Green Human Resource Management and Sustainable Performance: The Mediating Role of Green Innovation and Green Supply Chain Management

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Abstract

This study aims to examine the impact of green human resource management (GHRM) on sustainable performance, which encompasses economic, environmental, and social dimensions. Additionally, it investigates the mediating roles of green innovation and green supply chain management in this relationship. The study further explores the interaction mechanisms between GHRM, green innovation, and green supply chain management. Data were collected from 430 senior and middle-level managers in the human resources and supply chain management departments of manufacturing firms in Guangdong Province, China. The analysis was conducted using the PLS-SEM method via Smart PLS 4.1 software.

The results indicate that GHRM, green innovation, and GSCMall have significant positive effects on sustainable performance. Moreover, GHRM positively influences both green innovation and green supply chain management, while green innovation significantly impacts green supply chain management. Green innovation and GSCM serve as partial mediators in the relationship between GHRM and sustainable performance. The findings confirm that GHRM, green innovation, and GSCM can co-exist within a company's green management practices. When implemented in an integrated manner, these practices enhance the firm’s overall performance across the triple bottom line of environmental, economic, and social outcomes.

Keywords: Green Human Resource Management (GHRM); Green Innovation (GI); Green Supply Chain Management (GSCM); sustainable performance.

Introduction

Since the implementation of the reform and opening-up policy, China's manufacturing sector has made significant progress. However, its extensive growth model, characterized by "high input, high consumption, and high pollution," has resulted in excessive energy consumption and environmental degradation, leading to a decline in ecological carrying capacity and increasingly severe resource shortages (Jiang et al., 2020). As a result, addressing pollution and carbon reduction, promoting the transition to green production, and achieving a balance between economic development and environmental protection have become pressing issues for the manufacturing industry. Under the dual constraints of environmental protection and resource sustainability, the green transformation of China's manufacturing sector is not only an essential response to these challenges but also a critical pathway for driving sustainable development.

However, integrating green practices into the daily operations of enterprises presents a complex challenge. Companies must not only enhance environmental and social performance but also maintain economic profitability while embedding green concepts into their organizational culture (Al-Ghazali & Afsar, 2021; Al-Shammari et al., 2022). Dost et al. (2019) suggest that coordinating the cross-functional allocation of green development strategies is an effective way to address these challenges.

At present, GHRM, green innovation, and GSCM have become essential practices for organizations to tackle environmental challenges. However, studies on the synergistic effects of these practices remain limited. Particularly lacking is research on how GHRM and green innovation impact corporate sustainability throughout the entire supply chain. Lei et al., (2021) argue that it is necessary to further explore the distribution of green practices across different functional areas of firms and their interactions to fully understand their effects on environmental, economic, and social performance.

Given the urgent need for green development in China's manufacturing industry, an in-depth examination of the synergies between GHRM, green innovation, and GSCM is of significant practical importance. Such research not only contributes to achieving the national "dual carbon" goals but also facilitates the green transformation of China's manufacturing sector, ultimately promoting the coordinated and sustainable development of the economy, environment, and society.

Research Objective

This paper aims to investigate the impacts of GHRM, green innovation, and GSCM on corporate sustainability performance within the framework of China's dual carbon goals, focusing on the Guangdong manufacturing sector as a case study. Additionally, the study seeks to clarify the relationships and key influencing factors among GHRM, green innovation, and GSCM.

Literature reviews

GHRM and green innovation

The ability of companies to achieve innovation performance is influenced by the work environment, including employees' skills, experience, and motivation for innovation, as well as their ability to explore (create new products) and develop (produce products) (Anderson et al., 2014). GHRM practices contribute to developing green capabilities, motivating green employees, and providing green opportunities, thereby fostering a work environment conducive to achieving innovation performance (Renwick et al., 2013; Tang et al., 2018). Developing employees' skills and knowledge equips them with the necessary capabilities to generate innovative ideas and effectively implement them within the organization. Additionally, selecting and recruiting individuals with the requisite abilities, knowledge, and skills can enhance the organization's innovation outcomes. Material rewards linked to performance, such as bonuses, help create a motivating atmosphere that encourages employees to engage in positive behaviors and actively pursue innovations (Alkhalaf, 2024). Flexible work designs, green work teams, employee involvement, and information-sharing practices promoted by GHRM support the occurrence of green innovation behaviors (Guerci, 2014). Empirical studies have demonstrated the positive impact of GHRM on green innovation (Sobaih et al., 2020; Munawar et al., 2022; Fang et al., 2022; Aftab et al., 2023). GHRM significantly promotes green innovation, making its practices crucial for fostering employee innovation. Based on this analysis, the following hypothesis is proposed:

H1: GHRM has a significant positive impact on green innovation.

GHRM and GSCM

GSCM requires employees to identify, adopt, and implement ecological concepts throughout various stages of the supply chain, which poses certain challenges to employees' environmental awareness and capabilities. As a precursor to GSCM practices, GHRM practices must first establish the green capabilities of human resources within an organization to successfully implement GSCM practices (Acquah et al., 2020). On one hand, GHRM practices contribute to enhancing employees' pro-environmental behaviors (Iftikhar et al., 2022). Strategies such as green training, green performance management, green recruitment, and green rewards are part of GHRM practices that can improve employees' green awareness, green knowledge, and green capabilities, thereby increasing the success of GSCM (Aragao & Jabbour, 2017). On the other hand, previous studies have confirmed the positive impact of GHRM on GSCM (Xie & Buavaraporn, 2019; Kara et al., 2023; Nureen et al., 2024). These studies indicate the importance of GHRM in enhancing employees' green capabilities, empowering employees, and conducting environmental training to support GSCM within organizations, thereby helping to reduce barriers to implementing GSCM practices (Zaid et al., 2018). In summary, implementing GHRM to develop employees' environmental skills and intentions, and providing opportunities for them to engage in workplace ecological management operations, can promote GSCM practices (Nureen et al., 2024). Based on this analysis, the following hypothesis is proposed:

H2: GHRM has a significant positive impact on GSCM.

GHRM and sustainable performance

GHRM supports the development of sustainable ecological or social practices and uses HR policies to promote green resources within organizations (Jackson et al., 2011), thereby creating a sustainable competitive advantage and enhancing organizational performance (Ahakwa et al., 2021). Firstly, GHRM improves employees' environmental management awareness through environmental training, the implementation of green rewards, and green performance goal assessments. This strengthens the environmental management system, effectively enhances resource utilization efficiency, and reduces workplace waste and emissions, thus positively impacting environmental performance (Singh et al., 2020; Ahakwa et al., 2021; Aftab et al., 2023). Secondly, GHRM positively influences the economic performance of enterprises. By implementing GHRM, organizations promote environmental protection principles and adhere to the "reduce and reuse" strategy, which not only reduces costs and improves environmental performance but also leads to increased economic benefits (Kim et al., 2019). Additionally, through GHRM, such as setting green performance goals and strengthening green training, management can enhance employees' environmental awareness and capabilities, improve operational efficiency, and reduce costs associated with regulation and compliance fines (Acquah et al., 2020). Finally, GHRM also positively affects corporate social performance. From a social responsibility perspective, organizations with pro-environmental images are more likely to attract high-quality talent, alleviate stakeholder pressures, and meet societal demands, thereby enhancing the organization's reputation. GHRM practices create healthier living conditions and safer environments for employees and local communities, achieving environmental balance, economic stability, and sustainable development in health, social equity, and well-being for both the company and its employees (Rani & Mishra, 2014). Based on this analysis, the following hypothesis is proposed:

H3: GHRM has a significant positive impact on corporate sustainable performance.

Green Innovation and GSCM

Green innovation refers to the development of environmentally friendly products, energy conservation, pollution prevention, waste recycling, and the improvement of environmental management practices that support sustainability (Khaksar et al., 2016). It encompasses modifications in product design and manufacturing processes, including all stages such as design, production, usage, and disposal. This involves designing and producing environmentally friendly, durable, and safe products while reducing pollution, conserving energy, and recycling waste to minimize negative environmental impacts (Chiou et al., 2011; Novitasari & Agustia, 2022). In this regard, green innovation is considered an integral part of GSCM (Anjum et al., 2024). The relationship between GSCM practices and green innovation is supported by two theoretical frameworks: the evolutionary approach (Nelson and Winter, 1982) and innovation through co-creation models (Prahalad & Ramaswamy, 2004). Both theories propose that interactions among participants or stakeholders in the supply chain will foster greater environmental innovation to adapt to significant pressures from external factors such as government legislation and regulatory agencies. Through green innovation, manufacturers can integrate new ideas, methods, concepts, and/or technologies provided by stakeholders into the product development process, thereby facilitating the implementation of GSCM (Chiou et al., 2011). Furthermore, green innovation activities span the entire green supply chain, enhancing the efficiency and effectiveness of the chain by providing technological support, optimizing management, and achieving goals (Seman et al., 2019). Based on this analysis, the following hypothesis is proposed:

H4: Green innovation has a significant positive impact on green supply chain management.

The Mediating Role of Green Innovation

Green innovation serves as an indicator of a company's performance in creating better environmental conditions through effective and efficient management mechanisms (Ramadhany, 2021). It represents a strategic effort by companies to achieve new and improved products without harming the environment (Novitasari & Agustia, 2022). Empirical research utilizing content analysis on 209 A-share listed companies in heavily polluting industries in China found that both green process innovation and green product innovation can enhance financial performance (Xie et al., 2019). Another study employing structural equation modeling on a survey of 219 manufacturing companies in Turkey revealed that green innovation directly improves environmental performance through cost advantages and pollution prevention capabilities, while indirectly enhancing economic performance through resource conservation and cost reduction (Yurdakul & Kazan, 2020). Furthermore, implementing green innovation can reduce market volatility and credit risk, as well as improve market value and environmental performance (Liu et al., 2023). Thus, green innovation positively impacts a company's sustainable performance.

GHRM enhances employees' green capabilities, motivates green behavior, and provides opportunities for green participation (Renwick et al., 2013). This, in turn, raises employees' green awareness, encourages green behavior in the workplace, and accelerates green innovation activities within the company, thereby improving sustainable performance. Through GHRM practices, all employees become aware of the critical role of green innovation in enhancing corporate sustainability and are thus motivated to engage in green innovation practices. Additionally, companies can leverage the outcomes of green innovation to quickly capture market share, increase competitiveness, gain trust from government and consumers, and build a positive image, further promoting the enhancement of sustainable performance and achieving sustainability. Therefore, green innovation, focusing on continuous product optimization and production process upgrades, serves as a crucial link between GHRM and sustainable development. Research by Al-Shammari et al. (2022) indicates that green innovation partially mediates the relationship between green human resource practices and the sustainable performance of small and medium-sized enterprises. Based on this analysis, the following hypothesis is proposed:

H5: Green innovation significantly positively impacts sustainable performance.

H6: Green innovation plays a mediating role between GHRM and sustainable performance.

The Mediating Role of GSCM

GSCM is recognized as one of the most effective strategies for creating sustainability by improving sustainable performance and mitigating environmental issues (Silvestre & Ţîrcă, 2019). An effective GSCM can offer various advantages to organizations, including cost reduction, increased market share and sales, stakeholder satisfaction, and long-term consumer engagement, thereby enhancing competitive advantage and organizational performance (Khalili & Alinezhad, 2008). When examining the relationship between GSCM and corporate sustainability performance, exploring the dynamics from the perspective of drivers—practices—performance reveals that specific drivers may influence companies to adopt GSCM models, resulting in positive impacts on sustainable performance (Micheli et al., 2022).

GHRM is one of the driving factors for the implementation of GSCM (Zhu et al., 2008). Integrating GHRM with GSCM practices provides significant value-adding opportunities for corporate green development and serves as a crucial tool for motivating, inspiring, and encouraging employees to implement green practices, leading to improvements in sustainability performance (Bon et al., 2018). Recent studies have also investigated the synergistic effects of GHRM and GSCM practices on performance across social, environmental, and economic dimensions (Agyabeng-Mensah et al., 2020). The findings indicate that GSCM practices mediate the relationship between GHRM practices and sustainability performance. Green training programs are essential for the effective implementation of GSCM practices (Zaid et al., 2018). Furthermore, both GHRM and GSCM practices significantly enhance environmental performance, with companies adopting these practices demonstrating superior operational, environmental, and social performance compared to others (Senyo et al., 2020). Finally, the link between GHRM and GSCM practices can significantly improve customer satisfaction, loyalty, operational efficiency, and employee and social safety; prevent pollution and waste; reduce compliance and environmental fines; and enhance profitability, thereby contributing to the achievement of sustainability goals. Based on the above analysis, the following hypotheses are proposed:

H7: GSCM significantly positively impacts sustainable performance.

H8: GSCM mediates the relationship between GHRM and sustainable performance.

Conceptual framework

Based on literature research, this paper constructs a conceptual model involving GHRM, green innovation, green supply chain management, and sustainable performance, drawing on the resource-based view, AMO theory, and stakeholder theory. In this model, GHRM serves as the independent variable, while green innovation and GSCM function as mediating variables. Sustainable performance is the dependent variable. According to AMO theory, GHRM includes three dimensions: green capabilities, green motivation, and green opportunities. Following the Triple Bottom Line (TBL) theory, sustainable performance is evaluated across three dimensions: economic performance, environmental performance, and social performance. This is illustrated in Figure 1.

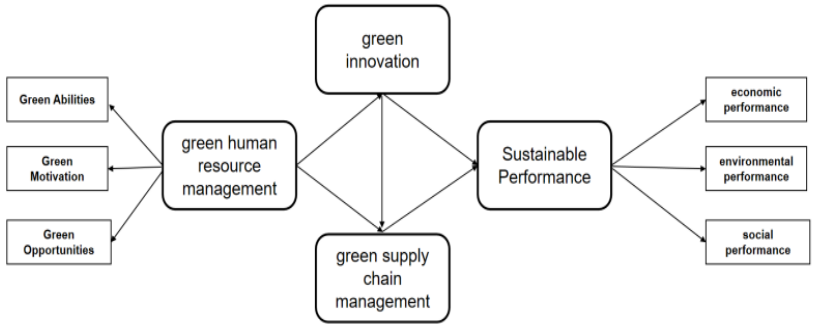

Figure 1: Conceptual Framework

Research Methodology

Sample Group

This study selected manufacturing enterprises in Guangdong Province, China, as the sample group. Guangdong is a leading region in China's manufacturing sector, with a comprehensive range of manufacturing categories and a robust industrial base. In 2023, the added value of manufacturing in Guangdong accounted for 32.7% of the regional GDP, and the number of large-scale industrial enterprises exceeded 71,000, ranking first nationwide. The study focuses on managers and supervisors from human resource management and supply chain management departments, as well as senior executives of the enterprises. Following Mitchell's (1993) guidelines, approximately 410 samples were planned to ensure a 95% level of statistical significance.

Research Tools

A mixed-methods approach was employed in this study to ensure the accuracy and reliability of the conclusions. Methods included inductive and deductive reasoning, survey questionnaires, and statistical analysis. Data collected from the surveys were analyzed using Smart PLS 4.1 software to assess the statistical significance of the conceptual models and research hypotheses, with PLS-SEM used to validate the related models and hypotheses.

Data Collection

Based on an extensive literature review and preliminary research, a questionnaire was designed for this study. The questionnaire was divided into two sections. The first section gathered demographic information, including respondents' age, gender, position, years of experience, company size, years of operation, industry type, and company nature. The second section contained 41 questions related to GHRM, green innovation, green supply chain management, and sustainable performance. GHRM was measured using 13 indicators derived from Kara et al. (2023); green innovation was assessed using 6 indicators from Shah and Soomro (2023); GSCM was evaluated using 7 indicators from Kara and Edinsel (2023); and sustainable performance was measured with 15 indicators from Habib et al. (2020), covering economic, environmental, and social performance. Respondents rated statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

The content validity of the questionnaire was evaluated by five industry experts. Three indicators (GA01, GA02, and SOP04) with scores below 0.5 were removed (Brown, 2005). A pretest involving 162 questionnaires yielded a KMO value of 0.902, and all Cronbach's alpha coefficients were above 0.7, indicating good reliability and validity. During the formal survey, 430 questionnaires were collected through colleagues, classmates, friends, and professional firms. After excluding 29 invalid responses, 401 valid questionnaires remained, resulting in a response rate of 93.26%.

Data Analysis

Among the 401 valid responses, 51.12% were male and 48.88% were female. The age distribution showed that 37.91% of respondents were aged 25-35, 31.42% were 36-45 years old, 24.44% were over 45 years old, and 6.23% were under 25 years old. The results indicate that the majority of participants are middle-aged employees who play a crucial role in their companies. Companies with more than 300 employees represented 74.56% of the sample, while 77.22% had been in operation for over 10 years. In terms of company nature, state-owned enterprises comprised 29.93%, private enterprises 35.66%, foreign enterprises 20.45%, and joint ventures 13.97%. The industry distribution was primarily in biotechnology, new pharmaceuticals, renewable energy, energy-saving technologies, machinery manufacturing, chemicals, petroleum, rubber, plastics, and textiles, accounting for 62.09%, with high-pollution industries making up 50.37%. The data are representative. Analysis using Smart PLS 4.1 revealed no missing values, with all mean values above 3. Skewness and kurtosis values were within the acceptable range of -2 to +2 (George & Mallery, 2019). The Cramér-von Mises test indicated a good fit of the model to the data.

Results

Model Estimation

In this study, PLS-SEM was employed to identify the research model, as this method has proven effective for handling both basic and complex frameworks (Fang et al., 2022). Compared to covariance-based SEM (CBS-SEM), PLS-SEM provides more accurate evaluations of variable validity (Hair et al., 2014). Smart PLS offers a direct approach to calculating all parameters (Hair et al., 2016; Usman Shehzad et al., 2022). The measurement model (Figure 2) was assessed using Smart PLS 4.1.

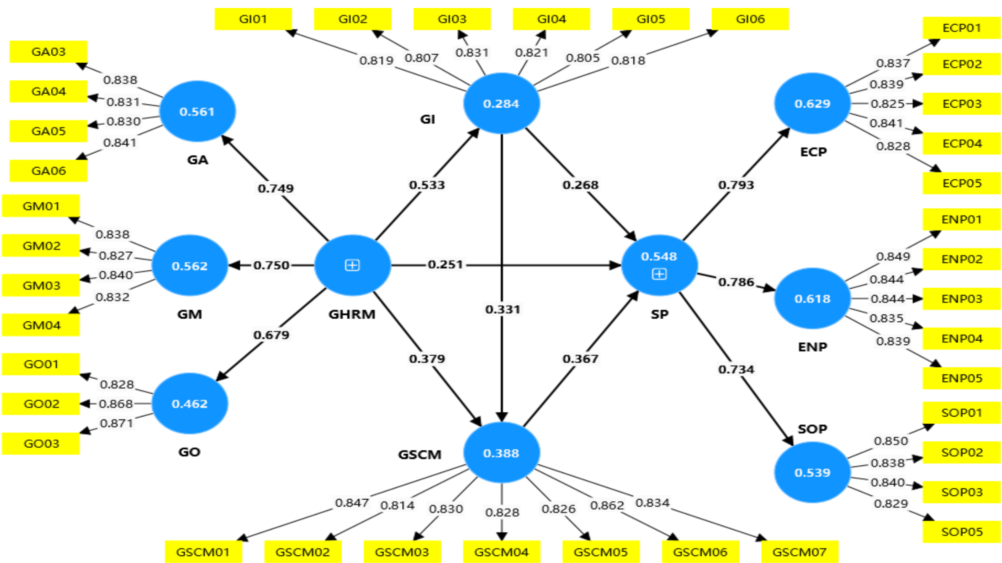

Figure 2 PLS-SEM results

Figure 2 presents the results of the PLS-SEM analysis. The numbers on the path relationships represent the standardized regression coefficients, while the numbers displayed within the circles of the endogenous latent variables are the R^2 values. A preliminary assessment indicates that GSCM has the strongest impact on SP (0.367), followed by GI (0.268) and GHRM (0.251). These three constructs account for 54.8% of the variance in the endogenous structure SP (i.e., the

R^2 value). Similarly, the relationships between the three-dimensional variables GA, GM, GO, and GHRM, as well as between ECP, ENP, SOP, and SP, and the relationships between the two mediating variables GI and GSCM, can be interpreted. However, before discussing these results, it is essential to evaluate the structural response measurement models.

Assessment of Measurement Model

First, the measurement model was evaluated using the PLS-SEM algorithm to compute factor loadings, reliability, and validity, as shown in Figure 3 and Table 2.

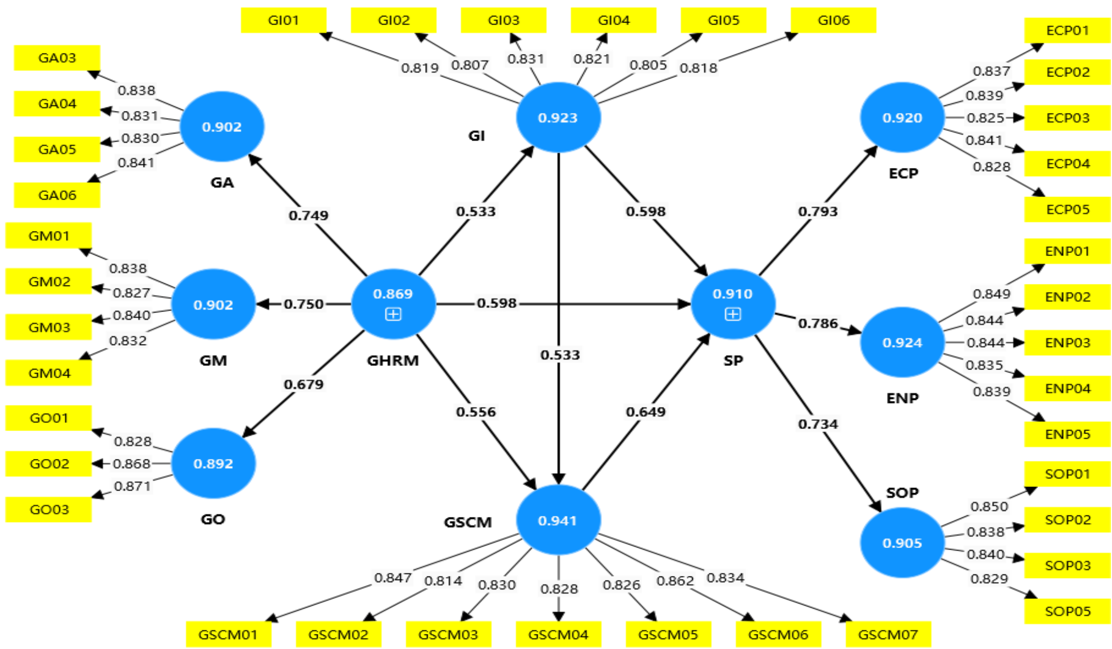

Figure 3 Composite Reliability

Factor Loadings Evaluation. According to Hair et al. (2019), factor loadings should exceed 0.708, indicating that the construct explains more than 50% of the indicator variance, thus providing acceptable item reliability. As shown in Table 2, all 38 indicators have factor loadings greater than 0.708, suggesting that further analysis is warranted.

Assessing Internal Consistency Reliability. The most commonly used measure is Jöreskog's (1971) composite reliability (CR). For instance, it can be posited by researchers that values ranging from 0.60 to 0.70 are deemed acceptable within the context of exploratory studies, whereas results falling between 0.70 and 0.95 are indicative of a satisfactory level of reliability (Chin, 1998; Hair et al., 2022). As shown in Table 2, all CR values exceed 0.7. Additionally, Hair et al. (2019) suggest that Cronbach's alpha might be overly conservative, while composite reliability might be too lenient.

Therefore, the true reliability of a construct is often viewed as being between these two extremes, and CR (rho_a) can serve as an alternative measure (Dijkstra & Henseler, 2015). CR (rho_a) generally falls between Cronbach's alpha and composite reliability. From Table 4.5, the CR (rho_a) values are between Cronbach's alpha and CR (rho_c), all exceeding 0.7. Furthermore, bootstrapping was used to test the confidence intervals for reliability, and the lower bounds of the 95% confidence intervals for construct reliability are above 0.70 (Hair et al., 2019). These results indicate high reliability for the model.

Table 2 Inner model evaluation

Variables	Constructs	Factor loading	Cronbach's α	CR (rho_a)	CR (rho_c)	AVE
GHRM						
Green Abilities	GA03	0.838	0.855	0.855	0.902	0.697
	GA04	0.831				
	GA05	0.83				
	GA06	0.841				
Green Motivation	GM01	0.838	0.855	0.855	0.902	0.696
	GM02	0.827				
	GM03	0.84				
	GM04	0.832				
Green Opportunities	GO01	0.828	0.818	0.821	0.892	0.733
	GO02	0.868				
	GO03	0.871				
Green innovation	GI01	0.819	0.9	0.901	0.923	0.667
	GI02	0.807				
	GI03	0.831				
	GI04	0.821				
	GI05	0.805				
	GI06	0.818				
Green supply chain management	GSCM01	0.847	0.927	0.928	0.941	0.696
	GSCM02	0.814				
	GSCM03	0.83				
	GSCM04	0.828				
	GSCM05	0.826				
	GSCM06	0.862				
	GSCM07	0.834				

Sustainable performance						
Economic performance	ECP01	0.837	0.891	0.891	0.92	0.696
	ECP02	0.839				
	ECP03	0.825				
	ECP04	0.841				
	ECP05	0.828				
Environmental performance	ENP01	0.849	0.898	0.898	0.924	0.71
	ENP02	0.844				
	ENP03	0.844				
	ENP04	0.835				
	ENP05	0.839				
Social performance	SOP01	0.85	0.86	0.861	0.905	0.705
	SOP02	0.838				
	SOP03	0.84				
	SOP05	0.829				

Table 3 Fornell–Larcker for discriminant validity

	GHRM	GI	GSCM	SP
GHRM	0.614			
GI	0.533	0.817		
GSCM	0.556	0.533	0.835	
SP	0.598	0.598	0.649	0.649

Assessing Convergent Validity. Convergent validity refers to the extent to which a construct converges to explain the variance of its items. The measure used to evaluate convergent validity is the Average Variance Extracted (AVE) for each construct (Hair et al., 2019). As a rule of thumb, an AVE of 0.5 or greater is acceptable, indicating that the construct explains at least 50% of the variance of its items (Hair et al., 2019). Table 4.5 shows that the AVE for each construct exceeds 0.5, indicating acceptable convergent validity for the model.

Assessing Discriminant Validity. Discriminant validity refers to the extent to which a construct is empirically distinct from other constructs in the model (Hair et al., 2019). The first method to assess discriminant validity is the Fornell-Larcker criterion, which posits that the square root of the AVE (on the diagonal) should be greater than the correlations with other latent variables (Fornell & Larcker, 1981). As shown in Table 3, the square roots of all AVEs are higher than their correlations with other latent variables, indicating good discriminant validity. The second method involves the Heterotrait-Monotrait (HTMT) ratio (Hair et al., 2019). Generally, HTMT values greater than 0.90 or

0.85 indicate a lack of discriminant validity (Hair et al., 2019). Specifically, researchers can check if the upper limit of the 95% confidence interval for HTMT is below 0.90 or 0.85 (Hair et al., 2019). As shown in Table 4, all HTMT values are below 0.85, and the upper limits of the 95% confidence intervals for HTMT are all below 0.85. Overall, both methods confirm that the model exhibits good discriminant validity.

Table 4 Heterotrait-monotrait ratio (HTMT) and VIF

	HIMT	2.50%	97.50%	inner model	VIF
GI <-> GHRM	0.609	0.531	0.682	GHRM -> GI	1
GSCM <-> GHRM	0.626	0.547	0.699	GHRM -> GSCM	1.397
GSCM <-> GI	0.582	0.502	0.649	GHRM -> SP	1.631
SP <-> GHRM	0.69	0.62	0.755	GI -> GSCM	1.397
SP <-> GI	0.666	0.601	0.724	GI -> SP	1.576
SP <-> GSCM	0.713	0.654	0.765	GSCM -> SP	1.633

(*The confidence interval is 95%.)

Structural Model Assessment

According to Hair et al. (2019), before evaluating structural relationships, it is crucial to check for multicollinearity to ensure it does not bias regression results. Typically, this is assessed using the variance inflation factor (VIF). A VIF value greater than 5 indicates potential multicollinearity issues between predictor constructs, with a preferable VIF value close to or below 3 (Hair et al., 2019). The results, shown in Table 4, indicate that the VIF values for the internal model range from 1 to 1.633, all below 3.

Next, GHRM (GHRM) will be analyzed as the independent variable, with green innovation and GSCM as mediating variables, and sustainable performance as the dependent variable. A bootstrapping method with 5,000 resamples using Smart PLS 4.1 will be employed to test the hypotheses (Hair et al., 2016 ; Hair et al., 2022), with a 95% confidence interval. The results are presented in Figure 3. In Figure 3, the numbers on the path relationships represent the path coefficients and t-values of the structural variables, while the external measurement model displays the t-values. The numbers within the circles of each structural variable indicate the R^2 values.

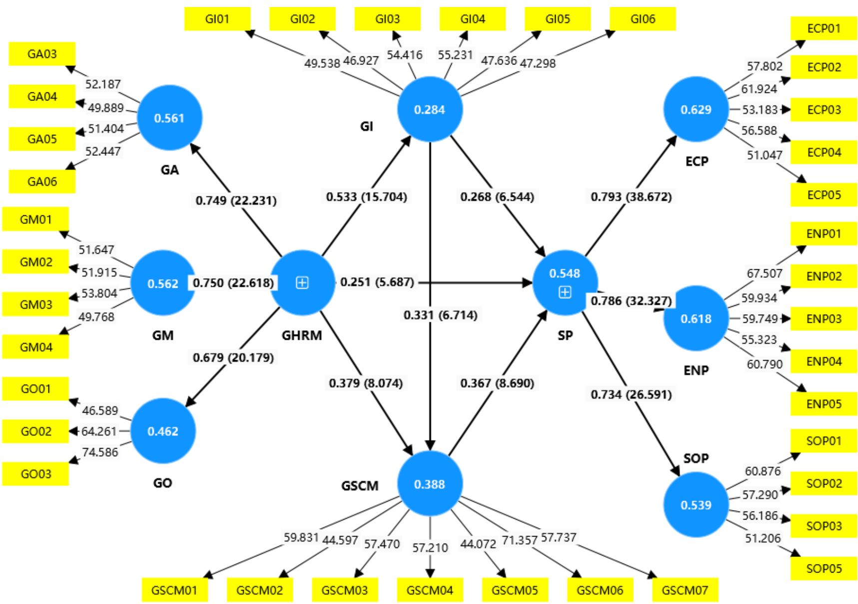

Figure 3 the result of Bootstrapping

Hypothesis Testing

Table 5 Hypothesis testing

Hypotheses	Paths	β values	SD	*t* Statistics	p Value	2.50%	97.50%	Remarks
H1	GHRM -> GI	0.533	0.034	15.704	0.000	0.465	0.6	Supported
H2	GHRM -> GSCM	0.379	0.047	8.074	0.000	0.289	0.475	Supported
H3	GHRM -> SP	0.251	0.044	5.687	0.000	0.164	0.339	Supported
H4	GI -> GSCM	0.331	0.049	6.714	0.000	0.229	0.423	Supported
H5	GI -> SP	0.268	0.041	6.544	0.000	0.187	0.35	Supported
H7	GSCM -> SP	0.367	0.042	8.69	0.000	0.284	0.448	Supported

(The confidence interval is 95%. Tested by Two tails, **p < 0.01, *p < 0.05.)

This study employed bootstrapping with 5,000 resamples in Smart PLS 4.1 to test the hypotheses (Hair et al., 2016), with a 95% confidence interval. The results, shown in Table 6, indicate that GHRM has a significant positive effect on green innovation (β=0.533, t=15.704, p=0.000<0.05); GHRM also significantly positively affects GSCM (β=0.379, t=8.074, p=0.000<0.05); and it significantly positively impacts sustainable performance (β=0.251, t=5.687, p=0.000<0.05). Additionally, green innovation has a significant positive effect on GSCM (β=0.331, t=6.714, p=0.000<0.05) and sustainable performance (β=0.268, t=6.544, p=0.000<0.05);

GSCM significantly positively affects sustainable performance (β=0.367, t=8.69, p=0.000<0.05). The results indicate that hypotheses H1, H2, H3, H4, H5, and H7 are all supported.

Assessment of the model's predictive validity

According to the recommendations of Hair et al. (2019), the evaluation of a structural model should consider several criteria, including the coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), and the statistical significance and relevance of path coefficients.

An R^2 greater than 0.2 signifies good explanatory power, with R^2 values of 0.67, 0.33, and 0.19 representing strong, moderate, and weak explanatory power, respectively (Hair et al., 2020). All models have R^2 values greater than 0.2, indicating good explanatory capability (see Table 6).

Table 6 The results of the model's predictive validity assessment

	R-square	R-square adjusted	Q^2	Effect size (f^2)		
				GHRM	GI	GSCM
GI	0.284	0.282	0.279	0.397		
GSCM	0.388	0.384	0.306	0.168	0.128	
SP	0.548	0.545	0.354	0.086	0.101	0.182

Additionally, all models have Q^2 values greater than 0, demonstrating predictive relevance. Finally, the f^2 effect size was assessed, which measures the impact of exogenous latent variables on endogenous latent variables. Values above 0.02, 0.15, and 0.35 describe small, medium, and large f^2 effect sizes (Hair et al., 2019). The results indicate that GHRM has a large effect on green innovation, a medium effect on green supply chain management, and a small effect on sustainable performance; green innovation has a low effect on both GSCM and sustainable performance; and GSCM has a medium effect on sustainable performance.

Mediation Effect Test

The results indicate that green innovation mediates the relationship between GHRM and sustainable performance. According to empirical rules, if the 95% confidence interval of the indirect effect does not include zero based on t-tests and p-tests, the mediation effect is statistically significant and supports the mediation role (Tan et al., 2019). A VAF (Variance Accounted For) value above 80% indicates full mediation, while a VAF between 20% and 80% suggests partial mediation, and a VAF below 20% indicates no mediation effect (Hair et al., 2016). The study results show that green innovation partially mediates the relationship between GHRM practices and sustainable performance. The indirect effect value is 0.143 (t=5.975, p=0.000<0.05), with a confidence interval between 0.191 and 0.598 not including 0, and VAF=23.91%, indicating a partial mediation effect, thus supporting hypothesis H6.

Additionally, the results show that GSCM mediates the relationship between GHRM and sustainable performance, supporting hypothesis H8. The indirect effect value is 0.139 (t=6.157, p=0.000<0.05), with a confidence interval between 0.097 and 0.185 not including 0, and VAF=23.24%, indicating a partial mediation effect.

Table 7 Mediation analysis

Hypotheses	Path	Indirect effects	t Statistics	P values	LLCI (2.5%)	ULCI (97.5%)	Total effects	VAF	Remarks
H6	GHRM -> GI -> SP	0.143	5.975	000	0.099	0.191	0.598	23.91%	Supported
H8	GHRM -> GSCM -> SP	0.139	6.157	000	0.097	0.185	0.598	23.24%	Supported

(The confidence interval is 95%. Tested by Two tails, **p < 0.01, *p < 0.05.)

Discussion

The results indicate that GHRM has a positive impact on green innovation, confirming H1. This finding is consistent with Al-Shammari et al. (2022), which supports the notion that GHRM is a necessary condition for promoting green innovation. Companies should enhance practices related to green capabilities, green motivation, and green opportunities to provide more talent support for green innovation. They should focus on selecting and training employees with a high level of environmental responsibility and improving their environmental management knowledge and skills to foster and sustain green innovation.

The results also show that GHRM significantly positively influences green supply chain management, validating H2. This finding aligns with the results of Xie & Buavaraporn (2019) and Trujillo-Gallego (2022). GHRM is a driving factor for implementing GSCM and can facilitate its execution. Given that manufacturing enterprises are resource-based industrial sectors, the findings support the necessity of implementing GHRM and GSCM within these enterprises. Considering the resource-intensive nature and environmental impact of the manufacturing industry, companies should actively embrace green-oriented management practices and implement GHRM strategies to enhance the environmental management awareness and capabilities of all employees.

The results demonstrate that green innovation has a significant positive impact on green supply chain management, confirming H4. This finding is consistent with Seman et al. (2019). The study shows that green innovation is both a part of and a driving force for green supply chain management, promoting its implementation. This underscores the importance of prioritizing green innovation to advance green supply chain management. In the face of resource constraints and pollution reduction challenges, emphasizing green innovation focused on continuous product optimization and production process upgrades can become a crucial path for achieving sustainable development.

The study's results indicate that GHRM, green innovation, and GSCM are simultaneously applied in corporate management, supporting the development of green principles and enhancing sustainable performance (H3, H5, and H7 are validated). The research further confirms that cross-functional integration is key to effective environmental management. The findings primarily support the hypothesis of a mediating model where GHRM, green innovation, and GSCM are coordinated and designed through cross-functional integration (H6 and H8 are validated), consistent with Al-Shammari et al. (2022). Companies should systematically design and implement human resource management policies within the organization, ensuring consistency in practice to reduce barriers to the implementation of green innovation and green supply chain management, thereby contributing to improved organizational sustainable performance.

New Knowledge

First, GHRM practices consist of green competence practices, green motivation practices, and green opportunity practices, which collectively enhance the impact of GHRM on sustainable performance.

Second, GHRM has a significant and positive effect on both green innovation and GSCM.

Third, green innovation and GSCM play a sequential mediating role in the relationship between GHRM and sustainable performance.

Fourth, green innovation has a significant and positive influence on GSCM. Moreover, green innovation partially mediates the relationship between GHRM and GSCM.

Fifth, both green innovation and GSCM exert significant positive impacts on sustainable performance, with GSCM partially mediating the relationship between green innovation and sustainable performance (shown in Table 8).

Table 8 Results of other mediation analysis

Path	Indirect effects	t values	P values	LLCI (2.5%)	Total effects	VAF	Remarks
GHRM -> GI -> GSCM -> SP	0.065	5.119	***	0.041	0.598	10.87%	No effect
GI -> GSCM -> SP	0.122	5.081	***	0.076	0.39	31.28%	partial mediation
GHRM -> GI -> GSCM	0.177	6.625	***	0.123	0.556	31.83%	partial mediation

The confidence interval is 95%. Tested by Two tails, **$p < 0.01$, *$p < 0.05$.)

Conclusion

This paper develops a conceptual model encompassing GHRM, Green Innovation, GSCM, and Sustainable Performance. The primary aim is to explore the relationship between GHRM and sustainable performance, as well as the mediating roles of green innovation and GSCM. Based on this framework, the collected sample data were tested using Partial Least Squares Structural Equation Modeling (PLS-SEM), and all hypotheses were validated. Through theoretical analysis and empirical research, the following conclusions were drawn.

First, the findings indicate that GHRM plays a crucial role in facilitating the implementation of green innovation. GHRM serves as a necessary condition for promoting green innovation.

Second, the study demonstrates that GHRM also enhances the implementation of GSCM. GHRM acts as a driving factor in GSCM by providing high-quality human resources, which in turn promotes green supply chain practices and improves performance.

Third, the research reveals that GHRM is pivotal for enhancing corporate sustainable performance. Through practices aimed at improving green competencies, green motivation, and green opportunities, GHRM significantly raises employees' green awareness and abilities, thereby reinforcing the implementation of environmental management systems and improving sustainable performance.

Fourth, the study shows that green innovation significantly influences the implementation of GSCM. Green innovation acts as a driver of GSCM, enhancing the overall efficiency and effectiveness of the supply chain. Finally, it was found that green innovation and GSCM mediate the relationship between GHRM and sustainable performance. Companies can achieve a synergistic improvement in sustainable performance by jointly implementing GHRM, green innovation, and GSCM, coordinating these elements through an integrated GHRM system.

Suggestion

Suggestions for the companies

This study holds significant managerial implications for manufacturing enterprises in Guangdong and other regions of China. First, companies must recognize the critical role of GHRM practices and proactively implement them. Specifically, green competence, green motivation, and green opportunity practices are essential components of GHRM and must be systematically designed and executed to enhance their impact on sustainable performance. Enterprises should focus on developing a robust GHRM system by establishing comprehensive regulations that integrate the "green competence–green motivation–green opportunity" framework. This will better mobilize employees' green initiatives and provide continuous support for green innovation and GSCM.

Second, companies should fully appreciate the importance of integrating GHRM, green innovation, and GSCM. A top-down approach should be adopted, with clear green development goals that align with the company's overall strategy and sustainability objectives. By efficiently allocating human, material, and financial resources, companies can ensure that GHRM fosters green innovation and supports GSCM practices, thereby maximizing sustainable performance.

Finally, companies should embrace independent innovation as a routine practice, investing actively in green technology research and transforming operational processes. Companies must recognize the driving effect of green innovation on GSCM and use it to facilitate the shift toward greener supply chains. Strategic planning for green innovation investment, along with coordination across the entire value chain, will strengthen sustainable supply chain management. This will help reduce green innovation costs while ensuring the delivery of higher-quality, environmentally friendly products and services to the market.

Suggestions for future research

This study was conducted within the context of a developing country with distinctive cultural and economic characteristics, which may limit the generalizability of the findings. As a result, the conclusions may not apply to other developing or developed countries. Future research could address this limitation by incorporating a broader sample of multinational corporations to validate the relationships between the variables examined in this study. Comparative analysis across different countries could further enhance the understanding of the results and provide deeper insights.

Moreover, this study did not investigate factors such as corporate culture, environmental values, or employee self-efficacy at the individual level, which may mediate the relationship between GHRM and sustainable corporate performance. Therefore, future research is recommended to explore the role of corporate culture, employees' environmental values, and self-efficacy in explaining how GHRM influences green innovation and green supply chain management. This would contribute to a more comprehensive understanding of the mechanisms at play.

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