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The moderating role of green human resource management practices on the relationship between green capital and sustainable manufacturing

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Abstract
This study examines the moderating role of green human resource management practices (GHRMP) in the relationship between green intellectual capital (GIC) and sustainable manufacturing. Green intellectual capital is operationalized through three dimensions: green human capital, green structural capital, and green social capital. Using a quantitative research design, data were collected from 234 respondents employed in a manufacturing firm whose operational context aligns with the study objectives. The research framework was tested using Partial Least Squares–Structural Equation Modeling (PLS-SEM). The analytical strategy comprised one main structural model assessing the direct effect of overall GIC on sustainable manufacturing and three sub-models examining the individual effects of the GIC dimensions, including the moderating role of GHRMP. In total, nine hypotheses were formulated and empirically tested. The findings reveal a significant positive effect of overall green intellectual capital on sustainable manufacturing, with GHRMP exerting a strengthening moderating effect. At the dimensional level, green human capital and green social capital demonstrated significant positive relationships with sustainable manufacturing, both directly and under moderation. In contrast, green structural capital exhibited a negative and non-significant moderating effect, indicating that insufficient institutionalized environmental knowledge and weak regulatory awareness may hinder sustainability outcomes. Overall, seven out of nine hypotheses were supported. The findings suggest that manufacturing firms should strategically strengthen green HRM practices-particularly green training, performance management, and employee engagement-to effectively leverage green human and social capital for sustainable manufacturing outcomes, while improving environmental governance structures to address weaknesses in green structural capital.

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1. Introduction

In recent decades, growing environmental concerns and the pressing need for sustainable development have urged industries across the globe to integrate eco-friendly practices into their strategic frameworks (Abo-Khalil, 2024; Sedovs et al., 2025). Manufacturing firms, in particular, face mounting pressure to adopt sustainable practices to reduce environmental impact, improve efficiency, and comply with emerging regulatory standards (Rame et al., 2024; Haleem et al., 2023). Globally, rising awareness of climate change is driving the adoption of diverse sustainable practices across countries and industries (Abbass et al., 2022). Sustainability is a growing global priority, with governments, businesses, and individuals all sharing responsibility for reducing environmental harm (Moghrabi et al., 2023).

Within this context, Green Intellectual Capital (GIC) has emerged as a critical driver of organizational sustainability, playing a key role in fostering innovation, adaptability, and sustainable solutions within organizations (Begum and

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Swamy, 2024). GIC comprises three main components, including Green Human Capital (GHC), Green Structural Capital (GSTC), and Green Social Capital (GSC). Each of these elements contributes uniquely to a firm's sustainable journey (Qiu et al., 2024). GHC refers to employees' environmental knowledge and attitudes, GSTC covers organizational systems supporting environmental practices, and GSC involves relationships and networks that promote eco-friendly collaboration (Ahmad et al., 2023).

However, prior research has primarily examined either the direct effects of GIC on sustainable or green performance or the standalone role of Green Human Resource Management Practices (GHRMP) in enhancing sustainability outcomes (Umar et al., 2024; Yusliza et al., 2020; Zaid et al., 2018). On the other hand, existing evidence also suggests that the mere presence of green intellectual capital may not be sufficient to ensure effective implementation of sustainable manufacturing practices. One such enabler is Green Human Resource Management Practices (GHRMP), which play a critical role in embedding sustainability into organizational processes by developing an eco-conscious workforce, fostering environmental skills, and ensuring that green initiatives are effectively implemented (Ullah et al., 2023; Yusliza et al., 2020). GHRMP aligns HR strategies with environmental goals through green hiring, training, performance management, and rewards, thereby strengthening the impact of intellectual capital on manufacturing outcomes (Din et al., 2025; Qiu et al., 2024).

The intersection of GIC and GHRMP remains underexplored, particularly regarding the moderating role of GHRMP on the relationships between GIC dimensions and sustainable manufacturing (Yu et al., 2020). Highlighting GHRMP's importance provides a clear rationale for focusing on HR practices as a key mechanism to translate intellectual capital into tangible sustainability results. By reinforcing environmental values and fostering green capabilities, GHRMP may strengthen the links between the various dimensions of GIC and sustainable manufacturing outcomes (Qiu et al., 2024; Sarfo et al., 2024).

The interaction between GIC and GHRMP provides a promising but underexplored pathway for achieving sustainable manufacturing. While prior studies have examined the direct effects of green HRM or green intellectual capital independently, empirical research investigating how GHRMP moderates the relationships between specific GIC dimensions and sustainable manufacturing remains limited (Anum et al., 2025; Pontillo et al., 2025; Shahbaz and Malik, 2025; Sarfo et al., 2024; Yusliza et al., 2020). This study advances the literature by moving beyond direct and mediating relationships to explicitly examine the moderating role of GHRMP on the relationships between distinct GIC dimensions (GHC, GSTC, and GSC) and sustainable manufacturing. Unlike earlier work that assumes uniformly positive effects of all GIC components, this research empirically tests whether HR systems amplify, neutralize, or constrain the effectiveness of specific green intellectual assets, thereby responding to calls for more nuanced, mechanism-based explanations of sustainability outcomes (Agyabeng-Mensah and Tang, 2021; Buhaya and Metwally, 2024).

The problem of the current study arises from accelerating climate change and the critical situation facing governments. It has become inevitable for them to move towards green industries and reduce pollution, and sustainable manufacturing has played a decisive role in this (Bolan et al., 2024). It has become an important issue to balance the environmental, social, economic, technical, and manufacturing aspects, and this can only be achieved by applying GIC as a driving force for sustainable manufacturing (Ni et al., 2023). To enhance impact, several environmental practices must be implemented through green human resource management. This study arises from the growing challenges organizations face due to competition and environmental changes, highlighting the need to rethink production processes. It is now essential for organizations to offer high-value, environmentally compatible products and services.

This gap is particularly pronounced in developing economies such as Iraq, where institutional constraints, regulatory enforcement, and uneven adoption of green practices can alter the effectiveness of intellectual capital in driving sustainability. In the Iraqi manufacturing context, empirical evidence on the integration of green intellectual capital and green HRM practices is scarce, despite increasing environmental pressures and regulatory expectations. The current study addresses this gap by investigating the direct effects of GIC on sustainable manufacturing, the moderating role of GHRMP, and the current status of green practices in Iraqi organizations. Accordingly, the present study identifies three key gaps in the literature:

(i) the lack of empirical evidence on the moderating role of GHRMP in the GIC–sustainable manufacturing relationship;

(ii) the limited understanding of differential effects among GIC dimensions, particularly the underperformance of green structural capital; and

(iii) the scarcity of context-specific evidence from developing economies, especially Iraq.

Accordingly, the purpose of this study is threefold:

(i) to examine the direct effects of green intellectual capital and its dimensions (GHC, GSTC, and GSC) on sustainable manufacturing;

(ii) to investigate the moderating role of green human resource management practices in strengthening or weakening these relationships; and

(iii) to assess the current level of green intellectual capital, green HRM practices, and sustainable manufacturing within Iraqi manufacturing organizations.

To achieve these objectives, a quantitative research design was employed, with survey data collected from 234 employees of a manufacturing organization in Iraq. Partial Least Squares–Structural Equation Modeling (PLS-SEM) was used to assess the measurement and structural models, ensuring robust evaluation of relationships between constructs. By integrating intellectual capital theory with green HRM perspectives and testing interaction effects in a developing-country manufacturing context, this study offers a distinct theoretical and empirical contribution beyond prior research. The study also examines six guiding research questions related to the levels of GIC, GHRMP, and sustainable manufacturing, and the interactions between these variables. The following questions were developed to guide the study,

- To what extent do organizations adhere to sustainable manufacturing standards?
- What is the relationship between green intellectual capital and sustainable manufacturing? Do green human resource management practices enhance this relationship?
- Does green intellectual capital affect sustainable manufacturing?
- What is the level of green intellectual capital among the sample of the current study?
- What is the level of sustainable manufacturing in the current study sample?
- Have green human resource management practices been applied correctly and completely?

The findings reveal that green intellectual capital has a significant positive impact on sustainable manufacturing, with green human capital and green social capital showing stronger effects. Green human resource management practices significantly enhance this relationship, while the moderating effect on green structural capital appears weak or negative, indicating gaps in institutionalized environmental systems and regulatory awareness. By addressing these issues, this study contributes to the literature by empirically clarifying the conditional role of green HRM practices in translating green intellectual capital into sustainable manufacturing outcomes, particularly in a developing-country context. Practically, it offers guidance for managers and policymakers seeking to design integrated green strategies that align human resources, intellectual capital, and sustainability objectives.

The study provides one of the first empirical investigations in the Iraqi manufacturing sector, offering context-specific evidence on how institutional limitations shape the interaction between GIC, GHRMP, and sustainable manufacturing-an aspect largely absent from prior studies conducted in more developed or institutionally mature settings.

The organization of this paper is as follows. Section 2 provides a theoretical framework and literature review. Section 3 describes the methodology, and the applied techniques are elaborated. In section 4, the results of the proposed model are reported, and in the last sections, the discussion and conclusions are presented.

2. Theoretical framework

2.1. Green intellectual capital

Growing global interest in environmental protection has increased awareness and driven the development of green intellectual capital (Marco-Lajara et al., 2022; Wei et al., 2023). GIC integrates intellectual assets with environmental concerns at both organizational and individual levels, encompassing knowledge, skills, experience, and relationships that enhance environmental performance and sustainable competitive advantage (Atalla et al., 2024; Alnaim and Metwally, 2024; Asiaei et al., 2023). It reflects a proactive organizational approach to mitigating environmental impacts while fulfilling social responsibilities and promoting awareness (Alnaim and Metwally, 2024). The key components of GIC are GHC, GSTC, and GSC, which collectively drive sustainable manufacturing by embedding environmental knowledge, systems, and collaborative networks into organizational operations (Bombiak, 2023; Ahmad et al., 2023).

The primary goal of GIC is to improve environmental conditions, foster innovation, and support sustainable manufacturing (Buhaya and Metwally, 2024). Organizations with strong GIC can generate new knowledge, innovate products, and develop effective solutions for environmental challenges, often leveraging green human resource management practices to maximize impact (Martínez-Falcó et al., 2024; Yadiati et al., 2019;).

2.2. Green human resources management practices

Environmental challenges, global competition, and technological changes have made green human resource management practices essential (Tahir et al., 2024). GHRMP aligns HR activities, including recruitment, training, performance evaluation, and rewards, with environmental objectives, fostering a green workforce capable of supporting sustainable initiatives (Gupta and Jangra, 2024; Vadithe et al., 2025).

Green HRM contributes to sustainability by enhancing operational efficiency, reducing costs, increasing employee engagement, and strengthening organizational competitiveness (Alfadel et al., 2025; Mamun, 2025; Montalvo-Falcón et al., 2023; Zihan et al., 2024). By cultivating eco-conscious employees and embedding sustainability in organizational processes, GHRMP operationalizes GIC and ensures the effective implementation of green initiatives, bridging the gap between intellectual capital and tangible sustainable outcomes (Faeni et al., 2025; Vadithe et al., 2025).

2.3. Sustainable manufacturing

Sustainable manufacturing focuses on producing goods with minimal waste and carbon footprint while optimizing resource use, aiming for environmental, social, and economic benefits (Verma et al., 2022; Ekins and Zenghelis, 2021). It emphasizes accountability, long-term impacts, and process efficiency, integrating energy conservation, renewable energy adoption, and resource optimization to safeguard the environment and improve product quality (Haleem et al., 2023; Gielen et al., 2019).

Organizations adopt sustainable manufacturing to boost operational efficiency, comply with regulations, enhance brand reputation, and capitalize on market opportunities (Chauhan et al., 2022; Rosen and Kishawy, 2012). When combined with GIC and supported by GHRMP, sustainable manufacturing outcomes are strengthened, as intellectual capital and green HR practices collectively foster innovation, environmental performance, and long-term competitiveness.

3. Methodology

3.1. Building hypotheses

Research highlights a strong link between GIC and SM, as widely discussed in academic and business literature. GIC encompasses an organization's environmental knowledge, skills, and capabilities, while SM focuses on minimizing environmental harm, conserving resources, and promoting long-term ecological balance. Organizations with robust GIC are better positioned to drive innovation in sustainable manufacturing, particularly when supported by effective GHRMP (Borah et al., 2023; Marco-Lajara et al., 2022).

Employees knowledgeable in environmental science and green practices are a key component of GIC, aiding the development and execution of sustainable processes (Khan et al., 2024). GIC also shapes strategic decisions by embedding sustainability into manufacturing and supply chains, especially through compliance with environmental regulations-a core element of GHRMP (Bhardwaj, 2016; Singh et al., 2025). The synergy between GIC and GHRMP enhances resource efficiency, reduces waste, and supports environmentally conscious operations (Qiu et al., 2024). Organizations committed to sustainability, empowered by GIC and green HR practices, often build stronger brand reputations, appealing to eco-conscious consumers (Sarfo et al., 2024; Verma et al., 2022). This study explores how GHRMP moderates the relationship between GIC and its components, and how it moderates the link between GIC and SM, focusing particularly on this moderating role alongside other hypotheses presented below.

Hypothesis 1: Direct Effects of Green Intellectual Capital on Sustainable Manufacturing

Research highlights a strong link between GIC and SM, as widely discussed in academic and business literature. GIC encompasses an organization's environmental knowledge, skills, and capabilities, while SM focuses on minimizing environmental harm, conserving resources, and promoting long-term ecological balance. Organizations with robust GIC are better positioned to drive innovation in sustainable manufacturing (Borah et al., 2023; Marco-Lajara et al., 2022).

H1: Green intellectual capital has a significant positive effect on sustainable manufacturing.

Given that GIC comprises three distinct dimensions – green human capital, green structural capital, and green social capital – each contributing uniquely to organizational sustainability outcomes, the following sub-hypotheses are proposed:

H1a: Green human capital has a significant positive effect on sustainable manufacturing.

H1b: Green structural capital has a significant positive effect on sustainable manufacturing.

H1c: Green social capital has a significant positive effect on sustainable manufacturing.

Hypothesis 2: Direct Effect of Green Human Resource Management Practices on Sustainable Manufacturing

Green HRM contributes to sustainability by enhancing operational efficiency, reducing costs, increasing employee engagement, and strengthening organizational competitiveness (Alfadel et al., 2025; Mamun, 2025; Montalvo-Falcón et al., 2023). By cultivating eco-conscious employees and embedding sustainability in organizational processes, GHRMP ensures the effective implementation of green initiatives (Faeni et al., 2025; Vadithe et al., 2025).

H2: Green human resource management practices have a significant positive effect on sustainable manufacturing.

Hypothesis 3: Moderating Role of Green Human Resource Management Practices

The mere presence of green intellectual capital may not be sufficient to ensure effective implementation of sustainable manufacturing practices. GHRMP plays a critical role in embedding sustainability into organizational processes by developing an eco-conscious workforce, fostering environmental skills, and ensuring that green initiatives are effectively implemented (Ullah et al., 2023; Yusliza et al., 2020). By reinforcing environmental values and fostering green capabilities, GHRMP may strengthen the links between the various dimensions of GIC and sustainable manufacturing outcomes (Qiu et al., 2024; Sarfo et al., 2024).

H3: Green human resource management practices positively moderate the relationship between green intellectual capital and sustainable manufacturing, such that the effect of GIC on SM is stronger when GHRMP is higher.

To examine the moderating role of GHRMP across distinct GIC dimensions, the following sub-hypotheses are proposed:

H3a: Green human resource management practices positively moderate the relationship between green human capital and sustainable manufacturing.

H3b: Green human resource management practices positively moderate the relationship between green structural capital and sustainable manufacturing.

H3c: Green human resource management practices positively moderate the relationship between green social capital and sustainable manufacturing.

3.2. Study population and sample

The study was conducted at the Al Noura factory in Karbala, selected for its industrial and environmental significance and alignment with the research objectives. Al Noura Factory is a lime and calcium carbonate production facility located in Karbala, Iraq, operating under the Iraqi General Cement Company and the Ministry of Industry and Minerals. The factory specializes in producing quick lime, hydrated lime, calcium carbonate filler, and crushed limestone, known for their high purity and fine consistency. The factory was selected for this study due to its industrial significance, alignment with sustainable manufacturing objectives, and potential for implementing green human resource management practices. Data were collected over three months, from October to December 2022. A random sample of employees from the administrative, technical, and production departments was invited to participate. Out of 447 permanent employees, 234 completed questionnaires were obtained, representing 52.3% of the workforce, which was considered adequate for statistical analysis. Incomplete or improperly filled questionnaires were excluded from the study. Participants were given 90 days to complete the survey, and the sample size was determined with a 3% margin of error, in accordance with Saunders et al. (2015).

The survey was designed to measure three primary constructs: Green Intellectual Capital (GIC), Green Human Resource Management Practices (GHRMP), and Sustainable Manufacturing (SM). The GIC construct was further divided into three dimensions: Green Human Capital (GHC), Green

Structural Capital (GSTC), and Green Social Capital (GSC). The GHRMP construct included multiple items assessing the extent to which the factory applied green recruitment, training, labor relations, health and safety, performance management, compensation, and job design practices. The SM construct was measured across five domains: social, manufacturing, environmental, economic, and technical aspects. Respondents rated all items using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The survey was structured into four main sections: (i) demographic information, (ii) assessment of GIC and its dimensions, (iii) evaluation of GHRMP, and (iv) assessment of SM performance.

Prior to structural model estimation, multicollinearity among the latent constructs and their indicators was assessed using the Variance Inflation Factor (VIF). VIF values were calculated for all predictor variables in the PLS-SEM model to ensure that collinearity did not bias the path coefficients. Following established guidelines, VIF values below the threshold of 3.3 were considered indicative of no critical multicollinearity issues, confirming the suitability of the data for regression-based analysis and PLS-SEM estimation.

3.3. Measures used for the study

3.3.1. Green intellectual capital (GIC)

The authors developed the green intellectual capital measurement based on the work of Mulatsih (2025) and Sarwar and Mustafa (2024), comprising three sub-dimensions: green human capital (GHC; 4 items), green structural capital (GSTC; 3 items), and green social capital (GSC; 6 items).

3.3.2. Green human resources management practices (GHRMP)

The scale was adopted from Freihat et al. (2024) and Tang et al. (2018) and comprises seven dimensions: green job design (GJD; 3 items), green recruitment and selection (GRS; 3 items), green training and development (GTD; 3 items), green performance management (GPM; 4 items), green compensation management (GCM; 4 items), green health and safety management (GHS; 2 items), and green labor relations (GLR; 4 items). Each dimension captures specific aspects of Green HRM practices within organizations.

3.3.3. Sustainable manufacturing (SM)

This variable was measured using the scale developed by Butt et al. (2024) and Keshav and Raut (2018), covering five dimensions: social dimension (SD; 4 items), manufacturing dimension (MD; 3 items), environmental dimension (END; 5 items), economic dimension (ECD; 3 items), and technical dimension (TD; 5 items). A five-point Likert scale was applied across all items, ranging from "Strongly Disagree" (1) to "Strongly Agree" (5).

3.4. Study scheme

Based on the conceptual frameworks of the study variables, as well as the research problem, hypotheses, and objectives, an analytical model was developed to illustrate the role of the moderating variable, green human resource management practices, in the relationship between the independent variable (green intellectual capital) and the dependent variable (sustainable manufacturing), as presented in Figure 1.

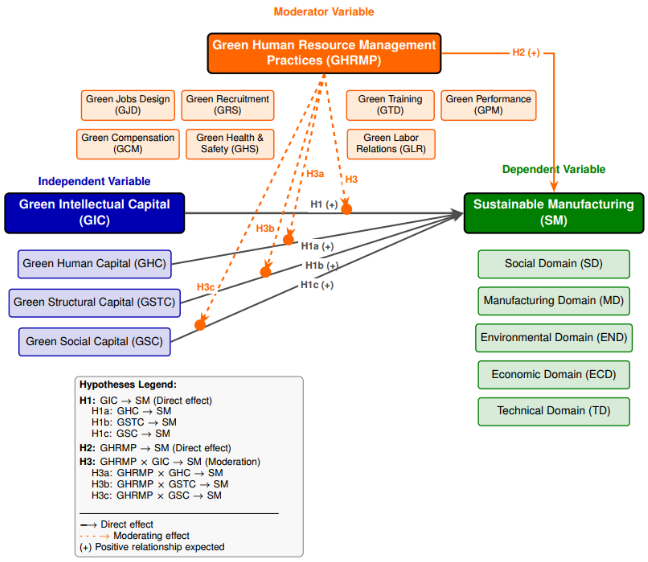

Fig. 1. Scheme of the study

4. Statistical analysis

The empirical examination employed a dual-platform analytical strategy combining IBM SPSS Version 29 with SmartPLS Version 4.1.1.6. This methodological approach facilitated a comprehensive investigation spanning foundational descriptive metrics through advanced structural equation modeling procedures. Partial Least Squares Structural Equation Modeling (PLS-SEM) was selected as the primary analytical framework due to its robust capability to simultaneously evaluate measurement properties while testing complex theoretical relationships, particularly when examining formative constructs and moderating mechanisms (Hair et al., 2022; Sarstedt et al., 2021). The technique proves especially advantageous when theoretical models incorporate multiple latent variables with intricate interdependencies, as observed in the current investigation linking green intellectual capital, sustainable manufacturing outcomes, and moderating influences of green human resource management practices.

Before proceeding with substantive analyses, potential methodological artefacts warranting investigation included common method variance, a systematic error source that artificially inflates construct relationships when single-source data collection occurs. Two complementary diagnostic procedures were implemented to evaluate this concern. Harman's single-factor test, executed through exploratory factor analysis with unrotated solutions, revealed that the initial component accounted for merely 13% of total variance explained, substantially below the conventional 50% threshold, indicating problematic method effects (Podsakoff et al., 2012; Kock, 2015). Additionally, collinearity diagnostics examining variance inflation factors across all predictor constructs demonstrated a maximum VIF value of 1.556, far beneath the conservative 3.3 cutoff suggested for PLS-SEM applications (Kock & Lynn, 2012). These convergent findings provide compelling evidence that common method bias does not compromise the integrity of subsequent analytical interpretations.

5. Results

5.1. Analysis of measurement assessment

Psychometric validation of the measurement instruments preceded structural model evaluation, following established two-stage assessment protocols for PLS-SEM applications (Henseler et al., 2016; Ringle et al., 2020). This preliminary phase scrutinizes whether operationalized indicators reliably and validly capture their intended latent constructs through systematic examination of individual item loadings, internal consistency coefficients, and discriminant validity metrics.

The measurement purification process necessitated the strategic removal of two problematic indicators to enhance overall model quality. Initially, the END2 item (Environmental domain) exhibited a standardized loading of 0.575, which, while marginally acceptable, contributed to discriminant validity concerns as evidenced by an inflated HTMT ratio of 1.045 between Environmental domain and Green human capital constructs. Upon its deletion, this ratio improved substantially to 0.936, falling within acceptable bounds (Henseler et al., 2015). Similarly, ECD2 (Economic domain) demonstrated an unacceptably weak loading of 0.336, substantially below the minimum 0.40 threshold recommended even for exploratory research contexts, necessitating its exclusion from subsequent analyses (Hair et al., 2019).

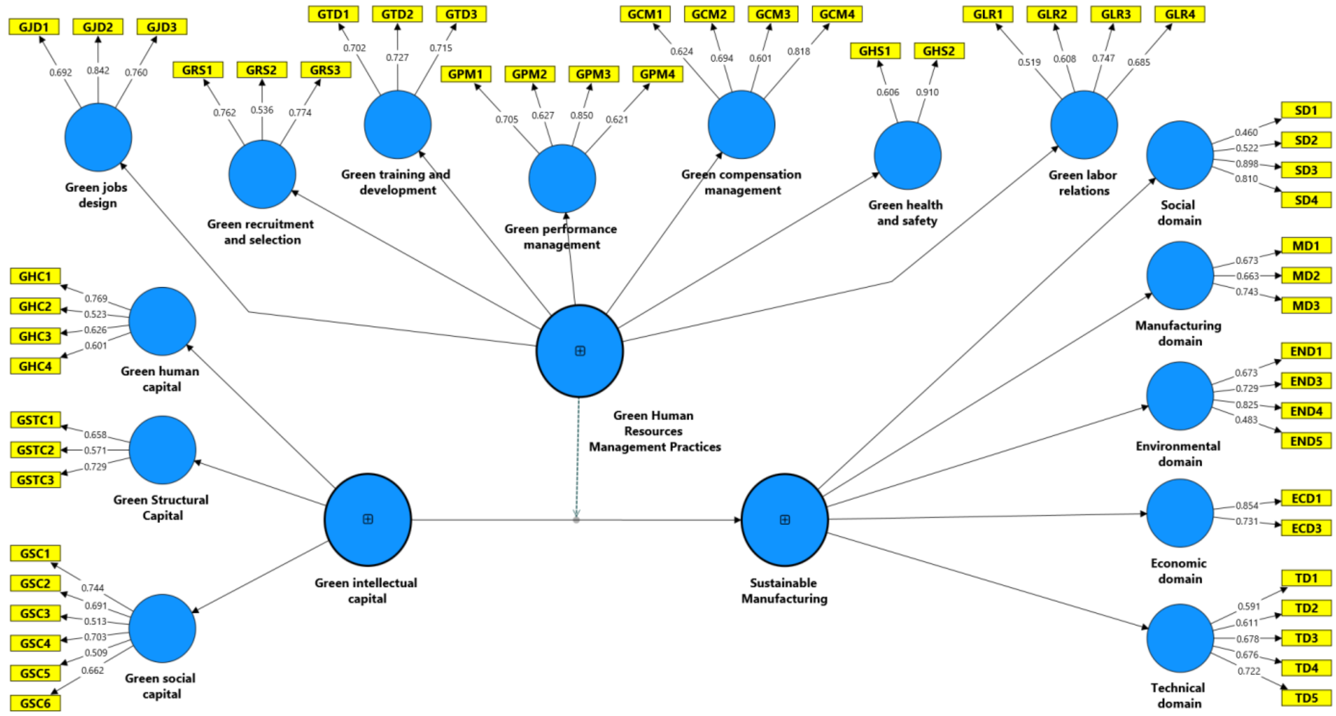

Fig. 2. Measurement model

Table 1. Reliability and convergent validity of constructs and their dimensions

	Loadings	Composite reliability (rhoc)	Average variance extracted (AVE)
GHC1 <- Green human capital	0.769	0.727	0.405
GHC2 <- Green human capital	0.523		
GHC3 <- Green human capital	0.626		
GHC4 <- Green human capital	0.601		
GSTC1 <- Green Structural Capital	0.658	0.691	0.43
GSTC2 <- Green Structural Capital	0.571		
GSTC3 <- Green Structural Capital	0.729		
GSC1 <- Green social capital	0.744	0.806	0.414
GSC2 <- Green social capital	0.691		
GSC3 <- Green social capital	0.513		
GSC4 <- Green social capital	0.703		
GSC5 <- Green social capital	0.509		

GSC6 <- Green social capital	0.662		
GJD1 <- Green jobs design	0.692		
GJD2 <- Green jobs design	0.842	0.81	0.589
GJD3 <- Green jobs design	0.760		
GRS1 <- Green recruitment and selection	0.762		
GRS2 <- Green recruitment and selection	0.536	0.737	0.489
GRS3 <- Green recruitment and selection	0.774		
GTD1 <- Green training and development	0.702		
GTD2 <- Green training and development	0.727	0.758	0.51
GTD3 <- Green training and development	0.715		
GPM1 <- Green performance management	0.705		
GPM2 <- Green performance management	0.627	0.797	0.5
GPM3 <- Green performance management	0.850		
GPM4 <- Green performance management	0.621		
GCM1 <- Green compensation management	0.624		
GCM2 <- Green compensation management	0.694	0.781	0.475
GCM3 <- Green compensation management	0.601		
GCM4 <- Green compensation management	0.818		
GHS1 <- Green health and safety	0.606	0.741	0.598
GHS2 <- Green health and safety	0.910		
GLR1 <- Green labor relations	0.519		
GLR2 <- Green labor relations	0.608	0.737	0.417
GLR3 <- Green labor relations	0.747		
GLR4 <- Green labor relations	0.685		
SD1 <- Social domain	0.460		
SD2 <- Social domain	0.522	0.779	0.487
SD3 <- Social domain	0.898		
SD4 <- Social domain	0.810		
MD1 <- Manufacturing domain	0.673		
MD2 <- Manufacturing domain	0.663	0.735	0.481
MD3 <- Manufacturing domain	0.743		
END1 <- Environmental domain	0.673		
END2 <- Environmental domain	Deleted		
END3 <- Environmental domain	0.729	0.778	0.475
END4 <- Environmental domain	0.825		
END5 <- Environmental domain	0.483		
ECD1 <- Economic domain	0.854		
ECD2 <- Economic domain	Deleted	0.773	0.631
ECD3 <- Economic domain	0.731		
TD1 <- Technical domain	0.591		
TD2 <- Technical domain	0.611		
TD3 <- Technical domain	0.678	0.791	0.432
TD4 <- Technical domain	0.676		
TD5 <- Technical domain	0.722		

Following these refinements, the measurement model demonstrated satisfactory psychometric properties across multiple criteria. All retained indicators achieved standardized loadings exceeding 0.40, with the majority surpassing the more stringent 0.70 benchmark, signaling adequate individual item reliability (Hulland, 1999). Construct-level assessments revealed composite reliability (ρc) coefficients ranging from 0.691 to 0.810 across all latent variables, comfortably exceeding the 0.60 minimum threshold while avoiding problematic redundancy above 0.95 (Sarstedt et al., 2017). Convergent validity, evaluated through average variance extracted (AVE), yielded values between 0.405 and 0.631, all surpassing the critical 0.40 cutoff that ensures each construct captures more systematic variance than measurement error (Fornell & Larcker, 1981; Bagozzi & Yi, 1988). These collective indicators affirm that the operationalized measurement framework possesses adequate reliability and validity to support meaningful interpretation of structural relationships in subsequent hypothesis testing phases.

Determining whether measurement scales genuinely differentiate between theoretical constructs stands as a critical validation checkpoint before advancing to hypothesis evaluation. The Heterotrait-Monotrait ratio offers a powerful lens through which researchers can detect whether supposedly distinct latent variables have collapsed into indistinguishable measurement artefacts (Henseler et al., 2015).

This diagnostic essentially asks: do correlations between items presumed to measure different phenomena approximate the strength of correlations among items designed to capture the same underlying attribute? When this ratio approaches unity, alarm bells should sound; the measurement framework may be failing its fundamental mission of construct separation

(Franke & Sarstedt, 2019). Conservative assessment protocols establish that HTMT values must remain beneath 1.0 to demonstrate acceptable discriminant validity (Gaskin et al., 2018). This unity threshold represents the point at which heterotrait correlations equal monotrait correlations, effectively signaling construct collapse. Table 2 systematically documents HTMT assessments across every possible construct pairing within the theoretical architecture. Results prove universally satisfactory. Not a single ratio breaches the critical 1.0 ceiling across all examined relationships. The highest observed value, 0.989 linking Green intellectual capital with the Environmental domain, approaches but critically stops short of problematic territory. Other noteworthy proximities include the 0.940 ratio between Green labor relations and Green health and safety, alongside the 0.933 connection between Green labor relations and Green human capital. These elevated associations make intuitive sense given the conceptual kinship among green human resource dimensions, yet their containment below unity confirms that empirical distinctiveness persists despite theoretical adjacency.

Table 2. Discriminant validity of constructs based on the Heterotrait-Monotrait (HTMT) ratio

	ED	END	GSTC	GCM	GHS	GHC	GJD	GLR	GPM	GRS	GSC	GTD	MD	SD	TD
ED															
END	0.495														
GSTC	0.587	0.452													
GCM	0.229	0.302	0.626												
GHS	0.588	0.459	0.553	0.452											
GHC	0.462	0.936	0.537	0.392	0.526										
GJD	0.311	0.472	0.489	0.476	0.669	0.490									
GLR	0.573	0.615	0.645	0.779	0.940	0.933	0.704								
GPM	0.229	0.380	0.470	0.463	0.226	0.817	0.231	0.475							
GRS	0.328	0.416	0.320	0.479	0.586	0.378	0.675	0.730	0.414						
GSC	0.559	0.966	0.728	0.323	0.589	0.613	0.541	0.536	0.264	0.585					
GTD	0.290	0.198	0.500	0.548	0.474	0.362	0.405	0.502	0.360	0.495	0.331				
MD	0.578	0.463	0.404	0.551	0.859	0.364	0.321	0.760	0.449	0.607	0.475	0.713			
SD	0.228	0.354	0.282	0.343	0.590	0.380	0.245	0.336	0.222	0.421	0.216	0.315	0.271		
TD	0.427	0.384	0.271	0.400	0.243	0.607	0.347	0.437	0.595	0.465	0.224	0.279	0.427	0.205	

5.2. Descriptive statistics and multiple correlations

Before examining intricate causal pathways within structural models, prudent analytical practice demands thorough exploration of variable distributions and bivariate association patterns. Descriptive profiling reveals whether data exhibit properties conducive to parametric modeling, specifically, whether respondent patterns cluster around meaningful central tendencies and whether distributions approximate normal or acceptably symmetric forms (Tabachnick & Fidell, 2019).

Correlation matrices subsequently illuminate preliminary relationship structures, exposing which theoretical constructs move in concert and flagging potential multicollinearity threats that could destabilize subsequent regression-based estimations. Together, these foundational diagnostics establish whether the empirical substrate possesses qualities necessary for reliable hypothesis adjudication.

Table 3. Descriptive statistics

Construct	N	Mean	SD	Skewness	Kurtosis
Green human capital	234	3.897	0.719	-0.399	-0.669
Green Structural Capital	234	3.682	0.764	-0.196	-0.833
Green social capital	234	3.925	0.794	-0.841	0.244
Green jobs design	234	3.886	0.901	-0.707	-0.296
Green recruitment and selection	234	3.903	0.811	-0.757	-0.025
Green training and development	234	3.558	0.881	-0.174	-0.895
Green performance management	234	3.703	0.820	-0.432	-0.674
Green compensation management	234	3.778	0.778	-0.189	-0.937
Green health and safety	234	3.468	0.826	0.178	-0.594
Green labor relations	234	3.919	0.690	-0.572	-0.249
Social domain	234	2.628	0.933	0.077	-0.851
Manufacturing domain	234	3.556	0.856	-0.160	-0.979
Environmental domain	234	3.847	0.894	-0.429	-0.905
Economic domain	234	3.741	0.977	-0.711	-0.009
Technical domain	234	3.830	0.756	-0.791	0.242
Green intellectual capital	234	3.835	0.559	-0.317	-0.916
Green Human Resources Management Practices	234	3.745	0.482	-0.385	-0.439
Sustainable Manufacturing	234	3.520	0.506	0.105	-0.589

Data collected from 234 organizational respondents reveal generally favorable distributional characteristics across the eighteen measured constructs. Central tendency indicators position most variables within the moderate-to-high agreement range on the five-point measurement scale, with means spanning from 2.628 for the Social domain through 3.925 for Green social capital, suggesting respondents generally endorsed rather than rejected the surveyed organizational practices and outcomes. Dispersion metrics prove relatively contained, with standard deviations ranging between 0.482 (Green Human Resources Management Practices) and 0.977 (Economic domain), indicating reasonable consensus among participants without problematic restriction of range that would artificially constrain correlational analyses (Hair et al., 2019). Shape diagnostics warrant closer attention: skewness coefficients predominantly register negative values – most notably -0.841 for Green social capital and -0.791 for Technical domain – signaling left-tailed distributions where responses concentrate toward higher scale anchors with extended tails toward disagreement (Kim, 2013). This pattern aligns with social desirability tendencies often observed in organizational surveys addressing socially valued practices like environmental stewardship. Kurtosis indicators similarly trend negative across most constructs, with values like -0.979 for Manufacturing domain and -0.937 for Green compensation management revealing platykurtic distributions characterized by flatter peaks and lighter tails compared to normal distribution benchmarks. While these departures from perfect normality merit acknowledgement, they remain within tolerable bounds for PLS-SEM applications, which demonstrate robustness to non-normal data distributions (Hair et al., 2017).

The correlation matrix unveils theoretically coherent association structures while simultaneously confirming the absence of pathological multicollinearity. Examining focal relationships first: Green intellectual capital demonstrates substantial positive linkages with Sustainable Manufacturing ($r = 0.62$, $p < 0.05$), corroborating theoretical expectations that knowledge-based organizational resources facilitate environmental performance achievements. Green Human Resources Management Practices similarly exhibits meaningful correlations with both the independent construct ($r = 0.46$ with Green intellectual capital) and dependent variable ($r = 0.40$ with Sustainable Manufacturing), positioning it appropriately as a moderating mechanism.

Within the intellectual capital domain, constituent dimensions display expected intercorrelations. Green human capital correlates 0.70 with the overarching construct, Green Structural Capital at 0.71, and Green social capital at 0.79, reflecting their status as facets of a unified higher-order concept. Sustainable Manufacturing's dimensional structure shows comparable coherence, with the Environmental domain ($r = 0.65$), the Economic domain ($r = 0.64$), and the Manufacturing domain ($r = 0.55$) all demonstrating substantive connections to the aggregate construct. Critically, no correlation approaches problematic magnitudes exceeding 0.90 that would signal redundancy concerns (Grewal et al., 2004). Several statistically non-significant relationships appear marked throughout the matrix, for instance, the Technical domain shows negligible associations with Green Structural Capital ($r = -0.01$) and the Social domain ($r = -0.02$, crossed out), suggesting appropriately discriminant measurement rather than pervasive correlational saturation. This pattern of selective, theoretically sensible associations combined with modest-to-moderate effect sizes creates optimal conditions for discerning genuine structural relationships in subsequent path modeling (Cohen et al., 2003).

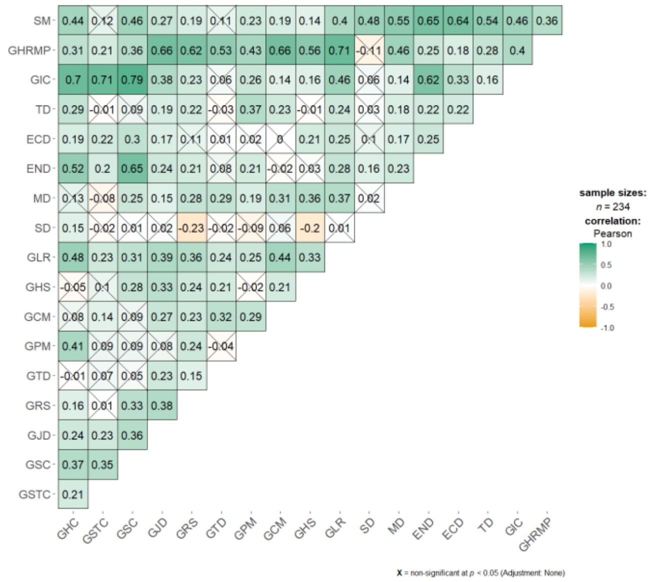

Fig. 3. Visualization of the correlation matrix

5.3. Analysis of Structural Model for the Direct Hypotheses

Path coefficient estimation within the structural framework quantifies hypothesized relationships between exogenous predictors and endogenous outcomes, while bootstrapping procedures generate inferential statistics that determine whether observed effects transcend sampling variability (Streukens & Leroi-Werelds, 2016). Standardized regression weights illuminate both magnitude and directionality of proposed influences, with accompanying significance tests adjudicating hypothesis fate. Visual depiction through path diagrams, supplemented by tabular precision, conveys this evidence compellingly.

The omnibus hypothesis positing green intellectual capital as a catalyst for sustainable manufacturing outcomes (***H1***) garnered robust empirical vindication. Standardized path estimation revealed a substantial positive coefficient of $\beta = 0.486$ ($t = 6.365$, $p < 0.001$, 95% CI [0.322, 0.618]), signifying that organizations elevating their environmentally-oriented knowledge assets by one standard deviation can anticipate approximately half a standard deviation improvement in manufacturing sustainability performance. This finding resonates with knowledge-based view perspectives that frame intangible intellectual resources as foundational drivers of organizational capabilities and competitive positioning.

Disaggregating this aggregate effect into constituent dimensions unveiled nuanced patterns. Green human capital, encompassing employee environmental competencies, awareness, and commitment, demonstrated commanding influence (β = 0.479, t = 6.038, p < 0.001, 95% CI [0.331, 0.632]), validating ***H1-1*** and underscoring how workforce-embedded green expertise directly translates into sustainable operational achievements.

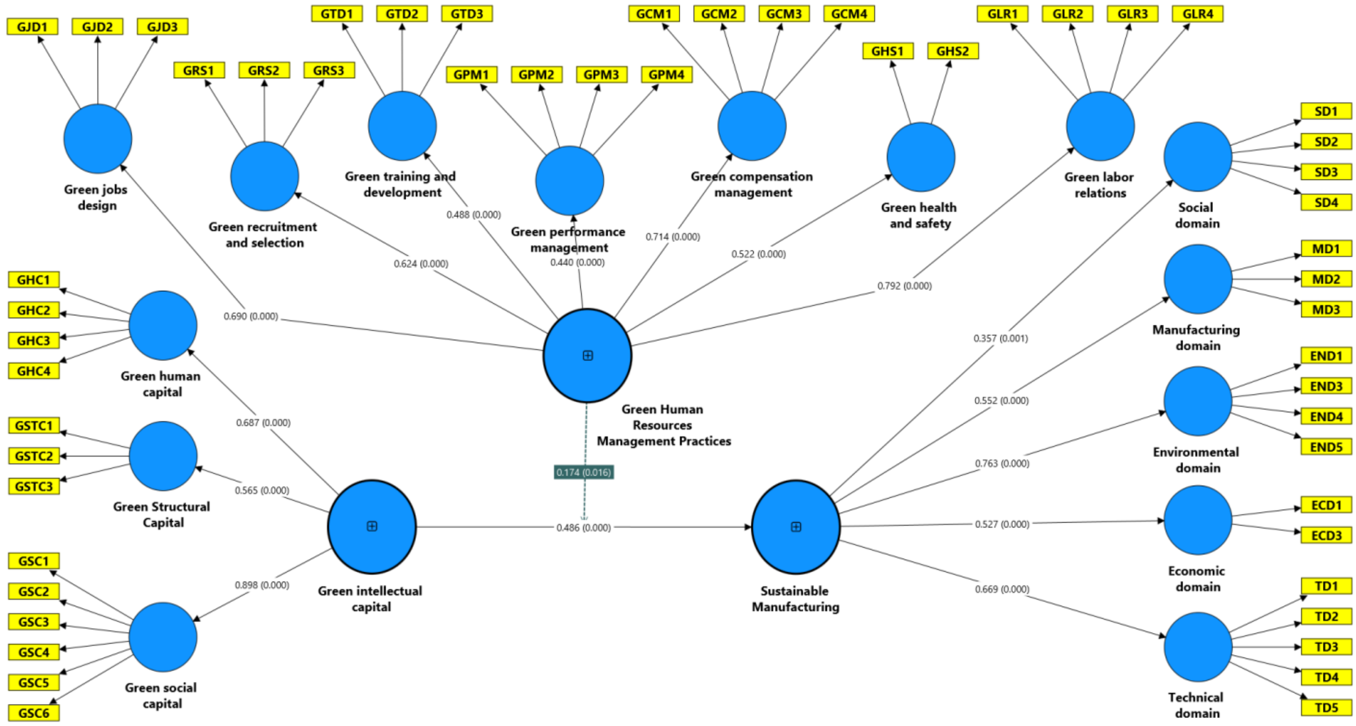

Fig. 4. Structural Mode

Table 4. Results of Direct Hypothesis Testing

H	Path "Direct Effect"	B	t-value	P-value	95% CI for B LB	95% CI for B UB	Remark
H1	***Green intellectual capital -> Sustainable Manufacturing***	**0.486**	**6.365**	**0.000**	**0.322**	**0.618**	☑
H1-1	*Green human capital -> Sustainable Manufacturing*	0.479	6.038	0.000	0.331	0.632	☑
H1-2	*Green Structural Capital -> Sustainable Manufacturing*	-0.09	0.913	0.361	-0.341	0.014	☒
H1-3	*Green social capital -> Sustainable Manufacturing*	0.518	4.499	0.000	0.283	0.712	☑
H2	***Green Human Resources Management Practices -> Sustainable Manufacturing***	**0.245**	**2.586**	**0.010**	**0.051**	**0.421**	☑

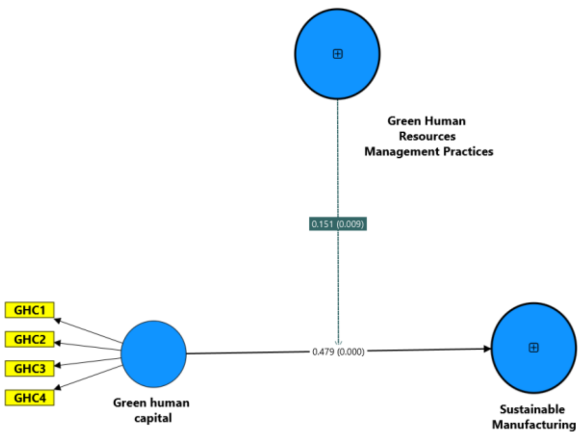

Fig. 5. Moderating role of GHRMP on the relationship from GHC to SM

Similarly, green social capital, reflecting relational networks and collaborative mechanisms supporting environmental objectives, exerted even stronger effects (β = 0.518, t = 4.499, p < 0.001, 95% CI [0.283, 0.712]), providing compelling support for ***H1-3***. These patterns align with social capital theorisations emphasising how inter-organizational ties and knowledge exchange networks facilitate capability development (Nahapiet & Ghoshal, 1998; Chen et al., 2021).

Conversely, green structural capital, embodied in organizational systems, databases, procedures, and codified environmental knowledge, failed to demonstrate significant predictive utility (β = -0.090, t = 0.913, p = 0.361, 95% CI [-0.341, 0.014]), necessitating ***H1-2*** rejection. The negative coefficient direction, though non-significant, invites speculation about potential suppression dynamics or measurement artefacts, though the confidence interval bracketing zero definitively establishes the absence of meaningful linear association.

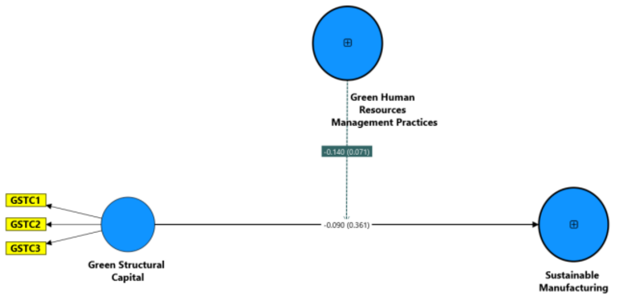

Fig. 6. Moderating role of GHRMP on the relationship from GSTC to SM

This unanticipated null finding contrasts with theoretical expectations but may reflect contextual particularities where formal environmental management systems remain underdeveloped or poorly integrated within manufacturing operations (Yusliza et al., 2020). Green Human Resources Management Practices independently predicted sustainable manufacturing (***H2***: β = 0.245, t = 2.586, p = 0.010, 95% CI [0.051, 0.421]), confirming that strategic HR interventions, spanning recruitment, development, performance evaluation, and compensation designed around environmental priorities, constitute autonomous pathways to sustainability beyond their moderating capacities. This aligns with strategic HRM scholarship, positioning people management systems as instrumental mechanisms linking organizational strategy with operational outcomes (Ren et al., 2018).

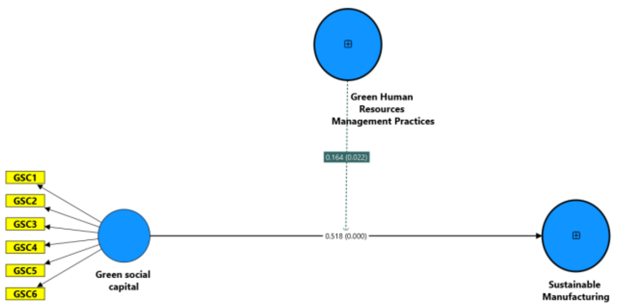

Fig. 7. Moderating role of GHRMP on the relationship from GSC to SM

5.4. Moderation Hypotheses Testing

Moderator analysis extends beyond additive main effects to investigate contingent relationships – circumstances under which predictor-outcome associations strengthen, weaken, or reverse depending on contextual conditions (Hayes, 2018). Product term methodology, operationalized through interaction variables multiplying focal predictors by moderators, tests whether relationship slopes vary systematically across moderator levels (Henseler & Fassott, 2010). Visualization through simple slope decomposition clarifies these conditional dynamics by plotting predicted outcome trajectories at representative moderator values, typically standardized levels positioned one deviation below the mean (low), at the mean (average), and one deviation above the mean (high) benchmarks.

The overarching moderation hypothesis (***H3***) proposing that GHRMP intensifies the green intellectual capital-sustainable manufacturing nexus received empirical confirmation (β = 0.174, t = 2.400, p = 0.016, 95% CI [0.032, 0.313]). The positive interaction coefficient signals synergistic complementarity – green knowledge assets yield amplified sustainability dividends when organizations simultaneously deploy sophisticated green HRM architectures. Graphical representation illustrates this amplification vividly: at elevated GHRMP levels (+1 SD, represented by the uppermost green line), the green intellectual capital-sustainability gradient escalates steeply, whereas at diminished GHRMP levels (-1 SD, depicted by the lower red line), this relationship considerably flattens. This pattern substantiates resource orchestration theories emphasizing that static resource possession alone proves insufficient – strategic bundling and systematic deployment mechanisms determine whether latent capabilities materialize into performance advantages (Sirmon et al., 2011; Barney & Wright, 1998).

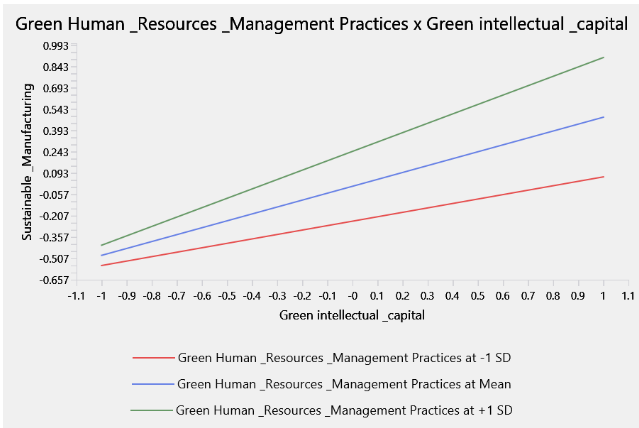

Fig. 8. Interaction plot for the moderating role of GHRMP on the relationship from GIC to SM

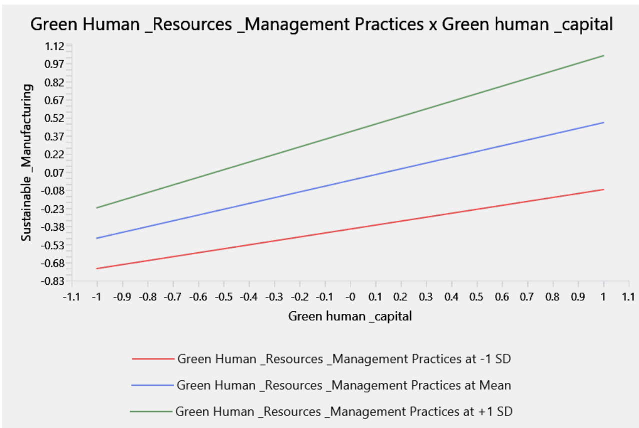

Fig. 9. Interaction plot for the moderating role of GHRMP on the relationship from GHC to SM

Dimensional decomposition revealed heterogeneous moderation patterns mirroring the direct effect architecture. GHRMP significantly enhanced the green human capital pathway (***H3-***

1: β = 0.151, t = 2.607, p = 0.009, 95% CI [0.055, 0.288]), demonstrating that environmentally-skilled employees deliver maximal sustainability contributions when organizational HR systems provide supportive infrastructure through targeted training investments, green performance metrics, and eco-innovation incentives. The interaction visualization portrays diverging trajectories where high-GHRMP contexts transform human capital into sustainability outcomes more efficiently than low-GHRMP environments – a finding harmonizing with ability-motivation-opportunity frameworks suggesting performance emerges from workforce capabilities intersecting with organizational enablers (Bos-Nehles et al., 2013).

Table 5. Results of Moderation Analysis

H	Path "Moderation Effect"	B	t-value	P-value	95% CI for B LB	UB	Remark
H3	***Green Human Resources Management Practices x Green intellectual capital -> Sustainable Manufacturing***	**0.174**	**2.400**	**0.016**	**0.032**	**0.313**	☑
H3-1	*Green Human Resources Management Practices x Green human capital -> Sustainable Manufacturing*	0.151	2.607	0.009	0.055	0.288	☑
H3-2	*Green Human Resources Management Practices x Green Structural Capital -> Sustainable Manufacturing*	-0.14	1.807	0.071	-0.264	-0.070	☒
H3-3	*Green Human Resources Management Practices x Green social capital -> Sustainable Manufacturing*	0.164	2.284	0.022	0.045	0.310	☑

Similarly, GHRMP amplified green social capital effects (***H3-3***: β = 0.164, t = 2.284, p = 0.022, 95% CI [0.045, 0.310]), indicating that collaborative networks and stakeholder relationships function optimally when reinforced by HRM practices fostering collective environmental responsibility.

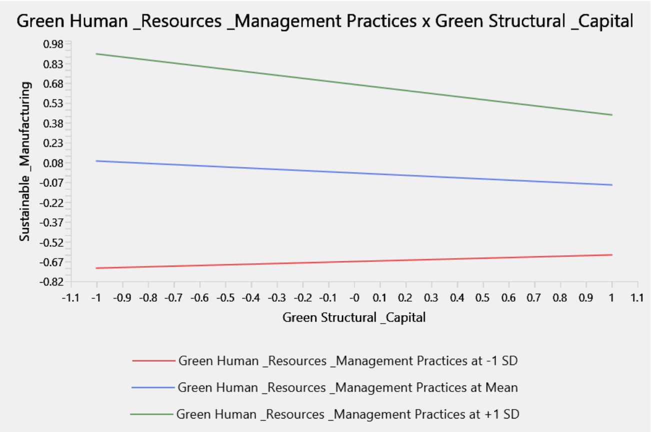

Fig. 10. Interaction plot for the moderating role of GHRMP on the relationship from GSTC to SM

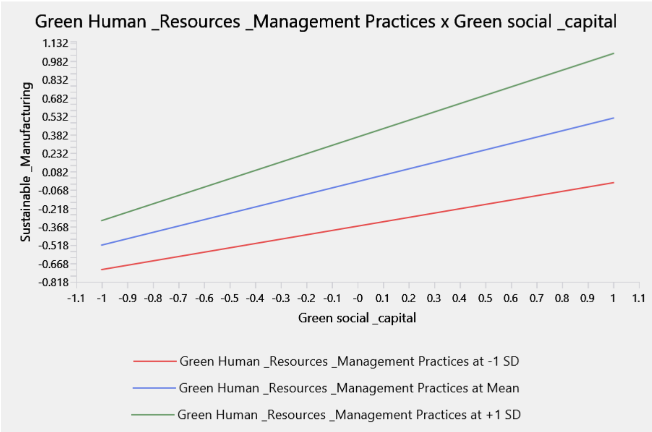

Fig. 11. Interaction plot for the moderating role of GHRMP on the relationship from GSC to SM

The interaction graph reveals nearly parallel positive slopes across GHRMP conditions, though steepening at higher levels, suggesting social capital maintains baseline efficacy but achieves superior potency within robust green HR ecosystems.

The structural capital interaction (***H3-2***) yielded a negative though non-significant coefficient (β = -0.140, t = 1.807, p = 0.071, 95% CI [-0.264, -0.070]), approaching but not breaching conventional significance thresholds. The marginally significant p-value, coupled with confidence intervals narrowly encompassing zero position this finding in ambiguous territory.

Intriguingly, the interaction plot displays a negative gradient – sustainability outcomes decline as structural capital increases, particularly pronounced at high GHRMP levels – contradicting theoretical expectations. This anomalous pattern may reflect competing mechanisms where bureaucratic environmental management systems, when combined with intensive HR interventions, generate implementation bottlenecks or compliance burdens that paradoxically hinder rather than facilitate sustainability progress (Jabbour & de Sousa Jabbour, 2016). Alternatively, multicollinearity concerns or measurement limitations may artifactually produce this pattern, warranting cautious interpretation and future replication efforts.

5.5. Model Fit Assessment

Beyond establishing that individual path coefficients achieve statistical significance, comprehensive model evaluation demands scrutiny of holistic predictive capability and specification adequacy. Coefficient of determination metrics quantify what proportion of endogenous variable fluctuation the theoretical architecture successfully captures, while complementary diagnostics assess whether models generate predictions that outperform naïve benchmarks when confronted with holdout observations (Shmueli et al., 2019). Effect size calculations further partition variance attributions, revealing which antecedents command dominant versus peripheral explanatory roles (Cohen, 1988). Collinearity surveillance ensures estimated relationships reflect genuine causal dynamics rather than statistical confounding, while prediction-oriented indices gauge practical forecasting utility beyond in-sample fit optimization (Sharma et al., 2023).

Explanatory power assessments reveal that the integrated theoretical framework accounts for substantial outcome variance. The full structural specification incorporating green intellectual capital, GHRMP, and their interactions explains 38.3% of sustainable manufacturing variability ($R^2 = 0.383$), positioning the model within respectable bounds for social science applications where unmeasured contextual factors inevitably introduce stochastic noise (Hair et al., 2019). Disaggregating by intellectual capital dimensions illuminates differential explanatory contributions. The green social capital pathway, augmented by its GHRMP interaction, demonstrates superior explanatory potency ($R^2 = 0.570$), capturing 57.0% of sustainability variance – an impressive feat approaching the upper echelon of organizational research benchmarks. Green human capital models achieve commendable performance ($R^2 = 0.498$), accounting for nearly half the outcome variation, while green structural capital specifications exhibit comparatively modest explanatory reach ($R^2 = 0.465$). These graduated R^2 magnitudes align with established classification schemes characterizing values near 0.25 as weak, proximate to 0.50 as moderate, and approaching 0.75 as substantial (Hair et al., 2017).

Table 6. Structural Model Assessment

H	Path	f-Square	VIF	R-Square	Q^2 predict	RMSE	MAE
H1	**Green intellectual capital -> Sustainable Manufacturing**	0.310	1.235	0.383	0.351	0.793	0.633
H2	**Green Human Resources Management Practices -> Sustainable Manufacturing**	0.080	1.226				
H3	**Green Human Resources Management Practices x Green intellectual capital -> Sustainable Manufacturing**	0.045	1.040				
H1-1	Green human capital -> Sustainable Manufacturing	0.293	1.556	0.498	0.428	0.747	0.607
H3-1	Green Human Resources Management Practices x Green human capital -> Sustainable Manufacturing	0.047	1.308				
H1-2	Green Structural Capital -> Sustainable Manufacturing	0.015	1.047	0.465	0.392	0.768	0.623
H3-2	Green Human Resources Management Practices x Green Structural Capital -> Sustainable Manufacturing	0.036	1.008				
H1-3	Green social capital -> Sustainable Manufacturing	0.507	1.232	0.570	0.499	0.692	0.529
H3-3	Green Human Resources Management Practices x Green social capital -> Sustainable Manufacturing	0.040	1.026				

Predictive validity diagnostics, operationalized through Stone-Geisser Q^2 metrics derived from blindfolding cross-validation procedures, universally register positive values – signaling that models systematically outperform mean-based predictions when forecasting withheld cases (Geisser, 1974; Stone, 1974). The overarching sustainable manufacturing model yields $Q^2 = 0.351$, indicating approximately 35% improvement over naïve benchmarks. Dimensional models replicate this pattern with Q^2 spanning 0.392 to 0.499, confirming genuine predictive capability rather than overfit in-sample artefacts. Root mean square error (RMSE) and mean absolute error (MAE) metrics provide complementary prediction accuracy indices in original measurement units. Values ranging from RMSE = 0.692 to 0.793 and MAE = 0.529 to 0.633 reflect average prediction deviations hovering around two-thirds of a scale point – a tolerance suggesting reasonable forecast precision given the five-point measurement framework, though room for specification enhancement remains (Sharma et al., 2023).

Effect size quantification through f^2 statistics reveals which predictors exert non-trivial unique contributions after accounting for competing influences (Cohen, 1988). Green social capital commands the most dominant explanatory role ($f^2 = 0.507$), exceeding Cohen's threshold for large effects ($f^2 \geq 0.35$) and demonstrating that relational capital constitutes a pivotal sustainability driver whose removal would substantially degrade model performance. Green human capital registers a robust medium effect ($f^2 = 0.293$), while the GHRMP main effect exhibits a small-to-medium contribution ($f^2 = 0.080$). Interaction terms generate modest effect sizes ranging from $f^2 = 0.036$ to 0.047, typical of moderation phenomena where incremental variance attributable to product terms inherently remains constrained (Aguinis et al., 2017). Green structural capital's negligible effect size ($f^2 = 0.015$) mirrors its non-significant path coefficient, cementing its empirical irrelevance within the current nomological network.

Multicollinearity surveillance through variance inflation factors provides reassuring evidence of model specification integrity. All VIF values cluster comfortably below 1.6 – dramatically beneath the conservative 3.3 threshold recommended for PLS-SEM applications and orders of magnitude from pathological zones exceeding 5.0 or 10.0 (Hair et al., 2017; Kock & Lynn, 2012). This benign collinearity profile confirms that predictor orthogonality suffices to isolate unique effects, ensuring path coefficients represent genuine incremental contributions rather than statistical artefacts arising from redundant measurement. The VIF distribution spanning 1.008 to 1.556 indicates minimal overlap among theoretical constructs, validating earlier discriminant validity assessments and affirming that each dimension captures empirically distinguishable facets of the broader conceptual domain.

6. Discussion

This investigation empirically tested an integrative framework positioning green intellectual capital as a catalyst for sustainable manufacturing performance, with green human resource management practices serving dual roles as autonomous predictor and contingent moderator. Methodological rigor characterized the analytical sequence – measurement validation preceded structural assessment, diagnostic scrutiny ruled out common method contamination, and comprehensive fit indices corroborated theoretical coherence.

Psychometric evaluations confirmed measurement adequacy across reliability, convergent validity, and discriminant validity dimensions. Strategic item deletions enhanced model quality, yielding indicator loadings predominantly exceeding 0.70, composite reliabilities spanning 0.691 to 0.810, and AVE coefficients surpassing 0.40 thresholds. HTMT ratios uniformly remained beneath unity, establishing construct separation. Correlation matrices revealed theoretically sensible association patterns featuring moderate effect magnitudes without pathological multicollinearity. Distributional assessments uncovered negatively skewed, platykurtic configurations reflecting left-tailed response concentrations – deviations from normality that remained tolerable for variance-based SEM procedures.

Hypothesis adjudication yielded nuanced insights distinguishing effective from ineffective intellectual capital dimensions. Green social capital emerged as the paramount sustainability driver ($\beta = 0.518$), followed closely by green human capital ($\beta = 0.479$), while green structural capital unexpectedly failed significance testing. The aggregated green intellectual capital construct demonstrated substantial predictive utility ($\beta = 0.486$), as did GHRMP operating independently ($\beta = 0.245$). Moderation analyses unveiled synergistic complementarities – GHRMP amplified the intellectual capital-sustainability nexus ($\beta = 0.174$), with dimensional decompositions confirming reinforcement patterns for human capital ($\beta = 0.151$) and social capital ($\beta = 0.164$) pathways, though structural capital interactions remained non-significant. Interaction visualizations depicted diverging simple slopes, illustrating how elevated GHRMP intensifies the transformation of knowledge assets into operational sustainability achievements.

Structural diagnostics attested to model robustness and predictive credibility. Variance explained metrics ($R^2 = 0.383$ to 0.570) positioned specifications within respectable-to-strong explanatory bands, while positive Q^2 indices (0.351 to 0.499) confirmed genuine out-of-sample forecasting capability, transcending in-sample optimization. Effect size decompositions identified social capital as commanding dominant unique contributions ($f^2 = 0.507$), with human capital delivering medium-magnitude effects ($f^2 = 0.293$). VIF values universally below 1.6 eliminated multicollinearity anxieties, validating coefficient interpretation.

7. Conclusions

The present study provides empirical evidence on the critical role of green intellectual capital (GIC) and green human resource management practices (GHRMP) in promoting sustainable manufacturing (SM) within an industrial context in Iraq. The findings reveal that green human capital (GHC) and green social capital (GSC) have a significant positive impact on sustainable manufacturing, while the effect of green structural capital (GSTC) is weak or negative when not adequately supported by GHRMP. This highlights that investments in environmental knowledge, eco-conscious employee behaviors, and collaborative networks are more readily translated into sustainable outcomes than organizational systems alone without proper HR support. The study confirms that GHRMP significantly moderates the relationship between GIC and SM, strengthening the influence of GHC and GSC on sustainable manufacturing outcomes. However, the weak moderating effect on GSTC underscores the need for organizations to institutionalize environmental systems and enhance regulatory awareness to fully leverage structural capital in sustainability initiatives. Overall, seven out of nine hypotheses were supported, demonstrating the pivotal role of GHRMP in translating intellectual capital into practical sustainable outcomes.

Practically, these findings suggest that manufacturing organizations in Iraq should focus on implementing targeted green HR practices, such as eco-friendly recruitment, green training programs, environmentally linked performance evaluation, and reward systems, to strengthen employee engagement and facilitate sustainability efforts. Additionally, organizations should develop formal environmental systems, standard operating procedures, and cross-functional collaborations to improve structural support for sustainability initiatives. By aligning human resources strategies with intellectual capital management, firms can achieve enhanced resource efficiency, process innovation, environmental compliance, and competitive advantage.

Despite the contributions, this study has certain limitations. First, the cross-sectional design restricts causal inference, suggesting that longitudinal studies are needed to examine dynamic effects over time. Second, the research relied on self-reported survey data, which may introduce bias; future studies could combine survey responses with objective performance indicators. Third, the study focused on a limited number of manufacturing organizations in Iraq, which may limit generalizability to other sectors or countries. Moreover, the operationalization of green structural capital may require further refinement to capture the full scope and effectiveness of organizational environmental systems.

Future research can build on these findings by exploring additional contextual factors influencing the effectiveness of GIC and GHRMP, such as institutional quality, regulatory frameworks, and organizational culture in developing countries. Longitudinal or experimental designs could assess the long-term impact of green HR interventions on sustainable manufacturing outcomes. Researchers could also investigate sector-specific differences or cross-country comparisons to identify best practices and contextual contingencies for implementing green intellectual capital and HR strategies effectively.

This study provides both theoretical and practical insights into how GIC and GHRMP jointly contribute to sustainable manufacturing. By addressing gaps in structural capital, leveraging employee knowledge and social networks, and integrating HR practices with intellectual capital, Iraqi manufacturing firms can enhance sustainability, innovation, and competitiveness while contributing to broader environmental preservation goals.

References

Abbass, K., Qasim, M.Z., Song, H., Murshed, M., Mahmood, H., Younis, I., 2022. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environ. Sci. Pollut. Res. 29, 42539–42559. DOI: 10.1007/s11356-022-19718-6

Abo-Khalil, A.G., 2024. Integrating sustainability into higher education challenges and opportunities for universities worldwide. Heliyon 10, e29946. DOI: 10.1016/j.heliyon.2024.e29946

Agyabeng-Mensah, Y., Tang, L., 2021. The relationship among green human capital, green logistics practices, green competitiveness, social performance and financial performance. J. Manuf. Technol. Manag. 32, 1377–1398. DOI: 10.1108/JMTM-11-2020-0441

Ahmad, F., Hossain, M.B., Mustafa, K., Ejaz, F., Khawaja, K.F., Dunay, A., 2023. Green HRM practices and knowledge sharing improve environmental performance by raising employee commitment to the environment. Sustainability 15, 5040. DOI: 10.3390/su15065040

Alfadel, A., Al-Kahtani, S.M., Al-Mekhlafi, A.-W.A.-G.S., Alhebri, A., Ahmed, A., 2025. Fostering sustainable development: the role of green HRM and green work engagement. Discov. Sustain. 6, 300. DOI: 10.1007/s43621-025-01167-z

Aguinis, H., Edwards, J. R., & Bradley, K. J. 2017. Improving our understanding of moderation and mediation in strategic management research. Organizational Research Methods, 20(4), 665-685. DOI: 10.1177/1094428115627498

Alnaim, M., Metwally, A.B.M., 2024. Green intellectual capital and corporate environmental performance: Does environmental management accounting matter? Adm. Sci. 14, 311. DOI: 10.3390/admsci14120311

Anum, Z., Nasir, A., Ejaz, F., Fodor, Z.J., Hossain, M.B., 2025. The impact of green HRM and intellectual capital on the environmental performance of the organizations: A mediating impact of green innovation. Int. J. Innov. Res. Sci. Stud. 8, 2965–2976. DOI: 10.53894/ijirss.v8i2.5935

Asiaei, K., O'Connor, N.G., Barani, O., Joshi, M., 2023. Green intellectual capital and ambidextrous green innovation: The impact on environmental performance. Bus. Strateg. Environ. 32, 369–386. DOI: 10.1002/bse.3136

Atalla, A.D.G., Elbassal, N.A.M.M., Kandil, F.S., El-Ashry, A.M., Mohamed, I.A.I., Behilak, S.E.G., Elseesy, N.A.M., 2024. Green intellectual capital: The secret ingredient for organizational competitive advantage in the nursing profession-a cross-sectional study from Egypt. Belitung Nurs. J. 10, 304–311. DOI: 10.33546/bnj.3306

Bagozzi, R. P., & Yi, Y. 1988. On the evaluation of structural equation models. Journal of the Academy of Marketing Science, 16(1), 74-94. DOI: 10.1007/BF02723327

Barney, J. B., & Wright, P. M. 1998. On becoming a strategic partner: The role of human resources in gaining competitive advantage. Human Resource Management, 37(1), 31-46. DOI: 10.1002/(SICI)1099-050X(199821)37:1<31::AID-HRM4>3.0.CO;2-W

Begum, M.A., Swamy, T.N.V.R.L., 2024. Harnessing green intellectual capital for sustainable development: The dynamic capabilities approach to environmental policy. Bus. Strateg. Dev. 7, e70041. DOI: 10.1002/bsd2.70041

Bhardwaj, B.R., 2016. Role of green policy on sustainable supply chain management. Benchmarking An Int. J. 23, 456–468. DOI: 10.1108/BIJ-08-2013-0077

Bolan, S., Padhye, L.P., Jasemizad, T., Govarthanan, M., Karmegam, N., Wijesekara, H., Amarasiri, D., Hou, D., Zhou, P., Biswal, B.K., Balasubramanian, R., Wang, H., Siddique, K.H.M., Rinklebe, J., Kirkham, M.B., Bolan, N., 2024. Impacts of climate change on the fate of contaminants through extreme weather events. Sci. Total Environ. 909, 168388. DOI: 10.1016/j.scitotenv.2023.168388

Bombiak, E., 2023. Effect of green intellectual capital practices on the competitive Advantage of companies: Evidence from Polish companies. Sustainability 15, 4050. DOI: 10.3390/su15054050

Bos-Nehles, A. C., Van Riemsdijk, M. J., & Kees Looise, J. 2013. Employee perceptions of line management performance: Applying the AMO theory to explain the effectiveness of line managers' HRM implementation. Human Resource Management, 52(6), 861-877. DOI: 10.1002/hrm.21578

Borah, P.S., Dogbe, C.S.K., Pomegbe, W.W.K., Bamfo, B.A., Hornuvo, L.K., 2023. Green market orientation, green innovation capability, green knowledge acquisition and green brand positioning as determinants of new product success. Eur. J. Innov. Manag. 26, 364–385. DOI: 10.1108/EJIM-09-2020-0345

Buhaya, M.I., Metwally, A.B.M., 2024. Green intellectual capital and green supply chain performance: do external pressures matter? Cogent Bus. Manag. 11, 2349276. DOI: 10.1080/23311975.2024.2349276

Butt, A.S., Ali, I., Govindan, K., 2024. The role of reverse logistics in a circular economy for achieving sustainable development goals: a multiple case study of retail firms. Prod. Plan. Control 35, 1490–1502. DOI: 10.1080/09537287.2023.2197851

Chauhan, C., Kaur, P., Arrawatia, R., Ractham, P., Dhir, A., 2022. Supply chain collaboration and sustainable development goals (SDGs). Teamwork makes achieving SDGs dream work. J. Bus. Res. 147, 290–307. DOI: 10.1016/j.jbusres.2022.03.044

Chen, Y. S., Chang, T. W., Lin, C. Y., Lai, P. Y., & Wang, K. H. 2021. The influence of proactive green innovation and reactive green innovation on green product development performance: The mediation role of green creativity. Sustainability, 13(18), 10191. DOI: 10.3390/su131810191

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. 2003. *Applied multiple* regression/correlation analysis for the behavioral sciences (3rd ed.). Routledge.

Din, A.U., Yang, Y., Zhang, Y., 2025. The psychological benefits of green HRM: A study of employee well-being, engagement, and green behavior in the healthcare sector. Acta Psychol. (Amst). 254, 104823. DOI: 10.1016/j.actpsy.2025.104823

Ekins, P., Zenghelis, D., 2021. The costs and benefits of environmental sustainability. Sustain. Sci. 16, 949–965. DOI: 10.1007/s11625-021-00910-5

Faeni, D.P., Oktaviani, R.F., Riyadh, H.A., Faeni, R.P., Beshr, B.A.H., 2025. Green human resource management and sustainable practices on corporate reputation and employee well-being: A model for Indonesia's F&B industry. Environ. Challenges 18, 101082. DOI: 10.1016/j.envc.2025.101082

Franke, G., & Sarstedt, M. 2019. Heuristics versus statistics in discriminant validity testing: A comparison of four procedures. Internet Research, 29(3), 430-447. DOI: 10.1108/IntR-12-2017-0515

Freihat, L., Al-Qaaida, M., Huneiti, Z., Abbod, M., 2024. Green human resource management/supply chain management/regulation and legislation and their effects on sustainable development goals in Jordan. Sustainability 16, 2769. DOI: 10.3390/su16072769

Fornell, C., & Larcker, D. F. 1981. Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18(1), 39-50. DOI: 10.2307/3151312

Gaskin, J., Godfrey, S., Vance, A., 2018. Successful system-use: It's not just who you are, But what you do. AIS Trans. Human-Computer Interact. 10, 57–81. DOI: 10.17705/1thci.00104

Geisser, S. 1974. A predictive approach to the random effect model. Biometrika, 61(1), 101-107. DOI: 10.1093/biomet/61.1.101

Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R., 2019. The role of renewable energy in the global energy transformation. Energy Strateg. Rev. 24, 38–50. DOI: 10.1016/j.esr.2019.01.006

Grewal, R., Cote, J. A., & Baumgartner, H. 2004. Multicollinearity and measurement error in structural equation models: Implications for theory testing. Marketing Science, 23(4), 519-529. DOI: 10.1287/mksc.1040.0070

Gupta, A., Jangra, S., 2024. Green human resource management and work engagement: Linking HRM performance attributions. Sustain. Futur. 7, 100174. DOI: 10.1016/j.sftr.2024.100174

Hair, J., Hollingsworth, C.L., Randolph, A.B., Chong, A.Y.L., 2017a. An updated and expanded assessment of PLS-SEM in information systems research. Ind. Manag. Data Syst. 117, 442–458. DOI: 10.1108/IMDS-04-2016-0130

Hair, J.F., Hauff, S., Hult, G.T.M., Richter, N.F., Ringle, C.M., Sarstedt, M., 2017b. A primer on partial Least Squares Structural Equation Modeling

(PLS-SEM), 2nd ed. Verlag Franz Vahlen GmbH, Munich. DOI: 10.15358/9783800653614

Hair, J.F., Risher, J.J., Sarstedt, M., Ringle, C.M., 2019. When to use and how to report the results of PLS-SEM. Eur. Bus. Rev. 31, 2–24. DOI: 10.1108/EBR-11-2018-0203

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. 2022. A primer on partial least squares structural equation modeling (PLS-SEM) (3rd ed.). Sage Publications.

Hayes, A. F. 2018. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach (2nd ed.). Guilford Press.

Haleem, A., Javaid, M., Singh, R.P., Suman, R., Qadri, M.A., 2023. A pervasive study on Green Manufacturing towards attaining sustainability. Green Technol. Sustain. 1, 100018. DOI: 10.1016/j.grets.2023.100018

Henseler, J., & Fassott, G. 2010. Testing moderating effects in PLS path models: An illustration of available procedures. In V. Esposito Vinzi, W. W. Chin, J. Henseler, & H. Wang (Eds.), Handbook of partial least squares (pp. 713-735). Springer.

Henseler, J., Ringle, C.M., Sarstedt, M., 2015. A new criterion for assessing discriminant validity in variance-based structural equation modeling. J. Acad. Mark. Sci. 43, 115–135. DOI: 10.1007/s11747-014-0403-8

Henseler, J., Hubona, G., & Ray, P. A. 2016. Using PLS path modeling in new technology research: Updated guidelines. Industrial Management & Data Systems, 116(1), 2-20. DOI: 10.1108/IMDS-09-2015-0382

Hulland, J. 1999. Use of partial least squares (PLS) in strategic management research: A review of four recent studies. Strategic Management Journal, 20(2), 195-204. DOI: 10.1002/(SICI)1097-0266(199902)20:2<195: AID-SMJ13>3.0.CO;2-7

Jabbour, C. J. C., & de Sousa Jabbour, A. B. L. 2016. Green human resource management and green supply chain management: Linking two emerging agendas. Journal of Cleaner Production, 112, 1824-1833. DOI: 10.1016/j.jclepro.2015.01.052

Keshav, V., Raut, D.N., 2018. Sustainable manufacturing implementation with SMEET framework for manufacturing industries. Am. J. Eng. Res. 7, 174–182.

Khan, A.N., Mehmood, K., Kwan, H.K., 2024. Green knowledge management: A key driver of green technology innovation and sustainable performance in the construction organizations. J. Innov. Knowl. 9, 100455. DOI: 10.1016/j.jik.2023.100455

Kim, H. Y. 2013. Statistical notes for clinical researchers: Assessing normal distribution (2) using skewness and kurtosis. Restorative Dentistry & Endodontics, 38(1), 52-54. DOI: 10.5395/rde.2013.38.1.52

Kock, N., & Lynn, G. S. 2012. Lateral collinearity and misleading results in variance-based SEM: An illustration and recommendations. Journal of the Association for Information Systems, 13(7), 546-580. DOI: 10.17705/1jais.00302

Kock, N., 2015. Common method bias in PLS-SEM. Int. J. e-Collaboration 11, 1–10. DOI: 10.4018/ijec.2015100101

Mamun, M.A. Al, 2025. Integrating Green Human Resource Management Practices (GHRMPs) with Human Resource Information Systems (HRIS) for sustainable organizational growth. J. Bus. Horizons Manag. 1, 1–3. DOI: 10.69517/jbhm.2025.01.01.0001

Marco-Lajara, B., Zaragoza-Sáez, P., Martínez-Falcó, J., Ruiz-Fernández, L., 2022. The effect of green intellectual capital on green performance in the Spanish wine industry: A structural equation modeling approach. Complexity 2022, 6024077. DOI: 10.1155/2022/6024077

Martínez-Falcó, J., Sánchez-García, E., Marco-Lajara, B., Zaragoza-Sáez, P., 2024. Green human resource management and green ambidexterity innovation in the wine industry: exploring the role of green intellectual capital and top management environmental awareness. Discov. Sustain. 5, 135. DOI: 10.1007/s43621-024-00333-z

Moghrabi, I.A.R., Bhat, S.A., Szczuko, P., AlKhaled, R.A., Dar, M.A., 2023. Digital transformation and its influence on sustainable manufacturing and business practices. Sustainability 15, 3010. DOI: 10.3390/su15043010

Montalvo-Falcón, J.V., Sánchez-García, E., Marco-Lajara, B., Martínez-Falcó, J., 2023. Green human resource management and economic, social and environmental performance: Evidence from the Spanish wine industry. Heliyon 9, e20826. DOI: 10.1016/j.heliyon.2023.e20826

Mulatsih, S.N., 2025. Green intellectual capital and eco-innovation in shaping sustainable financial performance: Evidence from Indonesia. Soc. Sci. Humanit. Open 11, 101345. DOI: 10.1016/j.ssaho.2025.101345

Mustafa, K., Hossain, M.B., Ahmad, F., Ejaz, F., Khan, H.G.A., Dunay, A., 2023. Green human resource management practices to accomplish green competitive advantage: A moderated mediation model. Heliyon 9, e21830. DOI: 10.1016/j.heliyon.2023.e21830

Nahapiet, J., & Ghoshal, S. 1998. Social capital, intellectual capital, and the organizational advantage. Academy of Management Review, 23(2), 242-266. DOI: 10.5465/amr.1998.533225

Ni, L., Ahmad, S.F., Alshammari, T.O., Liang, H., Alsanie, G., Irshad, M., Alyafi-AlZahri, R., BinSaeed, R.H., Al-Abyadh, M.H.A., Abu Bakir, S.M.M., Ayassrah, A.Y.A.B.A., 2023. The role of environmental regulation and green human capital towards sustainable development: The mediating role of green innovation and industry upgradation. J. Clean. Prod. 421, 138497. DOI: 10.1016/j.jclepro.2023.138497

Ren, S., Tang, G., & Jackson, S. E. 2018. Green human resource management research in emergence: A review and future directions. Asia Pacific Journal of Management, 35(3), 769-803. DOI: 10.1007/s10490-017-9532-1

Ringle, C. M., Sarstedt, M., Mitchell, R., & Gudergan, S. P. 2020. Partial least squares structural equation modeling in HRM research. The International Journal of Human Resource Management, 31(12), 1617-1643. DOI: 10.1080/09585192.2017.1416655

Podsakoff, P. M., MacKenzie, S. B., & Podsakoff, N. P. 2012. Sources of method bias in social science research and recommendations on how to control it. Annual Review of Psychology, 63, 539-569. DOI: 10.1146/annurev-psych-120710-100452

Pontillo, H.R., Dominguez, S.M., Bustamante, A.R., Genodiala, A., Gahum, S., Pontillo, V.A.R., Pontioso, E.J., Villaluz, F., 2025. The mediating role of green human capital in the relationship between green human resource management practices and green employee behavior for a sustainable future. Sustainability 17, 10767. DOI: 10.3390/su172310767

Qiu, X., Bashir, T., Gul, R.F., Sadiq, B., Naseem, A., 2024. Collaborative green initiatives: Integrating human resources, intellectual capital, and innovation for environmental performance. Sustainability 17, 224. DOI: 10.3390/su17010224

Rame, R., Purwanto, P., Sudarno, S., 2024. Industry 5.0 and sustainability: An overview of emerging trends and challenges for a green future. Innov. Green Dev. 3, 100173. DOI: 10.1016/j.igd.2024.100173

Rosen, M.A., Kishawy, H.A., 2012. Sustainable manufacturing and design: Concepts, practices and needs. Sustainability 4, 154–174. DOI: 10.3390/su4020154

Sarfo, P.A., Zhang, J., Nyantakyi, G., Lassey, F.A., Bruce, E., Amankwah, O., 2024. Influence of green human resource management on firm's environmental performance: Green employee empowerment as a mediating factor. PLoS One 19, e0293957. DOI: 10.1371/ journal.pone.0293957

Sarstedt, M., Ringle, C. M., & Hair, J. F. 2017. Partial least squares structural equation modeling. In C. Homburg, M. Klarmann, & A. Vomberg (Eds.), Handbook of market research (pp. 1-40). Springer.

Sarstedt, M., Hair, J. F., Cheah, J. H., Becker, J. M., & Ringle, C. M. 2021. How to specify, estimate, and validate higher-order constructs in PLS-SEM. Australasian Marketing Journal, 27(3), 197-211. DOI: 10.1016/j.ausmj.2019.05.003

Sarwar, A., Mustafa, A., 2024. Analysing the impact of green intellectual capital on environmental performance: the mediating role of green training and development. Technol. Anal. Strateg. Manag. 36, 3357–3370. DOI: 10.1080/09537325.2023.2209205

Saunders, M.N.K., Lewis, P., Thornhill, A., 2015. Research methods for business students, 8th ed. Pearson, London, UK.

Sedovs, E., Volkova, T., Ludviga, I., 2025. Sustainable development and strategic management - what is on the horizon in our non-ergodic world research? Sustain. Futur. 9, 100414. DOI: 10.1016/j.sftr.2024.100414

Shahbaz, M.H., Malik, S.A., 2025. The role of green HRM and intellectual capital in firm performance: a mediated-moderated analysis. J. Intellect. Capital, 2025, 1–27. DOI: 10.1108/JIC-01-2025-0005

Sharma, P. N., Sarstedt, M., Shmueli, G., Kim, K. H., & Thiele, K. O. 2023. PLS-based model selection: The role of alternative explanations in information systems research. Journal of the Association for Information Systems, 24(1), 346-382. DOI: 10.17705/1jais.00808

Shmueli, G., Sarstedt, M., Hair, J.F., Cheah, J.-H., Ting, H., Vaithilingam, S., Ringle, C.M., 2019. Predictive model assessment in PLS-SEM: guidelines for using PLSpredict. Eur. J. Mark. 53, 2322–2347. DOI: 10.1108/EJM-02-2019-0189

Sirmon, D. G., Hitt, M. A., Ireland, R. D., & Gilbert, B. A. 2011. Resource orchestration to create competitive advantage: Breadth, depth, and life cycle effects. Journal of Management, 37(5), 1390-1412. DOI: 10.1177/0149206310385695

Singh, R., Joshi, A., Dissanayake, H., Iddagoda, A., Khan, S., Félix, M.J., Santos, G., 2025. Integrating industry 4.0,circular economy, and green HRM: A framework for sustainable transformation. Sustainability 17, 3082. DOI: 10.3390/su17073082
Stone, M. 1974. Cross-validatory choice and assessment of statistical predictions. Journal of the Royal Statistical Society: Series B (Methodological), 36(2), 111-133. DOI: 10.1111/j.2517-6161.1974. tb00994.x
Streukens, S., & Leroi-Werelds, S. 2016. Bootstrapping and PLS-SEM: A step-by-step guide to get more out of your bootstrap results. European Management Journal, 34(6), 618-632. DOI: 10.1016/j.emj.2016.06.003
Tabachnick, B. G., & Fidell, L. S. 2019. Using multivariate statistics (7th ed.). Pearson.
Tahir, A.H., Umer, M., Nauman, S., Abbass, K., Song, H., 2024. Sustainable development goals and green human resource management: A comprehensive review of environmental performance. J. Environ. Manage. 370, 122495. DOI: 10.1016/j.jenvman.2024.122495
Tang, G., Chen, Y., Jiang, Y., Paillé, P., Jia, J., 2018. Green human resource management practices: scale development and validity. Asia Pacific J. Hum. Resour. 56, 31–55. DOI: 10.1111/1744-7941.12147
Ullah, S., Mehmood, T., Ahmad, T., 2023. Green intellectual capital and green HRM enabling organizations go green: mediating role of green innovation. Int. J. Innov. Sci. 15, 245–259. DOI: 10.1108/IJIS-12-2021-0222
Umar, M., Ahmad, A., Sroufe, R., Muhammad, Z., 2024. The nexus between green intellectual capital, blockchain technology, green manufacturing, and sustainable performance. Environ. Sci. Poll. Res. 31, 15026–15038. DOI: 10.1007/s11356-024-31952-8
Vadithe, R.N., Rajput, R.C., Kesari, B., 2025. Impact of Green HRM implementation on organizational sustainability in IT sector: A mediation analysis. Sustain. Futur. 9, 100507. DOI: 10.1016/j.sftr.2025.100507
Verma, D., Singh, V., Bhattacharya, P., Kishwan, J., 2022. Sustainable manufacturing strategies adopted by construction equipment manufacturing industries in India. Circ. Econ. Sustain. 2, 197–209. DOI: 10.1007/s43615-021-00091-4
Wei, F., Abbas, J., Alarifi, G., Zhang, Z., Adam, N.A., Queiroz, M.J. de, 2023. Role of green intellectual capital and top management commitment in organizational environmental performance and reputation: Moderating role of pro-environmental behavior. J. Clean. Prod. 405, 136847. DOI: 10.1016/j.jclepro.2023.136847
Yadiati, W., Nissa, N., Paulus, S., Suharman, H., Meiryani, M., 2019. The role of green intellectual capital and organizational reputation in influencing environmental performance. Int. J. Energy Econ. Policy 9, 261–268. DOI: 10.32479/ijeep.7752
Yu, W., Chavez, R., Feng, M., Wong, C.Y., Fynes, B., 2020. Green human resource management and environmental cooperation: An ability-motivation-opportunity and contingency perspective. Int. J. Prod. Econ. 219, 224–235. DOI: 10.1016/j.ijpe.2019.06.013
Yusliza, M.-Y., Yong, J.Y., Tanveer, M.I., Ramayah, T., Noor Faezah, J., Muhammad, Z., 2020. A structural model of the impact of green intellectual capital on sustainable performance. J. Clean. Prod. 249, 119334. DOI: 10.1016/j.jclepro.2019.119334
Zaid, A.A., Jaaron, A.A.M., Talib Bon, A., 2018. The impact of green human resource management and green supply chain management practices on sustainable performance: An empirical study. J. Cleaner Prod. 204, 965–979. DOI: 10.1016/j.jclepro.2018.09.062
Zihan, W., Makhbul, Z.K.M., Alam, S.S., 2024. Green human resource management in practice: Assessing the impact of readiness and corporate social responsibility on organizational change. Sustainability 16, 1153. DOI: 10.3390/su16031153