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The role of big data analytics and AI adoption on green innovation and sustainable SMEs performance

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Abstract

Green innovation has become a major factor in corporate sustainability in today's green economy era. Corporate sustainability is largely determined by the company's human resource management practices. This study investigates how green human resource management practices and digital learning orientation can enhance green innovation and improve sustainable SMEs performance. This study also examines the role of Big Data Analytic moderation and AI adoption in enhancing green innovation. The sample of this study was owners, managers, and supervisors of SMEs in Indonesia, who were obtained using purposive sampling techniques and data analysis methods using PLS-SEM. The results of this study show the important role of green human resource management practices in adapting to environmental changes and encouraging green digital learning orientation and green innovation. In addition, this study also found that green digital learning orientation has a significant effect on green innovation if moderated by Big Data Analytics and AI adoption. The results of this moderation indicate that employees who receive green digital learning will be stronger in practicing green innovation if supported by Big Data and AI. In addition, green innovation strongly influences sustainable SMEs performance and mediates the effect of green human resource management practices on sustainable firm performance.

Keywords

green innovation; GHRM; big data analyics; AI adoption; sustainable; SMEs performance

INTRODUCTION

High environmental pollution is caused by increasing industrial growth (Akhtar, Li, et al., 2024). Currently, many organizations or companies have realized how serious environmental problems are. Therefore, they have decided to develop strategies to maintain current resources and minimize emissions (Akhtar, et al., 2024; Altassan, 2024). Several studies have examined the concept of sustainability as a connection between a green environment, social justice, and economic development to develop resilient communities (Alshuaibi et al., 2024). Some companies prioritize environmental goals over profitability (Bartolacci et al., 2020). These green human resource management practices (GHRM) are designed to preserve natural ecosystems and reduce environmental pollution. The success of implementing sustainability goals and environmentally friendly activities is influenced by the organization's or company's internal resource factors (Awwad Al-Shammari et al., 2022; Cegarra-Navarro et al., 2024). Companies are adopting GHRM practices, sustainability goals, and internal development (Alshuaibi et al., 2024; Awwad Al-Shammari et al., 2022).

Modern human resource management must acknowledge the relevance of green innovation (GI) practices in building an ecologically responsible firm (Alshuaibi et al., 2024). The definition of "green innovation" is based on innovation theory that focuses on long-term sustainability to produce environmentally responsible policies (Akhtar, Li, et al., 2024). The implementation of sustainable business is challenging for many small and medium-sized businesses because they lack the essential resources, Green Innovation, employee engagement, and crucial competences (Al-Hakimi et al., 2022; Almeida & Wasim, 2023). Thus, green innovation and corporate sustainability depend on GHRM practices (Aldaas et al., 2022; M. T. Khan et al., 2024). Academics are currently increasingly studying the role of

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GHRM in the goals of the business world in achieving business sustainability. In the manufacturing industry, data-driven insights can improve the supply chain by reducing resource consumption and waste (Yadegaridehkordi et al., 2023; Zihan & Makhbul, 2024). AI can provide timely information and solutions to environmental issues (Abdelfattah et al., 2025).

Researchers have investigated GHRM and GI for environmental sustainability and organisational success in a competitive context. However, past research have overlooked comprehending the combined role of GHRM, green digital learning orientattion (GDLO), and GI (Alshuaibi et al., 2024). GDLO has an important role because it focuses on the tendency of companies to enhance green knowledge and facilitate green innovation behavior digitally. Many authors have studied green innovation and HRM models, outlining sustainable human resource management ideas and methods, but neglected to understand the role of GDLO in this relationship (Alshuaibi et al., 2024; A. N. Khan et al., 2024). While the specific effects of green innovation remain unknown, experts understand the relevance of management in creating green innovation and environmental performance (M. Altassan, 2024; Baeshen et al., 2021). The existing literature lacks a precise definition of the role of management, which leads to further exploration in the field (M. Altassan, 2024; Omar et al., 2024)

The purpose of this study is to gain a full understanding of the elements that influence company sustainability and long-term profitability. Investigating the moderating impact of Big Data Analytics (BDA) and AI, as well as the mediating role of green innovation (GI), will provide academics with fresh insights. Although substantial study has been conducted over the last decade on the influence of digitization and the circular economy on corporate sustainability performance in many countries, there is currently a paucity of research that particularly addresses this in the context of Indonesian manufacturing SMEs.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The Ability-Motivation-Opportunity (AMO) theory, created by Appelbaum et al. (2000), serves as the theoretical foundation for this study. This theoretical framework states that employee commitment can be increased using skills development, training, incentives, and effective opportunities (Alshuaibi et al., 2024; Iftikar et al., 2022). Implementing HRM solutions such as GDLO and GHRM can improve firm performance (Alshuaibi et al., 2024). These GHRM-compliant activities include greater efficiency, productivity, waste reduction, and output.

Sustainable firm performance

Increasing an organization's success in adopting sustainable practices requires active employee participation (Zihan & Makhbul, 2024). Employee responsibility includes offering feedback on environmental improvements, recycling, turning off equipment when users leave, using both sides of the paper, and eliminating waste products (Rehman et al., 2024).

Several studies examined the relationship between environmental management and HRM practices that impact companies' sustainability (Alshuaibi et al., 2024; Iftikar et al., 2022). Other studies have found that organizations that actively improve the competence of their employees by providing environmental education will improve sustainable business performance (Ishaq et al., 2024). A green environment is a standard to evaluate a company's sustainability performance. The approach to green HR and environmental practices is to increase profitability to impact the company's long-term sustainability performance (Iftikar et al., 2022; Ishaq et al., 2024; A. N. Khan et al., 2024).

GHRM and GDLO

Companies need the GHRM framework to build a production and consumption system for corporate sustainability (Aldaas et al., 2022). One way is that companies must be oriented towards digital learning. In digital learning, businesses need to teach their employees about things like modularization, creative green production, recycling, upkeep, repair, and shifting consumption habits (Chau et al., 2024). A study by Alshuaibi et al. (2024) found the importance of the relationship between GHRM practices and practices that focus on digital learning. Furthermore, GHRM practices and the success of sustainable green businesses in connection to sustainable practices in digital learning are positively correlated (Trujillo-Gallego et al., 2022).

Based on the results of previous studies, the following hypothesis is proposed:

H1: GHRM practices can improve GDLO in SMEs.

GHRM, GI and sustainable firm performance

Green human resource management strategies aim to implement environmental conservation initiatives to mitigate pollution by safeguarding natural ecosystems (A. Khan et al., 2023). Zihan and Makhbul (2024) assert that the GHRM framework comprises a set of regulations, methodologies, and structures employed by organizations to enhance societal welfare through the creation of environmentally and socially beneficial products. Shahzad et al. (2023) reveal that environmentally conscious organizations motivate their employees to engage with environmental initiatives and foster innovation within the company.

Green Innovation (GI) is an innovation theory focusing on long-term sustainability to produce environmentally responsible policies (Singh et al., 2020). The primary focus of this philosophy is to enhance innovative culture while preserving natural resources. The development of green HRM practices that prioritize GI is a significant area of research. GI refers to the utilization of technology to enhance and optimize industrial processes (Xie et al., 2024). Organizations focused on green innovation efficiently employ sustainable resources to develop environmentally friendly innovations. Numerous studies indicate that GI and GHRM practices foster policies aimed at emission reduction by emphasizing renewable energy sources, sustainable industrial processes, and eco-friendly technologies (Alshuaibi et al., 2024; A. N. Khan et al., 2024; Zihan & Makhbul, 2024). In light of these data, the hypothesis suggested in this study is as follows:

H2: GHRM practices can improve green innovation practices in SMEs.

GHRM methods seek to motivate employees in an eco-friendly manner by implementing procedures essential for company sustainability (Suleman et al., 2024). Educating employees on environmental issues is crucial for GHRM's objective to assist organizations. Research indicates that GHRM techniques assist organizations in executing GI (Aldaas et al., 2022; Alshuaibi et al., 2024). Akhtar, et al. (2024) shown that robust innovation capabilities and sustained performance can be enhanced by the implementation of GHRM methods. Rakin et al. (2020) shown that green innovation connects green human resource management approaches to the sustainable performance of SMEs. Recent research indicate that GI substantially influences the sustainable social and economic performance of SMEs (Schrank & Kijkasiwat, 2024; Singh et al., 2020). Additional research demonstrates that green innovation enhances the connection between GHRM practices and sustainable performance (Alshuaibi et al., 2024).

Other studies have found that the sustainability of economic performance and innovation strategy are positively correlated (M. A. Altassan, 2023; Aslam et al., 2025). In addition, the positive impact of green innovation on sustainable corporate performance can be identified in dimensions such as environmentally friendly products, processes, managerial, and marketing innovations (Ardyan et al., 2017; Baeshen et al., 2021; Bartolacci et al., 2020). Therefore, the following hypotheses are proposed:

H3: GI practices can improve the sustainable performance of SMEs.

H4: GI mediates the effect of GHRM on sustainable performance of SMEs.

Green digital learning orientation, GI and sustainable performance of SMEs

Green digital learning remains a largely underexplored subject, and this viewpoint might enhance human resource management strategies for the sustained success of organizations. Zhao et al. (2023) contend that a company's long-term success is directly affected by a green digital learning strategy that fosters green innovation. The research asserts that "green digital learning" refers to digital educational tools and platforms that prioritize ecological and environmental sustainability (Gawlik-Kobylińska et al., 2020). Green digital learning is an effective and environmentally sustainable approach to utilizing digital resources. Examples of these resources include online courses, e-books, and multimedia content featuring interactive aspects aimed at promoting environmental

conservation by minimizing the reliance on paper-based materials (Donath et al., 2020).

Muafi et al. (2022) assert that green technology solutions take into account energy consumption, manufacturing materials, recycling potential, and disposal methods. These elements are taken into account while making judgments regarding digital learning. Green IT practices encompass minimizing electronic waste, enhancing server efficiency, and employing energy-efficient solutions for the installation and maintenance of digital learning systems (Trujillo-Gallego et al., 2022). Integrating these topics into online education programs is a strategy employed by companies to attain environmental sustainability objectives, mitigate environmental impacts, and promote more responsible lifestyles. In light of this reasoning, the subsequent theories are posited:

H5: GDLO can improve GI practices.

H6: GDLO mediates the effect of GHRM on GI.

H7: GI mediates the effect of GDLO on SFP.

Big data analytics as moderation

Big data analytics (BDA) pertains to the examination of extensive data volumes and datasets that cannot be efficiently accessed, obtained, analyzed, or utilized by traditional data management methods. Big data analytics serves as a crucial technological facilitator, enhancing company capabilities and significantly contributing to sustainability (Papadopoulos & Balta, 2022). Furthermore, it can mitigate impulsive decision-making by offering supplementary assistance and ensuring precise outcomes that endorse sustainable behaviors (Halbusi et al., 2024). Big data analytics enhances and consolidates the examination and utilization of data pertaining to environmental concerns (e.g., green digital learning) and promotes efficient decision-making to tackle resource depletion and environmental pollution challenges (Rengarajan et al., 2022).

The function of big data facilitates the integration and evaluation of quantitative and qualitative data, hence enhancing predictive accuracy and effective decision-making, ultimately resulting in increased performance. Prior research indicates that big data analytics substantially influences innovation and sustainable performance (Awan & Hussain, 2021; Shah, 2022). This study posits that big data analytics enhances the decision-making process by evaluating information that results in improved learning outcomes. We propose that big data analytics is crucial for GDLO and therefore for sustainable performance (Halbusi et al., 2024; Shah, 2022).

Prior research indicated that BDA moderates GHRM practices and sustainable organizational performance. Research indicates that BDA substantially affects the implementation of GHRM practices, which in turn influence sustainable organizational performance (Halbusi et al., 2024; Singh & El-Kassar, 2019). Research indicates that companies utilize big data analytics to enhance their probability of success (Shah, 2022). GHRM procedures additionally affect GDLO in relation to green performance (Awan & Hussain, 2021; Chau et al., 2024). Additional research indicates that BDA intelligence enhances sustainable firm performance and GHRM procedures (Halbusi et al., 2024). Big Data Analytics enhances organizational performance through the cultivation of performance based on digital learning (Chauhan et al., 2022). This study's framework emphasizes the impact of Big Data Analytics on the interplay of GHRM, GDLO, sustainability, and GI. This study provides a novel perspective on achieving sustainable outcomes. Consequently, the subsequent hypotheses are posited:

H8: BDA strengthens the influence of GHRM practices on GI.

H9: BDA strengthens the influence of GDLO on GI.

AI adoption, green innovation, and Sustainable corporate performance

Artificial intelligence (AI) is a pivotal catalyst in green innovation, expediting the creation and deployment of sustainable products and services. Artificial intelligence facilitates the tailoring of sustainable solutions to correspond with consumer preferences, enhancing resource efficiency and customer happiness (Abdelfattah et al., 2025). Machine learning algorithms enhance industrial processes to minimize material waste and energy usage while ensuring products meet particular sustainability criteria (Eyo-udo, 2024).

The interplay among green innovation, sustainable corporate performance, and AI is

increasingly vital in tackling the intricate difficulties of the changing business environment (Di Vaio et al., 2020). This section analyzes AI's revolutionary impact on enhancing the integration of green innovation with sustainable corporate performance. AI has become a pivotal element that fosters the integration of corporate innovations to promote sustainable business practices and attain competitive advantage (Ahmad et al., 2022; Schoormann et al., 2023).

The utilization of AI is crucial for advancing the amalgamation of green innovation and business sustainability. The capacity of AI to produce insights, enhance processes, and facilitate 68ustomization offers numerous potential for firms to emerge as sustainability leaders in the digital age. Organizations may use the potential of AI to provide scalable and effective green solutions by fostering collaborative framework innovation and proactively tackling implementation difficulties (Abdelfattah et al., 2025; Ma, 2024). This integration aids the environment in attaining objectives, enhances the overarching digital transformation in business sustainability, and presents a bright outlook for research and development. In light of this reasoning, the subsequent theories are posited:

H10: AI adoption strengthens the influence of GHRM and GI.

H11: AI adoption strengthens the influence of GDLO and GI.

H12: AI adoption strengthens the influence of GI and sustainable performance of SMEs.

METHODS

This study uses a purposive sampling approach to ensure the representation of companies from various sectors and scales of SME businesses. This research method uses a quantitative approach. Therefore, our study uses a targeted data collection approach, focusing on owners, CEOs, managers, and supervisors in Indonesia. We use purposive sampling to concentrate on SMEs that have used digital technology in their businesses. This technique was chosen to identify individuals with in-depth knowledge of their organization and industry. We selected SMEs based on criteria such as a minimum of five years of operation in Indonesia, using digital technology in their business, and the number of employees being more than 30 employees.

Data collection was conducted in October-December 2024 using email, google form, and questionnaires given directly to respondents. Respondent information was obtained from the Cooperatives and SMEs Service in Central Java Province. Based on the established criteria, 270 samples were obtained consisting of 25% company owners, 45% managers, and 30% supervisors. The types of businesses include textile industry (31%), food and beverage (35%), plastic (15%), furniture and wood crafts (14%), and pharmaceutical (5%). The education level of respondents consists of high school (33%), undergraduate (58%), and postgraduate (9%).

To measure the GHRM and Sustainable corporate performance variable adapted from Halbusi et al., 2024). The green innovation was adapted from Chang et al. (2024), and GDLO was adapted from Benzidia et al. (2021). Big data was adapted from this study by Bag et al. (2021), and AI was adapted from the study Abdelfattah et al. (2025). The measurement of variables in this study uses a 7-point Likert scale.

The analysis method used is the partial least squares structural equation modeling (PLS-SEM) method; this method has been widely used by researchers such as Hair et al. (2018). SEM can detect measurement errors using observed variables (Hair et al., 2018). SEM can test all causal relationships between observed variables and latent variables simultaneously (Hair et al., 2018). Therefore, this study adopts the traditional PLS algorithm with bootstrapping set to 5,000 subsamples and no sign changes. PLS-SEM analysis was performed using SmartPLS 3.3.2 (Ringle et al., 2015).

RESULTS AND DISCUSSION

Results

Measurement model evaluation

The model's evaluation includes testing its validity and reliability, including assessments of loading factors, Cronbach alpha, composite reliability, and average variance extracted (AVE) (Hair et al., 2018). The Tables 1 will present the results of the data analysis and provide explanations.

Table 1.
Construct validity and reliability

Variable	Outer loading	Cronbach alpha	AVE
AI	0.884 – 0.935	0.954	0.844
BG	0.836 – 0.912	0.969	0.780
GDLO	0.950 – 0.958	0.950	0.910
GHRM	0.822 – 0.911	0.949	0.767
GI	0.921 – 0.943	0.970	0.869
SF	0.881 – 0.925	0.946	0.824

Table 2.
Heterotrait-monotrait ratio (HTMT)

	AI	AI*GD	AI*GH	AI*GI	BG*GD	BG*GH	BD	GD	GH	GI
AI*GDLO	0.302									
AI*GHRM	0.221	0.677								
AI*GI	0.274	0.432	0.444							
BG*GDLO	0.360	0.688	0.453	0.334						
BG*GHRM	0.311	0.577	0.724	0.359	0.705					
BG	0.732	0.360	0.304	0.336	0.441	0.399				
GDLO	0.498	0.430	0.446	0.482	0.339	0.357	0.618			
GH	0.603	0.426	0.471	0.371	0.332	0.357	0.545	0.747		
GI	0.401	0.500	0.402	0.122	0.411	0.317	0.431	0.574	0.650	
SFP	0.500	0.422	0.371	0.243	0.310	0.282	0.459	0.626	0.768	0.664

Table 1 demonstrates that all items or indicators possess outer loading values over 0.5. The construct remains acceptable provided its validity and reliability satisfy the criteria, and the model is newly established. Consequently, based on the validity of the outer loading, it is asserted that all items or indicators possess validity regarding item validity. All constructions exhibit Cronbach's Alpha and composite reliability over 0.70, therefore indicating that all constructs are reliable. The AVE value exceeding 0.50 demonstrates adequate convergent validity.

The evaluation of the measurement model also tests discriminant validity, namely, empirically testing the differences between constructs. The discriminant validity testing method used in this study is HTMT (Table 2).

Table 2 shows that all variables achieve discriminant validity according to the Heterotrait-monotrait correlation ratio (HTMT). The HTMT criteria are also met because the shared variance between constructs is lower than the limit value of 0.90, indicating that discriminant validity is achieved (Hair et al., 2018).

The second step in evaluating PLS-SEM results is assessing the structural model. The assessment includes multicollinearity (VIF), hypothesis testing (p-value), and its direct effect (f2), with f-square criteria of 0.02 being low, 0.15 being moderate, and 0.35 being high (Hair et al., 2018).

Table 3 shows that the inner VIF value between variables is less than 5, indicating no multicollinearity between variables. The results of the direct effect test show that the variables tested have an average moderate effect; only one has a high effect, and one is not significant.

The third evaluation is the goodness and suitability of the model. This study evaluates the goodness and suitability of the model using R^2 and SRMR (Hair et al., 2018). R Square measures how much endogenous variable variation can be explained variables in the model. According to the processing above, green human resource management influences green digital learning orientation by 0.505 or 50.5%. Green HRM, digital learning, big data, and AI adoption influence green innovation by 47.9% (moderate influence). Green human resource management, digital learning orientation, green innovation, big data, and AI adoption affect sustainable firm performance by 47.9% (moderate influence). The SRMR result is 0.070, which means the model has an acceptable fit. Table 5 shows six accepted hypotheses and six rejected hypotheses. The results of the direct influence test prove that GHRM has a significant effect on GDLO and GI, while GDLO does not have

Table 3.
Structural model evaluation

	B	P values	VIF	f^2	Category
AI -> GI	-0.032	0.680	2.339	0.001	Low
AI -> SF	0.244	0.000	1.260	0.092	Moderate
AI*GDLO -> GI	0.221	0.003	3.081	0.027	Moderate
AI*GHRM -> GI	0.029	0.733	3.640	0.000	Low
AI*GI -> SF	0.109	0.104	1.077	0.021	Moderate
BG*GDLO -> GI	0.167	0.023	3.334	0.015	Moderate

a

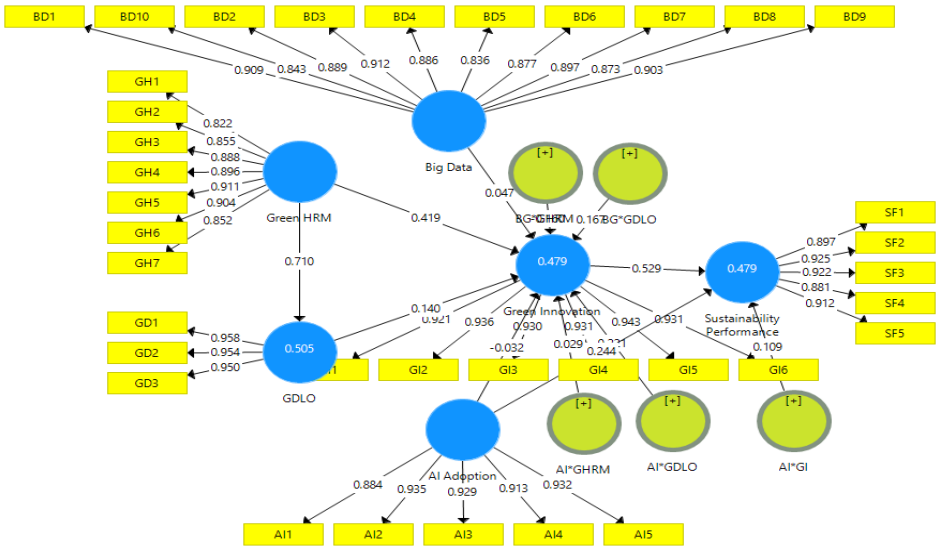

Figure 1.
Model test

significant effect on GI. GI has a significant effect on sustainable company performance.

The results of the mediation test show that GI mediates the effect of GHRM on sustainable company performance, but GI does not mediate the effect of GDLO on sustainable company performance. The results of the moderation test show that Big Data positively moderates the effect of GDLO on GI, and AI Adoption positively moderates the effect of GDLO on GI. The moderation results also show that Big Data and AI adoption do not moderate the effect of GHRM on GI. The results of the PLS-SEM analysis can be described in the following model.

Discussion

The influence of GHRM on GDLO

GHRM theory posits that green management is crucial for organizations as it guarantees sustained and substantial environmental performance via diverse positive policies and practices that promote eco-friendly behavior (Alshuaibi et al., 2024). Companies must prioritize digital learning. In digital education, organizations must instruct their employees on aspects such as modularization, sustainable production practices, recycling,

Table 4.
R square value

	R square	R square adjusted	SRMR
GD	0.505	0.503	0.070
GI	0.479	0.463	
SF	0.479	0.473	

maintenance, repair, and shifts in consuming behaviors (Chau et al., 2024).

The results of this study found that GHRM has a positive and significant effect on GDLO. The positive effect shows that the better the company's GHRM practices, the more GDLO will be increased. The results of this study support the study conducted by Abu Afifa and Nguyen (2022), who found the importance of the relationship between GHRM practices and practices that focus on digital learning. Based on the outer loading value of GHRM practices, the indicators that influence GHRM practices are the compatibility factors between personal identity and environmental management in recruitment and selection. This result means that the recruitment and selection process is very important in GHRM practices.

The influence of GHRM on green innovation and sustainable company performance

Strategic management concerns encompass innovation and sustainability, which seek to establish a competitive advantage for the organization. Consequently, management actions that emphasize the organization's long-term performance are deemed significant (Singh et al., 2020). Offering employee training on environmental issues is crucial to GHRM's objective of assisting companies.

The results of this study found that GHRM has a significant positive effect on green innovation. The positive effect shows that the better the company trains its employees on GHRM practices, the more green innovation it will increase. This study also found that GHRM positively and significantly affects sustainable company performance (SFP). The positive effect of GHRM and SFP shows that the better the GHRM practices are, the more sustainable the company's performance will be. The results of this study support the study conducted by Alshuaibi et al. (2024), A. N. Khan et al. (2024), and Zihan & Makhbul (2024), which found that a strong ability to innovate and long-term performance can be improved by implementing GHRM practices.

Green innovation in this study also strongly influences sustainable company performance and mediates the influence of GHRM on performance. The positive influence of GI on sustainable company performance shows that the better the company implements green innovation, the more sustainable its performance will be. The results of this study support other studies that found that green innovation builds a strong relationship between GHRM and sustainable company performance (Alshuaibi et al., 2024; A. N. Khan et al., 2024; Zihan & Makhbul, 2024). This study also supports the study conducted by Alshuaibi et al. (2024) and Rakin et al. (2020), which revealed that GI helps link green HRM practices to the sustainable performance of SMEs. Research Doghan et al. (2022) and Alshuaibi et al. (2024) proves that green innovation helps develop the relationship between GHRM practices and sustainable performance.

The influence of GDLO on green innovation

Learning-oriented enterprises consistently endeavor to enhance current workflows by adopting effective strategies for establishing cross-functional and inter-company teams (Abdelfattah et al., 2025). This study specifically examines GDLO, an intangible resource that affects inter-functional management and external partner coordination through learning processes in

Table 5.
Hypothesis testing

	B	P	Decisions
GH -> GD	0.710	0.000	H1 accepted
GH -> GI	0.419	0.000	H2 accepted
GI-> SF	0.529	0.000	H3 accepted
GH -> GI -> SF	0.222	0.000	H4 accepted
GD -> GI	0.140	0.100	H5 rejected
GH -> GD -> GI	0.099	0.108	H6 rejected
GD -> GI -> SF	0.074	0.106	H7 rejected
BD*GH -> GI	-0.160	0.079	H8 rejected
BD*GD -> GI	0.167	0.023	H9 accepted
AI*GHRM -> GI	0.029	0.733	H10 rejected
AI*GDLO -> GI	0.221	0.003	H11 accepted
AI*GI -> SF	0.109	0.104	B12 rejected

manufacturing, despite businesses adopting various learning orientations (Halbusi et al., 2024; Muafi et al., 2022). GDLO prioritizes education that promotes environmentally friendly practices by disseminating information via digital platforms (Alshuaibi et al., 2024). The findings of this study indicated that GDLO did not exert a direct influence on green innovation. This outcome may be attributed to the limited implementation of green digital learning by SME owners or staff. Consequently, knowledge and comprehension of green innovation cannot be effectively implemented. The findings of this study contradict those of Alshuaibi et al. (2024) and Halbusi et al. (2024), which indicated that GDLO significantly influences green innovation.

Moderation influence of big data analysis (BDA)

Big data facilitates economic and social transformations at the micro, meso, and macro levels to actualize the green economic development plan. By obtaining substantial quantities of real-time data, firms may utilize technology to derive value, precisely identify customer needs, and optimize production, operations, and marketing. Moreover, enterprises utilize big data technologies to execute digital transformation, enhance business models, and amalgamate online and offline resources. The outcome is enhanced production efficiency and less resource waste, hence attaining sustainable performance.

This study found that BDA positively moderates the effect of GDLO on green innovation. The results indicate that big data analysis helps the decision-making process by analyzing information that will lead to better learning outcomes. The results of this study support the studies conducted by Alshuaibi et al. (2024) and Halbusi et al. (2024), which have proven that big data analysis significantly affects innovation and is important for GDLO, green innovation, and sustainable performance.

This study also found that BDA did not significantly moderate the effect of GHRM on green innovation. These results indicate that GHRM practices have a stronger influence on green innovation. The results of this study do not support previous studies that revealed that BDA is a moderator between GHRM practices and green innovation Alshuaibi et al. (2024) and Halbusi et al. (2024).

Moderation influence of artificial intelligence (AI)

Artificial intelligence is a pivotal catalyst in sustainable innovation that expedites the creation and deployment of eco-friendly products and services. Artificial Intelligence facilitates the tailoring of sustainable solutions to correspond with consumer preferences, enhancing resource efficiency and customer happiness (Abdelfattah et al., 2025). AI presents significant potential to provide innovative environmental solutions and attain ambitious sustainability objectives (Abdelfattah et al., 2025; Salah et al., 2023).

The results of this study indicate that AI adoption positively moderates the effect of GDLO on green innovation. These results indicate that AI technology facilitates organizational learning and knowledge acquisition and lays a strong foundation for sustainable practices. The results of this study support the study conducted by (Abdelfattah et al., 2025; Ma, 2024). The results of this study also show that AI does not moderate the effect of GHRM on green innovation and the effect of green innovation on sustainable corporate performance. This result is because GHRM has a strong influence on green innovation, so without adopting AI, GHRM can increase green innovation. Green innovation can also affect sustainable corporate performance without AI adoption.

In conclusion, the deliberate incorporation of AI technology can substantially augment GDLO and green innovation, allowing firms to adeptly manage the intricacies of sustainable business practices and attain enhanced environmental performance. AI augments GHRM by offering sophisticated capabilities for resource optimization and fosters creativity by allowing firms to create customized and scalable green solutions. Despite existing challenges, the collaborative potential of AI and green innovation highlights the necessity for continued investigation and preventive measures. This research underscores the essential requirement for interdisciplinary collaboration to fully realize these synergies for the advantage of both business and the environment.

CONCLUSION

The results of this study show the important role of GHRM in adapting to environmental changes and encouraging green digital learning orientation and green innovation. In

addition, this study also found that green digital learning orientation has a significant effect on green innovation if moderated by Big Data Analytics and AI adoption. The results of this moderation indicate that employees who receive green digital learning will be stronger in practicing green innovation if supported by Big Data and AI. In addition, green innovation strongly influences sustainable company performance and mediates the influence of GHRM on sustainable company performance.

Some shortcomings in this study that require additional research are: First, the selected SME sample has not considered the ownership of ISO 9000 and 14000 certificates related to green environmental preservation; this is because there are still limited SMEs that have ISO 9000 and 14000 certificates, thus affecting the respondents' perceptions in understanding and answering the questionnaire submitted. Second, this study has not considered external factors such as politics, demographics, and culture. These three factors can hinder the success and sustainability of the company. Therefore, future research must consider these factors to obtain more accurate results.

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