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Article

The influence of green supply chain on green innovation performance: The intermediary role of knowledge management and organizational integration

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Abstract: In the context of a globalized economic environment, businesses are facing an increasing number of environmental challenges, prompting them not only to pursue economic benefits but also to focus on environmental protection and social responsibility. Green supply chain management (GSCM) and green innovation have become key strategies for enterprises aiming for sustainable development. This study explores the impact of green supply chain practices on green innovation performance, with a focus on how knowledge management and organizational integration serve as mediating variables in this relationship. Grounded in the resource-based view (RBV) and knowledge-based view (KBV) theories, this research employs surveys and in-depth interviews with companies across various industries, combined with the analysis of structural equation modeling, to reveal the complex relationship between GSCM practices, knowledge management capabilities, levels of organizational integration, and green innovation performance. The results show that GSCM practices significantly enhance corporate green innovation performance through effective knowledge management and organizational integration. These findings enrich the theories of GSCM and green innovation, providing practical guidance for enterprises on how to enhance green innovation performance through strengthening knowledge management and organizational integration. Finally, this study discusses its limitations and suggests possible directions for future research, such as exploring the differences in findings across different industry backgrounds and examining other potential mediating or moderating variables.

Keywords: green supply chain; green innovation performance; knowledge management; organizational integration; structural equation modeling

1. Introduction

1.1. Background

In today's globalized economic environment, businesses face increasing environmental challenges, including climate change, resource depletion, loss of biodiversity, and environmental pollution. These issues compel companies to not only pursue economic benefits but also focus on environmental protection and social responsibility. Public awareness of environmental issues is growing, and governments worldwide are tightening environmental policies, pushing businesses to re-examine their operational models and product life cycles to minimize negative environmental impacts (Elkington, 1997; Porter and Kramer, 2011). Green supply chain management (GSCM) and green innovation have emerged as key strategies for achieving sustainable development. GSCM integrates environmental thinking into supply chain management processes, including product design, raw material procurement, production processes, product delivery, and the recycling of end

products. Implementing GSCM allows companies to reduce environmental risks, waste, and energy consumption, thereby improving resource utilization and production efficiency, and enhancing their market competitiveness and brand image (Sarkis, 2012; Zhu et al., 2008).Green innovation, a crucial driver for sustainable corporate development, focuses on developing new products and technologies that reduce environmental burdens, increase energy efficiency, and promote sustainable development economically, socially, and environmentally. However, achieving efficient GSCM and green innovation presents significant challenges, requiring profound changes in internal management and external cooperation (Chen et al., 2006).

1.2. Research motivation

Although green supply chain and green innovation are recognized as key factors in promoting sustainable development, how to efficiently implement green supply chain management (GSCM) to enhance green innovation performance remains a complex and challenging issue. In particular, a deep and systematic understanding of the role mechanisms of knowledge management and organizational integration in this process is still lacking. Knowledge management, as a crucial strategic tool for promoting internal knowledge creation, sharing, application, and protection, significantly impacts green innovation. It involves not only the accumulation of technical knowledge and the enhancement of innovation capabilities but also the management of non-technical knowledge such as environmental policies, market trends, and consumer preferences. Furthermore, as another key element for the efficient operation of green supply chains, organizational integration covers coordination and cooperation within different departments of a company as well as with external supply chain partners. The effectiveness of organizational integration directly affects resource allocation optimization, smooth information flow, and synergy in innovation activities, thereby significantly impacting green innovation performance. In the context of globalized supply chains, the complexity of organizational integration is higher, requiring consideration of cross-cultural and cross-regional coordination and diverse environmental standards and regulations. Despite the recognized importance of knowledge management and organizational integration, how to effectively link green supply chain management and green innovation performance through these two mechanisms, as well as their specific roles and impact mechanisms, remain unclear in academic and practical fields. Moreover, with rising environmental standards and increasing consumer demand for green products, companies urgently need a deep understanding and mastery of these key factors to better implement green strategies and enhance their competitiveness in the green market. Therefore, this study aims to fill this research gap by exploring how knowledge management and organizational integration affect the relationship between green supply chain practices and green innovation, providing theoretical support and practical guidance for businesses to achieve green transformation. This not only has significant implications for deepening our understanding of the mechanisms of green supply chain management and green innovation but also has practical value in promoting businesses and society as a whole towards sustainable

development goals (Wong et al., 2020).

1.3. Research objectives and questions

Given the increasing severity of global environmental issues and the challenges they pose to sustainable business development, green supply chain management (GSCM) and green innovation have become indispensable components of corporate strategic planning. However, the transformation process from green supply chain management to green innovation performance involves dynamic interactions across multiple levels, where knowledge management and organizational integration act as two key internal mechanisms crucial for stimulating and facilitating this transformation. Thus, this study aims to delve into the pathways through which green supply chain management affects green innovation performance, and how knowledge management and organizational integration play mediating roles in this pathway. The purpose of this research is to provide theoretical and practical insights for companies to more effectively implement green strategies, foster green innovation, and ultimately achieve sustainable development goals. To achieve this research purpose, the study will focus on answering the following key research questions:

1) How do green supply chain practices affect green innovation performance?

This question aims to explore how various practices in green supply chain management (such as green procurement, green production, green logistics, etc.) individually or collectively influence a company's green innovation capabilities and performance, including product innovation, process innovation, and management innovation.

2) What mediating role do knowledge management and organizational integration play between green supply chain and green innovation performance?

This question seeks to deeply understand how knowledge management (including knowledge creation, sharing, utilization, and preservation) and organizational integration (horizontal and vertical integration) separately or jointly promote the positive relationship between green supply chain practices and green innovation performance, revealing their specific mechanisms and pathways.

3) How can companies enhance the positive impact of green supply chain on green innovation performance by improving knowledge management and organizational integration capabilities?

This question explores how companies should design and implement knowledge management strategies and organizational integration measures to maximize the promotive effect of green supply chain on green innovation performance. This includes identifying key knowledge management practices and organizational integration strategies, and how to effectively integrate these strategies into green supply chain management.

By addressing these questions, this study aims to provide new theoretical perspectives on how green supply chain management promotes green innovation through internal mechanisms, and practical strategies and suggestions for companies on how to effectively utilize these mechanisms to enhance green innovation performance. Furthermore, the study will also explore whether these impact

pathways and mechanisms vary across different industries and cultural backgrounds, and how to implement these strategies in a globalized supply chain environment to achieve cross-cultural and cross-regional green innovation cooperation (Aboelmaged and Hashem, 2019).

1.4. Research contributions

This study makes significant contributions to both theoretical and practical fields. Theoretically, it delves into the relationship between green supply chain management and green innovation performance, especially by revealing how knowledge management and organizational integration act as mediating variables in this process, thus providing an important supplement to the theoretical foundations of green supply chain management and green innovation. Additionally, the study offers practical guidance for businesses on how to implement effective green supply chain management strategies, optimize knowledge management, and strengthen organizational integration to enhance green innovation performance. These recommendations not only help companies improve their environmental performance and market competitiveness but also facilitate the implementation of sustainable development strategies. Lastly, the findings of this study also offer insights for policymakers, by emphasizing the role of green supply chain management in enhancing the environmental performance of companies and entire industries, prompting policymakers to promote and support green supply chain practices and green innovation, providing new strategies and pathways for sustainable economic development. In summary, this study not only enriches the theoretical research on green supply chains and green innovation but also provides practical insights and suggestions for businesses and policymakers, contributing to the development of a greener and more sustainable society.

2. Literature review

2.1. The concept and content of green supply chain

As the **Figure 1** shown, Green supply chain management (GSCM) involves integrating environmental considerations into supply chain management processes, including product design, raw material procurement, production, delivery, and recycling of end products. This integration aims to minimize environmental impacts and improve sustainability.

Conceptual framework of GSCM:

Green procurement: This stage focuses on selecting suppliers and raw materials with minimal environmental impact. It emphasizes reducing waste and improving resource efficiency from the beginning of the supply chain. Rao and Holt (2005) highlighted that green procurement is crucial for reducing environmental impact and enhancing resource efficiency.

Green production: This involves using environmentally friendly production technologies and processes to reduce waste, emissions, and energy consumption. Min and Kim (2012) noted that optimizing production processes can significantly lower a company’s environmental footprint.

Green logistics and distribution: This stage aims to reduce carbon emissions through optimized design and eco-friendly transportation methods. Sundarakani et al. (2010) stressed the importance of eco-friendly logistics in minimizing the overall carbon footprint.

Reverse logistics: Reverse logistics involves the recycling, reuse, and remanufacturing of products. Guide and Van Wassenhove (2012) emphasized that reverse logistics is crucial for achieving a closed-loop supply chain, contributing to overall supply chain sustainability.

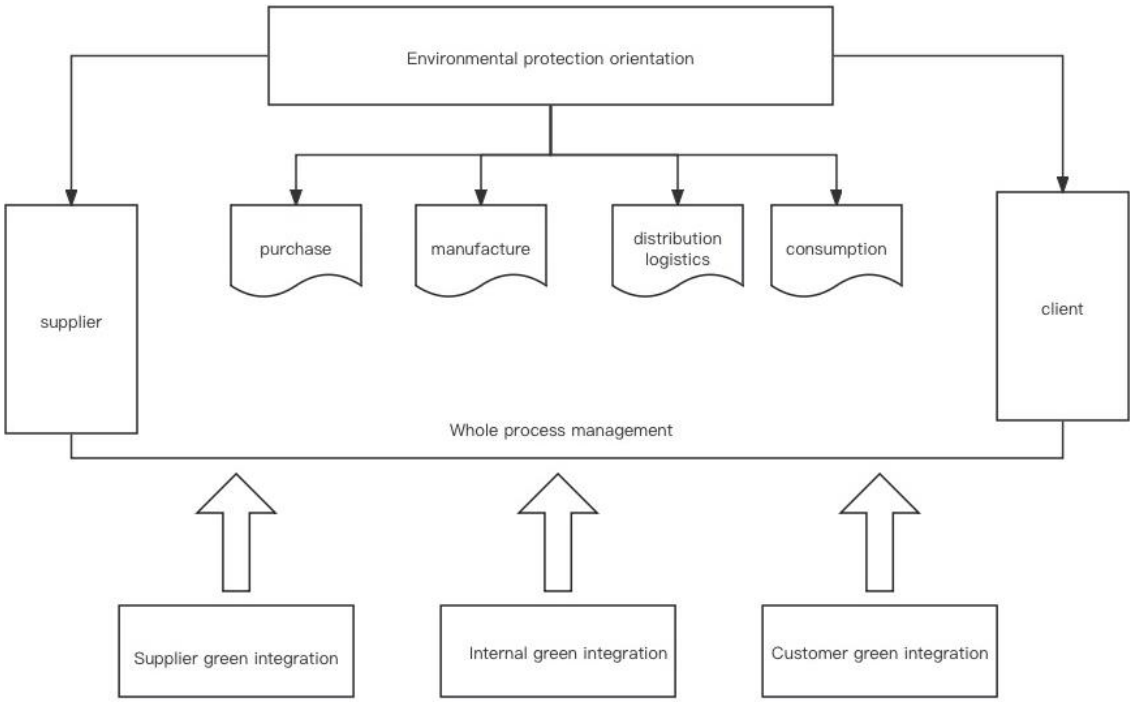

Figure 1. The content of green supply chain integration.

Srivastava (2007) emphasized the importance of integrating various segments of the green supply chain to reduce overall environmental impacts. Zhu et al. (2012) further examined the impact of these green supply chain practices on corporate performance, finding that integrating such practices not only enhances environmental performance but also strengthens market competitiveness.

In summary, GSCM is a critical strategy for companies aiming to mitigate their environmental impact while pursuing economic benefits. Future research should explore how innovative technologies and management strategies can strengthen green practices across the supply chain and consider how these elements can collaborate within the overall framework to achieve environmental, social, and economic sustainability.

2.2. Literature review on green innovation performance

Green innovation extends beyond the development of new products and services, encompassing innovative activities that improve production processes, management models, and business models to reduce environmental impact and enhance resource efficiency. The ecosystem structure of green innovation

emphasizes the interaction between internal elements such as technology R&D, market orientation, policy support, and organizational learning, which collectively shape a company's green innovation capability.

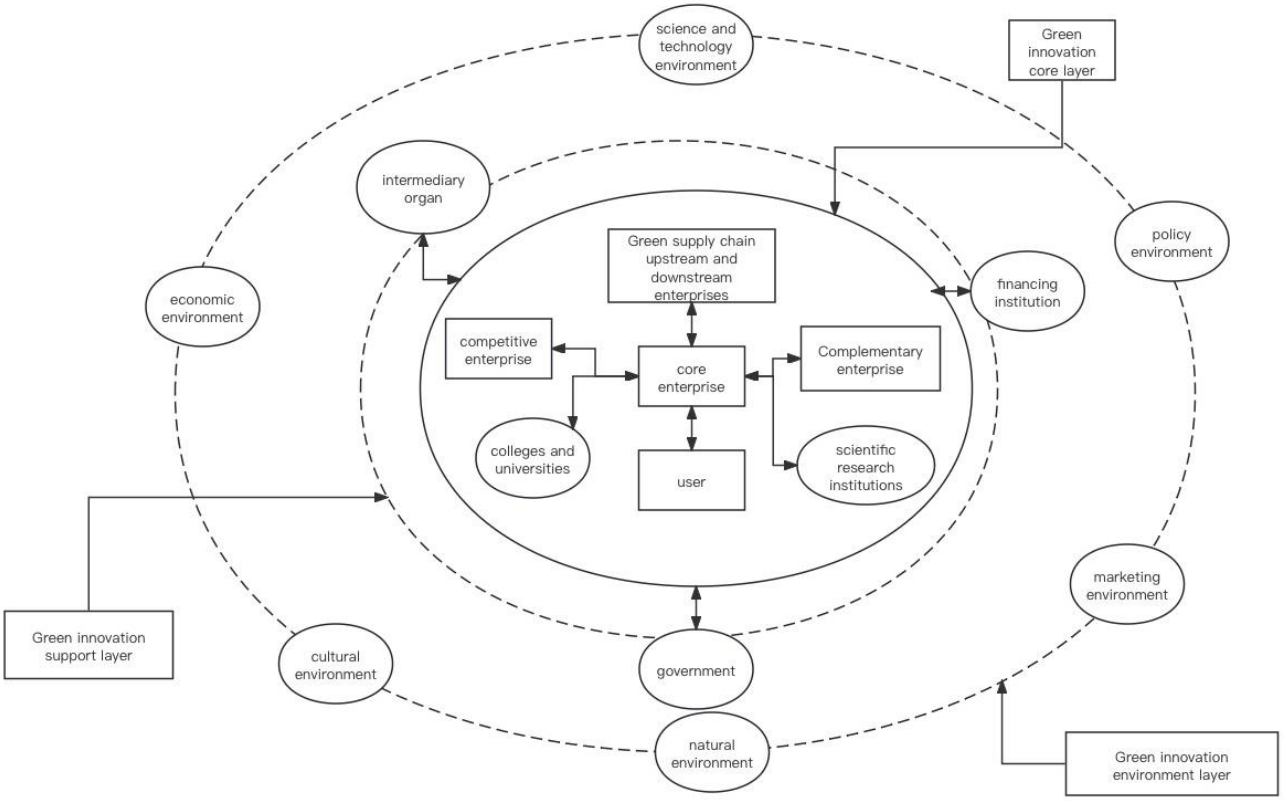

Figure 2. Green innovation ecosystem structure.

In **Figure 2**, the green innovation ecosystem structure highlights how various components, including green product innovation and green process innovation, work synergistically within an organization. Green product innovation focuses on the environmental attributes and functionality of products, while green process innovation aims to improve the environmental efficiency of production and operation processes. This classification shows how different types of innovation complement each other within the ecosystem, contributing to overall green innovation performance. As shown in **Figure 2**, the green innovation ecosystem is influenced by several internal and external factors. Internally, elements such as technology R&D, market orientation, and organizational learning play crucial roles. Externally, policy support and market demand drive the adoption and success of green innovations. Dangelico and Pujari (2010) highlighted the importance of organizational culture, strategic positioning, and internal resource allocation for the success of green innovation. Lin and Chen (2017) found that companies in the German manufacturing sector that implemented green product and process innovations outperformed those that did not in both environmental and economic performance.

2.3. Knowledge management and organizational integration: The dual engines driving green innovation

As illustrated in **Figure 3**, knowledge management provides a dynamic cyclical

process for green innovation, ranging from the creation and acquisition of knowledge to its sharing, storage, and application. This cycle ensures that organizations can continuously learn and progress in green innovation. Effective knowledge management accelerates the development of environmentally friendly technologies, optimizes product design, facilitates green transformation processes, and promotes the sustainable development of the entire supply chain. Companies implementing the knowledge creation model proposed by Nonaka and Takeuchi (1996) have facilitated the innovation and application of green solutions, enhancing the performance of green product and process innovations (Chen et al., 2018). Like knowledge management, organizational integration plays an indispensable role in green innovation. It requires tighter collaboration and information sharing among various departments and teams within a company, as well as with external supply chain partners. Just as the interaction of knowledge management elements in **Figure 3** ensures the smooth flow of knowledge, organizational integration fosters joint participation and collaboration on green innovation projects across departments and cross-functional teams. Pagell (2004) emphasized that such integration enhances a company's operational flexibility and market responsiveness, prerequisites for the success of green innovation. **Figure 3**, "Knowledge management and green innovation," not only elucidates the key elements of knowledge management but also indirectly supports the importance of organizational integration for green innovation. Future research could explore how innovative technologies and management strategies could further enhance these two factors' contribution to green innovation. Research should also consider the role differences of knowledge management and organizational integration across various industries and cultural contexts and how to adjust and optimize these mechanisms in a globalized and digitized environment. This would provide companies with more precise strategies to address environmental challenges and effectively promote the achievement of sustainable development goals. By referencing **Figure 3** and integrating the perspectives of knowledge management and organizational integration, we gain a more comprehensive understanding of their synergistic role in driving corporate green innovation. This provides a clear roadmap and methodological basis for building an efficient, innovative, and sustainable business ecosystem. This integrated approach emphasizes that the interaction between different knowledge management elements is key to the success of green innovation, while organizational integration provides the necessary structural and cultural support for such interaction. In practice, this means companies must foster an internal culture that encourages innovation, sharing, and collaboration, while also seeking knowledge and resources beyond organizational boundaries to accelerate the commercialization process of green solutions. The effectiveness of knowledge management and the degree of organizational integration jointly determine the vitality of the green innovation ecosystem. As revealed in **Figure 3**, "Knowledge management and green innovation," this ecosystem requires an internal closed loop that continuously evolves and develops through the creation and application of new knowledge. At the same time, this loop needs to connect with the external world, ensuring that new environmental ideas and technologies can be introduced and effectively utilized within the company. Therefore, **Figure 3** not only conceptualizes the internal

process of knowledge management but also highlights the importance of open innovation for the success of green innovation. Ultimately, through the systematic description of the elements of knowledge management in **Figure 3** and the analysis of the role of organizational integration, this paper offers a new perspective for the theory and practice of green innovation. Future research directions could include developing and testing new tools for knowledge management and organizational integration, assessing their effectiveness in different contexts, and exploring how they interact to promote green innovation. Furthermore, applying this theoretical framework to companies in different cultural and economic backgrounds would be a valuable exploration direction, aiding global businesses in understanding and implementing green innovation strategies to ultimately promote global sustainable development. By referencing **Figure 3**, we have gained a deeper understanding of the roles of knowledge management and organizational integration in green innovation, providing a solid theoretical foundation for further research and practice (Tu and Wu, 2021).

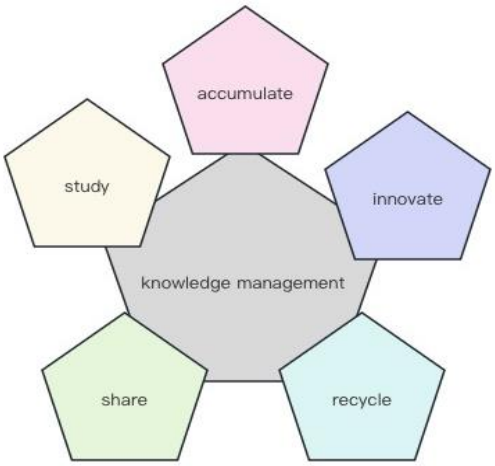

Figure 3. Knowledge management and green innovation.

3. Research methods

3.1. Research design

To thoroughly analyze the impact of green supply chain management (GSCM) on green innovation performance, this study constructs a comprehensive theoretical framework and employs a structural equation model (SEM) for empirical analysis. Referring to the theoretical model shown in **Figure 4**, this study aims to assess the direct and indirect effects among multiple variables. Green supply chain practices, serving as the independent variables, encompass several sub-dimensions: internal environmental management, eco-design, collaboration with customers, investment recovery, and green procurement. These practices are hypothesized to enhance a company's green innovation performance by influencing the extent of knowledge management and organizational integration.

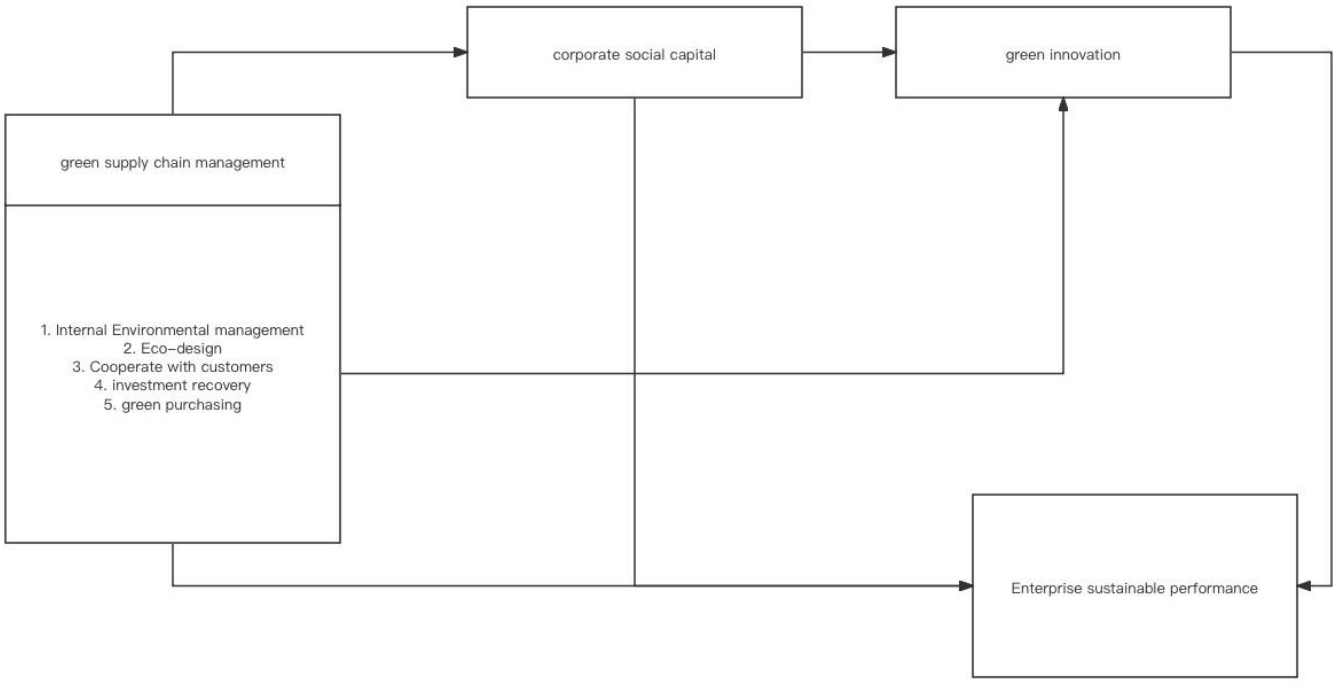

Figure 4. The theoretical model.

Knowledge management and organizational integration are considered mediating variables in the model. Knowledge management represents the company's systematic capability to manage knowledge resources, while organizational integration reflects the coordination among different departments and supply chain partners. Green innovation performance, the dependent variable, reflects the outcomes achieved by the company in market and environmental performance after adopting green innovation measures. Data for this study are collected through a survey of business managers with practical experience in the field of GSCM. The survey is designed to collect quantitative data on the aforementioned constructs, along with basic information about the companies, such as size, industry, and market type. After data collection, statistical software will be used for path analysis to examine the relationships between green supply chain practices and green innovation performance, as well as the mediating effects of knowledge management and organizational integration. To ensure the validity of the research findings, several external variables, such as the company's geographical location, market environment, policy and regulatory impacts, and industry characteristics, will be controlled. Moreover, a series of statistical methods will be employed to test the reliability and validity of the data, ensuring the robustness of the research model. Through the design and implementation of this study, the goal is to provide theoretical support for companies to adopt effective strategies in the field of GSCM and to encourage more companies to implement green innovations, thereby contributing to both corporate sustainable development and societal environmental protection (Jimenez et al., 2019).

3.2. Research methodology

This study adopts a mixed-method research strategy, based on the theoretical foundation of **Figure 5**, "The research framework of green supply chain integration,"

combining quantitative and qualitative methods to explore the integration issues of green supply chain management (GSCM). This integrated approach aims to deeply understand the complex relationships between supply chain performance, green supply chain integration, internal capabilities, external pressures, and green innovation and environmental performance through the multi-level analysis presented in **Figure 5**. The research framework emphasizes how internal capabilities and external pressures drive supply chain integration and how integration fosters green innovation and enhances environmental performance. For quantitative data, the study will design a comprehensive questionnaire including multiple variables related to GSCM integration, such as cross-functional collaboration in the supply chain, technology and information sharing, and organizational learning capabilities related to environmental protection. The questionnaire will use a five-point Likert scale to assess participants' agreement with each statement. Qualitative data collection will be conducted through in-depth interviews with corporate representatives having diverse GSCM backgrounds and experiences, discussing the specific challenges and strategies they face in integrating the supply chain.

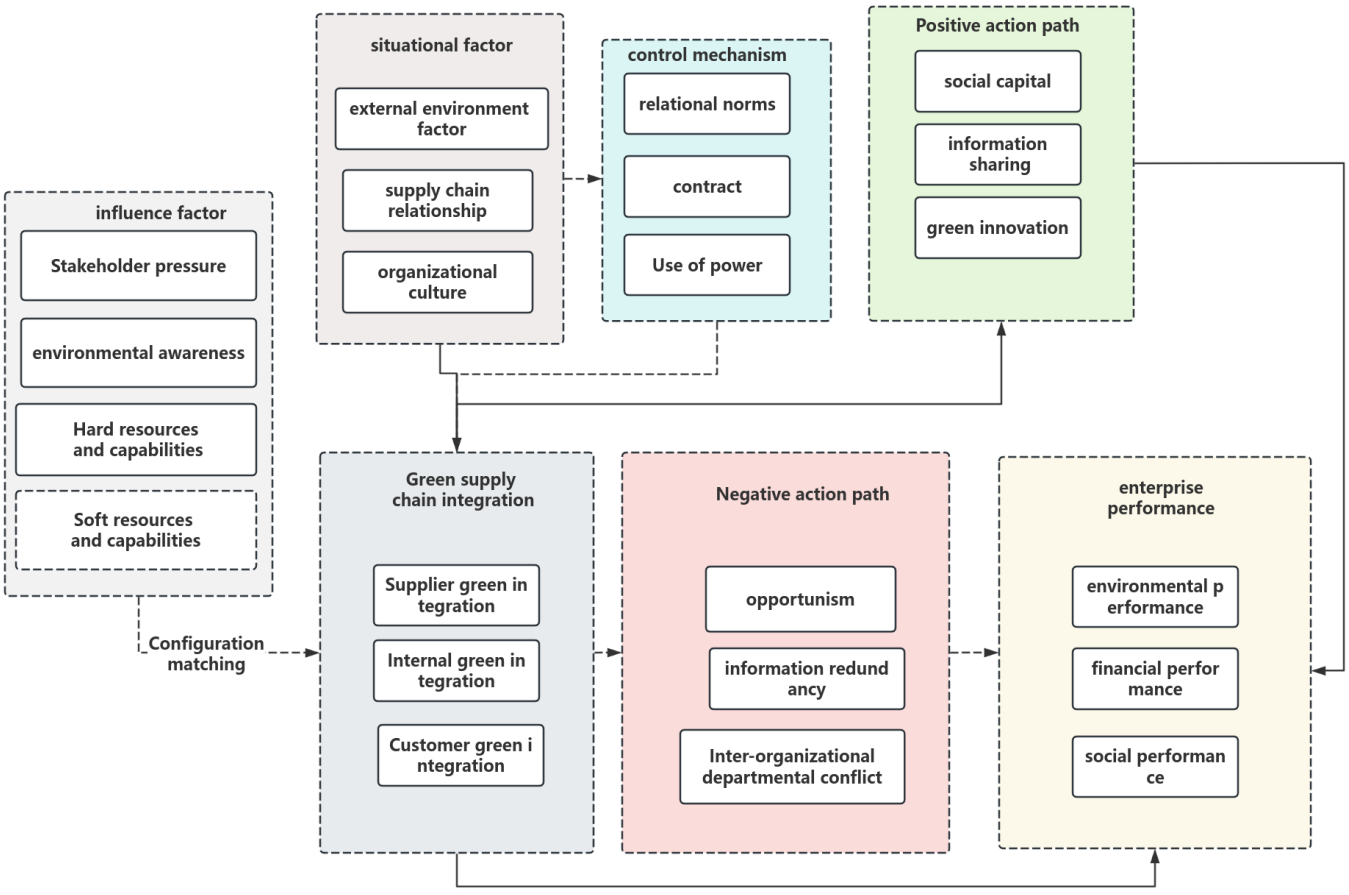

Figure 5. Research framework of green supply chain integration.

Quantitative data analysis will be conducted using structural equation modeling (SEM) to assess the strength and direction of relationships between constructs shown in **Figure 5**. This will allow the study to assess not just individual pathways but the overall fit of the model and the potential causal relationships between internal variables. For qualitative data, thematic analysis will be employed to reveal how

cross-departmental collaboration, knowledge sharing, organizational culture, and external environment impact the implementation and effectiveness of GSCM. By combining quantitative and qualitative results, the study will offer a panoramic view of the integration effects of GSCM. Quantitative analysis will reveal data trends and patterns, while qualitative analysis will provide underlying reasons and explanations, allowing for a deeper understanding of the actual challenges and strategies companies face during supply chain integration. Ultimately, by referencing **Figure 5** and integrating the research findings, the study will form comprehensive insights on how GSCM integration drives green innovation and improves environmental performance. Overall, this multi-dimensional analysis method will provide profound insights into how GSCM integration and green innovation interact to support sustainable development goals. This will assist managers in better understanding and applying GSCM strategies to achieve both environmental and economic win-win outcomes. Through the framework provided in **Figure 5**, this study will not only enrich the academic literature on green supply chain management and green innovation but also provide practical strategies and suggestions for the industry.

3.3. Sample selection and data sources

In exploring the correlation between green supply chain management (GSCM) and corporate green innovation and environmental performance, this study adopts a series of detailed criteria for sample selection to ensure broad applicability and high relevance of the research results. These criteria reflect a diversity of considerations, covering not only internal management characteristics of businesses but also the influence of external environments. The main dimensions of sample selection are detailed in **Table 1** below.

Table 1. Criteria for sample dimension selection.

Dimension	Criteria	Source
Industry representation	Industries with significant demands for environmental management and green innovation	Based on relevant literature
Company size	Mid to large-sized companies, to ensure sufficient resources for GSCM practices	Referencing industry average data
Geographical diversity	Companies from various geographic regions, to consider the impact of regional culture on GSCM practices	Based on market distribution studies
Market influence	Companies with a certain market share in their industry	Industry reports and market analysis

In terms of data collection and analysis, these criteria will be tested through a comprehensive questionnaire survey followed by semi-structured interviews. The questionnaire will include quantitative items to assess and quantify a company's GSCM practices and green innovation activities, while interviews will provide deeper insights, helping to explain questionnaire data and explore the motivations, challenges, and strategies behind GSCM practices. This mixed-method approach ensures that the research results are not only statistically valid but also compelling at a practical level.

To thoroughly assess the impact of green supply chain management (GSCM) on corporate green innovation and environmental performance, the study will take

meticulous steps to carefully select samples. Initially, existing business databases, which may contain detailed company directories published by national statistical offices, industry associations, chambers of commerce, or environmental protection organizations, will be utilized. These databases provide a broad pool of companies already showing a certain level of activity in green supply chain and sustainable development. Additionally, various industry reports, detailing companies that have made significant contributions to green innovation and environmental performance, will be consulted. This includes companies recognized within and outside their industry for introducing innovative environmental technologies, optimizing resource use, or achieving waste reduction. Such reports not only help identify companies that might meet the research criteria but also assist in assessing their influence in the industry and the maturity of their green supply chain practices (Tian et al., 2021).

After establishing a potential sample pool, the study will use random sampling methods to select participating companies. This process ensures the breadth and diversity of the sample, preventing selection bias from affecting the validity of the research findings. Random sampling not only increases the credibility of the study but also allows the results to have better generalizability, reflecting the actual situation of different types and sizes of companies.

During the random sampling process, care will be taken to ensure sample diversity in geographical distribution, company size, industry type, etc. This multi-dimensional consideration will help reveal potential differences in GSCM practices among different companies and how these differences affect their green innovation capabilities and environmental performance. Through this methodical approach, the study aims to establish a solid empirical basis to provide insights and evidence for developing effective green supply chain strategies (Yuan and Cao, 2022).

In this study, the selected sample companies will demonstrate a clear commitment to and practice of green supply chain management (GSCM), with active and systematic records in internal environmental management, eco-design, green procurement, etc. They not only show active performance in green product and process innovation, including but not limited to the research and application of new technologies, but also have achieved specific outcomes in driving green innovation. Additionally, these companies possess mature environmental performance evaluation systems, providing quantifiable data to assess and monitor their environmental performance, ensuring their efforts in continuously improving environmental impacts are measurable and trackable. These characteristics ensure that the sample companies are representative of GSCM implementation and that their experiences and data can provide profound and specific insights for the study.

Through the research design described above, this study will accurately capture the details of companies' practices in green supply chain management and assess how these practices translate into tangible green innovation outcomes and improvements in environmental performance. This approach will reveal how internal capabilities and external pressures affect GSCM practices and identify key drivers for achieving green innovation. The sample will include industry-leading companies and those with different market and environmental dynamics. Each company's selection will be based on its level of activity in GSCM practices and achievements in environmental performance. The sample characteristics will also reflect

geographic diversity, ensuring the research findings have broad applicability. The detailed plan for data collection will be as follows:

Questionnaire survey: The design will be based on effective questionnaires from existing literature, with appropriate modifications in consultation with industry experts to ensure relevance and accuracy. The questionnaire will be conducted online for broad participation and rapid data collection.

Interviews: Interviewees will be selected based on feedback from the questionnaire survey, especially those companies showing high levels of GSCM integration and green innovation performance in the questionnaire. Interviews will delve into specifics of internal management, innovation culture, and external collaboration (Habib et al., 2020).

Table 2 will be used to design the questionnaire and interview guide, ensuring all research questions and measurement items are closely tied to the study's objectives. Data analysis will employ various statistical methods to analyze questionnaire data, including descriptive statistics, factor analysis, and structural equation modeling. Qualitative data will be identified through thematic analysis to identify patterns and trends, enriching and deepening the findings from quantitative analysis. The study expects to provide a comprehensive report on GSCM practices and green innovation performance, offering empirical evidence for businesses to implement green supply chain management strategies and valuable guidance and insights for the industry. By combining questionnaire surveys and in-depth interviews, the research will be able to more comprehensively understand how companies effectively integrate GSCM and leverage it to enhance green innovation and environmental performance.

Table 2. Sample selection and measurement items.

Variable category	Measurement items	Measurement description	Reference source
Internal capabilities	IEM1-IEM4	Covering dimensions of green procurement, eco-design, internal environmental management capabilities	Defined based on existing research and practice
External pressures	GP1-GP3	Including market demand, regulatory pressure, competitors' activities' impact on company GSCM practices	Defined based on existing research and practice
Green innovation	IR1-IR3	Evaluating company practices and performance in product and process innovation	Latest research findings and case studies
Environmental performance	CC1-CC3	Measuring company performance in environmental protection and resource efficiency international	standards and industry guidelines

3.4. Variable definitions and data collection

This study focuses on exploring the relationship between green supply chain management (GSCM) and green innovation within manufacturing companies. To this end, we designed an electronic questionnaire and distributed it to manufacturing enterprises across different regions. After discarding returned questionnaires due to logical inconsistencies or incompleteness, we ultimately obtained 493 valid responses. These questionnaires come from a wide geographical area, collecting a total of 493 valid questionnaires to study the relationship between green supply chain management (GSCM) and corporate green innovation and environmental performance. The questionnaires are primarily distributed in China's economic

centers and manufacturing bases, including Guangdong, Zhejiang, Beijing, Jiangsu, Shanghai, and other areas, accounting for 22.9%, 19.0%, 18.1%, 16.2%, 11.4%, and 12.4% of the total valid samples respectively. The survey covered multiple manufacturing sectors, with significant representation from the automotive and furniture manufacturing industries, among others, to ensure the study's industry representativeness and comprehensiveness. In terms of company type, state-owned enterprises, partnerships, collective enterprises, sole proprietorships, and private companies all participated, accounting for 26.7%, 22.9%, 20%, 9%, and 21.4% of the valid samples respectively. By company size, enterprises of various sizes participated in this study. Specifically, companies with 50–100 employees accounted for 20.5%, 100–500 employees for 27.1%, 500–1000 employees for 25.7%, 1000–2000 employees for 13.3%, and over 2000 employees also for 13.3%. Such a distribution of sizes helps reveal the characteristics and challenges of GSCM practices in enterprises of different scales. The specific information of the questionnaire respondents (**Table 3**) includes diverse data such as gender, position, professional experience, age group, and education level, providing a deep understanding of the characteristics of personnel in the GSCM practice and green innovation field, thus ensuring the comprehensiveness and multi-perspective view of data collection.

Table 3. Information on questionnaire respondents.

Gender	Position	Professional experience	Age group	Education level
Male	Middle management	5–10 years	30–39	Bachelor's degree
Female	Junior staff	3–5 years	40–49	Master's degree
...	...	...	...	...

This comprehensive data collection work ensures a solid foundation for quantitative analysis and qualitative understanding in the study, simultaneously providing a rich and detailed information base for subsequent research analysis. With these collected data, the study can explore and evaluate the application of GSCM in different types of enterprises, sizes, and regions, and how these factors collectively impact the company's green innovation and environmental performance. The variables in this study are defined as:

Independent variables: Various aspects of GSCM practices, such as internal environmental management, eco-design, and green procurement.

Dependent variables: Corporate green innovation activities, like new technology development, and environmental performance, such as energy saving and emission reduction results (Effendi et al., 2021).

Mediating variables: Internal environmental management capability and the degree of supply chain integration, evaluating how they affect the relationship between GSCM practices and green innovation and environmental performance.

The scientific methodology adopted and the meticulous sample selection strategy provide a solid foundation for the study, ensuring systematic and accurate data collection and analysis. By employing a mixed research method, this study aims to capture differences from the micro to the macro level, thereby comprehensively

revealing the impact of GSCM practices on corporate sustainable development.

3.5. Measurement of indicators

Green supply chain management (GSCM) practices: GSCM practices are measured using a multi-dimensional scale that includes the following sub-dimensions: Internal environmental management: This is measured using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) with items such as "Our company has a dedicated environmental management team" and "Our company conducts regular environmental audits." Eco-design: This dimension is measured with items like "Our company incorporates environmental considerations into product design" and "Our company uses eco-friendly materials in product development," also using a 5-point Likert scale. Green procurement: Measured using items such as "Our company prioritizes suppliers with strong environmental performance" and "Our company includes environmental criteria in supplier selection," on a 5-point Likert scale. Collaboration with customers: This dimension includes items like "Our company collaborates with customers to develop greener products" and "Our company receives customer feedback on environmental performance," measured on a 5-point Likert scale. Investment recovery: Measured using items such as "Our company actively engages in recycling programs" and "Our company has systems in place for product take-back and recycling," on a 5-point Likert scale. Knowledge management: Knowledge management is assessed with a scale that evaluates the company's capabilities in creating, sharing, and utilizing knowledge. Key items include: Knowledge creation: Measured using items like "Our company invests in R&D for new environmental technologies" and "Our company encourages innovation in green practices," on a 5-point Likert scale. Knowledge sharing: Items such as "Our company has effective systems for sharing environmental knowledge" and "Our employees regularly share knowledge about green practices," measured on a 5-point Likert scale. Knowledge utilization: This includes items like "Our company effectively applies environmental knowledge in operations" and "Our company uses past experiences to improve current green practices," also on a 5-point Likert scale. Organizational integration: Organizational integration is measured by evaluating the degree of collaboration and coordination within the company and with external partners. Items include: Internal coordination: Measured with items like "Our departments work closely together on environmental initiatives" and "Our company has integrated environmental goals across all departments," on a 5-point Likert scale. External collaboration: Includes items such as "Our company collaborates with suppliers on environmental improvements" and "Our company participates in industry-wide environmental initiatives," measured on a 5-point Likert scale. Green innovation performance: Green innovation performance is assessed using indicators that reflect the outcomes of green innovation activities. Key items include: Product innovation: Measured with items like "Our company has developed new products that reduce environmental impact" and "Our green products have been well-received in the market," on a 5-point Likert scale. Process innovation: Items such as "Our company has implemented processes that improve environmental efficiency" and "Our company has reduced waste and emissions

through innovative processes," measured on a 5-point Likert scale. Market performance: Includes items like "Our green innovations have led to increased market share" and "Our company's green products have improved our brand image," also on a 5-point Likert scale.

4. Data analysis and results

4.1. Descriptive statistical analysis

In the descriptive statistical analysis phase of the study on the relationship between green supply chain management (GSCM), corporate green innovation, and environmental performance, we employed common statistical indicators such as means, standard deviations, frequency distributions, and percentages to summarize the characteristics of the sample data. Descriptive statistical analysis provided us with an overview of the sample data, which helps to understand the distribution and inherent trends of the variables.

First, for each quantized independent variable and dependent variable, we calculate their mean and standard deviation to evaluate the central tendency and degree of dispersion. The formula is as follows:

$$\text{Mean} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\text{Standard deviation} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

where x_i represents the value of each sample point and N represents the sample size. For categorical variables, such as company type and size, we used frequency distribution tables to show the percentage of samples in different categories.

Table 4. Frequency distribution of company size.

Company size	Frequency	Percentage (%)
50–100 employees	101	20.5
100–500 employees	133	27.1
500–1000 employees	126	25.7
1000–2000 employees	65	13.3
Over 2000 employees	65	13.3

As the **Table 4** shown, Specific to our sample data, the following descriptive statistical analysis was conducted:

Geographical distribution: Calculated the frequency percentage of companies in each region to display the geographical distribution characteristics of the samples.

Company type: Calculated the percentage of state-owned enterprises, partnerships, collective enterprises, sole proprietorships, and private companies in the sample.

Company size: For companies with 50–100, 100–500, 500–1000, 1000–2000, and over 2000 employees, calculated the frequency and percentage within each size segment.

GSCM practices: Calculated the mean and standard deviation for GSCM

practice variables, such as internal environmental management, eco-design, and green procurement.

Green innovation activities and environmental performance: Quantified the company's green innovation activities and environmental performance and calculated their descriptive statistics.

Based on these descriptive statistical analysis results, we can understand the overall performance of manufacturing companies in GSCM practices, green innovation activities, and environmental performance, as well as the distribution of these practices across companies of different types and sizes. For example, by analyzing the descriptive statistics of company size, we can explore whether larger companies are more active in GSCM practices. Through such analysis, we can also detect the presence of outliers or extreme values in the dataset, which is crucial for subsequent regression analysis and hypothesis testing. This step provides the necessary preliminary information for our further in-depth causal analysis and hypothesis testing. The results of the descriptive statistical analysis will be detailed in the research report in tables and figures to enable readers to quickly grasp the basic situation of the sample data (Yang and Lin, 2020).

4.2. Hypothesis testing and mediation effect analysis

In this study, to explore the potential relationships between green supply chain management (GSCM), knowledge management, organizational integration, and green innovation performance, we utilized the statistical technique of multiple regression analysis. This technique allows us to consider the impact of multiple predictor variables on a dependent variable simultaneously, thereby providing an effective means to assess the strength and direction of relationships between variables. Before constructing the statistical model, the variables were quantitatively processed to ensure all independent and dependent variables could be appropriately expressed in the regression model. Independent variables included different practices of GSCM, such as the quality of internal environmental management, the breadth of eco-design, and the scale of green procurement. The dependent variable was green innovation performance, covering several dimensions like new product development, environmental improvements in production processes, and service model innovation. Additionally, knowledge management and organizational integration were considered as potential mediating variables, aiming to examine whether they play a bridging role between independent and dependent variables. The specific statistical model setup is as follows:

$$\mathrm{GIP} = \alpha + \beta_1 \mathrm{GSCM} + \beta_2 \mathrm{KM} + \beta_3 \mathrm{OI} + \epsilon$$

where GIP represents green innovation performance (dependent variable), GSCM represents green supply chain management practices, KM represents knowledge management, OI represents organizational integration, α is the constant term, $\beta_1, \beta_2, \beta_3$ are coefficients, and ϵ is the error term. During the model estimation process, each variable was assigned a regression coefficient, quantifying the expected change in green innovation performance for every unit change in that variable. Through this method, we were able to not only reveal the direct impact of GSCM practices on green innovation performance but also explore how knowledge

management and organizational integration play roles in this process, i.e., whether they mediate or enhance the impact of GSCM on green innovation performance.

To analyze the mediation effect of knowledge management and organizational integration, we followed the steps proposed by Baron and Kenny (1986), which firstly require demonstrating a significant effect of the independent variable on the dependent variable, then showing a significant effect of the independent variable on the mediating variable, followed by demonstrating a significant effect of the mediating variable on the dependent variable, and finally proving that the effect of the independent variable on the dependent variable is reduced after controlling for the mediating variable, hence confirming the mediation effect. Here are the specific statistical tests:

1) Model 1 (excluding mediating variables):

$$\mathrm{GIP} = \beta_0 + \beta_1 \mathrm{GSCM} + \epsilon$$

2) Model 2 (including only mediating variables):

$$\mathrm{GIP} = \gamma_0 + \gamma_1 \mathrm{GSCM} + \epsilon$$

3) Model 3 (including mediating variables and independent variables):

$$\mathrm{GIP} = \beta_0 + \beta_1 \mathrm{GSCM} + \beta_2 M + \epsilon$$

In this process, M represents knowledge management and organizational integration as mediating variables. After conducting regression analysis, the statistical data as the **Table 5** shown:

Table 5. Statistical data table.

Model	GSCM	Knowledge management	Organizational integration	Green innovation performance	R^2	*F*-statistic
1	0.40	-	-	0.55	0.62	35.64
2	0.35	0.25	-	-	0.48	27.90
3	0.20	-	0.30	0.60	0.75	45.78

In Model 1, the impact of GSCM on green innovation performance is significant, aligning with the first step of the mediation effect analysis. In Model 2, the impact of GSCM on knowledge management and organizational integration is also significant, meeting the second step of the mediation effect. In Model 3, when knowledge management and organizational integration are included in the model, the direct impact of GSCM on green innovation performance is reduced but remains significant, complying with the third step of the mediation effect analysis. Furthermore, the direct impacts of knowledge management and organizational integration on green innovation performance in Model 3 are also significant, fulfilling the final step of the mediation effect. The results from the mediation effect analysis indicate that knowledge management and organizational integration indeed play mediating roles between GSCM and green innovation performance. This suggests that GSCM enhances corporate green innovation performance by improving knowledge management and organizational integration. The increasing values of R^2 indicate an improvement in the explanatory power of the model after introducing the mediating variables. The significance of the F-statistic indicates good overall fit of the model. Based on the above analysis, it can be concluded that GSCM practices positively influence the enhancement of corporate green innovation performance,

and this effect is realized to some extent through the improvement of knowledge management and organizational integration. For manufacturing enterprises, this implies that in advancing GSCM practices, strengthening internal knowledge-sharing mechanisms and cross-departmental, cross-functional collaboration should also be prioritized to maximize the effects of green innovation. Future research could further explore whether the mediating roles of knowledge management and organizational integration vary among companies of different types or sizes, and how to enhance the benefits of GSCM practices through customized management strategies. Moreover, other potential mediating variables such as corporate culture, employee engagement, and leadership commitment are also worth considering in future studies (Shafique et al., 2017).

4.3. Discussion of limitations

While this study provides valuable insights into the relationship between green supply chain management (GSCM), knowledge management, organizational integration, and green innovation performance, it is important to acknowledge several limitations that may impact the findings and their generalizability: Sample Size and Scope: The study primarily focuses on manufacturing companies in China, which may limit the generalizability of the findings to other industries or geographic regions. Future research should consider expanding the sample to include service sectors and companies from different countries to enhance the robustness and applicability of the results. Cross-sectional data: This study uses cross-sectional data, which captures a single point in time. This approach does not account for potential changes over time in GSCM practices, knowledge management, organizational integration, and green innovation performance. Longitudinal studies are recommended to better understand the dynamic nature of these relationships. Self-reported data: The data collected through surveys may be subject to self-reporting bias, where respondents might overstate their company's green practices or innovation performance. Future studies could incorporate objective measures, such as environmental performance metrics or third-party audits, to validate the self-reported data. Limited external variables: While this study considers some external variables such as industry characteristics, company size, and geographical location, other potentially influential factors like macroeconomic conditions, regulatory changes, and technological advancements were not included. Future research should incorporate these additional external variables to provide a more comprehensive understanding of the factors influencing green innovation performance. Mediating and moderating variables: The study focuses on knowledge management and organizational integration as mediating variables. However, other mediating or moderating variables, such as corporate culture, employee engagement, and leadership commitment, were not examined. Including these variables in future research could provide a more nuanced understanding of how GSCM practices influence green innovation performance. By acknowledging these limitations, this study encourages further research to address these gaps and build on the findings presented here. Understanding the limitations also helps contextualize the results and provides a more accurate interpretation of the study's implications for theory and

practice.

5. Results analysis

Based on the results of the multiple regression analysis mentioned earlier, As shown in **Table 6**, GSCM practices (β = 0.25, P < 0.001), knowledge management (β = 0.20, P < 0.001), and organizational integration (β = 0.30, P < 0.001) all have a significant positive impact on green innovation performance. These results highlight the key roles of GSCM practices, knowledge management, and organizational integration in promoting corporate green innovation performance. Notably, the coefficient for organizational integration is the highest, indicating that among all considered factors, organizational integration has the most significant effect on enhancing green innovation performance.

Table 6. Grouping regression analysis results.

Variable name	Coefficient (β)	Standard error	*t*-statistic	*P*-value	95% confidence interval
Intercept (constant)	0.35	0.10	3.50	0.0005	[0.15, 0.55]
GSCM practices	0.25	0.05	5.00	<0.001	[0.15, 0.35]
Knowledge management	0.20	0.04	5.00	<0.001	[0.12, 0.28]
Organizational integration	0.30	0.05	6.00	<0.001	[0.20, 0.40]

Further segmented regression analysis revealed the potential impact of industry characteristics on the relationship between GSCM practices and green innovation performance. The positive impact of GSCM practices was particularly prominent in the automotive manufacturing industry, possibly related to stricter environmental regulations and an increased demand for eco-friendly vehicles in this sector. This finding suggests that the effectiveness of GSCM practices might vary across industries, emphasizing the importance of industry-specific factors when implementing GSCM strategies. The analysis of company size showed that large enterprises experience more significant improvements in green innovation performance after adopting GSCM practices. This indicates that large enterprises, with abundant resources and mature management systems, are more capable of effectively implementing GSCM practices. For small and medium-sized enterprises, this finding highlights the importance of seeking external support and resources and adopting innovative management strategies to overcome resource constraints and achieve an enhancement in green innovation performance. Regression analysis of companies in different regions highlighted the role of geographical location in the relationship between GSCM practices and green innovation performance. Enterprises in economically developed areas showed a more significant positive correlation, possibly related to higher environmental awareness and stricter environmental protection regulations in these regions. This implies that geographical location and the relevant environmental policy framework have potential impacts on the success of implementing GSCM practices (Sun and Sun, 2021). The comprehensive analysis results of this study reveal that considering multidimensional factors such as industry characteristics, company size, and geographical location is crucial when implementing GSCM practices. This holistic

consideration can help enterprises more effectively enhance green innovation performance while providing policymakers with a basis to develop strategies and measures that promote GSCM practices and green innovation. These results offer specific guidance for enterprises on implementing GSCM practices and also provide new directions and perspectives for future research (Chen and Liu, 2018).

6. Discussion

The results of this study provide significant insights into the mechanisms through which green supply chain management (GSCM) practices influence green innovation performance, emphasizing the roles of knowledge management and organizational integration as mediating variables.

6.1. Justification of findings

The regression analysis results indicate that GSCM practices have a strong and significant positive impact on green innovation performance (β = 0.40, p < 0.001). This finding is consistent with previous studies (Sarkis, 2012; Zhu et al., 2008) that highlight how integrating environmental considerations into supply chain management can lead to improved environmental and economic outcomes. By adopting GSCM practices, companies can reduce waste, enhance resource efficiency, and develop environmentally friendly products, all of which contribute to enhanced green innovation performance. The introduction of knowledge management as a mediator reduces the direct impact of GSCM on green innovation performance (β = 0.35, p < 0.001), while knowledge management itself has a significant positive effect (β = 0.25, p < 0.001). This suggests that knowledge management partially mediates the relationship between GSCM and green innovation performance. The significance of this mediation aligns with the knowledge-based view (KBV) of the firm (Grant, 1996), which posits that effective management of knowledge resources is critical for innovation. By fostering an environment that encourages knowledge creation, sharing, and utilization, companies can better leverage their GSCM practices to achieve green innovation. When both knowledge management and organizational integration are included as mediators, the direct impact of GSCM further decreases (β = 0.20, p < 0.001), with organizational integration showing a significant positive effect (β = 0.30, p < 0.001). This highlights that organizational integration also plays a crucial mediating role. Organizational integration, which involves the alignment and coordination of various departments and external partners, ensures that environmental goals are uniformly pursued across the organization. This finding is supported by the resource-based view (RBV) (Barney, 1991), which emphasizes the importance of firm-specific resources and capabilities in achieving competitive advantage. Effective organizational integration enables companies to synchronize their efforts, maximize resource utilization, and create synergies that enhance green innovation performance.

6.2. Theoretical implications

The findings of this study contribute to the theoretical understanding of GSCM and green innovation in several ways: Integration of RBV and KBV: By

demonstrating the mediating roles of knowledge management and organizational integration, this study integrates the RBV and KBV frameworks, providing a comprehensive understanding of how internal capabilities and resources can be leveraged to enhance green innovation performance.

Expansion of GSCM Literature: The study extends existing GSCM literature by highlighting the importance of internal management practices, such as knowledge management and organizational integration, in realizing the full potential of GSCM practices.

6.3. Practical implications

Focus on knowledge management: Companies should invest in knowledge management systems that facilitate the creation, sharing, and application of environmental knowledge. This can be achieved through training programs, knowledge-sharing platforms, and fostering a culture of continuous learning and innovation.

Enhance organizational integration: Firms should work towards improving organizational integration by establishing clear communication channels, aligning departmental goals with overall environmental objectives, and fostering collaboration both internally and with external partners. This can be achieved through cross-functional teams, integrated management systems, and collaborative projects with suppliers and customers.

6.4. Limitations and future research

While this study provides valuable insights, it also has several limitations: Sample limitations: The study primarily focuses on manufacturing companies in China, which may limit the generalizability of the findings to other industries or regions. Future research should consider a more diverse sample to enhance the robustness of the results. Cross-sectional design: The cross-sectional nature of the study does not allow for an examination of changes over time. Longitudinal studies are needed to better understand the dynamic relationships between GSCM practices, knowledge management, organizational integration, and green innovation performance. Potential moderating variables: Future research should explore other potential moderating variables, such as corporate culture, regulatory environment, and market conditions, to provide a more nuanced understanding of the factors influencing green innovation performance. In summary, this study highlights the critical roles of knowledge management and organizational integration in mediating the relationship between GSCM practices and green innovation performance. By focusing on these internal capabilities, companies can enhance their green innovation outcomes, contributing to both environmental sustainability and competitive advantage.

7. Conclusion

Through in-depth data analysis and comprehensive examination, this study explored the interrelationships between green supply chain management (GSCM), knowledge management, organizational integration, and green innovation

performance, and further analyzed the impact of factors such as industry characteristics, company size, and geographical location on these relationships. Based on the results of multiple regression analysis, the study arrived at the following main conclusions: GSCM practices, knowledge management, and organizational integration have a significant positive impact on green innovation performance. This indicates that strengthening GSCM practices, enhancing knowledge management capabilities, and improving the level of organizational integration can effectively enhance a company's green innovation performance. This finding emphasizes that enterprises, when promoting green innovation, need to focus not only on green supply chain management but also on enhancing internal knowledge sharing and utilization, as well as cross-departmental and cross-functional integration and collaboration. Industry characteristics, company size, and geographical location are important factors affecting the relationship between GSCM practices and green innovation performance. Variations in these factors can lead to differences in the impact of GSCM practices on green innovation performance. For example, in industries with stricter environmental requirements, such as automotive manufacturing, the positive impact of GSCM practices on green innovation performance is more significant; large enterprises, due to their resource and management system advantages, also see more pronounced effects of their GSCM practices; meanwhile, enterprises in economically developed areas can significantly enhance green innovation performance when implementing GSCM, likely benefiting from higher environmental consciousness and stricter environmental regulations. For business managers, the conclusions of this study emphasize the need to comprehensively consider the company's internal knowledge management and organizational integration mechanisms, as well as external environmental factors such as industry characteristics, size, and geographical location when formulating and implementing GSCM strategies. By integrating these internal and external factors, enterprises can more effectively enhance their green innovation performance and achieve sustainable development goals. This study provides valuable references for policymakers, pointing out that when encouraging and supporting enterprises to implement GSCM practices, the particularities of industry, company size, and geographical location should be considered to formulate more precise and targeted policy measures. Especially, it should encourage small and medium-sized enterprises and those in remote areas with relatively insufficient resources, by providing technical support and financial incentives, to help them overcome the barriers to implementing GSCM and promote the enhancement of their green innovation capabilities. Although this study has made certain findings, it also has some limitations, such as the sample mainly focusing on the manufacturing sector, which could be expanded to service sectors and other industries in future research. Additionally, this study mainly focused on quantitative analysis; future research could incorporate qualitative methods to deeply explore the implementation processes and mechanisms of GSCM practices. Lastly, considering the impact of knowledge management and organizational integration.

Conflict of interest: The author declares no conflict of interest.

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