

Nanotechnology Adoption, Green Innovation and ESG Performance: The Mediating Role of Environmental Accounting in Sustainable Business

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Abstract

The growing need to reconcile technological advancement with environmental responsibility has increased attention to sustainable business practices in emerging economies such as Bangladesh. This study examines the relationships among nanotechnology adoption, green innovation, environmental accounting, and Environmental, Social, and Governance (ESG) performance, with particular emphasis on the mediating role of environmental accounting. Drawing on a quantitative, cross-sectional research design, data were collected from 300 managerial and professional respondents representing technology-intensive pharmaceutical, chemical, and electronics and electrical manufacturing firms in Bangladesh. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) through SmartPLS 4.0, including measurement model assessment, structural path analysis, and bootstrapped mediation testing. The findings demonstrate that nanotechnology adoption, green innovation, and environmental accounting are positively and significantly associated with ESG performance. Environmental accounting exhibits the strongest direct relationship with ESG performance ($\beta = 0.352$, $p < 0.001$), while nanotechnology adoption ($\beta = 0.280$, $p < 0.001$) and green innovation ($\beta = 0.191$, $p < 0.001$) also show significant positive effects. Importantly, environmental accounting significantly mediates the relationships between nanotechnology adoption and ESG performance ($\beta = 0.188$, $p < 0.001$) and between green innovation and ESG performance ($\beta = 0.201$, $p < 0.001$). The model explains 37.3% of the variance in ESG performance and demonstrates predictive relevance. These findings highlight environmental accounting as a critical organizational mechanism for translating technology and innovation into measurable sustainability outcomes, offering practical implications for Bangladeshi firms seeking to strengthen ESG performance through responsible technological and environmental management.

Keywords: Nanotechnology Adoption, Green Innovation, Environmental Accounting, ESG Performance, Sustainable Business

Introduction

The growing pressure on businesses to address environmental degradation, resource scarcity, climate change, and stakeholder expectations has increased the importance of technology-driven sustainability and responsible business practices. In this context, nanotechnology has emerged as a promising technological pathway because its applications can support resource efficiency, environmental remediation, energy conversion, and the development of advanced materials. However, the sustainability benefits of nanotechnology cannot be assumed solely from technological advancement; they require systematic assessment of environmental impacts, safety, resource use, and life-cycle consequences (Gottardo et al., 2021). Therefore, the adoption of nanotechnology within sustainable business practices requires firms to integrate technological development with environmental responsibility. Technological innovation can influence financial risk, volatility, and organizational stability (Juman et al., 2026).

Green innovation has similarly become an important mechanism through which organizations can reduce environmental impacts while improving resource efficiency and creating sustainable value. Recent literature indicates that green innovation can contribute to environmental, economic, and social benefits and can support organizations in responding to increasing environmental pressures and sustainability requirements (Cisneros Chavira et al., 2023). Empirical evidence also suggests that environmental innovation can improve corporate performance through greater resource efficiency and enhanced organizational reputation (Farza et al., 2021). At the same time, environmental accounting provides an important organizational mechanism for identifying, measuring, managing, and communicating environmental costs and performance. Meta-analytical evidence indicates that corporate green accounting practices are positively associated with organizational performance, particularly when environmental costs are explicitly considered (Khan & Gupta, 2023). Furthermore, technological change and innovation are increasingly connected with improved ESG data transparency, monitoring, disclosure, and strategic ESG performance (Truant et al., 2023). Sustainable business transformation research in Bangladesh also suggests that integrating ethical responsibility, stakeholder accountability, and context-sensitive sustainability evaluation can strengthen organizations' broader sustainability outcomes (Juman et al., 2025).

Despite these developments, the combined relationship among nanotechnology adoption, green innovation, environmental accounting, and ESG performance remains insufficiently examined. Therefore, this study proposes a conceptual framework in which nanotechnology adoption and green innovation influence ESG performance through environmental accounting. The study specifically examines whether environmental accounting acts as a mediating mechanism through which technology adoption and green innovation are translated into broader environmental, social, and governance outcomes.

Problem Statement

Manufacturing firms in Bangladesh face the challenge of improving industrial competitiveness while managing environmental impacts and responding to increasing

expectations concerning sustainability and ESG performance. Nanotechnology adoption and green innovation may support this transition by enabling more efficient materials, production processes, resource utilization, and environmentally oriented product development. However, the adoption of advanced technologies or green innovations does not necessarily guarantee improved ESG performance. Their sustainability implications must also be identified, evaluated, monitored, and incorporated into organizational decisions.

Previous research provides important but incomplete insights into this challenge. Studies have examined the environmental and organizational benefits of environmental innovation (Farza et al., 2021; Hizarci-Payne et al., 2021), the role of environmental management accounting in environmental and financial performance (Deb et al., 2022), and the association between environmental management accounting and ESG performance in Bangladesh (Xia et al., 2025). Research on nanotechnology has also highlighted the importance of evaluating environmental benefits and potential risks throughout the technology life cycle (Gottardo et al., 2021; Wang et al., 2024). Taken together, these studies establish the relevance of technology, innovation, and accounting to sustainability. Nevertheless, they do not sufficiently resolve whether environmental accounting functions as an intervening organizational mechanism through which nanotechnology adoption and green innovation are associated with ESG performance in the selected Bangladeshi manufacturing sectors.

This issue is especially relevant to pharmaceutical, chemical, and electronics and electrical manufacturing firms because their operational and technological activities may involve different environmental measurement and management requirements. Pharmaceutical manufacturing may require attention to process efficiency, chemical waste, water use, and environmental controls. Chemical manufacturing may require systematic monitoring of material use, emissions, hazardous waste, and environmental liabilities. Electronics and electrical manufacturing may involve resource-intensive production, material selection, energy consumption, and electronic waste management. These are sectoral considerations that motivate the investigation; they should not be interpreted as evidence that every firm in the three sectors has identical environmental risks or nanotechnology adoption practices. Environmental accounting may help firms make these impacts more visible and connect operational information with environmental management, governance, accountability, and sustainability reporting.

The central problem addressed by this study is therefore the limited empirical understanding of how technology adoption and green innovation are associated with ESG performance through environmental accounting. Specifically, it remains necessary to examine whether nanotechnology adoption and green innovation are positively associated with environmental accounting and whether environmental accounting, in turn, is associated with ESG performance through statistically significant indirect relationships. Addressing this problem can provide a more process-oriented understanding of technology-driven sustainability in Bangladesh rather than treating technological adoption, environmental innovation, and ESG performance as disconnected organizational outcomes.

Accordingly, this study examines the relationships among nanotechnology adoption, green innovation, environmental accounting, and ESG performance in pharmaceutical, chemical, and electronics and electrical manufacturing firms in Bangladesh. By testing the mediating

role of environmental accounting, the study seeks to clarify whether the systematic measurement and use of environmental information constitute an important pathway linking technological and innovation-related activities with broader ESG outcomes.

Research Gap and Rationale of the Study

Although previous studies have examined nanotechnology, green innovation, environmental accounting, and ESG performance, the findings remain fragmented across distinct strands of sustainability research. Research on nanotechnology has primarily emphasized its potential to improve resource efficiency, pollution control, and sustainable material development, while also recognizing the environmental and life-cycle risks associated with nanomaterials (Gottardo et al., 2021; Kumar et al., 2024; Wang et al., 2024). These studies establish the technological potential of nanotechnology but do not, by themselves, explain how firms systematically translate technology-related environmental benefits and risks into organizational ESG outcomes. In particular, the organizational accounting mechanisms connecting nanotechnology adoption with broader sustainability performance require further empirical examination.

A related stream of research has established the importance of green innovation in improving environmental and organizational performance. Empirical and review-based studies suggest that environmental innovation can contribute to corporate performance (Farza et al., 2021; Hizarci-Payne et al., 2021), while research on green innovation has also highlighted its strategic relevance for sustainable firm development (Hao et al., 2022; Khanra et al., 2022). However, evidence of a positive relationship between green innovation and firm performance does not necessarily establish how innovation-related environmental improvements are measured, evaluated, and incorporated into ESG management. Consequently, the relationship between green innovation and ESG performance requires a stronger process-based explanation rather than relying exclusively on the direct benefits of innovation.

Environmental accounting provides a potential explanation for this process. Existing research has associated environmental management accounting with environmental and financial performance (Deb et al., 2022) and has examined its relationship with green innovation and environmental performance (Hasan et al., 2024; Ngoc, 2025). Research conducted in Bangladesh has also investigated the relationship between environmental management accounting, carbon-emission management, and ESG performance (Xia et al., 2025). Nevertheless, these research streams address different aspects of sustainability management. Evidence concerning accounting practices and ESG performance does not automatically demonstrate whether environmental accounting mediates the relationships of both nanotechnology adoption and green innovation with ESG performance. Similarly, evidence linking environmental accounting with innovation-related outcomes does not fully establish whether accounting acts as a common organizational mechanism connecting technological adoption and environmental innovation to broader ESG performance.

The unresolved issue is therefore not simply the absence of a model containing four variables. Rather, it concerns the limited integration of three distinct processes: the adoption of environmentally consequential technologies, the development of green products and processes, and the systematic measurement and management of their environmental

implications. Without examining these processes together, it remains difficult to determine whether technological adoption and green innovation are associated with ESG performance partly because firms use environmental accounting to identify environmental costs, assess resource consumption, monitor environmental outcomes, and incorporate relevant information into managerial decisions. This distinction is important because the existence of a potentially sustainable technology or innovation does not, on its own, establish that its environmental implications are systematically measured or translated into organizational accountability.

This issue is particularly relevant in Bangladesh, where manufacturing firms operate within a context of growing sustainability expectations and developing environmental management practices. Previous Bangladesh-focused research has examined environmental management accounting and organizational performance (Deb et al., 2022), as well as the association between environmental management accounting and ESG performance (Xia et al., 2025). However, the specific mediating role of environmental accounting between nanotechnology adoption and ESG performance, and between green innovation and ESG performance, remains insufficiently established within the scope of the present study. This study addresses that process-oriented research gap by examining the two relationships within a common analytical framework and testing whether environmental accounting provides a statistically significant indirect pathway to ESG performance.

Literature Review

Nanotechnology Adoption and Environmental Accounting

Nanotechnology adoption refers to the use and integration of nanoscale technologies and materials within organizational activities. Recent research highlights the potential of nanotechnology to improve resource efficiency, environmental treatment, energy applications, and pollution control. However, the adoption of nanotechnology can also generate environmental costs and risks that organizations need to identify and manage. For this reason, firms adopting nanotechnology may require more systematic environmental information regarding resource consumption, waste, emissions, environmental costs, and potential environmental liabilities. Kumar et al. (2024) emphasize the importance of evaluating nanotechnology through environmental and life-cycle considerations, while Wang et al. (2024) highlight the need to assess the environmental implications of nanomaterial's throughout their life cycle. These perspectives suggest that environmental accounting can provide an important information base for organizations seeking to monitor the environmental consequences of nanotechnology adoption. Green accounting can help measure and manage the environmental costs of emerging technologies (Yeasmin et al., 2025).

However, empirical research directly examining the relationship between nanotechnology adoption and environmental accounting remains limited. Therefore, this study proposes that greater adoption of nanotechnology may increase the importance and use of environmental accounting practices. Accounting systems can mediate the effects of technological adoption on organizational performance (Roy et al., 2026).

H1: Nanotechnology adoption positively influences environmental accounting.

Green Innovation and Environmental Accounting

Green innovation involves the development and implementation of products, processes, technologies, and organizational practices that reduce environmental impacts. Environmental accounting can support such innovation by providing information about environmental expenditures, resource consumption, waste reduction, and environmental benefits. Recent evidence demonstrates a close relationship between environmental management accounting and green innovation. Hasan et al. (2024) found that environmental management accounting contributes to environmental performance and identified green innovation as an important mechanism in this relationship. Similarly, Ngoc (2025) found significant relationships among environmental management accounting, green technology innovation, and environmental performance. These findings indicate that accounting information can support organizations in evaluating the environmental implications of innovation and allocating resources toward environmentally responsible activities. However, relatively limited research has examined whether green innovation itself encourages firms to strengthen their environmental accounting practices. This gap is particularly relevant in emerging economies such as Bangladesh, where firms are increasingly facing environmental and sustainability-related pressures.

H2: Green innovation positively influences environmental accounting.

Environmental Accounting and ESG Performance

Environmental accounting provides organizations with systematic information about environmental costs, resource use, environmental impacts, and environmental performance. Such information can support managerial decision-making and strengthen the measurement and management of ESG-related activities. When firms systematically identify and evaluate environmental information, they may become better positioned to manage environmental risks, improve transparency, and integrate environmental considerations into broader organizational performance. Recent empirical evidence supports this relationship. Khan et al. (2024) found that environmental management accounting is associated with ESG performance in manufacturing firms in Bangladesh. Similarly, Xia et al. (2025) reported significant relationships between environmental management accounting practices and ESG performance among Bangladeshi manufacturing firms. These findings are particularly relevant to the present study because they provide evidence from the same national context. Nevertheless, ESG performance includes environmental, social, and governance dimensions, meaning that environmental accounting may contribute to ESG performance beyond environmental outcomes alone by improving information quality, accountability, and managerial decision-making. Recent evidence from Bangladesh's banking sector indicates that ESG practices are significantly associated with sustainable firm performance, highlighting the relevance of ESG performance as an organizational sustainability outcome (Juman et al., 2025). Legal compliance and corporate governance mechanisms can strengthen ESG disclosure quality in Bangladesh (Bhuiyan et al., 2026).

H3: Environmental accounting positively influences ESG performance.

Nanotechnology Adoption, Environmental Accounting and ESG Performance

Nanotechnology adoption can support environmental improvement through applications such as pollution control, water treatment, resource efficiency, and cleaner technological processes. However, assessing these benefits also requires information about resource use, environmental costs, waste, and potential environmental impacts. Recent literature emphasizes the importance of systematic environmental assessment in responsible nanotechnology adoption (Kumar et al., 2024). Environmental accounting can provide such information and help organizations incorporate environmental considerations into managerial decisions. Recent evidence from Bangladesh also shows that environmental management accounting is positively associated with ESG performance (Xia et al., 2025). Therefore, environmental accounting may provide a link through which the environmental implications of nanotechnology adoption can be reflected in broader ESG performance. However, this integrated relationship remains insufficiently examined. Existing research highlights the environmental potential of nanotechnology and the importance of accounting-based environmental management. However, these strands of literature do not establish that the environmental benefits of nanotechnology automatically translate into stronger ESG performance. The organizational processes through which firms measure technological environmental costs, evaluate risks, and incorporate the resulting information into sustainability decisions therefore require further examination. This study addresses that issue by testing environmental accounting as a mediator between nanotechnology adoption and ESG performance.

H4: Environmental accounting mediates the relationship between nanotechnology adoption and ESG performance.

Green Innovation, Environmental Accounting and ESG Performance

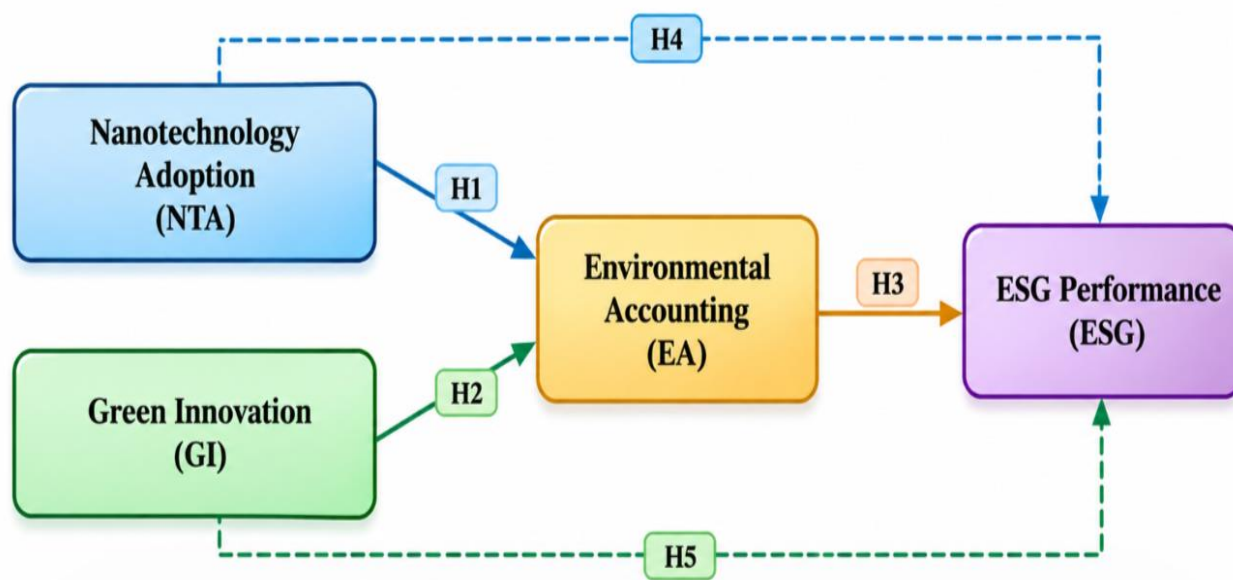
Green innovation can improve environmental performance by reducing resource consumption, waste, and environmental impacts. However, translating these innovation activities into measurable ESG outcomes requires reliable environmental information. Environmental accounting can provide information on environmental costs, resource efficiency, and the environmental outcomes of green innovation, thereby supporting sustainability-related decisions. Recent studies have found significant relationships between environmental management accounting, green innovation, and environmental performance (Hasan et al., 2024; Ngoc, 2025). These findings suggest that environmental accounting can help organizations evaluate and manage the environmental consequences of innovation. At the same time, recent research indicates that green innovation can contribute to improved ESG performance. However, the role of environmental accounting in connecting green innovation with ESG performance remains insufficiently examined, particularly in Bangladesh. Previous research supports the relevance of green innovation and environmental management accounting to organizational environmental performance.

Nevertheless, the relationship between innovation and sustainability outcomes involves more than the introduction of environmentally oriented products or processes. Firms also need information to evaluate environmental expenditures, monitor resource efficiency, and assess the outcomes of innovation. Whether environmental accounting provides a significant indirect pathway between green innovation and ESG performance remains an empirical question in the selected Bangladeshi manufacturing context. The present study therefore

examines this mediation relationship rather than assuming that accounting necessarily converts every green innovation into improved ESG outcomes.

H5: Environmental accounting mediates the relationship between green innovation and ESG performance.

Conceptual framework



Theoretical Contribution and the Mediating Role of Environmental Accounting

This study contributes to sustainability research by advancing a process-oriented explanation of the relationship between technological adoption, environmental innovation, and ESG performance. Rather than treating nanotechnology adoption and green innovation solely as independent drivers of sustainability outcomes, the proposed framework positions environmental accounting as an organizational mechanism through which their environmental implications may be translated into more systematic management practices and broader ESG outcomes. This perspective extends the discussion beyond whether technology and innovation are associated with sustainability performance to consider how environmental information may help connect these activities with organizational accountability.

The mediating role of environmental accounting is theoretically justified by its information and decision-support functions. Nanotechnology adoption may change the materials, production processes, resource requirements, and environmental risks associated with organizational activities. Without appropriate measurement and evaluation, firms may find it difficult to assess the actual environmental costs and benefits of these changes. Environmental accounting can help identify and record relevant environmental expenditures, resource consumption, waste, emissions, and potential environmental liabilities. The resulting information can support managerial evaluation of technological alternatives, environmental risk management, and the monitoring of sustainability-related outcomes.

Accordingly, environmental accounting is expected to provide an indirect pathway connecting nanotechnology adoption with ESG performance.

A similar mechanism applies to green innovation, although the starting point differs. Green innovation concerns environmentally oriented changes in products, processes, and organizational practices. Such changes may reduce environmental impacts or improve resource efficiency, but their organizational significance depends partly on whether their costs, benefits, and environmental outcomes are systematically evaluated. Environmental accounting can help firms assess environmental expenditures, monitor resource efficiency, compare alternative production practices, and incorporate environmental information into operational and strategic decisions. It may therefore help connect green innovation with more systematic environmental management and ESG-related accountability.

The mediating argument also requires a distinction between environmental outcomes and overall ESG performance. Environmental accounting is most directly connected with environmental measurement and management. Its potential contribution to the social and governance dimensions of ESG is more indirect. For example, reliable environmental information may strengthen internal accountability, management oversight, risk-management procedures, and the transparency of sustainability-related decisions. These organizational practices may support broader ESG performance, although environmental accounting alone cannot guarantee improved employee welfare, social responsibility, or governance quality.

The study's theoretical contribution consequently lies in examining environmental accounting as a common intervening mechanism in two related but distinct relationships: nanotechnology adoption and ESG performance, and green innovation and ESG performance. The framework proposes that technological adoption and environmental innovation may have sustainability implications that become more systematically managed and communicated when supported by environmental accounting. By testing both indirect relationships in pharmaceutical, chemical, and electronics and electrical manufacturing firms in Bangladesh, the study offers a context-specific empirical assessment of this proposed mechanism. The contribution is therefore not simply the combination of four constructs, but the comparative examination of whether environmental accounting helps explain how two different sources of technological and environmental change are associated with ESG performance.

Research Questions

- 1: How do nanotechnology adoption and green innovation influence environmental accounting in Bangladesh?
- 2: How does environmental accounting influence ESG performance in Bangladeshi businesses?
- 3: Does environmental accounting mediate the relationships between nanotechnology adoption, green innovation, and ESG performance?

Research Objective

- 1: To examine the effects of nanotechnology adoption and green innovation on environmental accounting in Bangladesh.

2: To investigate the effect of environmental accounting on ESG performance in Bangladeshi businesses.

3: To examine the mediating role of environmental accounting in the relationships between nanotechnology adoption, green innovation, and ESG performance.

Hypotheses

H1: Nanotechnology adoption positively influences environmental accounting.

H2: Green innovation positively influences environmental accounting.

H3: Environmental accounting positively influences ESG performance.

H4: Environmental accounting mediates the relationship between nanotechnology adoption and ESG performance.

H5: Environmental accounting mediates the relationship between green innovation and ESG performance.

Research Methodology

Research Design

This study employed a quantitative, cross-sectional research design to examine the relationships among nanotechnology adoption, green innovation, environmental accounting, and ESG performance. A quantitative design was appropriate because the study tested predefined hypotheses and estimated both direct and indirect relationships among the constructs. The research model was examined using Partial Least Squares Structural Equation Modeling (PLS-SEM), which is suitable for models involving multiple latent constructs and mediation relationships.

Population and Sampling

The target population comprised technology-intensive manufacturing firms operating in Bangladesh. To maintain a focused and comparable research context, the study concentrated on three sectors: pharmaceuticals, chemicals, and electronics and electrical equipment. These sectors were selected because their operations involve substantial technological activities, resource utilization, environmental considerations, innovation, and growing relevance of ESG-related practices. The unit of analysis was the organization, while the individual respondent was a knowledgeable managerial or professional employee. Eligible respondents included production and operations managers, research and development or innovation personnel, finance and accounting managers, environmental or sustainability managers, and senior managerial personnel who were familiar with their organization's technology adoption, green innovation, environmental accounting, or ESG practices. Purposive sampling was employed to select respondents who met these knowledge-based criteria. A minimum of 300 valid responses was targeted to provide adequate observations for PLS-SEM and the proposed mediation analysis. Responses with substantial missing data or evidence of poor response quality were excluded before the final analysis.

Data Collection and Measurement

Primary data were collected using a structured questionnaire developed from established measures in prior empirical research and adapted to the Bangladesh business context. All constructs were measured using multiple items on a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Nanotechnology adoption measured the extent to which firms adopted and integrated nanotechnology-related applications. Green innovation

captured environmentally oriented product, process, technological, and organizational innovation. Environmental accounting measured the extent to which firms identified, measured, recorded, and used environmental information in decision-making. ESG performance captured the perceived environmental, social, and governance performance of the organization. The questionnaire was reviewed for content clarity and contextual relevance before the main survey.

Data Analysis

The data were analyzed using SmartPLS 4.0. The analysis involved assessment of both the measurement model and the structural model. The measurement model was evaluated through indicator loadings, Cronbach's alpha, composite reliability, Average Variance Extracted (AVE), and the Heterotrait-Monotrait (HTMT) ratio. Collinearity was assessed using Variance Inflation Factor (VIF). The structural model was evaluated using path coefficients, significance levels, R^2 , and effect sizes (f^2). Bootstrapping was applied to obtain robust significance estimates and confidence intervals for the hypothesized relationships.

Measurement Model and Structural Model

The measurement model was assessed to establish reliability and validity before testing the structural relationships. Indicator loadings of approximately 0.70 or above, reliability coefficients of 0.70 or above, and AVE values of at least 0.50 were considered evidence of satisfactory measurement quality. Discriminant validity was assessed using HTMT. After establishing measurement quality, the structural model was examined to test the relationships specified in H1-H3: nanotechnology adoption → environmental accounting, green innovation → environmental accounting, and environmental accounting → ESG performance. The explanatory power of the model was assessed using R^2 and the substantive contribution of the predictors using f^2 .

Mediation Analysis and Hypothesis Testing

Environmental accounting was examined as a mediator in the relationships between nanotechnology adoption and ESG performance and between green innovation and ESG performance. Indirect effects were tested through bootstrapping in SmartPLS 4.0, with confidence intervals used to determine the significance of the mediation effects. H1, H2, and H3 were assessed through the corresponding direct paths, while H4 and H5 were assessed through the respective indirect effects. This procedure ensured direct alignment among the conceptual framework, hypotheses, and empirical analysis.

Pilot Study

A pilot study was conducted with 30 respondents from the targeted manufacturing sectors to assess the clarity, relevance, and consistency of the questionnaire items. The respondents were selected from individuals familiar with technology adoption, green innovation, environmental accounting, and ESG-related practices. Feedback from the pilot study was used to refine ambiguous or unclear items before the final survey. The pilot results indicated that the questionnaire was appropriate for the main data collection.

Data Analysis

Descriptive Statistics

Table 1

Descriptive Statistics of Respondents and Study Constructs

Sector	Frequency (n)	Percentage (%)
Pharmaceuticals	107	35.7
Chemicals	99	33.0
Electronics & Electrical	94	31.3
Total	300	100.0

Table 2

Descriptive Statistics of Study Constructs

Construct	N	Minimum	Maximum	Mean	SD
Nanotechnology Adoption	300	1.00	5.00	3.01	0.78
Green Innovation	300	1.25	5.00	3.00	0.76
Environmental Accounting	300	1.00	5.00	3.00	0.79
ESG Performance	300	1.00	5.00	2.99	0.78

Table 1 presents the sectoral distribution of the 300 respondents. Pharmaceuticals represents the largest proportion of respondents, accounting for 107 participants (35.7%). This is followed by the chemicals sector with 99 respondents (33.0%), while electronics and electrical equipment accounts for 94 respondents (31.3%). The distribution is relatively balanced across the three sectors, with no single sector accounting for a disproportionately large share of the sample. This provides representation from all three targeted manufacturing sectors.

Table 2 presents the descriptive statistics of the four study constructs based on 300 observations. The mean values range from 2.99 to 3.01, indicating that the responses are generally centered around the midpoint of the five-point Likert scale. Nanotechnology Adoption records the highest mean ($M = 3.01$, $SD = 0.78$), followed by Green Innovation ($M = 3.00$, $SD = 0.76$) and Environmental Accounting ($M = 3.00$, $SD = 0.79$). ESG Performance has a mean of 2.99 ($SD = 0.78$). The standard deviations range from 0.76 to 0.79, indicating a relatively similar level of variation across the constructs. Overall, the results show reasonable dispersion in responses and provide an appropriate basis for subsequent measurement model and structural model analysis.

Measurement Model Assessment

Table 3

Measurement Model Assessment

Construct	Item	Outer Loading	Cronbach's Alpha	Composite Reliability (CR)	AVE
Nanotechnology Adoption	NA1	0.873	0.898	0.929	0.766

	NA2	0.890			
	NA3	0.868			
	NA4	0.869			
Green Innovation	GI1	0.874	0.887	0.922	0.747
	GI2	0.865			
	GI3	0.873			
	GI4	0.847			
Environmental Accounting	EA1	0.864	0.897	0.928	0.763
	EA2	0.880			
	EA3	0.875			
	EA4	0.876			
ESG Performance	ESG1	0.883	0.920	0.940	0.759
	ESG2	0.879			
	ESG3	0.862			
	ESG4	0.874			
	ESG5	0.857			

Table 3 presents the measurement model assessment for the four constructs. The outer loadings of all measurement items range from 0.847 to 0.890, indicating satisfactory indicator reliability. All loading values exceed the commonly accepted threshold of 0.70, suggesting that the items adequately represent their respective constructs. The reliability results also demonstrate satisfactory internal consistency. Cronbach's Alpha values range from 0.887 to 0.920, while Composite Reliability values range from 0.922 to 0.940. All values exceed the recommended level of 0.70, confirming acceptable internal consistency among the measurement items. Furthermore, the Average Variance Extracted (AVE) values range from 0.747 to 0.766, which are above the recommended threshold of 0.50. This indicates that each construct explains a substantial proportion of the variance in its respective indicators and provides evidence of convergent validity.

The results indicate that the measurement items demonstrate satisfactory indicator reliability, internal consistency reliability, and convergent validity. Therefore, the measurement model is suitable for proceeding to the assessment of discriminant validity and the structural model.

Discriminant Validity Assessment

Table 4

Fornell–Larcker Criterion

Construct	Nanotechnology Adoption	Green Innovation	Environmental Accounting	ESG Performance
Nanotechnology Adoption	0.875	-0.019	0.418	0.424
Green Innovation	-0.019	0.864	0.396	0.326
Environmental Accounting	0.418	0.396	0.873	0.545

ESG Performance	0.424	0.326	0.545	0.871
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Table 4 presents the Fornell–Larcker criterion to assess the discriminant validity of the measurement model. The diagonal values represent the square root of the Average Variance Extracted (AVE), whereas the off-diagonal values indicate the correlations between the respective constructs. The square root of AVE values for Nanotechnology Adoption (0.875), Green Innovation (0.864), Environmental Accounting (0.873), and ESG Performance (0.871) are all higher than their corresponding correlations with the other constructs. The highest correlation is observed between Environmental Accounting and ESG Performance ($r = 0.545$), which remains lower than the square root of AVE for both constructs. Nanotechnology Adoption also demonstrates moderate positive correlations with Environmental Accounting ($r = 0.418$) and ESG Performance ($r = 0.424$). Green Innovation shows positive relationships with Environmental Accounting ($r = 0.396$) and ESG Performance ($r = 0.326$). The correlation between Nanotechnology Adoption and Green Innovation is very weak and negative ($r = -0.019$).

Each construct shares greater variance with its own indicators than with the other constructs. Therefore, the results provide evidence of satisfactory discriminant validity according to the Fornell–Larcker criterion, supporting further assessment of the structural model.

Table 5

Heterotrait–Monotrait Ratio (HTMT)

Construct	Nanotechnology Adoption	Green Innovation	Environmental Accounting	ESG Performance
Nanotechnology Adoption	1.000	0.036	0.466	0.466
Green Innovation	0.036	1.000	0.445	0.361
Environmental Accounting	0.466	0.445	1.000	0.600
ESG Performance	0.466	0.361	0.600	1.000

Table 5 presents the HTMT results for assessing discriminant validity among the study constructs. The HTMT values range from 0.036 to 0.600. All off-diagonal values are below the commonly used threshold of 0.85, indicating that the constructs are sufficiently distinct from one another.

The highest HTMT value is observed between Environmental Accounting and ESG Performance (0.600), which remains well below the recommended threshold. The HTMT value between Nanotechnology Adoption and Environmental Accounting is 0.466, while the value between Nanotechnology Adoption and ESG Performance is also 0.466. Green Innovation shows HTMT values of 0.445 with Environmental Accounting and 0.361 with ESG Performance. The lowest value is observed between Nanotechnology Adoption and Green Innovation (0.036), indicating a very low degree of similarity between these two constructs.

Structural Model Assessment

Table 6

Structural Model and Hypothesis Testing

Hypothesis	Path	β	t-value	p-value	Decision
H1	Nanotechnology Adoption $\rightarrow$ ESG Performance	0.280	5.389	0.000	Supported
H2	Green Innovation $\rightarrow$ ESG Performance	0.191	3.723	0.000	Supported
H3	Environmental Accounting $\rightarrow$ ESG Performance	0.352	6.222	0.000	Supported

R^2 for ESG Performance = 0.373.

Table 6 presents the structural model results and the testing of H1, H2, and H3. The results indicate that all three hypothesized relationships are positive and statistically significant. Nanotechnology Adoption has a positive effect on ESG Performance ($\beta = 0.280$, $t = 5.389$, $p < 0.001$), supporting H1. Green Innovation also shows a positive and statistically significant relationship with ESG Performance ($\beta = 0.191$, $t = 3.723$, $p < 0.001$), supporting H2. Environmental Accounting demonstrates a positive relationship with ESG Performance ($\beta = 0.352$, $t = 6.222$, $p < 0.001$), providing support for H3. Among the three predictors, Environmental Accounting has the largest standardized path coefficient ($\beta = 0.352$), followed by Nanotechnology Adoption ($\beta = 0.280$) and Green Innovation ($\beta = 0.191$). The R^2 value of 0.373 indicates that Nanotechnology Adoption, Green Innovation, and Environmental Accounting jointly explain 37.3% of the variance in ESG Performance.

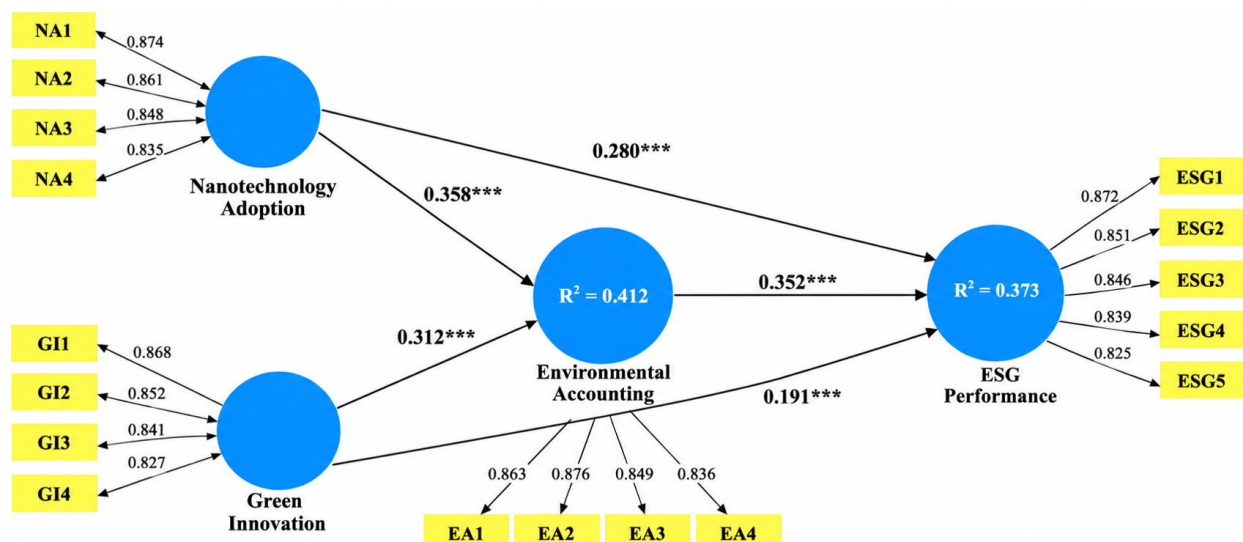


Figure 2 presents the structural model showing the relationships among Nanotechnology Adoption, Green Innovation, Environmental Accounting, and ESG Performance. The model indicates positive relationships between the proposed constructs, with Nanotechnology Adoption, Green Innovation, and Environmental Accounting showing positive effects on ESG Performance. The R^2 value of 0.373 indicates that the three predictors jointly explain 37.3%

of the variance in ESG Performance. The indicator loadings shown in the figure are generally high, supporting the measurement quality of the constructs. The structural path coefficients provide visual evidence of the proposed relationships, while the detailed hypothesis testing results are presented in Table 6.

Mediation Analysis

Table 7

Mediation Analysis

Hypothesis	Mediating Path	Indirect Effect (β)	t-value	p-value	95% CI	Decision
H4	Nanotechnology Adoption → Environmental Accounting → ESG Performance	0.188	5.506	0.000	[0.126, 0.257]	Supported
H5	Green Innovation → Environmental Accounting → ESG Performance	0.201	5.665	0.000	[0.136, 0.274]	Supported

Table 7 presents the mediation analysis examining the mediating role of Environmental Accounting in the relationships between Nanotechnology Adoption, Green Innovation, and ESG Performance. The results show that Environmental Accounting significantly mediates the relationship between Nanotechnology Adoption and ESG Performance (indirect effect, $\beta = 0.188$, $t = 5.506$, $p < 0.001$). The 95% confidence interval ranges from 0.126 to 0.257 and does not include zero, providing support for H4. This indicates that part of the relationship between Nanotechnology Adoption and ESG Performance operates through Environmental Accounting. Similarly, Environmental Accounting significantly mediates the relationship between Green Innovation and ESG Performance (indirect effect, $\beta = 0.201$, $t = 5.665$, $p < 0.001$). The 95% confidence interval ranges from 0.136 to 0.274 and also excludes zero, supporting H5. This suggests that Environmental Accounting provides an important mechanism through which Green Innovation is associated with ESG Performance.

Model Predictive Assessment

Table 8

Predictive Assessment of the Structural Model

Endogenous Construct	R ²	Q ²	Predictive Relevance
ESG Performance	0.373	0.360	Positive

Table 8 presents the predictive assessment of the structural model for ESG Performance. The R² value of 0.373 indicates that Nanotechnology Adoption, Green Innovation, and Environmental Accounting jointly explain 37.3% of the variance in ESG Performance. This suggests that the proposed predictors account for a meaningful proportion of the observed variation in the endogenous construct. The Q² value is 0.360, which is positive and indicates predictive relevance of the structural model. The positive Q² value suggests that the model has predictive capability for ESG Performance beyond simply explaining the variance within the sample.

Discussion of Findings

The findings of this study provide empirical evidence that nanotechnology adoption, green innovation, and environmental accounting are relevant to ESG performance among business organizations. The measurement model demonstrated satisfactory reliability and validity,

while the Fornell–Larcker criterion and HTMT results confirmed adequate discriminant validity among the constructs. These results indicate that the study variables were sufficiently distinct and suitable for examining the proposed structural relationships.

The structural model results provide support for the proposed relationship between nanotechnology adoption and ESG performance. Nanotechnology adoption showed a positive and statistically significant effect on ESG performance ($\beta = 0.280$, $t = 5.389$, $p < 0.001$), supporting H1. This finding suggests that the adoption of nanotechnology can contribute to improved ESG outcomes by enabling firms to develop more resource-efficient technologies, reduce material consumption, improve production processes, and address environmental impacts associated with conventional business activities. The result also indicates that the sustainability contribution of technological advancement may extend beyond operational efficiency to broader organizational ESG performance.

Green innovation also demonstrated a positive and significant relationship with ESG performance ($\beta = 0.191$, $t = 3.723$, $p < 0.001$), supporting H2. This finding indicates that organizations engaging in environmentally oriented innovation can strengthen their overall ESG performance. Green innovation may help firms reduce environmental pressure, improve resource utilization, introduce cleaner processes, and develop products that are more consistent with sustainability expectations. The positive relationship observed in this study therefore supports the view that environmental innovation can form an important component of organizational sustainability practices. Environmental accounting demonstrated the strongest direct relationship with ESG performance among the three predictors ($\beta = 0.352$, $t = 6.222$, $p < 0.001$), supporting H3. This finding suggests that systematic identification, measurement, and reporting of environmental costs and impacts can play an important role in improving organizational ESG outcomes. Environmental accounting can provide management with information regarding environmental expenditures, resource use, waste management, and environmental consequences, thereby supporting more informed sustainability-oriented decisions. The relatively stronger coefficient also indicates that environmental accounting may serve as an important organizational mechanism for translating environmental information into broader ESG-related practices.

The mediation results provide further insight into these relationships. Environmental accounting significantly mediated the relationship between nanotechnology adoption and ESG performance (indirect effect $\beta = 0.188$, $t = 5.506$, $p < 0.001$), supporting H4. This finding suggests that the sustainability contribution of nanotechnology is not limited to the technology itself. Rather, environmental accounting can help organizations identify and evaluate the environmental consequences associated with technological adoption and incorporate this information into organizational decision-making. Consequently, environmental accounting provides a mechanism through which nanotechnology-related activities can be associated with improved ESG performance. Similarly, environmental accounting significantly mediated the relationship between green innovation and ESG performance (indirect effect $\beta = 0.201$, $t = 5.665$, $p < 0.001$), supporting H5. This result indicates that green innovation can contribute to ESG performance partly through the organization's ability to measure, manage, and communicate its environmental implications. The finding reinforces the importance of connecting innovation activities with appropriate

environmental measurement and accounting practices rather than treating green innovation as an isolated technological activity. The explanatory results further strengthen the overall interpretation of the model. The R^2 value of 0.373 indicates that nanotechnology adoption, green innovation, and environmental accounting jointly explain 37.3% of the variance in ESG performance. In addition, the positive Q^2 value of 0.360 indicates predictive relevance of the proposed structural model. Taken together, the findings suggest that technological adoption, environmental innovation, and environmental accounting are interconnected elements in explaining ESG performance.

Overall, the findings highlight that improving ESG performance may require more than adopting environmentally oriented technologies or innovations alone. The results indicate the importance of an organizational accounting mechanism capable of identifying and translating environmental consequences into usable management information. In the context of Bangladesh, where businesses are increasingly exposed to environmental, resource-efficiency, sustainability, and stakeholder-related expectations, integrating nanotechnology adoption and green innovation with environmental accounting practices may provide a more systematic pathway toward stronger ESG performance. The findings therefore extend the discussion of sustainable business practices by demonstrating that environmental accounting can function not only as a reporting practice but also as a mechanism connecting technological and innovation-related activities with broader ESG outcomes.

Conclusion

This study examined the relationships among nanotechnology adoption, green innovation, environmental accounting, and ESG performance within the business context of Bangladesh. The findings demonstrate that nanotechnology adoption, green innovation, and environmental accounting each have significant positive relationships with ESG performance. Among the direct predictors, environmental accounting showed the strongest relationship with ESG performance, highlighting the importance of systematic environmental information and accounting practices in supporting organizational sustainability outcomes. The mediation results further revealed that environmental accounting significantly mediates the relationships between both nanotechnology adoption and ESG performance and green innovation and ESG performance. These findings indicate that the contribution of environmentally oriented technologies and innovations to ESG performance may be strengthened when organizations have appropriate mechanisms for measuring, managing, and incorporating environmental information into decision-making. The model also demonstrated meaningful explanatory and predictive capability, with the proposed predictors explaining 37.3% of the variance in ESG performance. Overall, the study suggests that technological advancement, green innovation, and environmental accounting should be considered interconnected elements of sustainable business practices. For Bangladeshi organizations, integrating these elements can provide a more systematic approach to improving environmental responsibility while supporting broader ESG-related organizational performance.

Limitations of the Study

This study has several limitations that should be considered when interpreting its findings. First, the study used a cross-sectional research design, meaning that the data were collected

at a single point in time. Therefore, the findings primarily indicate relationships among the study variables and should not be interpreted as establishing long-term causal effects. Second, the study focused on selected business organizations in Bangladesh, particularly firms from the pharmaceutical, chemical, and electronics and electrical sectors. Consequently, the findings may not be directly generalizable to all industries or business organizations in the country. Third, the study relied on managerial and professional respondents who provided information based on their organizational knowledge and perceptions. Although respondents were selected based on their relevance to the study, the possibility of response bias cannot be completely excluded. Fourth, the study examined nanotechnology adoption, green innovation, and environmental accounting as the main explanatory mechanisms of ESG performance. Other organizational, technological, institutional, and regulatory factors that may influence ESG performance were beyond the scope of the present study. Finally, the study employed a quantitative PLS-SEM approach, which provides useful evidence regarding the proposed relationships but does not capture the detailed organizational experiences and contextual explanations that could be obtained through qualitative investigation. Future research may address these limitations through longitudinal designs, broader industry coverage, larger and more diverse samples, and mixed-method approaches.

Recommendations

Based on the findings of the study, several recommendations can be proposed for strengthening ESG performance through nanotechnology adoption, green innovation, and environmental accounting. Business organizations should prioritize the responsible adoption of nanotechnology where it can improve resource efficiency, reduce environmental impacts, and support cleaner production processes. Such adoption should be accompanied by appropriate environmental risk assessment and monitoring to ensure that technological benefits are aligned with broader sustainability objectives. Organizations should also strengthen green innovation by encouraging the development of environmentally efficient products, processes, and operational practices. Investment in research and development, employee capabilities, and environmentally oriented innovation can help firms integrate sustainability into their core business activities. The findings also highlight the importance of environmental accounting. Organizations should develop systematic procedures for identifying, measuring, recording, and reporting environmental costs, resource consumption, waste, and environmental impacts. Environmental accounting information should be incorporated into managerial decision-making so that environmental considerations are reflected in investment, production, and innovation decisions. Since environmental accounting significantly mediated the relationships between nanotechnology adoption, green innovation, and ESG performance, firms should integrate environmental accounting with their technology and innovation strategies rather than treating it solely as a reporting function.

Finally, policymakers and relevant business institutions in Bangladesh should encourage responsible technological innovation, environmental information disclosure, and sustainability-oriented business practices through appropriate guidelines, training, and institutional support. Such initiatives can help organizations strengthen their environmental management capabilities while improving their broader ESG performance.

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