve	Firm type -> RGI	-0.008	0.013	-0.583	0.560		-0.034	0.018	Not Supported
+Ve	Ownership -> RGI	0.072	0.054	1.332	0.184		-0.034	0.178	Not Supported
+Ve	Firm size -> RGI	0.023	0.018	1.258	0.209		-0.013	0.059	Not Supported
+Ve	Firm age -> RGI	0.010	0.020	0.517	0.605		-0.029	0.049	Not Supported
+Ve	Firm type -> IGI	0.002	0.018	0.085	0.932		-0.033	0.036	Not Supported
+Ve	Ownership -> IGI	-0.040	0.071	-0.566	0.572		-0.181	0.100	Not Supported
+Ve	Firm size -> IGI	0.025	0.024	1.012	0.312		-0.023	0.072	Not Supported
+Ve	Organization age -> IGI	0.006	0.026	0.211	0.833		-0.046	0.057	Not Supported
Direct effects									
Hypothesis 1a	OR -> RGI	0.387	0.069	5.608	0.000	0.149	0.255	0.524	Supported
Hypothesis 1a	OR -> IGI	0.374	0.054	6.953	0.000	0.136	0.264	0.476	Supported
Moderating effects									
Hypothesis 3a	EOC x GKM -> RGI	0.138	0.063	2.173	0.030	0.028	0.008	0.251	Supported
Hypothesis 3b	EOC x GKM -> IGI	0.062	0.050	1.240	0.215	0.006	-0.040	0.155	Not Supported

Note: OR=Organizational readiness; GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation; EOC=Environmental organizational culture

The Johnson-Neyman (J-N) technique was used to identify regions of significance for the moderating effect of EOC on the relationship between GKM and RGI. This technique determines the specific values of the moderator (EOC), where the impact of the independent variable (GKM) on the dependent variable (RGI) transitions from non-significant to significant (Johnson & Neyman, 1936). The J-N plot (see Figure 2) shows the conditional effect of GKM on RGI at different levels of EOC. The point where the confidence interval (CI) lower limit crosses zero indicates the threshold at which the effect becomes statistically significant. The J-N plot reveals that the impact of GKM on RGI becomes statistically substantial when EOC is greater than 1.600. At this threshold (EOC = 1.495), the impact of GKM on RGI was β = 0.119, T = 2.230, P = 0.026, with a CI ranging from 0.014 to 0.224. As EOC increased, the effect size and significance level increased. For example, at EOC = 2.000, the effect is β = 0.155, T = 3.410, P = 0.001, with a CI of 0.066 to 0.244. These results indicate that EOC moderates the relationship between GKM and RGI, such that the positive effect of GKM on RGI is significant only when EOC is above 1.600. This highlights the importance of considering EOC as a moderating variable in understanding the conditional impact of GKM on RGI.

Table 7. Mediation results

		Direct effects		Indirect effects		Total effects		
	Relationships	β (p-values)	T Values	β (p-values)	T Values	β (p-values)	T Values	Conclusion
Hypothesis 2a	OR -> GKM -> RGI	0.387(0.000)	5.608	0.129(0.003)	3.016	0.517(0.000)	10.827	Partial mediation
	BCI-LL	0.255		0.047		0.424		
	BCI-UL	0.524		0.214		0.612		
Hypothesis 2b	OR -> GKM -> IGI	0.374(0.000)	6.953	0.141(0.000)	3.897	0.514(0.000)	13.042	Partial mediation
	BCI-LL	0.264		0.078		0.437		
	BCI-UL	0.476		0.218		0.592		

Note: OR=Organizational readiness; GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation; EOC=Environmental organizational culture

Table 8. Conditional effect of focal predictor (GKM) at values of the moderator

EOC	Effect	SE	t	p	LLCI-ULCI
1.000	0.065	0.067	0.963	0.336	[-0.067 - 0.197]
1.200	0.083	0.062	1.328	0.185	[-0.040 - 0.205]
1.400	0.101	0.058	1.747	0.082	[-0.013 - 0.214]
1.495	0.109	0.056	1.917	0.052	[0.000 - 0.219]
1.600	0.119	0.053	2.230	0.026	[0.014 - 0.224]
1.800	0.137	0.049	2.783	0.006	[0.040 - 0.234]
2.000	0.155	0.046	3.410	0.001	[0.066 - 0.244]
2.200	0.173	0.042	4.107	0.000	[0.090 - 0.256]
2.400	0.191	0.039	4.851	0.000	[0.114 - 0.269]
2.600	0.209	0.037	5.603	0.000	[0.136 - 0.283]
2.800	0.227	0.036	6.301	0.000	[0.156 - 0.298]
3.000	0.246	0.036	6.875	0.000	[0.175 - 0.316]
3.200	0.264	0.036	7.273	0.000	[0.192 - 0.335]
3.400	0.282	0.038	7.483	0.000	[0.208 - 0.356]
3.600	0.300	0.040	7.527	0.000	[0.221 - 0.378]
3.800	0.318	0.043	7.449	0.000	[0.234 - 0.402]
4.000	0.336	0.046	7.295	0.000	[0.245 - 0.427]
4.200	0.354	0.050	7.100	0.000	[0.256 - 0.452]
4.400	0.372	0.054	6.890	0.000	[0.266 - 0.478]
4.600	0.390	0.058	6.679	0.000	[0.275 - 0.505]
4.800	0.408	0.063	6.476	0.000	[0.284 - 0.532]
5.000	0.426	0.068	6.285	0.000	[0.293 - 0.560]

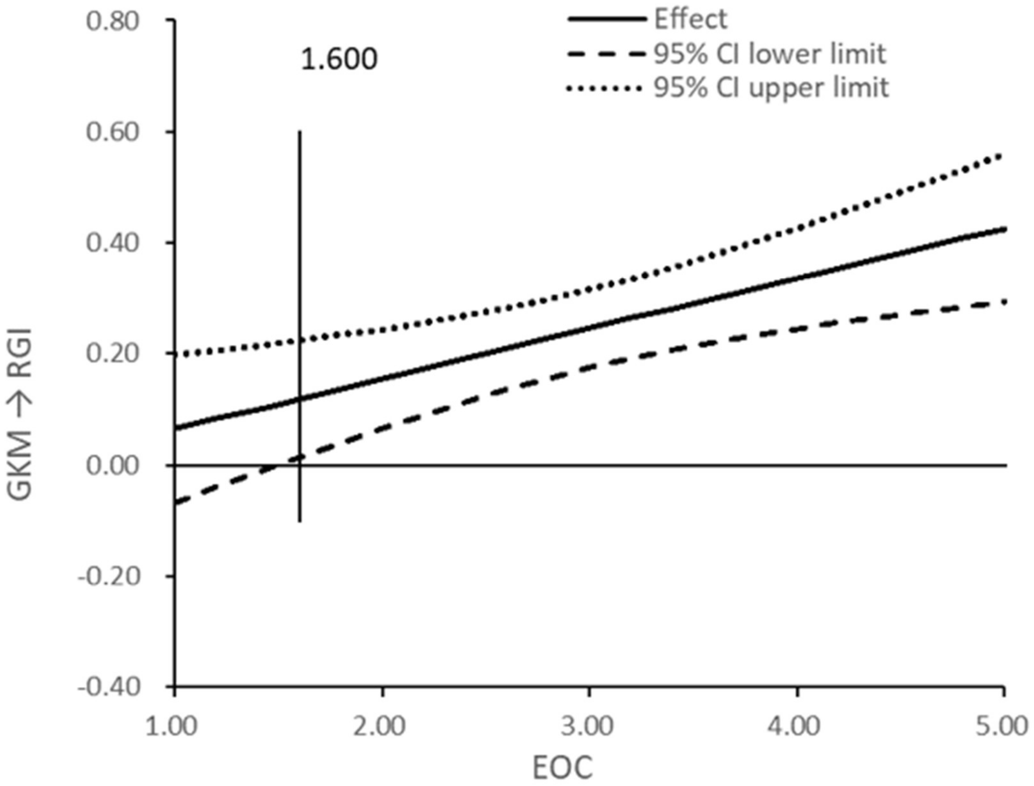

Figure. 2. Moderating Influences of EOC on the relationship between GKM and RGI with Johnson-Neyman point.

4.4. Moderated mediation analysis

Next, the index of moderated mediation is positive and statistically significant (b = 0.079, 95% CI [0.012, 0.148]), indicating that EOC moderates the indirect effect of OR on RGI through GKM. Table 5 shows the conditional indirect effects of OR on the RGI. At a low level of EOC, the indirect effect was positive but not statistically significant (b = 0.051, 95% CI [-0.050, 0.156]). At the mean EOC level, the indirect effect was positive and significant (b = 0.130; 95% CI [0.045–0.225]). At high EOC, the indirect effect was also positive and significant (b = 0.209, 95% CI [0.092, 0.339]). These results support the hypothesis and show that EOC moderates the positive path from OR through GKM to RGI; that is, higher levels of EOC strengthen the positive indirect effect of OR on RGI through GKM. Thus, H4a is supported.

Table 9. Moderated mediation results

	At different Level of moderator	Effect	BootSE	BootLLCI	BootULCI	T-values
Hypothesis 4a	OR → GKM → RGI					
	Low level of EOC	0.051	0.053	-0.050	0.156	0.968
	Mean level of EOC	0.130	0.046	0.045	0.225	2.803
	High level of EOC	0.209	0.063	0.092	0.339	3.306
	Index of moderated mediation	0.079	0.035	0.012	0.148	2.249
Hypothesis 4b	OR → GKM → IGI					
	Low level of EOC	0.105	0.044	0.023	0.197	2.367
	Mean level of EOC	0.141	0.038	0.075	0.222	3.696
	High level of EOC	0.097	0.051	0.086	0.283	1.903
	Index of moderated mediation	0.036	0.029	-0.021	0.093	1.245

Note: OR=Organizational readiness; GKM=Greem knowledge management; RGI=Radical green innovation; IGI=Incremental green innovation; EOC=Environmental organizational culture

The index of moderated mediation was positive but not statistically significant (b = 0.036, 95% CI [-0.021, 0.093]), indicating that the overall moderated mediation effect was insignificant. Table 5 shows the conditional indirect effects of OR on IGI through GKM at different levels of EOC. At a low level of EOC, the indirect impact was positive and statistically significant (b = 0.105, 95% CI [0.023, 0.197]), with a T-value of 2.367. At the mean level of EOC, the indirect effect was positive and statistically significant (b = 0.141, 95% CI [0.075, 0.222]), with a T-value of 3.696. At a high level of EOC, the indirect effect was positive but not statistically significant (b = 0.097, 95% CI [0.086, 0.283]), with a T-value of 1.903. These results indicate that while the overall moderated mediation effect is not significant, the indirect impacts of OR on IGI through GKM at low and mean levels of EOC are substantial. This suggests that EOC moderates the indirect effect of OR on IGI through GKM at these specific levels, although the overall moderated mediation effect is not significant. Therefore, H4b is not supported.

5. Discussion

This study examined the role of EOC in promoting GI, focusing on the impact of OR and GKM. Based on the RBV and dynamic capabilities theory, our findings comprehensively analyse the interactions between these factors in driving both radical and incremental GI. This section discusses the implications of our findings by examining the relationships between OR, GKM, and EOC.

The results revealed that the relationship between OR and green innovation was significant and supported the role of OR in facilitating radical and incremental GI. Consistent with results from previous studies by Zhang et al. (2020) and Ullah et al. (2024), this study concluded that an organization's preparedness (i.e., having necessary resources, supportive culture and capability development) could enhance its capability to initiate and implement sustainability initiatives. Results are specific that OR permits sampled firms to undertake top-level R&D, to foster collaborative efforts amongst functional teams and to motivate new, high-risk project-like initiatives that are critical to RGI. In parallel, OR helps IGI harvest existing knowledge, tweak standard operating procedures, and develop and sustain a continuous improvement mindset that yields cost-effective, environmentally responsible outcomes. Drawing on DCT, these improvements decrease resource usage and make the sampled firm more flexible in answering changing environmental regulations and market requirements. In line with the view of Tjahjadi et al. (2023), our findings imply that firms capitalizing on RGI and IGI through strong organizational readiness can achieve better competitive advantage and long-term sustainability.

The findings also revealed that GKM is a significant mediator between the relationship of OR with RGI and IGI, but the GKM mediating mechanisms may differ because GKM has a more robust partial mediating effect on the OR-IGI relationship than the OR-RGI relationship. Consistent with the findings of Shehzad et al. (2023) and Sahoo et al. (2022), this study's results identify GKM as a strategic lever for RGI of sampled firms to find and utilize new environmental knowledge that enhances risk-taking and boundary spanning, which are necessary for innovative breakthrough sustainability solutions. Given this, it builds on RBV and DCT as firms' ability to sense and seize disruptive eco-opportunities relies on superior knowledge-capturing processes and an enabling culture. On the contrary, for IGI, GKM helps make the best use of existing knowledge bases using continuous learning and collaboration to improve or refine current products and processes systematically (Idrees et al., 2023). This way, GKM enhances the sampled firm's capability to scan for eco-friendly incremental improvements and channel the collected tacit knowledge for effective implementation. One justification for the study findings could be that elaborating knowledge infrastructure is important for both forms of innovation, but the knowledge flows, and routines are different: intensive explorations for radical ventures versus iterative exploitation for incremental improvements.

The role of EOC as a moderator demonstrates mixed results, highlighting the intricate relationship between GKM and GI. The findings show that stronger EOC amplifies the positive effect of GKM on radical GI. This implies that when an organisation deeply embeds environmental values, the impact of GKM on radical innovation is intensified. A strong EOC creates a supportive environment for radical GI by fostering a culture of sustainability, encouraging innovative thinking, and providing the necessary resources and motivation to pursue groundbreaking innovation (Wang et al., 2020). Conversely, the results indicate that EOC does not significantly enhance the effect of GKM on incremental GI. This suggests that while a strong EOC is crucial for radical innovations, it may not have the same level of influence on incremental improvements. Incremental GI, which involves smaller, more gradual enhancements, may be more influenced by operational efficiencies, technical improvements, or market demands rather than organisational culture alone. These findings highlight the need for a nuanced approach to fostering GI, recognising that different types of innovation may require different cultural and managerial interventions.

The research also investigates conditional indirect effects and reveals that the mediating effect of GKM on the relationship between OR and radical GI is stronger when EOC is high. This highlights the synergistic impact of combining robust GKM practices with a strong environmental culture to drive innovation. When EOC is high, an organisation's commitment to ecological values reinforces the positive influence of GKM, resulting in more substantial and transformative innovations. However, the results indicate that EOC does not strengthen the mediating role of GKM in incremental GI. This could be due to the nature of incremental innovations, which may depend more on existing capabilities and less on cultural influence. Incremental GI often involves optimising current processes, technologies, and products, which may be driven more by technical expertise and efficiency improvements than by a strong environmental culture.

5.1. Theoretical contributions

This study makes significant theoretical contributions by integrating the RBV and dynamic capabilities theories to examine the interplay between OR, GKM, and EOC in driving GI. This study extends RBV by demonstrating how OR, as an internal resource, significantly influences both radical and incremental GI, emphasising the importance of readiness as a preparatory stage and a critical driver of innovation. Furthermore, it integrates dynamic capabilities theory by highlighting GKM as a mediating mechanism, showing how effective GKM practices enable firms to transform their readiness into tangible innovative outcomes.

This study contributes to the existing literature on OR in radical and incremental GI by adopting the lenses of RBV and DCT frameworks. It expands RBV by understanding OR as a complex, environmental awareness and innovation capability for radical and incremental innovations. It supports DCT by noting OR as a dynamic capability that can help firms solve environmental issues and coordinate resources for green innovation. By linking OR to radical and incremental GI, the study extended the prior work of Zhang et al. (2020) and (Ullah et al., 2024), highlight the significance of readiness strategies for sustaining transformational change goals and incremental advancements to enrich the theoretical understanding of the concept of OR in innovation sustainability.

This study adds to the knowledge management literature by providing evidence of how GKM mediates the relationship between OR and GI. This underlines GKM as an essential competence organisation must acquire to efficiently utilise their readiness. This adds to the theoretical context of dynamic capabilities by specifying the roles of GKM toward radical and incremental GI. Furthermore, by analysing the moderating effect of EOC, this paper enriches the literature on organisational culture and innovation. Therefore, By extending the work of Wang et al. (2020) and Abbas and Khan (2023) showed that although a robust EOC enhances the relationship between GKM and radical GI, it has a weaker direct association with incremental GI, highlighting the moderating effect of culture in distinct innovation types.

The distinction between radical and incremental GI offers a more nuanced understanding of the innovation process, showing that the drivers and enablers of radical innovation differ significantly from those of incremental innovation. This insight refines innovation models by acknowledging the pathways through which different types of innovation can be achieved. Finally, this study enhances the understanding of OR by directly linking it to GI, highlighting that OR, with its multifaceted nature, influences GI directly and indirectly. This underscores the importance of developing a comprehensive readiness strategy to support sustainable innovation.

5.2. Practical contributions

This study offers valuable insights for managers and organizations seeking to enhance their GI. The significant influence of OR on radical and incremental GI underscores the importance of developing readiness through strategic alignment, flexibility, and preparedness. To achieve this, organizations should invest in training programs, create adaptive strategies, and allocate resources to support innovation initiatives. Moreover, the mediating role of GKM emphasizes the need for systematic environmental knowledge management. By implementing robust GKM practices, such as knowledge-sharing platforms and cross-functional collaboration, firms can translate their readiness into tangible GI outcomes.

In addition, fostering strong EOC is crucial for radical innovation. To cultivate such a culture, organizations should prioritize sustainability and innovative thinking by embedding environmental goals into their corporate mission and providing incentives for sustainable practices. While the impact of EOC on incremental GI may be less pronounced, maintaining a strong environmental culture still contributes to a firm's overall innovative capacity. To achieve this, organizations should promote continuous improvement and innovation through environmental values and sustainability-focused initiatives.

From a policy perspective, encouraging OR for GI through incentives, grants, or subsidies can significantly impact sustainability. Policymakers should support effective knowledge management practices by facilitating knowledge-sharing networks, funding R&D initiatives, and promoting collaboration between industry, academia, and the government. Additionally, fostering a strong EOC at the national or regional level through environmental education, awareness, and corporate social responsibility initiatives can create an environment conducive to sustainability. These practical and policy measures can drive the transition towards a more sustainable and innovative future.

5.3. Limitations and Future Research Directions

While the current research has made important contributions, further exploration in certain areas is necessary to overcome the identified limitations and provide valuable insights for future studies. Although effective in statistical validation, the use of a quantitative approach may overlook the intricate, context-specific insights that qualitative methods could reveal. Future research could employ mixed-methods approaches, combining quantitative data with qualitative interviews or case studies, to better understand the mechanisms by which OR, GKM, and EOC influence GI. Additionally, the cross-sectional design of this study restricts its ability to infer causality and observe dynamic changes over time. Longitudinal research could provide valuable insights into how OR, GKM, and EOC evolve and interact, offering a more comprehensive view of their long-term impacts on GI. Furthermore, this study focused on a specific set of moderating and mediating variables. Future research could explore other potential moderators, such as market conditions, regulatory environments, and technological advancements, to provide a more nuanced understanding of the determinants of GI. Expanding the research across different industries and geographical regions would enhance the generalisability of the findings. Each sector and region may present unique challenges and opportunities for GI, influenced by varying levels of regulatory pressure, market demand, and cultural attitudes towards sustainability. Such comparative studies could provide broader insights into practices and policies that foster sustainable innovation. By addressing these limitations, future research can build on the findings of this study and offer more detailed and contextually relevant recommendations for practitioners and policymakers aiming to promote GI.

5.4. Conclusion

This study offers crucial insights into GI by examining the roles of OR, GKM, and EOC. The findings highlight that OR significantly influences both radical and incremental GI. Organisations should invest in preparedness and strategic alignment to foster innovation. GKM has emerged as a crucial mediator, translating readiness into innovative outcomes. EOC amplifies the impact of GKM on radical GI but has less impact on incremental GI. These results have valuable practical implications for managers and policymakers. Organisations should enhance their readiness, implement robust GKM practices, and cultivate a strong environmental culture. Policymakers can support these efforts by providing incentives and promoting environmental education and awareness. This study contributes to the theoretical framework of RBV and dynamic capabilities by elucidating the interconnected roles of OR, GKM, and EOC in driving GI. Future research should explore longitudinal effects and diverse industrial and geographical contexts.

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