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Analysing sustainability-orientated determinants of green HRM: a hybrid SEM-ANN modelling approach

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Abstract

Purpose – This study aims to explore how sustainability factors, drawn from the Resource-Based View (RBV), stakeholder and institutional theory, influence the adoption of Green Human Resource Management (GHRM) and their mediating effect on improving Corporate Sustainable Performance (CSP) in Indian manufacturing firms.

Design/methodology/approach – The study uses a hybrid Structural Equation Modelling (SEM)-Artificial Neural Networks (ANN) model to examine both linear and non-linear relationships, using data from 279 managers across 37 ISO 14001-certified companies in Kerala gathered through a cross-sectional survey. SEM tested the hypotheses, whereas ANN focused on identifying the key predictors.

Findings – This study identifies stakeholder pressure (SP), green transformational leadership (GTL), green intellectual capital (GIC) and corporate social responsibility (CSR) as key determinants of GHRM. GHRM enhances CSP and fully mediates the relationship between each determinant and CSP. ANN analysis showed that SP and GTL were the most influential factors.

Research limitations/implications – The findings suggest that managers in Indian manufacturing companies certified with ISO 14001 should focus on SP and GTL, as these are the key drivers of GHRM adoption.

Originality/value – This study uniquely combines SEM and ANN methodologies to identify and rank the factors affecting GHRM adoption in India's manufacturing sector. SEM confirms the significance and direction of impacts, while ANN quantifies their relative importance, enabling prioritisation of SP, GTL, GIC and CSR beyond traditional linear analysis. Integrating RBV, stakeholder theory and institutional theory into a validated model, it presents a comprehensive framework for understanding GHRM adoption and its influence on CSP.

Keywords Green HRM, Sustainable performance, Green intellectual capital, Green transformational leadership, Stakeholder pressure, CSR

Paper type Research paper

1. Introduction

Managing environmental sustainability in modern organisations has become increasingly important. Stakeholder pressures (SP) compel manufacturing firms to adopt sustainable

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practices, alter decision-making and develop strategies that balance environmental goals with competitiveness (Singh *et al.*, 2022). Sustainability efforts offer benefits such as lower costs, reduced ecological impact, enhanced reputation, economic gains, innovation and attraction of eco-conscious consumers (WBCSD, 2021; Chatterjee *et al.*, 2023). However, India's manufacturing sector remains a significant user of resources and a major polluter, requiring proactive sustainability measures (Ndubisi *et al.*, 2021). As the third-largest greenhouse gas emitter, India faces major environmental challenges; however, research on its firms' environmental strategies remains limited (India Energy Outlook Report (IEA), 2021). Green Human Resource Management (GHRM) integrates environmentalism with human resources (HR) to promote sustainable performance through green hiring, training and management (Islam *et al.*, 2021; Zaid *et al.*, 2018). Despite its importance, research on GHRM's antecedents, especially in India, where factors such as green transformational leadership [GTL], green intellectual capital [GIC] and SP vary, remains limited (Ren *et al.*, 2018; Yong *et al.*, 2019). Contextual differences also affect GHRM adoption across industries and regions (Ren *et al.*, 2018).

This gap remains significant and underexplored because prior GHRM studies have mainly concentrated on outcomes such as organisational citizenship behaviour for the environment, green innovation and environmental performance, rather than exploring the factors that drive their adoption – particularly in the manufacturing sectors of emerging economies (Ren *et al.*, 2018; Faheem *et al.*, 2024). Moreover, there is a notable gap regarding GHRM's role: although it is believed that GHRM enhances sustainability outcomes, it is unclear whether GHRM functions as a mediator between determinants and corporate social performance (CSP) or whether determinants influence performance directly. This study aims to address these questions to fill these gaps:

RQ1. What are the primary sustainability-focused factors influencing GHRM in ISO 14001-certified Indian manufacturing companies and how important are they comparatively?

RQ2. In what way does GHRM act as a mediator between these factors and CSP?

To answer these questions, this study adopts a hybrid Structural Equation Modelling (SEM) and Artificial Neural Networks (ANNs) approach to explore both the linear and nonlinear relationships among GHRM determinants. SEM tests hypotheses and validates models, whereas ANN captures complex interactions and ranks variable importance (Asadi *et al.*, 2021; Al-Sharafi *et al.*, 2023). Combining these methods creates a significant gap, as prior GHRM research has primarily focused on outcomes such as organisational citizenship behaviour for the environment, green innovation and environmental performance. This gap remains significant and underexplored. Specifically, the factors influencing the adoption of these outcomes have not been examined, particularly in the manufacturing sectors of emerging economies (Ren *et al.*, 2018; Faheem *et al.*, 2024). Further, there is a significant discrepancy in the understanding of GHRM's role. While it is widely believed that GHRM enhances sustainability outcomes, it is uncertain whether GHRM serves as a mediator between determinants and corporate social performance (CSP) or if determinants directly affect performance. In an effort to resolve these deficiencies, our investigation intends to address these enquiries. Comprehensive understanding, helping organisations prioritise key factors and optimise resources (Fu and Chang, 2016). The study offers three key contributions. Firstly, it combines RBV, stakeholder and institutional theories into a comprehensive multi-theory framework to analyse factors influencing GHRM adoption. Secondly, it empirically examines GHRM determinants in ISO 14001-certified Indian

manufacturing companies, illustrating the country's changing environmental regulations. Thirdly, its hybrid SEM-ANN method enables hypothesis testing and data-driven ranking of nonlinear predictors, overcoming limitations of studies that use a single methodology. Collectively, these contributions offer practical insights to help Indian manufacturing firms prioritise key sustainability drivers and align their HR and environmental strategies.

2. Literature review and hypotheses development

GHRM is widely used in environmental management. Wehrmeyer (1996) linked HRM to environmental principles, making him the father of this concept. The term "Green HRM" was coined by Douglas Renwick in 2008 (Renwick *et al.*, 2013). Renwick *et al.* (2013) describe GHRM as an environmental aspect of HRM. Yusoff *et al.* (2020) defined it as HRM practices that sustain and protect organisations from environmental harm.

GHRM involves techniques and policies that promote eco-friendly behaviour at work, boost sustainability commitment and create environmentally conscious staff (Ren *et al.*, 2018; Masri and Jaaron, 2017; Nejati *et al.*, 2017). It helps achieve financial, social and ecological goals, influencing operations and relationships (Wikhamn, 2019). Core policies include green recruitment, training, performance, rewards and participation (Tang *et al.*, 2018). GHRM enables management to communicate, train, empower and incentivise environmental responsibility (Kim *et al.*, 2018). While most research focuses on outcomes like organisational citizenship behaviour for environment (OCBE), green innovation and sustainability, few explore their drivers or relationships. As organisations face strategic challenges in integrating sustainability with HRM, advanced methods like hybrid SEM–ANN are used to improve research, following Lee *et al.* (2020).

The literature review highlights the RBV (Barney, 1991) as the primary explanation for GHRM predictors. Stakeholder Theory (Freeman, 1984) illustrates how external legitimacy pressures encourage firms to adopt GHRM practices. Meanwhile, Institutional Theory highlights regulatory, normative and mimetic influences that drive manufacturing companies to implement green HR strategies. These frameworks enhance the Resource-Based View (RBV) by explaining both resource mobilisation and external pressures. RBV views organisations as assemblages of resources, where those that are valuable, rare, inimitable and non-substitutable (VRIN) confer a competitive edge (Yadegaridehkordi *et al.*, 2023). GHRM practices, such as green recruitment, training and employee engagement, serve as strategic resources that reduce costs, boost reputation and increase commitment (Sidney *et al.*, 2022; Zihan and Makhbul, 2024). This study uses RBV to identify GHRM determinants: SP, GIC, GTL and Corporate Social Responsibility (CSR). The hypotheses and conceptual model (Figure 1) were developed based on this framework.

2.1 Stakeholder pressure and green human resource management

Stakeholders, including internal (owners, managers and employees) and external (governments, non-governmental organisations (NGOs), customers and communities) groups, influence business policies and performance (Freeman, 1984; Seroka-Stolka, 2023). Ecologically, SP demands better environmental performance (Kitsis and Chen, 2021), driving green strategies like GHRM (Vázquez-Brust *et al.*, 2022; Guerci *et al.*, 2016). According to stakeholder theory, organisations must meet diverse expectations for legitimacy (Freeman, 1984), which influence environmental practices (Jakhar *et al.*, 2019). Singh *et al.* (2022) found that SP affects green capabilities and innovation and Vázquez-Brust *et al.* (2022) linked environmental demands to green strategies. GHRM responds to these demands, enhancing environmental outcomes (Guerci *et al.*, 2016). Moreover, SP serves as both an external coercive force and a motivation for organisations to strategically

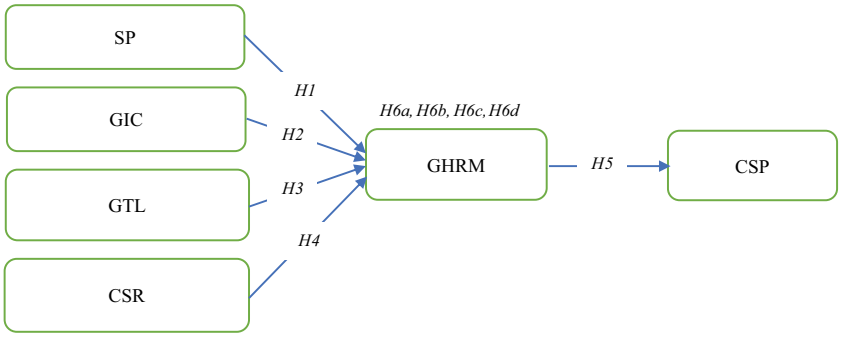


Figure 1. Research model

integrate environmental values into their HR systems. As a result, companies that proactively respond to stakeholder expectations through GHRM are more likely to strengthen their environmental credibility and stay competitive. Thus, by combining stakeholder theory with RBV, external pressures can become valuable resources, boosting sustainability.

Therefore, the hypothesis is as follows:

H1. Stakeholder pressure positively influences GHRM.

2.2 Green intellectual capital and green human resource management

GIC expands intellectual capital by incorporating environmental concerns: green human capital (skills and attitudes), green structural capital (organisational systems for environmental practices) and green relational capital (stakeholder relationships that promote sustainability) (Chang and Chen, 2012). From an RBV perspective, these rare resources offer a competitive edge. Theories suggest organisational wealth results from transforming intellectual capital (Kianto *et al.*, 2017). GIC serves as a resource pool for green strategies, supporting innovation and environmental performance (Asiaei *et al.*, 2022) and influencing GHRM adoption (Ali *et al.*, 2022). Yong *et al.* (2023) find that human and relational capital strengthen GHRM. Organisations with mature GICs excel at integrating environmental values into HR systems and cultivating a workforce that supports sustainability. Consequently, GIC becomes a crucial capability that enables the effective adoption and execution of GHRM practices.

Therefore, this study proposes:

H2. GIC has a positive effect on GHRM.

2.3 Green transformational leadership and green human resource management

Leadership influences HRM practices and strategy, with GTL inspiring sustainability (Chang and Chen, 2012). GHRM embeds environmental goals into HR, aligning employee actions with organisational aims (Dumont *et al.*, 2017). The literature supports the link between GTL and GHRM; for example, Renwick *et al.* (2013) and Sidney *et al.* (2022) show that leaders influence eco-friendly practices, especially in SMEs and manufacturing (Farrukh *et al.*, 2022). GTL serves as a strategic catalyst, encouraging organisations to integrate environmental sustainability into their HR policies and employee management. Leaders who champion

green principles foster an organisational culture where GHRM practices are more easily adopted, embraced and sustained at all levels. In short, GTL promotes a sustainability-orientated culture and ensures that HR practices support environmental goals. Accordingly, we propose the following hypothesis:

H3. GTL is positively related to GHRM.

2.4 Corporate social responsibility and green human resource management

CSR is a firm's responsibility to meet economic, legal, ethical and philanthropic expectations (Carroll, 1991). It balances environmental, social and economic performance, strengthening sustainability. Studies identify CSR as a key component of GHRM (Yusliza *et al.*, 2019; Tanveer *et al.*, 2023). Two views exist: GHRM practices implement CSR or CSR drives GHRM, motivated by social and environmental commitments (Sheopuri and Sheopuri, 2015; Voegtlin and Greenwood, 2016). Under RBV, CSR is a strategic capability fostering innovative HR practices for sustainable benefits. Empirical studies support CSR's role in promoting GHRM (Úbeda-García *et al.*, 2022; Yusliza *et al.*, 2019). Organisations with robust CSR integrate environmental principles into employee practices via GHRM as part of their sustainability initiatives. Combining CSR and GHRM enhances employees' environmental awareness and responsibility, thereby reinforcing overall sustainability. This study hypothesises that:

H4. CSR has a positive effect on GHRM.

2.5 Green human resource management as an intervening mechanism for corporate sustainable performance

Corporate Sustainable Performance (CSP) denotes the concurrent achievement of environmental, social and economic objectives (Schaltegger and Wagner, 2006). Prior studies show that SP, GIC, GTL and CSR are each associated with CSP (Baah *et al.*, 2021; Khan *et al.*, 2021); however, these works primarily treat these factors as direct predictors, lacking explanations of the mechanisms linking them to CSP. This research proposes that these four determinants influence CSP indirectly through GHRM, based on an integration of three theories that clarify different parts of the process. Stakeholder theory explains why firms encounter environmental expectations and feel compelled to respond (Freeman, 1984), but it does not specify how this pressure results in measurable performance. The RBV addresses this gap, suggesting that resources – such as external sources like SP, knowledge-based GIC and strategic CSR – only produce outcomes when mobilised through organisational capabilities (Barney, 1991). GHRM functions as such a capability: the operational HR system that channels these resources into specific employee behaviours and routines. Institutional theories further clarify why GTL drive firms towards conformity; however, these normative and coercive pressures only influence outcomes when integrated into HR practices. Since no single theory fully explains the entire chain from antecedents to mechanisms to outcomes, a multi-theoretical approach is essential, rather than merely listing theories.

Accordingly, GHRM is positioned as the intervening mechanism linking the determinants to CSP. The following hypotheses are proposed and the research model is shown in Figure 1.

H5. GHRM is positively related to Corporate Sustainable Performance.

H6a. GHRM mediates the relationship between Stakeholder Pressure and Corporate Sustainable Performance.

H6b. GHRM mediates the relationship between GIC and Corporate Sustainable Performance.

H6c. GHRM mediates the relationship between GTL and Corporate Sustainable Performance.

H6d. GHRM mediates the relationship between CSR and Corporate Sustainable Performance.

3. Research methodology

This study used an exploratory quantitative approach to analyse factors influencing GHRM adoption in Indian manufacturing firms. The sample included 148 large firms from Kerala's Directorate of Industries, Commerce and MSME centres, chosen for visibility and resources. Applying the Micro, Small and Medium Enterprises Development Act (2006), the list was narrowed to 98 firms by turnover; after removing non-ISO 14001 firms, 44 remained. Email consent was obtained from 37 firms, with questionnaires sent to strategy managers and follow-ups to reduce non-responses. The estimated minimum sample size was 273 (Yamane, 1967) and 279 valid responses from 37 companies were received, exceeding the requirements for partial least square-structural equation modeling (PLS-SEM) and satisfying the "ten-times rule" (Hair *et al.*, 2013), supporting cross-validation in ANN. Missing data was under 5%, and non-response bias tests showed no significant differences. Table 1 presents descriptive statistics for respondents.

Seven to eight senior managers per organisation involved in environmental strategy, HR or sustainability reporting were selected through initial contact with a liaison, ensuring understanding of GHRM practices. Multiple responses from the same organisation focused on perceptions, aligning with GHRM research (Dumont *et al.*, 2017; Farrukh *et al.*, 2022). The measures, which assessed perceptions individually, made a multilevel analysis unnecessary. The instrument underwent two pre-tests:

(1) expert review for content validity and clarity; and

(2) a pilot test for comprehension and consistency.

Non-response bias was assessed via an early-versus-late respondent comparison using *t*-tests, which showed no significant differences, indicating that bias was unlikely to skew the results.

To address common method bias (CMB), procedures included separating scale items and maintaining respondent anonymity, reducing bias and social desirability effects

Table 1. Profile of respondents

Characteristics	Categories	Frequency	%
Age	Below 30	5	1.79
	30–40	78	27.96
	40–50	103	36.91
	50–60	78	27.96
	Above 60	15	5.38
Gender	Male	208	74.55
	Female	71	25.45
Experience	Below 10 years	36	12.90
	10–20 years	112	40.14
	20–30 years	87	31.18
	Above 30 years	44	15.78

Table 2. Measurement model estimates

Constructs	Items	Outer loading	VIF	Cronbach's α	rho_a	AVE
Green HRM (GHRM)	GHRM1	0.768	1.746	0.817	0.826	0.525
	GHRM2	0.804	2.048			
	GHRM3	0.819	2.232			
	GHRM4	0.674	1.433			
	GHRM5	0.704	1.838			
	GHRM6	0.659	1.777			
Stakeholder pressure (SP)	SP1	0.605	1.842	0.794	0.930	0.559
	SP2	0.771	2.203			
	SP3	0.736	1.361			
	SP4	0.685	1.483			
	SP5	0.691	1.857			
	SP6	0.819	1.543			
Green intellectual capital (GIC)	GIC1	0.847	2.916	0.860	0.901	0.546
	GIC2	0.845	2.090			
	GIC3	0.843	2.569			
	GIC4	0.737	2.081			
	GIC5	0.674	1.949			
	GIC6	0.607	1.590			
	GIC7	0.651	1.786			
Green transformational leadership (GTL)	GTL1	0.655	1.718	0.840	0.864	0.553
	GTL2	0.643	1.687			
	GTL3	0.765	2.116			
	GTL4	0.806	2.077			
	GTL5	0.797	2.301			
	GTL6	0.778	2.175			
Corporate social responsibility (CSR)	CSR1	0.854	2.064	0.869	0.923	0.649
	CSR2	0.830	2.170			
	CSR3	0.763	2.376			
	CSR4	0.785	2.642			
	CSR5	0.792	2.004			
Corporate sustainable performance (CSP)	CSP1	0.726	2.225	0.939	0.942	0.580
	CSP2	0.724	2.114			
	CSP3	0.749	3.038			
	CSP4	0.766	3.192			
	CSP5	0.796	3.368			
	CSP6	0.815	3.195			
	CSP7	0.819	3.080			
	CSP8	0.803	2.743			
	CSP9	0.823	3.049			
	CSP10	0.802	3.278			
	CSP11	0.749	2.069			
	CSP12	0.658	1.880			
	CSP13	0.644	1.706			

(Podsakoff *et al.*, 2012). Harman's test showed the first unrotated factor explained less than 20% of the variance, below the 50% threshold, indicating low CMB. Indicator collinearity values in Table 2 (all VIFs < 5) support this. Heterotrait-monotrait (HTMT) ratios below 0.85 (Table 3) further confirm discriminant validity.

This instrument had three parts:

(1) Part A was an introductory letter;

Table 3. Discriminant validity statistics – HTMT ratio

Constructs	CSP	CSR	GHRM	GIC	GTL	SP
CSP						
CSR	0.783					
GHRM	0.557	0.448				
GIC	0.551	0.617	0.563			
GTL	0.694	0.799	0.472	0.605		
SP	0.467	0.516	0.538	0.842	0.573	

(2) Part B collected demographic data; and

(3) Part C evaluated constructs.

Items used a 5-point Likert scale from "1 = strongly disagree" to "5 = strongly agree." Some items were from previous research. GHRM was assessed using Dumont *et al.* (2017) 6-item scale, e.g. "My company sets green goals for its employees." SP was assessed using Chiappetta Jabbour *et al.*'s (2020) 6-item scale, e.g. "Stakeholder pressure on environmental practices – Customers." GIC was measured with Zaragoza-Sáez *et al.* (2020) 7-item scale, e.g. "Employees have environmental knowledge." GTL was evaluated with Chen and Chang (2013) 6-item scale, e.g. "Green project leaders provide environmental visions." CSR was assessed with Kim *et al.*'s (2010) 5-item scale, e.g. "My company profits support communities." CSP was measured with Paulraj's (2011) 13-item scale, e.g. "Reduction in air emissions." These scales ensured the study's reliability.

4. Results

SEM tests hypotheses (Le and Ikram, 2022) but is limited by its linear assumptions in complex decision-making and factor ranking (Kalinic *et al.*, 2019). ANNs overcome these limitations by capturing linear and nonlinear correlations, outperforming traditional methods such as Decision Trees, Support Vector Machines (SVMs) and Gradient Boosting (Sharma *et al.*, 2021; Abbasi *et al.*, 2021). They are more effective for data where linear models fall short and are less sensitive to violations of assumptions (Al-Sharafi *et al.*, 2022). This study used a hybrid SEM–ANN approach (see Figure 2): SEM for causal inference and ANN for modelling non-linearities and ranking determinants (Chong, 2013; Ahani *et al.*, 2018). PLS-SEM with SmartPLS validated the model, offering more power than Covariance-Based SEM (CB-SEM) in exploratory research (Hair *et al.*, 2013; Al-Sharafi *et al.*, 2022). Reliability, validity, hypothesis testing and model performance were assessed using measurement modelling, bootstrapping, path coefficients, T and P values, R^2 and Q^2 (Iranmanesh *et al.*, 2022).

4.1 Measurement model

Confirmatory factor analysis (CFA) was used to assess convergent validity, internal consistency, discriminant validity and overall fit (Sarstedt *et al.*, 2014). Table 2 shows indicator reliability values mostly above 0.7, confirming the item reliability (Shahzad *et al.*, 2021). Cronbach's alpha and composite reliability, both over 0.7, support internal consistency (Hair *et al.*, 2013). All AVEs exceeded 0.5, establishing convergent validity (Shahzad *et al.*, 2021). Variance inflation factor (VIF) below 5 indicates the absence of multicollinearity (Martins *et al.*, 2023). Table 3 shows HTMT ratios below 0.85, confirming discriminant validity (Henseler *et al.*, 2016).

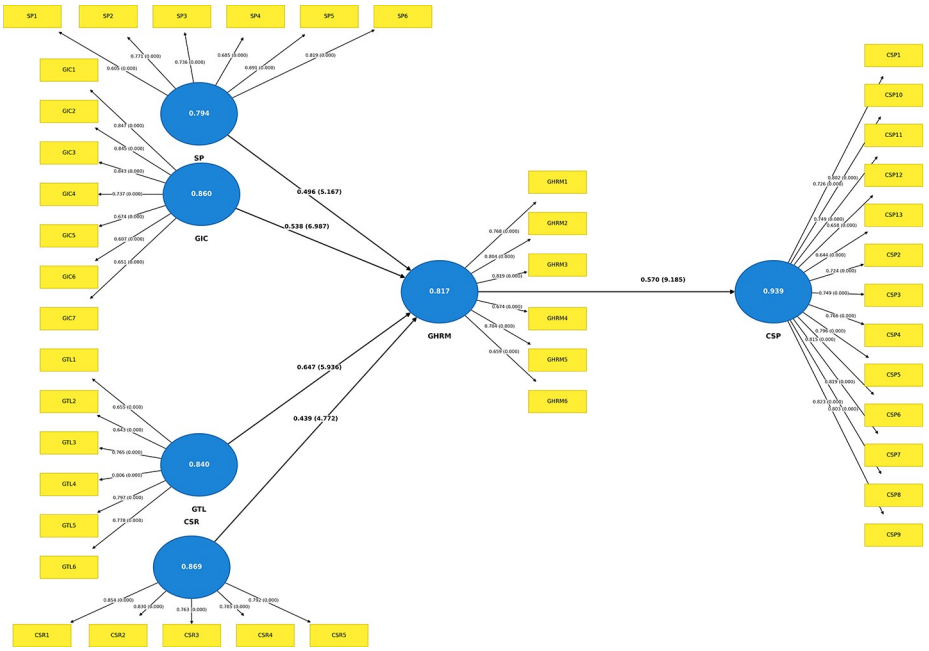


Figure 2. SEM path diagram

Table 4. Hypotheses test results

Hypotheses	Relationship	β	STDEV	*t*-value	*p*-values	Decision
H1	SP → GHRM	0.496	0.096	5.167	0.000	Supported
H2	GIC → GHRM	0.538	0.077	6.987	0.000	Supported
H3	GTL → GHRM	0.647	0.109	5.936	0.000	Supported
H4	CSR → GHRM	0.439	0.092	4.772	0.001	Supported
H5	GHRM → CSP	0.570	0.062	9.185	0.000	Supported
H6a	SP → GHRM → CSP	0.528	0.102	5.176	0.000	Supported
H6b	GIC → GHRM → CSP	0.394	0.083	4.747	0.000	Supported
H6c	GTL → GHRM → CSP	0.562	0.079	7.114	0.000	Supported
H6d	CSR → GHRM → CSP	0.468	0.084	5.571	0.001	Supported

4.2 Structural model assessment

To run the hypothesis tests, this study used a PLS-SEM bootstrapping programme ($n = 5000$). Table 4 presents the results of the hypothesis tests.

Based on Table 4 and Figure 2, the effects of SP, GIC, GTL and CSR on GHRM were 0.496 ($p < 0.001$), 0.538 ($p < 0.001$), 0.647 ($p < 0.05$) and 0.439 ($p < 0.05$), supporting *H1*, *H2*, *H3* and *H4*. Additionally, GHRM's impact on CSP was 0.570 ($p < 0.001$), confirming *H5*. We also examined the mediating role of GHRM between its determinants and Corporate Sustainable Performance (CSP). As shown in Table 5, all determinants positively influenced CSP through GHRM. Finally, the predictive relevance of the model between the independent and dependent variables is shown by R^2 and Stone-Geisser's Q^2, listed in Table 5. Both R^2 and Q^2 were above 0.26 and 0, respectively, indicating strong predictive relevance (Khan *et al.*, 2021).

Table 5. Predictive relevance

Constructs	R^2	Q^2
GHRM	0.344	0.312
CSP	0.271	0.269

To assess the nature of mediation, direct effects from SP, GIC, GTL and CSR to CSP (paths bypassing GHRM) were also tested using bootstrapping. These effects were not statistically significant ($p > 0.05$ for all paths), indicating GHRM fully mediates each antecedent-CSP relationship. This supports that GHRM is a key operational mechanism through which sustainability antecedents improve corporate sustainable performance.

4.3 Artificial neural network analysis

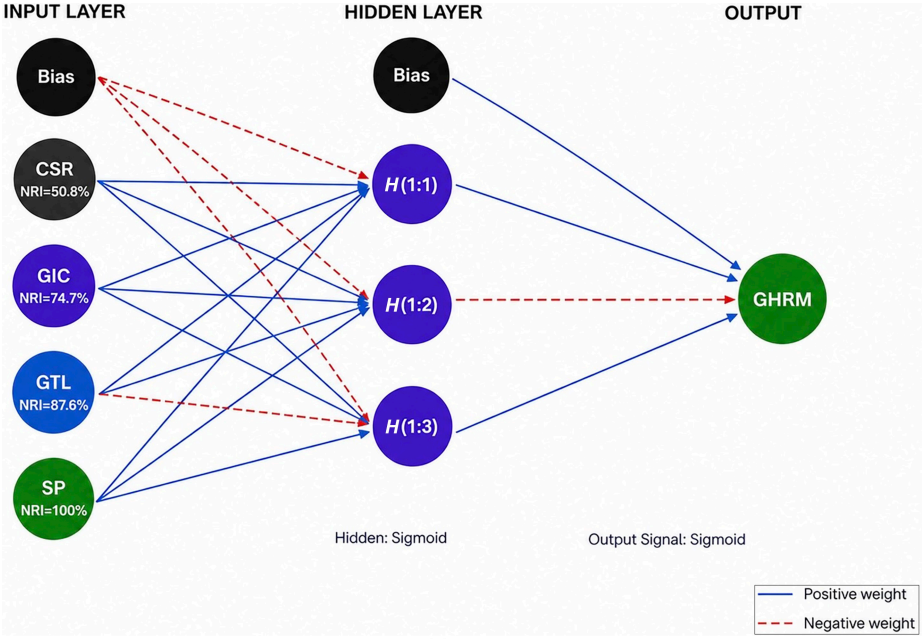
In the secondary analysis, ANN models were developed using significant variables identified by SEM, with PLS-SEM output as the input. The multilayer perceptron (MLP) used in IBM SPSS uses sigmoid functions for both the output and hidden layers. Tenfold cross-validation splits the data into 90% for training and 10% for testing to evaluate forecast accuracy using the standard deviation and root mean square error (RMSE).

Two ANN models are created in SPSS to examine non-linear relationships. Model 1 assesses antecedents (SP, GIC, GTL, CSR) for GHRM, while Model 2 predicts CSP based on GHRM. This approach mirrors SEM's mediation pattern by ranking antecedents and confirming the mediating role of GHRM.

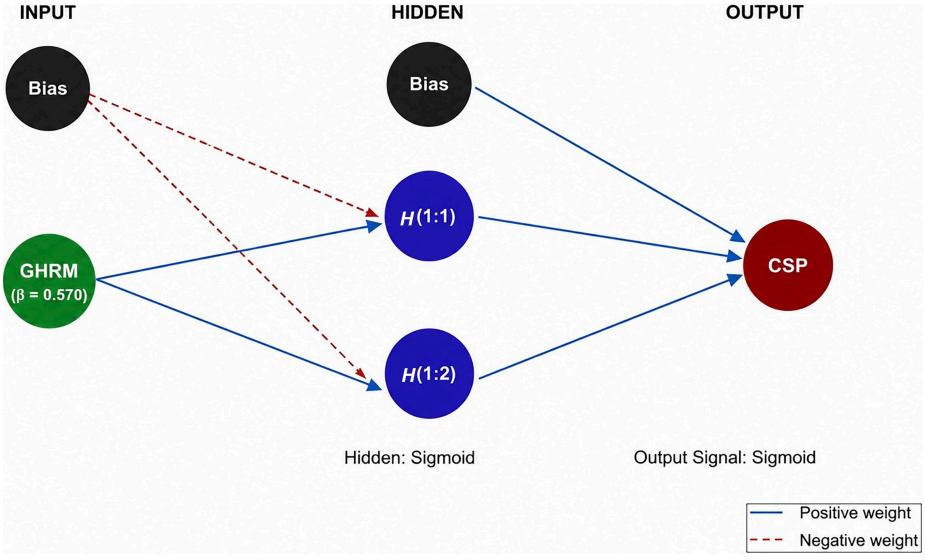
4.3.1 Artificial neural network model 1: Predicting green human resource management from antecedents. ANN Model 1 was developed with SP, GIC, GTL and CSR as input nodes and GHRM as the single output node (Figure 3(a). The MLP architecture included a single hidden layer with three neurones (*H1*:1, *H1*:2, *H1*:3), illustrated in Figure 3. Both the hidden and output layers used sigmoid activation functions. The optimal number of hidden neurones was determined through iterative testing to minimise RMSE across validation folds. Training incorporated early stopping based on error stabilisation over cross-validation folds to prevent overfitting and enhance model robustness. The RMSE evaluates model performance; lower RMSE values indicate better predictive accuracy. Model 1 achieved mean RMSEs of 0.136 (training) and 0.127 (testing), indicating stable and reliable predictive performance with no evidence of overfitting.

4.3.2 Sensitivity analysis – model 1. A sensitivity analysis was conducted to determine and rank the relative importance of the four predictors in predicting GHRM using Normalised Relative Importance (NRI). Table 6 presents the results. SP recorded the highest importance value (0.319, NRI = 100%), followed by GTL (0.280, NRI = 87.6%), GIC (0.238, NRI = 74.7%) and CSR (0.162, NRI = 50.8%). These rankings confirm that all four antecedents contribute meaningfully to GHRM adoption, with SP and GTL exerting the dominant non-linear influence.

4.3.3 Artificial neural network model 2: Predicting corporate social performance from green human resource management. To validate GHRM's role as the key operational mediator under non-linear conditions, ANN Model 2 was developed with GHRM as the sole input and CSP as the output (see Figure 3b and Table 7). This model evaluates GHRM's ability to predict CSP without assuming linearity in SEM, providing non-linear evidence for the GHRM → CSP relationship. It includes a single hidden layer with 2 neurones and sigmoid activation. The model achieved mean RMSE values of 0.141 on the training set and



(a)



(b)

Figure 3. (a) ANN Model 1 – Architecture for Predicting GHRM (b) ANN Model 2 – Architecture for Predicting CSP from GHRM

Table 6. Sensitivity analysis/independent variable importance – model 1

Predictor	Importance	Normalised importance	Rank	SEM β (for comparison)
SP	0.319	100%	1	0.496 ($p < 0.001$)
GTL	0.280	87.6%	2	0.647 ($p < 0.001$)
GIC	0.238	74.7%	3	0.538 ($p < 0.001$)
CSR	0.162	50.8%	4	0.439 ($p < 0.001$)

Note(s): NRI = normalised relative importance. RMSE (training) = 0.136; RMSE (testing) = 0.127 Sigmoid activation. SEM β values are provided for cross-method comparison

Table 7. ANN Model 2 – GHRM predicting CSP

Predictor	Importance	Normalised importance	RMSE (train/test)
GHRM	0.412	100%	0.141 / 0.133

Note(s): Model 2 confirms GHRM as the dominant predictor of CSP under non-linear conditions. Full mediation is supported as direct antecedent effects on CSP remain non-significant when GHRM is present in both SEM and ANN analyses

0.133 on the test set, demonstrating reliable predictive accuracy. Sensitivity analysis showed GHRM's NRI was 100%, consistent with the SEM path coefficient ($\beta = 0.570$, $p < 0.001$), confirming GHRM as the primary operational antecedent of CSP rather than merely a correlated variable. Even when other antecedents were added, GHRM remained the strongest predictor, validating complete non-linear mediation.

5. Discussion

This study investigates factors influencing GHRM and their effect on CSP in Indian manufacturing using SEM–ANN analysis. SEM identified SP as a significant driver ($\beta = 0.496$, $p < 0.001$), which was confirmed as the most influential by ANN Model 1 (NRI = 100%). GTL was the second most important, fostering a sustainability culture (SEM $\beta = 0.647$, $p < 0.001$; NRI = 87.6%). GIC (NRI = 74.7%, $\beta = 0.538$, $p < 0.001$) emphasises green knowledge, while CSR (NRI = 50.8%, $\beta = 0.439$, $p < 0.001$) also positively impacts GHRM. GHRM, in turn, improves CSP ($\beta = 0.570$, $p < 0.001$), serving as a mediator for all factors, with ANN Model 2 confirming this relationship non-linearly (GHRM NRI = 100%). The combined use of SEM and ANN captures both linear and non-linear effects, broadening RBV and stakeholder theory by demonstrating how sustainability factors influence GHRM and CSP.

The dominance of SP (NRI = 100% in ANN Model 1) aligns with existing GHRM research. Guerci *et al.* (2016) demonstrated that external stakeholder demands shape environmental practices through green HRM, while Singh *et al.* (2022) highlighted SP as crucial for developing green capabilities in SMEs. In India's manufacturing industry, institutional theory suggests that firms subjected to regulatory, buyer and civil society pressures are driven to adopt GHRM practices to gain legitimacy (Freeman, 1984; Darnall *et al.*, 2010). Kerala's ISO 14001 environmental certification showcases this: certified firms experience greater stakeholder scrutiny, positioning SP as a vital driver of GHRM.

GTL's second-place ranking (NRI = 87.6%) aligns with Farrukh *et al.* (2022) and Sidney *et al.* (2022), who identify green transformational leaders as crucial internal advocates connecting environmental vision with HR implementation. Importantly, GTL's SEM β

(0.647) is the highest among all antecedents, while its ANN NRI ranks second to SP – a notable divergence: SEM β reflects the linear strength of the GTL-GHRM relationship alone, whereas ANN NRI shows the relative importance considering all predictors. The slight drop in rank from SEM to ANN suggests that, although GTL is a strong predictor, it has a lower unique non-linear contribution than SP, likely due to overlapping institutional pathways.

GIC's significance (NRI = 74.7%) corresponds with Yong *et al.* (2023), who identified human and relational capital as key drivers of GHRM, surpassing structural capital alone. ANN reveals that GIC's contribution, partially shared with SP in a non-linear manner, is most impactful when external stakeholder demands are present, suggesting implications for resource allocation. Meanwhile, CSR's moderate importance (NRI = 50.8%), confirmed by SEM results, aligns with Tanveer *et al.* (2023), positioning CSR as a strategic enabler rather than a direct driver, indirectly influencing GHRM through culture and reputation.

The dual-ANN approach improves mediation analysis in GHRM research. ANN Model 2 indicates GHRM achieves a 100% NRI for CSP prediction, supporting SEM's full mediation findings under non-linear conditions. Both approaches – SEMs showing non-significant direct paths and ANN highlighting GHRM's influence on CSP – provide strong multi-method evidence that GHRM is the crucial link transforming pressures, leadership, knowledge and CSR into sustainability outcomes. This builds on Vázquez-Brust *et al.* (2022) and confirms that GHRM converts greening pressures into environmental practices through both linear (SEM) and non-linear (ANN) methods.

6. Conclusion

6.1 Main findings

This research investigates GHRM as a strategic method for enhancing Corporate Sustainable Performance (CSP) in Indian manufacturing firms certified under ISO 14001. It examines how SP, GTL, GIC and CSR impact GHRM implementation and how GHRM, in turn, boosts CSP. All four factors are significant predictors of GHRM adoption. Specifically, SP ($\beta = 0.496$, NRI = 100%) and GTL ($\beta = 0.647$, NRI = 87.6%) are the most influential, with GIC ($\beta = 0.538$, NRI = 74.7%) and CSR ($\beta = 0.439$, NRI = 50.8%) also playing important roles. GHRM fully mediates all the examined pathways ($\beta = 0.570$, $p < 0.001$), as demonstrated by both linear (SEM: non-significant direct effects) and non-linear (ANN Model 2: GHRM NRI for CSP = 100%) analyses. The combined SEM–ANN approach provides complementary insights that are not achievable with a single method.

6.2 Theoretical implications

This study applies RBV, stakeholder theory and institutional theory to deepen understanding of GHRM as a VRIN resource influenced by external legitimacy pressures and internal strengths (Masri and Jaaron, 2017; Tanveer *et al.*, 2023). GHRM fully mediates all four antecedent-CSP pathways under both conditions, offering empirical support for RBV's view of HR capabilities as key mediators between resources and outcomes (Barney, 1991). The integrated model provides a comprehensive explanation of how external pressures (stakeholder theory), internal leadership (RBV + institutional theory), knowledge resources (RBV) and social responsibility (stakeholder theory + RBV) drive GHRM adoption. The ANN approach improves mediation analysis in HRM by providing a non-linear complement to SEM bootstrapping.

6.3 Practical implications

The importance ranking helps managers allocate resources effectively. Since SP has the highest NRI (100%), organisations should focus on stakeholder engagement, including

environmental consultations with customers, regulators and communities, to leverage external pressure for GHRM. With GTL second (NRI = 87.6%), investing in green leadership and training in environmental vision and culture is key. Developing GIC (NRI = 74.7%) through knowledge management and green teams will boost GHRM. CSR strategies should align with HR practices like green recruitment, sustainability appraisals and environmental incentives to promote sustainability. Policymakers can support GHRM by enforcing regulations and encouraging ISO 14001 certification.

6.4 Limitations

This study has limitations. Firstly, its cross-sectional design ca not establish causality; SEM and ANN offer strong associations and predictions, but longitudinal data is needed to confirm sequences of antecedents, GHRM and CSP. Secondly, focusing on ISO 14001-certified companies in Kerala limits generalisability to non-certified firms, other Indian regions or countries. Thirdly, despite efforts to reduce bias, self-reported data may still be biased. Finally, GHRM is treated as a single construct, ignoring sub-dimensions such as recruitment, training, performance management and incentives, which may have distinct effects.

6.5 Future research directions

Future research should use longitudinal studies to clarify causal links among antecedents, GHRM and CSP. Cross-national studies can test if the SP-GHRM-CSP pathway is consistent across cultures. Analysing GHRM sub-dimensions separately can identify which practices are most affected by specific antecedents. Variables like firm size, industry, values and technology should be examined as boundary conditions. Exploring the effects of technology-enabled GHRM and digital reporting offers promising future research directions.

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