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Research Article

Navigating Environmental Uncertainty and Sustainability Orientation for Environmental Performance: The Mediating Role of Green Innovation and the Moderating Role of Technological Intensity

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Conflict of Interest

The authors declare that they have no conflict of interest.

Abstract

Environmental sustainability has become a strategic priority for manufacturing firms operating amid increasing environmental uncertainty and technological change. This study examines the effects of environmental sustainability orientation and perceived environmental uncertainty on environmental performance, considering green innovation as a mediating mechanism and technological intensity as a moderating condition. Drawing on the Natural Resource-Based View, the study employed a quantitative cross-sectional design using data from 358 managerial respondents representing manufacturing firms in Punjab, Pakistan. The proposed relationships were analyzed through partial least squares structural equation modeling using SmartPLS 4. The findings indicate that environmental sustainability orientation and perceived environmental uncertainty positively influence environmental performance. Green innovation significantly mediates both relationships, demonstrating its role in translating strategic environmental priorities and perceived external uncertainty into improved environmental outcomes. Technological intensity further strengthens the positive relationship between green innovation and environmental performance. The study extends the Natural Resource-Based View by integrating strategic orientation, environmental uncertainty, innovation, and technological capability within an emerging-economy manufacturing context. Practically, the findings emphasize aligning sustainability strategies and green innovation initiatives with firms' technological capabilities to achieve stronger environmental outcomes.

Keywords: Environmental sustainability orientation; perceived environmental uncertainty; green innovation; technological intensity; environmental performance.

How to Cite this Work:

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1 INTRODUCTION

Environmental sustainability has become an increasingly important strategic concern for manufacturing firms as economic development continues to intersect with pressures to reduce pollution, emissions, resource consumption, and other adverse environmental impacts (Akram *et al.*, 2025; Jayantilal *et al.*, 2026). This challenge is particularly pronounced in developing economies, where rapid industrialization often occurs alongside institutional constraints, technological disparities, and increasing environmental pressures. Pakistan represents an important context in this regard. As one of the world's most populous countries, it continues to face serious environmental challenges, including air, water, and land pollution (Bag et al., 2021). At the same time, the manufacturing sector contributes substantially to national economic activity and employment while generating considerable environmental pressures (Sarwar et al., 2023). Manufacturing firms therefore face the continuing challenge of maintaining productivity and competitiveness while improving their Environmental Performance (EP) (Zawislak et al., 2018). Environmental Sustainability Orientation (ESO) represents an important strategic response to these pressures. It reflects the extent to which environmental considerations are incorporated into organizational priorities, decision-making, and business practices. Firms with a stronger ESO are more likely to devote attention and resources to environmental objectives and integrate sustainability considerations into their operations (El-Garaihy *et al.*, 2022). However, a strong environmental orientation may not, by itself, be sufficient to produce meaningful improvements in EP. Firms differ substantially in their organizational resources, capabilities, technological development, and institutional environments, which can influence their ability to transform sustainability commitments into tangible environmental outcomes (Rehman et al., 2022; Saeed & Cek, 2025). An important issue, therefore, concerns the mechanisms through which firms translate sustainability-oriented strategic intentions into improved EP.

Green Innovation (GI) is particularly relevant to this process because it provides an operational mechanism through which environmental objectives can be incorporated into products, processes, and technologies. GI can enable firms to reduce pollution, emissions, waste, and resource consumption while improving the environmental efficiency of their operations (Tetteh et al., 2025). Previous studies have demonstrated the importance of environmental orientation, green capabilities, and innovation in shaping organizational environmental outcomes (Aftab et al., 2023; Rehman et al., 2022). Nevertheless, firms do not pursue these environmental initiatives in isolation from the conditions prevailing in their external environment. Perceived Environmental Uncertainty (PEU) is particularly important in this regard because managers make strategic and environmental decisions under changing regulatory, competitive, market, and resource conditions (Cheng *et al.*, 2025). Greater uncertainty can complicate environmental investment decisions by making future requirements, market conditions, and expected returns less predictable (Li *et al.*, 2025). At the same time, changes in the external environment may encourage firms to reconsider existing practices and search for innovative responses to emerging environmental demands (Chen et al., 2022). PEU may therefore have important implications for firms' environmental strategies and their ability to improve EP. This issue is especially relevant in emerging economies, where regulatory enforcement, market conditions, and technological development may be comparatively unstable.

Another important consideration is Technological Intensity (TI). Manufacturing firms differ considerably in their R&D infrastructure, technical knowledge, technological resources, and capacity to adopt and utilize advanced technologies (Zawislak et al., 2018). Such differences may influence the extent to which GI can be translated into improvements in EP. Marquet-Pondeville et al. (2013) stated firms with stronger technological capabilities may be better positioned to implement, integrate, and scale environmentally oriented innovations, whereas firms with lower TI may depend more heavily on incremental process improvements or external technological support (Wang *et al.*, 2025). Understanding differences in EP therefore requires consideration not only of firms' sustainability orientation and perceptions of environmental uncertainty but also of the innovation mechanisms and technological conditions surrounding their environmental strategies. Despite growing scholarly attention to ESO, GI, and EP (Aftab et al., 2023; Rehman et al., 2022), important questions remain regarding how these factors operate together under conditions of environmental uncertainty and differing technological capabilities. Existing research has largely examined individual relationships among sustainability orientation, environmental uncertainty, green capabilities, innovation, and environmental outcomes, providing a less integrated understanding of the mechanisms and conditions through which firms achieve improved EP. In particular, further attention is required to understand how ESO and PEU are translated into EP through GI and whether the contribution of GI to EP depends on firms' TI. This gap is particularly relevant in Pakistan, where industrialization occurs alongside environmental pressures, technological disparities, and challenges associated with environmental regulation and enforcement.

Against this background, the present study investigates the influence of ESO and PEU on EP in Pakistan's manufacturing sector, with particular attention to the mediating role of GI and the moderating role of TI. The study draws on the Natural Resource-Based View (NRBV), which emphasizes the strategic importance of organizational resources and capabilities in responding to environmental challenges (Hart & Dowell, 2011). By integrating internal sustainability orientation, perceived external uncertainty, green innovation, and technological capability within a unified theoretical perspective, the study seeks to provide a more comprehensive explanation of how manufacturing firms can translate environmental priorities into improved environmental outcomes. This study contributes to the sustainability and manufacturing literature in several respects. Theoretically, it extends the application of NRBV by considering sustainability orientation, environmental uncertainty, green innovation, and technological capability within an integrated framework rather than examining these factors in isolation. It further contributes by examining GI as an explanatory mechanism linking firms' strategic and environmental conditions with EP while considering TI as an important boundary condition. Contextually, the study provides evidence from Pakistan's manufacturing sector, where environmental pressures and technological capabilities vary considerably across firms. From a practical perspective, the study offers insights for managers seeking to align sustainability priorities with green innovation and technological capabilities and for policymakers seeking to encourage environmentally responsible manufacturing in an emerging economy.

Section 1 introduces the study, Section 2 reviews the literature and develops the hypotheses, Section 3 presents the methodology, Section 4 reports the results, Section 5 discusses the findings, and Section 6 presents the conclusion, implications, limitations, and future research directions.

2 LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

This study is theoretically grounded in the NRBV, which extends the resource-based perspective by incorporating the constraints and opportunities associated with the natural environment into explanations of firm resources, capabilities, and competitive advantage (Hart, 1995; Hart & Dowell, 2011). From this perspective, superior environmental outcomes depend not merely on firms' environmental intentions but on their ability to develop and deploy organizational resources and capabilities toward pollution prevention, resource efficiency, cleaner technologies, and sustainable development. In this study, ESO represents the strategic orientation that directs organizational attention and resources toward environmental priorities, while GI provides an organizational capability through which these priorities can be translated into operational environmental improvements (Rehman et al., 2022; Awan et al., 2021). Firms, however, operate under changing regulatory, market, and technological conditions; consequently, managerial perceptions of environmental uncertainty can shape organizational responses and the pursuit of green technological innovation (Chen et al., 2022). At the same time, differences in technological capability influence firms' capacity to develop, absorb, and exploit innovation effectively (Zawislak et al., 2018). Integrating these elements through the NRBV therefore provides a coherent theoretical foundation for explaining how strategic environmental orientation and perceived external uncertainty contribute to EP through GI, while recognizing TI as an important technological boundary condition.

2.1 ESO and EP

ESO reflects the extent to which environmental considerations are embedded in a firm's strategic priorities and organizational practices (Oke *et al.*, 2025; Usman *et al.*, 2025). In manufacturing settings, firms with a stronger ESO are more likely to integrate environmental concerns into production, procurement, resource allocation, and stakeholder-related decisions. Such an orientation encourages systematic efforts to reduce resource consumption, waste generation, and pollutant emissions (Song et al., 2022). Consistent with the NRBV, environmental orientation can therefore direct organizational resources and capabilities toward practices capable of improving EP. The effectiveness of ESO nevertheless depends on firms' ability to operationalize their environmental commitments. Environmental management systems and related organizational capabilities can convert sustainability intentions into measurable and actionable practices (Johnstone, 2022). Firms possessing stronger technological and R&D capabilities may also be better positioned to incorporate environmental objectives into product development and production processes. Although differences in organizational and technological capacity may influence the magnitude of environmental gains, ESO provides the strategic foundation for prioritizing environmental objectives (El-Garaihy *et al.*, 2022; Murtaza *et al.*, 2024). Firms that systematically incorporate sustainability considerations into strategic and operational decisions should therefore be more capable of improving their environmental outcomes.

H1: ESO has a positive relationship with EP.

2.2 PEU and EP

PEU captures managers' perceptions of the unpredictability and complexity of external conditions, including changes in markets, competition, regulations, and resource availability (Peng & Lai, 2012). For manufacturing firms, such uncertainty may emerge through changing environmental regulations, inconsistent enforcement, fluctuating energy and input prices, and evolving stakeholder expectations (Al-Obaidly *et al.*, 2026; Chaudhry *et al.*, 2020). These conditions can influence how managers prioritize environmental investments and respond to environmental challenges. The implications of PEU are not necessarily restrictive (Cheng *et al.*, 2025). Although uncertainty can discourage long-term investment when firms anticipate regulatory instability or uncertain returns, it can also signal emerging risks that require proactive organizational responses (Li *et al.*, 2025). Firms operating under uncertain conditions may strengthen environmental practices to anticipate regulatory changes, protect organizational reputation, and respond to changing stakeholder expectations. This adaptive response is particularly relevant in emerging economies, where firms may have limited ability to rely on stable institutional signals (Kong et al., 2022). From this perspective, greater perceived uncertainty can increase managerial attention to environmental issues and stimulate actions intended to strengthen EP.

H2: PEU has a positive relationship with EP.

2.3 Mediating Role of GI between PEU and EP

The influence of PEU on EP may extend beyond a direct managerial response because uncertainty can stimulate organizational adaptation through GI (Lodhi *et al.*, 2026; Yang *et al.*, 2026). When regulatory, market, and stakeholder expectations are changing, managers must determine how existing products and processes can be adjusted to accommodate emerging environmental requirements (Akram *et al.*, 2025). Although uncertainty may initially make firms cautious about substantial long-term investments, it can simultaneously increase the value of flexible and innovative environmental responses (Zhang et al., 2020). GI provides such a response by enabling firms to modify products, processes, and technologies in ways that reduce environmental impacts while increasing preparedness for future requirements. Incremental innovations can allow firms to adapt progressively to uncertain conditions, whereas anticipated regulatory or market changes may encourage more substantial environmental innovation when early adaptation offers strategic benefits (Trần *et al.*, 2026). Organizational capabilities, employee involvement, and sustainability-oriented practices can further facilitate this transformation by reducing resistance to environmental changes and supporting the implementation of new routines (Aftab et al., 2023). Capability development can likewise strengthen firms' ability to adopt environmentally responsible and energy-efficient practices (Sarwar et al., 2023). GI can therefore function as an organizational mechanism through which managerial perceptions of external uncertainty are converted into actions capable of improving EP.

H3: GI mediates the relationship between PEU and EP.

2.4 Mediating Role of GI between ESO and EP

ESO establishes environmental sustainability as an organizational priority, but strategic orientation alone does not guarantee improvements in environmental outcomes (Li *et al.*, 2025). Firms must translate environmental commitments into changes in products, processes, technologies, and operational routines. GI provides an important mechanism for accomplishing this transformation because it embeds environmental considerations directly into organizational activities (Zhang et al., 2020). A strong ESO encourages firms to identify environmental challenges as strategically important and allocate organizational attention and resources toward addressing them. GI subsequently transforms these priorities into practical initiatives, such as cleaner production processes, environmentally improved products, efficient resource utilization, and technologies designed to reduce waste and emissions (Malik *et al.*, 2024). In this way, GI bridges the gap between sustainability-oriented strategic intentions and observable environmental improvements (AlQershi *et al.*, 2023). Although the implementation of these innovations may vary according to organizational resources and technological capabilities, the underlying mechanism remains that ESO encourages environmentally oriented innovation, which provides firms with practical means of improving EP. GI is therefore expected to explain an important part of the relationship between ESO and environmental outcomes.

H4: GI mediates the relationship between ESO and EP.

2.5 Moderating Role of TI

TI represents differences in firms' technological capability, including R&D infrastructure, advanced equipment, technical expertise, and the ability to acquire and apply technological knowledge (Zawislak et al., 2018). Such differences are important because possessing or introducing a green innovation does not necessarily mean that every firm can implement and scale it with equal effectiveness (Mei *et al.*, 2026). Firms with stronger technological capabilities generally have greater capacity to integrate new technologies into product development, production engineering, and operational processes. High-TI firms are typically better equipped to absorb technical knowledge and implement technologically sophisticated environmental solutions, whereas low-TI firms may require greater time, resources, or external technical assistance to adopt comparable innovations (Adomako & Nguyen, 2025). Consequently, the environmental benefits generated by GI may vary according to the technological infrastructure available within the firm. Strong technological capabilities can facilitate the integration and scaling of GI across production activities, increasing its potential contribution to environmental improvement (Song et al., 2022). Conversely, technological limitations may restrict implementation and reduce the environmental gains that firms obtain from otherwise valuable innovations. From an NRBV perspective, TI therefore acts as an enabling technological condition that determines how effectively an environmentally relevant capability can be deployed (Alfarizi *et al.*, 2024; Khurshid *et al.*, 2024). Rather than independently producing environmental improvements, TI strengthens firms' capacity to convert GI into superior EP. Accordingly, the positive contribution of GI to EP is expected to become stronger as firms' TI increases.

H5: TI positively moderates the relationship between GI and EP, such that the positive relationship between GI and EP is stronger at higher levels of TI.

Figure 1 presents the proposed conceptual framework and the hypothesized direct, mediating, and moderating relationships examined in this study.

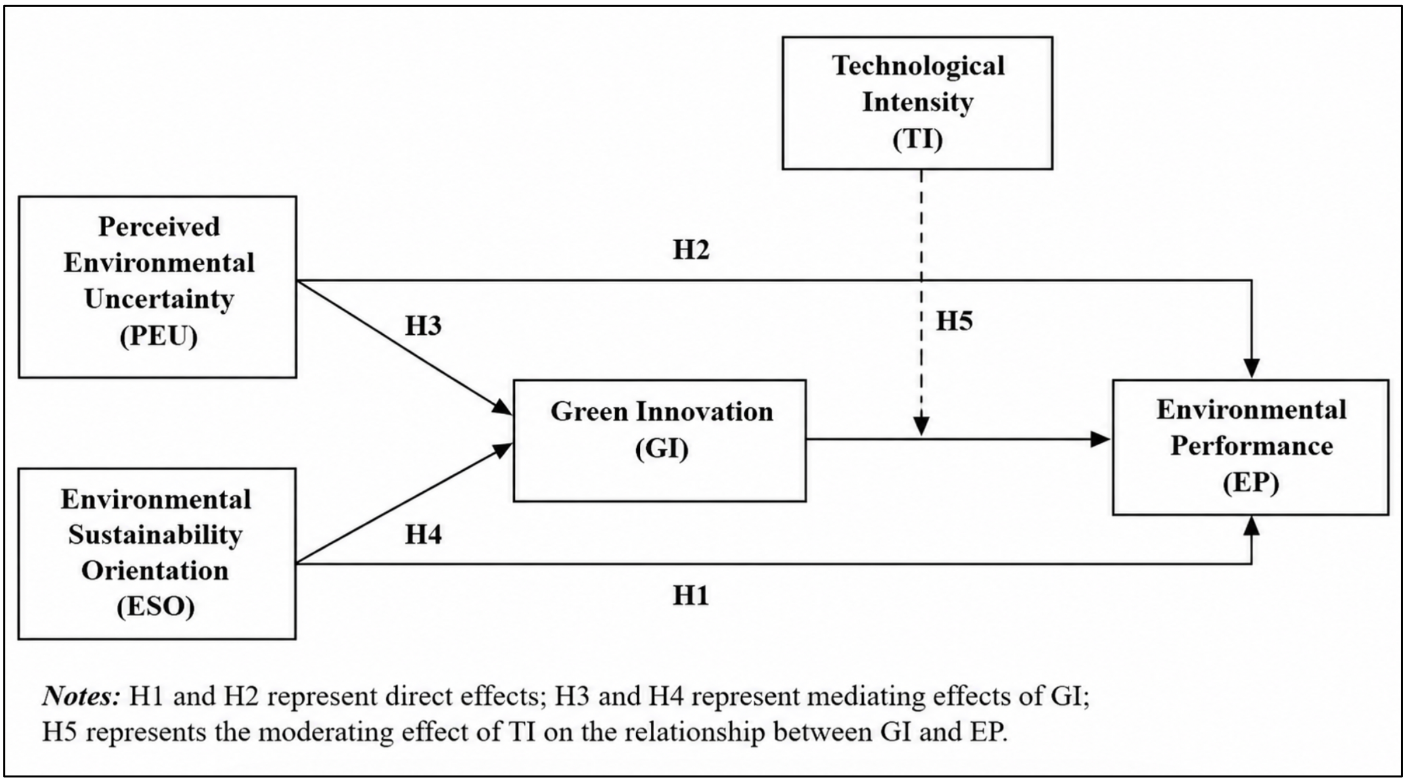

Figure 1. Research framework of the study
Source: Authors' conceptualization

3 RESEARCH METHODOLOGY

3.1 Research Design and Data Collection

This study adopted a quantitative, cross-sectional survey design to examine the proposed relationships among the study constructs in the manufacturing sector of Punjab, Pakistan. A survey-based design was appropriate because several constructs examined in the study, particularly ESO and PEU, reflect organizational orientations and managerial perceptions that require direct responses from organizational decision-makers. Such perceptions are difficult to capture adequately through secondary data because they depend on how managers interpret environmental priorities, regulatory conditions, market changes, and organizational capabilities (Kong et al., 2022). Punjab was selected as the empirical setting because it represents one of Pakistan's major industrial regions and includes a broad concentration of manufacturing activity. The study focused specifically on manufacturing firms because environmental sustainability issues in this sector are closely connected with production processes, resource consumption, waste generation, technological upgrading, and regulatory compliance. This context is also relevant because much of the existing research on environmental resources and organizational performance has been conducted in developed economies, leaving comparatively less evidence from emerging-economy manufacturing environments (Rehman et al., 2022). Primary data were collected through a structured questionnaire administered to managerial-level respondents from manufacturing firms. Managers were considered appropriate respondents because they were expected to possess sufficient knowledge of their firms' environmental strategies, innovation activities, technological capabilities, and environmental practices. A total of 380 questionnaires were administered. Following data screening, 22 questionnaires were excluded due to incomplete responses, resulting in a final sample of 358 valid questionnaires and a usable response rate of approximately 94.2%. These 358 responses were subsequently retained for the final empirical analysis.

3.2 Sampling and Respondent Selection

A non-probability purposive sampling technique was employed to select firms and respondents that were directly relevant to the objectives of the study. Purposive sampling was considered suitable because the research required respondents with adequate knowledge of environmental management, sustainability practices, technological activities, and organizational decision-making rather than responses from the general workforce. Three specific inclusion criteria were applied in selecting participating firms. First, firms were required to operate in one of six manufacturing subsectors: chemical, leather, food, plastics, textile or pharmaceutical manufacturing. These subsectors were selected because of their comparatively greater exposure to environmental issues associated with production activities, resource use, waste generation, and pollution control. Second, participating firms were required to be members of a recognized chamber of commerce in Lahore, Faisalabad, Gujranwala, or Rawalpindi. This criterion provided an identifiable organizational base for selecting established manufacturing firms operating within the target region. Third, each participating firm was required to possess ISO 14001 or an equivalent environmental certification. The environmental certification criterion was particularly important because it ensured that the participating firms had at least a basic environmental management infrastructure and sufficient familiarity with formal environmental practices.

3.3 Measurement of Constructs

The questionnaire measures were adapted from previously established scales in the relevant literature in order to maintain consistency with prior empirical research and support content validity. All constructs were measured using established multi-item scales on a five-point Likert scale, ranging from strongly disagree to strongly agree. ESO was operationalized as a second-order construct using 17 items adapted from Roxas et al. (2017), comprising Practices (8 items), Knowledge (5 items), and Commitment (4 items). PEU was measured using 7 items adapted from Marquet-Pondeville et al. (2013), covering perceived uncertainty associated with environmental regulatory and market conditions. GI was assessed using 4 items adapted from Al-Swidi et al. (2024), reflecting the adoption of environmentally friendly materials, technologies, and pollution-control practices. TI was measured using 4 items adapted from Al-Khatib and Al-Ghanem (2022), capturing R&D support, advanced technology investment, external knowledge utilization, and innovation-related training. Finally, EP was measured using 7 items adapted from Paillé et al. (2014), Melnyk et al. (2003), and Ilinitch et al. (1998), reflecting improvements in resource conservation, emissions and waste reduction, and broader environmental outcomes.

3.4 Data Analysis Techniques and Common Method Bias

The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4. PLS-SEM was appropriate for assessing the latent constructs and the direct, mediating, and moderating relationships in the proposed model (Wong, 2013). The measurement model was evaluated using factor loadings, AVE, CR, Cronbach's alpha (α), HTMT, and collinearity, including assessment of ESO as a reflective–reflective second-order construct. Subsequently, the structural model was assessed using path coefficients, t-statistics, p-values, effect sizes, and relevant model statistics to test the proposed hypotheses. Given that the study relied on self-reported data collected from managerial respondents through a single questionnaire, potential common method bias (CMB) was assessed using the full collinearity approach. Following Kock (2015), full collinearity variance inflation factor (VIF) values below 3.3 indicate that common method bias is unlikely to be a serious concern. The full collinearity VIF values obtained in the present study ranged from 1.172 to 2.427, all substantially below the recommended threshold of 3.3. Therefore, the results indicate that common method bias was unlikely to materially affect the empirical findings.

3.5 Ethical Considerations

The study involved organizational respondents and collected information for academic research purposes. Participation in the survey was treated as voluntary, and responses were used only for research analysis. Respondents were not required to disclose unnecessary personally identifying information, and the data were handled in a manner intended to preserve confidentiality and anonymity. The study therefore followed the general principles of voluntary participation, informed consent, confidentiality, and responsible use of research data.

4 EMPIRICAL ANALYSIS

The demographic characteristics of the 358 respondents are presented in Table 1. The sample was predominantly male (83.24%), while female respondents represented 16.76%. In terms of hierarchical position, 69.82% of the respondents were senior managers and 30.18% were junior managers, indicating that the majority of responses were obtained from individuals holding relatively senior organizational positions. Regarding firm type, textile firms accounted for the largest proportion of the sample (38.55%), followed by food and allied firms (22.90%), chemicals (14.52%), leather and tanneries (11.17%), medicine and drugs (6.71%), and plastic and PVC firms (6.15%). With respect to education, 49.72% of respondents held bachelor's degrees, 29.60% held master's degrees, 9.49% held M.Phil/MS qualifications, and 11.19% reported other qualifications. Finally, firm size varied across the sample, with the largest proportion of respondents representing firms with 101–500 employees (44.41%), followed by firms with fewer than 100 employees (25.14%), 501–1,000 employees (23.18%), and more than 1,000 employees (7.27%). Overall, the demographic profile indicates that the sample represents managers from firms of varying sizes and manufacturing backgrounds. The substantial representation of senior managers further supports the suitability of the respondents for providing informed assessments of their firms' environmental strategies, innovation activities, technological capabilities, and environmental performance.

Table 1. Demographic Profile of Respondents

Demographics	Frequency	Percentage (%)
Gender		
Male	298	83.24
Female	60	16.76
Managerial Level		
Junior Manager	108	30.18
Senior Manager	250	69.82
Firm Type		
Textile	138	38.55
Chemicals	52	14.52
Leather and Tanneries	40	11.17
Plastic and PVC	22	6.15
Food and Allied	82	22.90
Medicine and Drugs	24	6.71
Education Level		
Bachelor's	178	49.72
Master's	106	29.60
M.Phil/MS	34	9.49
Others	40	11.19
Firm Size		
Fewer than 100 employees	90	25.14
101–500 employees	159	44.41
501–1,000 employees	83	23.18
More than 1,000 employees	26	7.27

Note: n = 358. **Source:** Authors' calculations.

4.1 Measurement Model Assessment

The measurement model was assessed before evaluating the hypothesized structural relationships. As ESO was modeled as a reflective–reflective higher-order construct, the first-order measurement model was examined initially. As presented in Table 2, indicator loadings ranged from 0.726 to 0.979, demonstrating satisfactory indicator reliability across the constructs. Cronbach's α values ranged from 0.821 to 0.934, while CR values ranged from 0.859 to 0.961, indicating adequate internal consistency reliability. The AVE values ranged from 0.604 to 0.860, exceeding the recommended threshold of 0.50 and therefore supporting convergent validity. In addition, full collinearity VIF values ranged from 1.172 to 2.427 and remained below the threshold of 3.3, indicating no serious collinearity concerns. Taken together, the results demonstrate satisfactory indicator reliability, internal consistency reliability, convergent validity, and acceptable collinearity levels, supporting the adequacy of the first-order measurement model for subsequent analysis.

Table 2. First-Order Measurement Model Assessment

Constructs	Items	Factor Loading	Cronbach's α	CR	AVE	VIF
Practices of ESO	PES1	0.787	0.921	0.939	0.660	1.603
	PES2	0.741				
	PES3	0.892				
	PES4	0.881				
	PES5	0.792				
	PES6	0.781				
	PES7	0.803				
	PES8	0.809				
Knowledge of ESO	KES1	0.944	0.917	0.945	0.778	2.427
	KES2	0.758				
	KES3	0.945				
	KES4	0.979				
	KES5	0.758				
Commitment of ESO	CES1	0.842	0.869	0.904	0.701	2.395
	CES2	0.851				
	CES3	0.817				
	CES4	0.838				
Perceived Environmental Uncertainty	PEU1	0.780	0.934	0.932	0.663	1.839
	PEU2	0.863				
	PEU3	0.842				
	PEU4	0.753				
	PEU5	0.789				
	PEU6	0.887				
	PEU7	0.775				
Technological Intensity	TI1	0.976	0.931	0.961	0.860	1.172
	TI2	0.921				
	TI3	0.910				
	TI4	0.901				
Environmental Performance	EVP1	0.754	0.887	0.919	0.619	1.678
	EVP2	0.848				
	EVP3	0.773				
	EVP4	0.749				
	EVP5	0.767				
	EVP6	0.776				
	EVP7	0.834				
Green Innovation	GI1	0.726	0.821	0.859	0.604	1.656
	GI2	0.841				
	GI3	0.749				
	GI4	0.787				

Notes: α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted; VIF = variance inflation factor. **Source:** Authors' calculations.

Discriminant validity at the first-order level was examined using the HTMT criterion. As shown in Table 3, all reported HTMT values were below 0.85, ranging from 0.254 to 0.731. The highest value was observed between CES and KES (0.731), while the remaining inter-construct correlations were lower. These results indicate adequate discriminant validity among the first-order constructs.

Table 3. HTMT Results for the First-Order Measurement Model

Constructs	CES	EVP	GI	KES	PEU	PES	TI
CES	-						
EVP	0.518	-					
GI	0.351	0.654	-				
KES	0.731	0.421	0.602	-			
PEU	0.531	0.615	0.531	0.625	-		
PES	0.367	0.401	0.476	0.333	0.540	-	
TI	0.321	0.597	0.396	0.292	0.259	0.254	-

Source: Authors' calculations

4.2 Higher-Order Measurement Model

Following the assessment of the first-order constructs, the higher-order measurement model was evaluated. As presented in Table 4, the three first-order dimensions loaded satisfactorily on ESO, with loadings of 0.735 for Practices, 0.826 for Knowledge, and 0.823 for Commitment. At the higher-order level, ESO demonstrated adequate internal consistency and convergent validity, with a Cronbach's α of 0.713, CR of 0.838, and AVE of 0.633. The full collinearity VIF value of 1.853 was also below the recommended threshold of 3.3. Overall, these results support the reliability and validity of ESO as a higher-order construct.

Table 4. Higher-Order Measurement Model Assessment

Second-Order Construct	First-Order Constructs	Loading	Cronbach's α	CR	AVE	VIF
Environmental Sustainability Orientation	Practices of ESO	0.735	0.713	0.838	0.633	1.853
	Knowledge of ESO	0.826				
	Commitment of ESO	0.823				

Notes: α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted; VIF = variance inflation factor. **Source:** Authors' calculations.

Discriminant validity for the higher-order model was further examined through HTMT. As presented in Table 5, the HTMT values ranged from 0.359 to 0.786. The highest value was observed between ESO and PEU (0.786), while all reported values remained below the commonly applied threshold of 0.85. The results therefore provide evidence that the constructs in the higher-order model are empirically distinguishable.

Table 5. HTMT Results for the Higher-Order Measurement Model

Constructs	EVP	ESO	GI	PEU	TI
Environmental Performance	-				
Environmental Sustainability Orientation	0.636	-			
Green innovation	0.654	0.534	-		
Perceived Environmental Uncertainty	0.612	0.786	0.612	-	
Technological Intensity	0.579	0.463	0.465	0.359	-

Source: Authors' calculations

4.3 Structural Model and Hypothesis Testing

After establishing the measurement properties of the constructs, the structural model was assessed to examine the proposed hypotheses. Table 6 reports the standardized path coefficients, t-values, p-values, effect sizes, and hypothesis decisions. H1 proposed a positive relationship between ESO and EP, which was supported ($\beta = 0.301$, $t = 2.785$, $p = 0.036$). H2 also showed a positive and significant relationship between PEU and EP ($\beta = 0.475$, $t = 2.753$, $p = 0.000$), supporting H2. Among the two direct effects, PEU exhibited the stronger relationship with EP.

Table 6. Structural Model and Hypothesis Testing

Hypothesis	Relationship	β	t-value	p-value	f²	Decision
H1	ESO → EP	0.301	2.785	0.036	0.032	Supported
H2	PEU → EP	0.475	2.753	0.000	0.078	Supported
H3	PEU → GI → EP	0.053	2.025	0.046	—	Supported
H4	ESO → GI → EP	0.079	2.130	0.002	—	Supported
H5	TI × GI → EP	0.224	4.353	0.000	—	Supported

Notes: β = standardized path coefficient; t = t-statistic; p = significance level; f² = effect size. **Source:** Authors' calculations

The mediation analysis further showed that GI significantly mediated the relationship between PEU and EP (β = 0.053, t = 2.025, p = 0.046), supporting H3. Similarly, the indirect effect of ESO on EP through GI was positive and significant (β = 0.079, t = 2.130, p = 0.002), supporting H4. Finally, the interaction between TI and GI had a positive and significant effect on EP (β = 0.224, t = 4.353, p = 0.000), supporting H5. This positive interaction indicates that the relationship between GI and EP becomes stronger as TI increases. Overall, all five proposed hypotheses were supported.

5 DISCUSSION

This study examined how ESO and PEU contribute to EP in Pakistan's manufacturing sector, while considering GI as a mediating mechanism and TI as a boundary condition. The findings provide support for all five proposed hypotheses and offer a more integrated understanding of how strategic orientation, perceived external uncertainty, innovation, and technological capability interact in shaping firms' environmental outcomes. The positive relationship between ESO and EP supports H1 and reinforces the importance of embedding environmental considerations within organizational strategy and decision-making. Rather than functioning merely as a statement of environmental commitment, ESO appears to provide strategic direction for allocating resources, adjusting production practices, and incorporating ecological considerations into organizational routines. This interpretation is consistent with Yaghoubi Farani et al. (2024), who emphasize the role of sustainability orientation in shaping environmentally responsible organizational behavior. In Pakistan's manufacturing context, the finding is particularly relevant given the growing environmental awareness surrounding industrial activities (Al-Swidi et al., 2024). From an NRBV perspective, the result suggests that environmental orientation can contribute to EP when it guides the deployment of organizational resources toward environmentally responsible practices (Hart and Dowell, 2011).

H2 is also supported, indicating a positive relationship between PEU and EP. This finding suggests that perceived uncertainty does not necessarily result in managerial inaction. Instead, uncertainty surrounding environmental regulation, market expectations, resource conditions, and competitive pressures may increase managerial attention to environmental issues and encourage firms to respond proactively. This interpretation is particularly relevant in an emerging-economy setting where regulatory and market signals may be less predictable. Firms may view such uncertainty as an indication that existing practices need to be reconsidered, thereby encouraging anticipatory environmental responses as per Marquet-Pondeville et al. (2013). The result complements previous evidence that organizational responses to environmental pressures depend substantially on how managers perceive and interpret external conditions (Akram et al., 2025; Rehman et al., 2022). The mediation findings provide further insight into the mechanisms underlying these relationships. H3 demonstrates that GI mediates the relationship between PEU and EP. This indicates that part of the environmental response to perceived uncertainty occurs through firms' innovative activities. When managers perceive changes or unpredictability in external conditions, GI provides a practical mechanism through which firms can adapt products, processes, and technologies to emerging environmental requirements (Cheng *et al.*, 2025; Li *et al.*, 2025). Rather than responding to uncertainty solely through compliance-oriented actions, firms may use innovation to develop more flexible and environmentally responsible operating practices.

Similarly, support for H4 demonstrates that GI mediates the relationship between ESO and EP. This finding is important because it clarifies how a strategic sustainability orientation can be translated into tangible environmental outcomes. ESO establishes environmental priorities, while GI operationalizes those priorities through changes in production processes, products, resource utilization, and technologies. The finding is consistent with Sarwar et al. (2023), who highlight the importance of organizational capabilities and environmentally oriented practices in improving environmental outcomes. GI therefore represents an important bridge between strategic environmental intentions and actual environmental improvements. The moderating result provides an additional contribution. Support for H5 indicates that TI strengthens the positive relationship between GI and EP. Thus, the environmental benefits associated with GI are greater when firms possess stronger technological capabilities. High-TI firms are generally better equipped to absorb technical knowledge, integrate advanced technologies, and scale innovations across production activities. This interpretation is consistent with the capability perspective advanced by Awan et al. (2021), whereby technological resources and absorptive capacity facilitate the effective deployment of environmental innovations. Conversely, firms with lower TI may face greater technological, financial, or implementation constraints, limiting their ability to obtain the full environmental benefits of GI (Farrukh Shahzad *et al.*, 2025; Mei *et al.*, 2026).

6 CONCLUSION

Drawing on the NRBV, the study provides an integrated explanation of how firms' internal sustainability orientation, perceptions of external uncertainty, innovation activities, and technological capabilities are associated with environmental outcomes. The findings demonstrate that both ESO and PEU have positive relationships with EP. These results suggest that environmental performance is shaped not only by firms' internal commitment to sustainability but also by how managers interpret and respond to uncertainty in their external environment. More importantly, the findings establish GI as a significant mechanism connecting both ESO and PEU with EP. Environmental orientation and awareness of changing external conditions therefore become more meaningful when firms translate them into concrete innovations in products, processes, and technologies. The study further demonstrates that the contribution of GI to EP depends on firms' TI. The positive moderating effect indicates that firms with stronger technological capabilities are better positioned to transform green innovations into environmental improvements. Taken together, these findings suggest that environmental performance should not be understood as the outcome of a single organizational factor. Rather, it emerges from the combination of strategic environmental orientation, responsiveness to external uncertainty, the development of green innovation, and the technological capacity to implement such innovation effectively.

6.1 Theoretical Implications

This study offers several theoretical implications for the sustainability and environmental management literature. First, it extends the NRBV by demonstrating the importance of considering environmental orientation together with the organizational mechanisms through which environmental objectives are operationalized (Hart and Dowell, 2011). ESO provides strategic direction toward environmental priorities, while GI represents a capability through which these priorities can be translated into improved EP. The findings therefore reinforce the NRBV argument that environmentally oriented resources create value when firms are capable of deploying them through organizational processes and capabilities (Jetty *et al.*, 2024). Second, the study incorporates PEU into this resource-and-capability explanation. Much of the environmental strategy literature emphasizes internal organizational resources or external environmental pressures separately. The present findings indicate that managers' perceptions of uncertainty are also relevant to environmental outcomes and that GI provides an important mechanism connecting such perceptions with EP. This broadens the explanatory scope of the framework by showing that organizational environmental responses are shaped by the interaction between internally developed orientations and managers' interpretations of changing external conditions. Third, the study contributes by identifying TI as a boundary condition of the GI–EP relationship. The environmental value of GI is therefore not uniform across firms. Its effectiveness depends partly on whether firms possess the technological infrastructure and capabilities necessary to implement and scale environmentally oriented innovations. This extends the NRBV perspective by demonstrating that possession of an environmentally relevant capability alone may be insufficient; complementary technological capabilities influence the extent to which that capability generates environmental outcomes.

6.2 Practical Implications

The findings provide actionable implications for manufacturing managers and policymakers. For managers, the positive role of ESO indicates that environmental sustainability needs to be incorporated into routine strategic and operational decisions rather than managed primarily as a compliance exercise. For example, manufacturing firms can include measurable targets for energy consumption, material waste, water use, and emissions in departmental performance plans and require production and procurement managers to consider these targets when selecting equipment, suppliers, and production processes. Linking environmental objectives with managerial performance indicators can help convert sustainability commitments into operational accountability. The mediating role of GI further suggests that environmental intentions must be converted into specific innovation projects. Rather than allocating a general sustainability budget, firms can establish a portfolio of targeted green initiatives. A food-processing manufacturer, for example, could invest in water-recycling systems and energy-efficient processing equipment, while a plastics manufacturer could redesign production processes to reduce material losses and increase the use of recyclable inputs. Chemical and pharmaceutical manufacturers could prioritize process modifications that reduce hazardous waste, emissions, and resource consumption. Such initiatives provide concrete channels through which ESO can generate measurable improvements in EP.

The findings concerning PEU also have practical relevance. Rather than postponing environmental investment under uncertain regulatory, market, or energy conditions, managers should periodically assess emerging risks and adopt flexible or scalable cleaner technologies. The moderating role of TI further suggests that environmental innovation strategies should reflect firms' technological capacity. High-TI firms can integrate GI with R&D, digital monitoring, and advanced production technologies, whereas low-TI firms may initially emphasize lower-cost measures such as energy-efficiency improvements, waste reduction, process redesign, and employee training while gradually strengthening technological capabilities. External support from industry associations, universities, and technology providers can further facilitate this transition. For policymakers, the findings suggest that a uniform approach to environmental regulation and technological support may not generate equivalent outcomes across manufacturing firms. Environmental standards can be accompanied by differentiated support mechanisms based on firms' technological capacity. For example, low-TI firms could receive subsidized environmental audits, technical training, concessional green financing, or support for cleaner-equipment upgrades, whereas technologically advanced firms could be encouraged through R&D incentives, green-technology grants, and performance-based environmental targets. Such an approach can combine regulatory expectations with capability development rather than relying exclusively on compliance enforcement.

6.3 Limitations and Future Research

Several limitations provide opportunities for further research. First, the cross-sectional design captures organizational perceptions and environmental practices at a particular point in time and therefore limits conclusions about how these relationships develop over time. Future studies could employ longitudinal designs to examine whether changes in ESO, PEU, GI, and technological capabilities produce corresponding changes in EP. Second, the study employed purposive sampling and focused on selected manufacturing subsectors in Punjab. Although this approach was appropriate for identifying environmentally relevant firms and knowledgeable managerial respondents, it limits the generalizability of the findings to other industries and geographical settings. Future research could replicate the model across other provinces of Pakistan and in comparable emerging economies. Third, the study relied primarily on managerial survey responses. Future research could complement perceptual measures with objective indicators such as energy consumption, emissions, waste reduction, environmental investment, or resource-efficiency data. Combining survey and archival measures would provide a more comprehensive assessment of firms' environmental outcomes. Finally, future studies could explicitly compare high-TI and low-TI industries to determine whether the mechanisms identified in this study differ systematically across technological contexts. Researchers could also examine additional organizational or institutional boundary conditions, such as regulatory pressure, green financing, digital capabilities, or supply-chain requirements.

ARTIFICIAL INTELLIGENCE (AI) STATEMENT

Artificial intelligence (AI)-assisted tools were used solely to improve the language, grammar, readability, and presentation of this manuscript. The authors were fully responsible for the study design, data collection, analysis, interpretation of the results, and all scientific content, and they reviewed and approved the final version of the manuscript.

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