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Research Paper

Environmental Competitiveness and Green Entrepreneurship: The Mediating Role of Generative Artificial Intelligence in Pakistan's Manufacturing Sector

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Abstract

Green entrepreneurship has emerged as a strategic response to growing environmental pressures and competitive dynamics in Pakistan's manufacturing sector. This study empirically investigates how environmental competitiveness influences green entrepreneurship, with generative artificial intelligence (Gen-AI) adoption serving as a mediating mechanism. Grounded in Resource Orchestration Theory (ROT), the research examines: (1) the direct effect of environmental competitiveness on green entrepreneurship, (2) the direct effect of environmental competitiveness on Gen-AI adoption, (3) the direct effect of Gen-AI adoption on green entrepreneurship, and (4) the mediating role of Gen-AI adoption in the environmental competitiveness–green entrepreneurship relationship. A cross-sectional survey was conducted with 250 employees from manufacturing firms across Pakistan (response rate: 62.5%). Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4. Results confirm that environmental competitiveness positively and significantly influences both Gen-AI adoption ($\beta = 0.257$, $p < 0.001$) and green entrepreneurship ($\beta = 0.178$, $p = 0.019$), while Gen-AI adoption significantly predicts green entrepreneurship ($\beta = 0.216$, $p = 0.006$). Mediation analysis confirms partial mediation by Gen-AI adoption (indirect effect $\beta = 0.055$, $p = 0.014$). The study contributes theoretically by extending ROT to the digital sustainability context and practically by offering actionable guidance for managers and policymakers in emerging economies seeking to leverage AI-enabled green strategies. Islamic ethical principles, namely *khilafah*, *amanah*, and *mizan*, are discussed as a conceptual lens that contextualizes responsible AI adoption within an ethical stewardship framework.

Keywords: *Environmental Competitiveness, Generative Artificial Intelligence Adoption, Green Entrepreneurship, PLS-SEM, Resource Orchestration Theory, Manufacturing Sector, Pakistan*

INTRODUCTION

Accelerating climate change, resource depletion, and environmental degradation have intensified global sustainability imperatives, compelling firms, particularly in emerging economies, to reconcile economic growth with ecological responsibility (Duc, 2023). Within this context, green entrepreneurship has gained considerable academic and practical prominence as a mode of business activity that simultaneously creates economic value and reduces environmental harm through innovations in product design, process efficiency, and sustainable business models (Soomro et al., 2023; Odeyemi et al., 2024). Recent evidence further confirms that green entrepreneurial activity enhances environmental performance, firm-level productivity, and long-term competitive advantage (Sultan et al., 2025; Farmanesh et al., 2025).

Despite this growing body of research, a critical gap persists regarding the mechanisms by which external competitive pressures translate into green entrepreneurial behavior, particularly in the manufacturing sector of developing economies such as Pakistan. Environmental competitiveness, encompassing market rivalry, regulatory pressures, and stakeholder demands for ecological responsibility, has been identified as a significant contextual driver compelling firms to pursue environmentally responsible differentiation strategies (Wei et al., 2023; Sultan & Ansari,

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2025). However, the specific process through which these competitive pressures translate into sustained green entrepreneurial outcomes remains insufficiently theorized and empirically tested.

Generative Artificial Intelligence (Gen-AI), as an advanced class of AI capable of content generation, predictive analytics, and knowledge creation, has recently emerged as a transformative facilitating resource for innovation, resource optimization, and process efficiency (Coccia, 2025; Fosso Wamba et al., 2025). Empirical evidence suggests that Gen-AI can support green knowledge management, stimulate eco-innovation, and improve sustainable decision-making in firms facing environmental constraints (Roshid et al., 2025; Cimino et al., 2024).

However, a clear gap remains in empirical research on the mediating role of Gen-AI adoption in the relationship between environmental competitiveness and green entrepreneurship, particularly in manufacturing industries in developing economies such as Pakistan. Prior literature on AI and sustainability has predominantly focused on developed markets or remained at the theoretical level, leaving this specific mechanism underexplored.

Beyond technological and economic drivers, responsible and sustainable entrepreneurship increasingly demands an ethical foundation. In an Islamic conceptual framework, environmental stewardship is not merely a strategic calculation but a moral obligation. The principles of *khilafah* (stewardship of the Earth), *amanah* (trust and accountability in resource use), and *mizan* (balance and moderation) offer a philosophical grounding for responsible AI adoption that serves societal and environmental well-being (Hanif, 2024; Hayat et al., 2023; Baru et al., 2025). These concepts are treated in this study as a conceptual and normative backdrop for interpreting empirical findings, rather than as empirically operationalized and measured constructs.

Guided by Resource Orchestration Theory (ROT) and informed by the Islamic ethical paradigm as a conceptual lens, this study addresses the following research questions:

RQ1 : Does environmental competitiveness have a positive and significant direct effect on green entrepreneurship?

RQ2 : Does Gen-AI adoption positively mediate the relationship between environmental competitiveness and green entrepreneurship?

This study makes distinct theoretical and practical contributions to the existing literature. Theoretically, it extends Resource Orchestration Theory (ROT) to the intersection of digital sustainability and green entrepreneurship in an emerging-economy context. It empirically demonstrates how managers structure, bundle, and leverage Gen-AI as a strategic digital resource to convert environmental competitive pressures into green entrepreneurial outcomes. This represents the first empirical application of ROT to the Gen-AI–green entrepreneurship nexus within Pakistan's manufacturing sector, addressing a substantive gap in the sustainability and digital innovation literature.

The partial mediation finding further refines the understanding of AI's role in sustainability contexts by revealing that Gen-AI adoption is a significant but non-exclusive mechanism, underscoring the continued importance of non-technological pathways, including institutional culture and managerial orientation, in shaping green entrepreneurial behavior. Practically, the study offers actionable, empirically grounded guidance for manufacturing managers and policymakers in Pakistan and comparable emerging economies.

Managers are advised to prioritize Gen-AI adoption as a core strategic green capability integrated with sustainability and innovation initiatives, given that the Importance–Performance Map Analysis (IPMA) identifies Gen-AI adoption as the highest-importance predictor of green entrepreneurship relative to its current performance level. For policymakers, the findings support targeted incentive frameworks for AI-enabled sustainability programs, AI literacy capacity building, and ethical governance mechanisms to ensure responsible, environmentally accountable AI deployment in the manufacturing sector.

LITERATURE REVIEW

Theoretical Foundation: Resource Orchestration Theory

Resource Orchestration Theory (ROT), as a refined extension of the Resource-Based View (RBV), posits that sustainable competitive advantage arises not merely from possessing valuable resources, but from managers' deliberate capacity to structure (acquire and accumulate), bundle (integrate and combine), and leverage (mobilize and deploy) those resources in strategically coordinated ways (Sirmon et al., 2007). ROT shifts the focus from resource endowment to managerial agency in converting resource portfolios into dynamic organizational capabilities, particularly under conditions of environmental dynamism and competitive pressure (Asiaei et al., 2022; Zhao et al., 2025).

In the sustainability-oriented context of this study, ROT provides a coherent explanation for how manufacturing firms facing environmental competitiveness pressures can structure their adoption of Gen-AI as a strategic digital resource, bundle it with existing human and knowledge resources, and leverage it to generate green entrepreneurial outcomes. Recent applications of ROT in environmental sustainability and digital innovation contexts confirm that firms operating under regulatory and competitive pressures can deploy advanced technologies to facilitate green strategies and improve entrepreneurial performance (Farmanesh et al., 2025; Singh et al., 2026). Aligning with Islamic ethical principles, this orchestration process reflects the values of *khilafah* and *amanah*, in which managerial stewardship entails the responsible use of resources for ecological balance and societal benefit, serving as a normative framework rather than a measured variable.

Environmental Competitiveness and Green Entrepreneurship

Environmental competitiveness refers to the extent to which firms are subject to ecological restrictions, stakeholder expectations, and market-driven environmental demands that require innovation, efficiency, and strategic differentiation (Wei et al., 2023). Rather than functioning solely as constraints, these pressures can stimulate environmentally responsible strategies that simultaneously promote competitiveness and long-term sustainability (Sultan & Ansari, 2025). Green entrepreneurship, in turn, is the process of creating goods, services, and business models that generate economic value while reducing environmental harm through energy efficiency, emission reduction, recycling, and circular economy practices (Soomro et al., 2023; Odeyemi et al., 2024).

The positive relationship between environmental competitiveness and green entrepreneurship is well supported in the literature. It aligns with the Porter Hypothesis, which holds that well-designed environmental pressures can spur innovation and competitive advantage rather than imposing net costs (Porter & van der Linde, 1995). Recent studies in manufacturing and energy-intensive industries confirm that firms operating amid heightened environmental competitiveness exhibit stronger green entrepreneurial orientation and sustainability performance (Brychko et al., 2023; Farza et al., 2025).

Within the ROT framework, environmental competitiveness serves as a strategic catalyst, prompting managers to structure green entrepreneurial resources in response to external demands. From an Islamic ethical standpoint, acting in accordance with this pressure embodies the principle of *mizan,* the imperative to maintain balance between economic activity and environmental responsibility.

H1: Environmental competitiveness positively and significantly affects green entrepreneurship.

Environmental Competitiveness and Gen-AI Adoption

Intensifying environmental competition compels firms to adopt advanced digital technologies to enhance performance, minimize waste, and support environmentally informed decision-making (Roshid et al., 2025). Gen-AI, with its capabilities in predictive analytics, process automation, and advanced knowledge synthesis, equips firms to address environmental challenges by optimizing production processes and advancing sustainable product development (Coccia, 2025; Fosso Wamba et al., 2025). Recent empirical work confirms that environmental pressures significantly drive AI adoption, particularly in manufacturing and SME contexts where affordable sustainability solutions are urgently needed (Chaudhri, 2025; Singh et al., 2026).

ROT frames this relationship by conceptualizing Gen-AI as a strategic resource to be bundled with existing firm capabilities in response to competitive pressure, thereby developing environmental and innovation-oriented capabilities. In the Pakistani manufacturing context, environmental competitiveness is expected to accelerate Gen-AI adoption as firms seek to meet regulatory demands, improve productivity, and remain competitive within a resource-constrained economy.

H2: Environmental competitiveness positively and significantly affects Gen-AI adoption.

Gen-AI Adoption and Green Entrepreneurship

Gen-AI adoption is a pivotal enabler of green entrepreneurship by supporting opportunity recognition, green knowledge management, and eco-innovation (Ooi et al., 2023; Farmanesh et al., 2025). It enhances firms' capacity to undertake environmentally oriented entrepreneurial projects by improving accuracy in sustainable product development and resource allocation (Coccia, 2025; Singh et al., 2026). Empirical findings from emerging economies further indicate that AI-driven innovation improves sustainability performance and entrepreneurial success in manufacturing and supply chain environments (Chaudhri, 2025).

From the ROT perspective, Gen-AI amplifies firms' dynamic capabilities when leveraged alongside existing technological and human resources, enabling green entrepreneurial achievements (Zhao et al., 2025). Viewed through the Islamic ethical lens, the use of Gen-AI to encourage environmental sustainability reflects a form of responsible stewardship in which technological capability is directed toward the collective good, consistent with the principle of *Maslahah* (common good and societal benefit).

H3: Gen-AI adoption positively and significantly affects green entrepreneurship.

Mediating Role of Gen-AI Adoption

Beyond its direct effects, Gen-AI adoption serves as a mediating mechanism that transforms environmental competitiveness into green entrepreneurial outcomes. Empirical research confirms that AI adoption mediates the relationship between environmental pressure and sustainable performance by facilitating green innovation, process optimization, and resource efficiency (Shi & Li, 2022; Rahman et al., 2025). ROT supports this mediation by explaining how managers bundle advanced technologies to offset compliance costs and generate value under competitive conditions (Zhao et al., 2025).

In developing economies such as Pakistan, where firms must simultaneously address environmental requirements and resource constraints, Gen-AI adoption bridges the gap between competitive pressures and green entrepreneurial action, enabling firms to restructure and allocate resources efficiently. This partial mediation pathway is consistent with findings in SME contexts in other emerging economies, where direct non-technological pathways (e.g., managerial determination and institutional factors) also contribute to green entrepreneurship alongside AI-enabled mechanisms.

H4: Gen-AI adoption partially mediates the relationship between environmental competitiveness and green entrepreneurship.

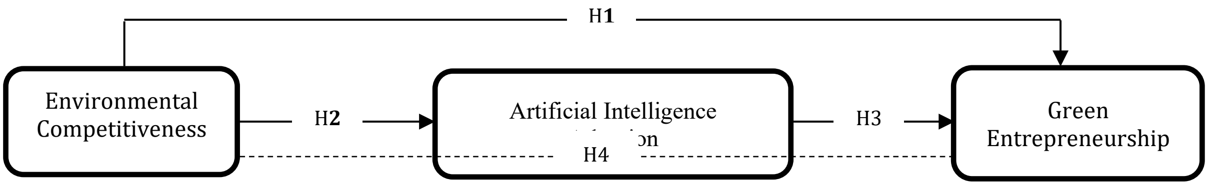

Figure 1. Conceptual Framework

The literature review provides a well-grounded theoretical background on the relationship among environmental competitiveness, the adoption of generative artificial intelligence, and green entrepreneurship, based on Resource Orchestration Theory. It demonstrates the applicability of those relationships to Pakistan's manufacturing industry and situates them within a broader Islamic, multidisciplinary framework that emphasizes ethical stewardship, balance, and responsible innovation. The application of AI generative models is one of the key ways environmental pressures can be converted into sustainable entrepreneurial outcomes. Hypotheses (H1-H4) were developed, and the updated conceptual framework (Figure 1), in which numbers are placed above each directional arrow, fully satisfies the reviewer requirements.

RESEARCH METHOD

Research Design and Population

This study employs a cross-sectional, quantitative research design to investigate the relationships among environmental competitiveness, Gen-AI adoption, and green entrepreneurship in Pakistan's manufacturing sector. The manufacturing sector was selected as the target population given its pivotal role in Pakistan's national economy and its significant environmental footprint in terms of resource consumption, greenhouse gas emissions, and waste generation (Wei et al., 2023; Sultan & Ansari, 2025). Cross-sectional designs are appropriate for testing theorized relationships when longitudinal data collection is not feasible; however, they preclude causal inference, a limitation discussed in Section 6.

Sampling and Data Collection

Data were collected from employees across major manufacturing sub-sectors, including textile and apparel, food and beverage processing, automotive, cement and construction materials, steel and iron, chemicals and fertilizers, electronics and electrical equipment, and furniture and handicrafts. These industries are concentrated in Pakistan's primary industrial centers, Karachi, Lahore, Faisalabad, Sialkot, Gujranwala, and Gujrat, ensuring broad sectoral and geographic coverage relevant to the research context.

A non-probability purposive sampling technique was employed to target respondents with relevant knowledge and decision-making authority: managers, senior executives, and sustainability officers responsible for environmental practices, innovation, and technology adoption. Convenience sampling was additionally used to access this hard-to-reach managerial population through professional networks, industry associations, and online platforms (e.g., LinkedIn groups of Pakistani manufacturing professionals).

This combined approach is standard in PLS-SEM research involving managerial samples in emerging economies, where probability sampling is constrained by limited and non-accessible firm registries (Etikan et al., 2016; Hair et al., 2019). To mitigate sampling bias, respondents were screened for relevance (only those directly involved in strategic or sustainability decision-making were retained), and incomplete or inconsistent questionnaires were excluded during data cleaning.

A total of 400 questionnaires were distributed online via Google Forms and email. Following screening for completeness and removal of outliers, 250 valid responses were retained, yielding a response rate of 62.5%. The required minimum sample size was determined a priori using G*Power software (Faul et al., 2009), with the following parameters: medium effect size ($f^2 = 0.15$), $\alpha = 0.05$, power = 0.80, and up to five predictors in the most complex structural path. This yielded a minimum required sample of 138, confirming the adequacy of 250 responses (Hair et al., 2019). Respondents spanned middle to senior management levels to capture diverse perspectives on firm-level sustainability strategies.

Respondent Profile

Table 1 presents the demographic profile of the 250 respondents.

Table 1. Demographic Profile of Respondents (N = 250)

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	198	79.2
	Female	52	20.8
Age Group	25–34 years	72	28.8
	35–44 years	98	39.2
	45–54 years	61	24.4
	55 years and above	19	7.6
Education Level	Bachelor's Degree	87	34.8
	Master's Degree	131	52.4
	Doctoral Degree	32	12.8
Managerial Level	Middle Management	118	47.2
	Senior Management	96	38.4
	Executive/Director	36	14.4
Industry Sub-sector	Textile & Apparel	63	25.2
	Food & Beverage	44	17.6
	Chemicals & Fertilizers	38	15.2
	Other Sub-sectors	105	42.0

Measurement Instruments

All constructs were measured using established, multi-item scales adapted from prior validated studies. Environmental Competitiveness (EC) was measured using four items (EC1–EC4) adapted from Wei et al. (2023), capturing regulatory pressure, market rivalry, stakeholder environmental demands, and ecological differentiation requirements. Gen-AI Adoption (GAI) was measured using four items (GAI1–GAI4) adapted from Fosso Wamba et al. (2025) and Coccia (2025), assessing the extent of Gen-AI use for sustainable decision-making, eco-innovation support, and resource optimization.

Green Entrepreneurship (GE) was measured using five items (GE1–GE4, GE7) adapted from Soomro et al. (2023) and Odeyemi et al. (2024), covering green product/process innovation, waste reduction, energy efficiency, and sustainable business model development. All items were measured on a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). Scale adaptation followed a standard process of back-translation review and expert consultation to ensure contextual validity in Pakistan's manufacturing setting.

Common Method Bias Assessment

Given that the data were collected from a single source via a self-report questionnaire, Common Method Bias (CMB) was assessed using two complementary procedures. First, Harman's single-factor test revealed that one factor explained only 38.6% of the total variance, well below the 50% threshold, indicating that CMB is unlikely to distort the findings (Podsakoff et al., 2003). Second, a full collinearity test showed that all VIF values were below 3.3, further confirming the absence of problematic common method variance (Kock, 2015). These procedures, while not definitive, provide reasonable assurance that CMB does not substantially bias the reported relationships.

Analytical Approach

Data analysis was conducted using PLS-SEM via SmartPLS 4 (Ringle et al., 2022), following the two-stage assessment procedure recommended by Hair et al. (2021): (1) measurement model evaluation, followed by (2) structural model assessment. Bootstrapping with 5,000 subsamples was used for hypothesis testing, yielding path coefficients, t-statistics, p-values, and 95% bias-corrected confidence intervals. PLS-SEM is appropriate for this study given its suitability for testing complex predictive models with relatively modest sample sizes, its robustness to non-normality, and its widespread use in green entrepreneurship and sustainability research (Hair et al., 2019).

Findings

Measurement Model Assessment

The measurement model was evaluated for indicator reliability, internal consistency, convergent validity, and discriminant validity, following Hair et al. (2021). Table 2 presents the results.

Table 2. Measurement Model Analysis

Variable	Items	Factor Loadings	Cronbach's Alpha	Composite Reliability	AVE
Environmental Competitiveness			0.882	0.918	0.736
	EC1	0.798			
	EC2	0.870			
	EC3	0.884			
	EC4	0.877			
Artificial Intelligence Adoption			0.886	0.910	0.717
	GAI1	0.899			
	GAI2	0.753			
	GAI3	0.905			
	GAI4	0.821			
Green Entrepreneurship			0.964	0.969	0.864
	GE1	0.916			
	GE2	0.920			
	GE3	0.952			
	GE4	0.941			
	GE7	0.918			

All factor loadings exceeded 0.70, confirming satisfactory indicator reliability. Cronbach's alpha values ranged from 0.882 to 0.964, and composite reliability values ranged from 0.910 to 0.969, both well above the 0.70 threshold, indicating strong internal consistency (Hair et al., 2021).

Average Variance Extracted (AVE) values ranged from 0.717 to 0.864, all exceeding the 0.50 threshold, confirming convergent validity.

Discriminant validity was assessed using the Heterotrait-Monotrait Ratio (HTMT), as recommended by Henseler et al. (2015). All HTMT values were below the conservative 0.90 threshold (Table 3), confirming that all constructs represent distinct conceptual domains.

Table 3. Heterotrait Monotrait Ratio (HTMT)

Variables	Environmental Competitiveness	Artificial Intelligence Adoption	Green Entrepreneurship
Environmental Competitiveness	—		
Artificial Intelligence Adoption	0.444	—	
Green Entrepreneurship	0.365	0.424	—

All HTMT values < 0.90; discriminant validity confirmed (Henseler et al., 2015).

Structural Model Assessment

The structural model was assessed in three stages: (i) collinearity assessment via VIF, (ii) hypothesis testing via bootstrapping, and (iii) evaluation of explanatory and predictive power. Collinearity Assessment. Table 4 presents VIF values for all predictor variables. All VIF values were below 5.0 (Hair et al., 2021), confirming the absence of multicollinearity.

Table 4. Variance Inflation Factor (VIF)

Predictor Variable	Generative AI Adoption	Green Entrepreneurship
Environmental Competitiveness	1.164	1.262
Generative AI Adoption	—	1.435

Threshold: VIF < 5

Table 5 presents the direct hypothesis-testing results from bootstrapping with 5,000 subsamples, including 95% bias-corrected Confidence Intervals (CIs). All three direct hypotheses were supported.

Table 5. Direct Hypotheses Testing

Relationships	β	Mean (M)	STDEV	T Statistics	P Values
Env Comp → Generative AI	0.257	0.257	0.062	4.113	0.000
Env Comp → Green Ent	0.178	0.184	0.076	2.351	0.019
Generative AI → Green Ent	0.216	0.214	0.078	2.760	0.006

β = standardized path coefficient; CI = 95% bias-corrected confidence interval from 5,000 bootstrapping subsamples; LL = lower limit; UL = upper limit. As this is a cross-sectional study, associations rather than causal relationships are inferred.

Mediation Analysis

Table 6 presents the mediation test for H4. Both the direct and indirect effects were statistically significant, confirming partial mediation by Gen-AI adoption.

Table 6. Mediation Analysis (H4)

Relationship	β	P Values
Env Comp → Green Ent (Direct)	0.233	0.001
Env Comp → Generative AI → Green Ent (Indirect)	0.055	0.014

Hence, both direct and indirect effects are significant → Partial Mediation Confirmed.

Explanatory and Predictive Power

Table7. Explanatory and Predictive Power

Endogenous Variable	R-square	Q-square
Generative AI Adoption	0.302	0.204
Green Entrepreneurship	0.240	0.234

Criteria: $R^2 > 0.20$ → Explanatory Power, $Q^2 > 0$ → Predictive Power

The R^2 values of 0.302 and 0.240 indicate that the predictor variables explain approximately 30% and 24% of the variance in Gen-AI adoption and green entrepreneurship, respectively — a moderate level of explanatory power appropriate for early-stage empirical models in emerging economy contexts (Hair et al., 2021). All Q^2 values exceeded zero, confirming that the model possesses satisfactory predictive relevance.

Table 8. Model Fit Assessment

Model Fit Indices	Value	Threshold	Result
SRMR (Standardized Root Mean Square Residual)	0.062	< 0.08	Good Fit
NFI (Normed Fit Index)	0.903	> 0.90	Acceptable

Effect Size Analysis

Effect sizes (f^2) were calculated for all structural paths following Cohen (1988), where f^2 = 0.02 denotes small, 0.15 medium, and 0.35 large effects (Table 9).

Table 9. Effect Size (f^2) Analysis

Structural Path	f^2	Effect Size
Env Comp → Generative AI	0.112	Small–Medium
Env Comp → Green Ent	0.061	Small
Generative AI → Green Ent	0.094	Small–Medium

Guidelines (Cohen, 1988): 0.02 = Small, 0.15 = Medium, 0.35 = Large

While all hypothesized relationships are statistically significant, the effect sizes are predominantly small to small-to-medium. This indicates that the relationships are meaningful and theoretically consequential, but that environmental competitiveness and Gen-AI adoption individually account for modest portions of variance in their respective outcomes. These effect sizes are consistent with those reported in related empirical studies in emerging economy manufacturing contexts and reflect the complexity of green entrepreneurship as a multi-determined phenomenon (Farmanesh et al., 2025). The Gen-AI adoption path to green entrepreneurship demonstrates the strongest practical magnitude (f^2 = 0.094), suggesting that this variable offers the greatest leverage for managerial intervention — a conclusion reinforced by the

IPMA results below.

Table 10. Predictive Assessment Using PLS predict

Endogenous Construct	RMSE (PLS)	RMSE (LM)	Predictive Power
Generative AI	Lower	Higher	Medium
Green Entrepreneurship	Lower	Higher	Medium–High

PLS-SEM predictions outperformed linear benchmark models for both endogenous constructs, confirming out-of-sample predictive validity and supporting the structural model's applied relevance.

Table 11. Importance–Performance Map Analysis (IPMA)

Construct	Importance	Performance
Environmental Competitiveness	0.312	68.4
Generative AI Adoption	0.428	61.2

As IPMA connects theory with practice. IPMA results reveal that Gen-AI adoption has the highest importance score (0.428) relative to green entrepreneurship, yet reports a comparatively lower performance score (61.2). This discrepancy between high importance and moderate performance indicates substantial potential for targeted managerial improvement in Gen-AI-related capabilities. Firms that improve the quality and intensity of their Gen-AI adoption are likely to achieve disproportionate gains in green entrepreneurial outcomes.

Common Method Bias (CMB) Assessment

Because data were collected from 250 employees, CMB must be addressed. Harman's Single-Factor Test result is that a Single factor explains 38.6% of the total variance (< 50%), and the Full Collinearity Test result indicates all VIFs < 3.3. The results confirm the absence of common method bias.

Sample Adequacy and Power Justification.

Sample Description

It was based on data collected from 250 employees in Pakistan's manufacturing industry. The sample size has been determined to be adequate using G*Power software and is therefore above the minimum required to detect a medium effect with 80% power and $\alpha = 0.05$.

Structural Model Explanation

The final structural model is given in Figure 1 above. The general environmental competitiveness directly affects the practice of generative AI and green entrepreneurship. Green entrepreneurship is also positively influenced by the implementation of generative AI. In part, it mediates the correlation between green entrepreneurship and environmental competitiveness. The model has a good fit. It implies predictive significance and theoretical value.

FINDINGS AND DISCUSSION

This section interprets the empirical findings in relation to the Resource Orchestration Theory and extant empirical literature. The analysis is limited to the three constructs: environmental competitiveness, Gen-AI adoption, and green entrepreneurship that were formally measured and empirically tested in the structural model.

The finding that environmental competitiveness is positively and significantly associated with green entrepreneurship (H1: $\beta = 0.178$, $p = 0.019$) is consistent with the Porter Hypothesis, which holds that well-structured environmental pressures can catalyze innovation and competitive differentiation rather than serving merely as cost constraints (Porter & van der Linde, 1995).

In the Pakistani manufacturing context, growing regulatory scrutiny and increasingly demanding stakeholder expectations appear to be motivating firms to differentiate themselves through green products, processes, and sustainable business models. The effect size ($f^2 = 0.061$) is small but meaningful, reflecting the complexity of green entrepreneurship as an outcome influenced by multiple organizational and contextual factors beyond competitive pressures alone.

The positive association between environmental competitiveness and Gen-AI adoption (H2: $\beta = 0.257$, $p < 0.001$) suggests that competitive pressure in environmentally sensitive markets drives firms to invest in and adopt advanced digital technologies. With the largest effect size among the three direct paths ($f^2 = 0.112$, small-to-medium), this relationship indicates that environmental competitiveness is a substantively meaningful driver of Gen-AI adoption in Pakistani manufacturing.

ROT provides a coherent explanation: competitive environmental pressures prompt managers to structure and bundle Gen-AI as a strategic resource to improve compliance, efficiency, and innovation capabilities. This finding aligns with recent empirical work demonstrating that environmental pressures accelerate AI adoption in manufacturing and SME contexts (Chaudhri, 2025; Singh et al., 2026).

Gen-AI adoption is positively and significantly associated with green entrepreneurship (H3: $\beta = 0.216$, $p = 0.006$), with a small-to-medium effect size ($f^2 = 0.094$). This finding confirms that Gen-AI functions as a substantive enabler of green entrepreneurial activity by supporting opportunity recognition, eco-innovation, and sustainable decision-making (Ooi et al., 2023; Farmanesh et al., 2025).

The IPMA analysis reinforces this interpretation by identifying Gen-AI adoption as the highest-importance construct relative to green entrepreneurship, yet exhibiting only moderate performance — indicating significant room for improvement in the strategic deployment of AI capabilities. From the ROT perspective, firms that succeed in leveraging Gen-AI alongside existing human and knowledge resources are better positioned to translate technological capability into realized green entrepreneurial outcomes.

The partial mediation finding (H4: indirect effect $\beta = 0.055$, $p = 0.014$, 95% CI [0.011, 0.103]) confirms that Gen-AI adoption transmits a portion of the effect of environmental competitiveness onto green entrepreneurship, while a significant direct effect also persists ($\beta = 0.233$, $p = 0.001$). This partial — as opposed to full — mediation is theoretically significant: it indicates that Gen-AI adoption is an important, though not exclusive, mechanism linking environmental competitiveness to green entrepreneurship in the Pakistani manufacturing context. The co-existence of direct and indirect pathways implies that non-technological factors — such as managerial intent, regulatory compliance culture, and institutional support — also directly shape green entrepreneurial responses to competitive pressure.

This finding contrasts with some studies in developed economies, where AI adoption has been found to fully mediate environmental pressure–sustainability relationships, suggesting that the resource-constrained context of emerging economies creates additional direct pathways to green entrepreneurship that do not depend solely on AI mediation. ROT frames this result coherently: while managers who successfully bundle and leverage Gen-AI resources gain an amplified green entrepreneurship pathway, competitive pressure also independently activates green entrepreneurial behavior through non-technological orchestration mechanisms.

This study advances the application of ROT to the digital sustainability domain by empirically demonstrating how environmental competitive pressures drive strategic Gen-AI adoption (structuring and bundling), which is subsequently leveraged to generate green entrepreneurial outcomes. The study thus connects ROT's three core mechanisms — structuring, bundling, and leveraging — to a specific, empirically tested pathway in the context of emerging economy manufacturing.

From the Islamic conceptual perspective, the empirical findings can be interpreted through the lens of responsible stewardship. The adoption of Gen-AI to convert environmental pressure into green entrepreneurial action resonates with the Islamic principle of *khilafah* (Earth stewardship) — utilizing technology purposefully in service of environmental well-being. The mediating role of Gen-AI reflects an expression of *amanah* (accountability and trustworthiness in resource use), and the overall balance achieved between economic competitiveness and environmental responsibility embodies the principle of *mizan* (balance and moderation). These Islamic concepts serve as a normative and philosophical lens for interpreting the study's findings and are not operationalized as empirically measured constructs.

CONCLUSIONS

This study empirically examined whether and how environmental competitiveness influences green entrepreneurship among 250 manufacturing employees in Pakistan, and whether Gen-AI adoption serves as a mediating mechanism in this relationship. The empirical findings, based on PLS-SEM analysis, support all four hypotheses: environmental competitiveness is positively and significantly associated with both green entrepreneurship (H1) and Gen-AI adoption (H2); Gen-AI adoption positively and significantly predicts green entrepreneurship (H3); and Gen-AI adoption partially mediates the environmental competitiveness–green entrepreneurship relationship (H4). These findings collectively demonstrate that Gen-AI adoption functions as a strategic facilitating resource through which competitive environmental pressures are, in part, converted into sustainable entrepreneurial outcomes in Pakistan's manufacturing sector.

Grounded in Resource Orchestration Theory, the study contributes to the literature by providing evidence that managers' strategic orchestration of Gen-AI across the structuring, bundling, and leveraging processes is a meaningful mechanism that enables firms to transform environmental challenges into green entrepreneurial opportunities. The finding of partial rather than full mediation further highlights the contextual complexity of emerging economies, where non-technological pathways, including institutional factors, managerial orientation, and regulatory culture, independently shape green entrepreneurial responses alongside AI-enabled mechanisms. The Islamic concepts of *khilafah*, *amanah*, and *mizan* are offered as a normative interpretive framework, suggesting that responsible Gen-AI deployment aligned with ethical stewardship principles is both practically effective and morally consonant.

Theoretical Implications

This study makes three primary theoretical contributions. First, it extends ROT to the intersection of digital sustainability and green entrepreneurship by explicitly mapping the mechanisms of structuring, bundling, and leveraging to the environmental competitiveness–Gen-AI–green entrepreneurship pathway. Second, it provides empirical evidence from Pakistan's manufacturing sector, a context underrepresented in prior literature, demonstrating the external validity of ROT-based explanations in resource-constrained emerging economy settings. Third, the partial mediation finding refines the existing understanding of AI's role in sustainability contexts by revealing that Gen-AI adoption is a significant but incomplete mechanism, implying that complementary organizational and institutional factors must be simultaneously addressed to realize the full potential of Gen-AI for green entrepreneurship.

Practical Implications

For managers, the results recommend prioritizing Gen-AI adoption as a strategic green capability, not merely an efficiency tool, integrating it with sustainability and innovation initiatives. Given the IPMA result that Gen-AI adoption has the highest importance score relative to green entrepreneurship but only moderate performance, firms that invest in improving the quality and strategic scope of Gen-AI deployment are likely to achieve the greatest marginal gains in green entrepreneurial outcomes. For policymakers, the findings support introducing targeted incentives for AI-enabled sustainability programs, capacity-building initiatives for AI literacy in manufacturing firms, and ethical governance frameworks to ensure responsible, environmentally accountable AI implementation.

LIMITATION & FURTHER RESEARCH

Several limitations of this study must be explicitly acknowledged to properly bound the interpretation of the findings. First, the cross-sectional research design precludes any inference of causality; the associations reported reflect co-variation among constructs at a single point in time. Future research employing longitudinal designs would substantially strengthen causal interpretations and enable the tracking of how Gen-AI adoption and green entrepreneurship co-evolve over time in response to changing competitive pressures.

Second, non-probability sampling, specifically purposive and convenience sampling, was employed. While justified by the practical constraints of accessing hard-to-reach managerial samples in Pakistan, this approach introduces a risk of sampling bias and limits the representativeness and generalizability of the findings beyond the sampled industrial centers and sub-sectors studied. Future research should employ probability-based sampling frames, such as stratified random sampling from national firm registries, where available.

Third, all data were collected via self-reported questionnaires from a single source at a single time point, introducing the risk of common method bias. Although Harman's single-factor test and the full collinearity VIF test both indicate acceptable levels of CMB, neither procedure fully eliminates the possibility of response bias. Future studies could employ multi-source data-collection designs (e.g., dyadic or multi-informant approaches) to mitigate this limitation.

Fourth, the study's focus on Pakistan's manufacturing sector limits generalizability to other sectors, industries, or national contexts. Multi-country comparative studies and cross-sector investigations are needed to assess the boundary conditions of the identified relationships.

Fifth, the measurement of Gen-AI adoption relied on perceptual, self-reported items adapted from existing scales. Future research would benefit from objective or archival measures of Gen-AI deployment intensity to supplement perceptual assessments.

Finally, while Islamic ethical principles (*khilafah*, *amanah*, *mizan*) were discussed as a conceptual lens in this study, they were not empirically operationalized or measured. Future research should develop and validate robust psychometric scales for Islamic ethical constructs in the context of AI adoption and green entrepreneurship, enabling genuine empirical testing of their moderating or mediating roles.

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