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Do Green Innovation and Environmental Management Accounting Jointly Enhance Competitive Advantage? Evidence from Saudi Listed Basic Materials Companies

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Abstract This study investigates the individual and interactive associations between green innovation (GI) and environmental management accounting (EMA) and competitive advantage among Saudi-listed Basic Materials companies. Drawing on a capability-based perspective, the study examines whether the joint deployment of GI and EMA yields additional competitive benefits beyond their respective contributions. Data were collected through a structured questionnaire administered to managers and professionals knowledgeable about their organizations' environmental practices. Following data screening, 258 valid responses were retained from 304 submitted questionnaires. Measurement assessments indicated satisfactory reliability, convergent validity, and discriminant validity. The findings reveal significant positive associations between competitive advantage and both GI ($\beta = 0.288, p < 0.001$) and EMA ($\beta = 0.518, p < 0.001$), with the model explaining 69.7% of the variance in competitive advantage ($R^2 = 0.697$; adjusted $R^2 = 0.693$). Contrary to the hypothesized complementarity, the GI $\times$ EMA interaction is negative and statistically significant ($\beta = -0.078, p = 0.010$). Simple-slope analysis indicates that the positive association between GI and competitive advantage weakens as EMA increases. However, supplementary robustness analyses show that the negative interaction is sensitive to model specification and becomes statistically insignificant at the 5% level after controlling for respondent-reported organizational characteristics. These findings suggest that GI and EMA are individually associated with stronger competitive positioning, whereas their joint contribution does not necessarily generate additional synergistic benefits. The study contributes to the literature by distinguishing the individual associations of environmental capabilities from their conditional interaction and highlights the importance of strategically aligning green innovation initiatives with environmental accounting practices in Saudi Arabia's Basic Materials sector.

Keywords Green Innovation; Environmental Management Accounting; Competitive Advantage; Basic Materials companies; Saudi Arabia

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1. Introduction

Environmental sustainability is now embedded in core corporate strategy rather than treated as a peripheral responsibility. Industrial organizations are consequently expected to pursue operational efficiency while meeting environmental expectations, conserving scarce inputs, limiting waste and emissions, and addressing stakeholder assessments of both economic and ecological outcomes. These demands are particularly important in resource-intensive activities because environmental costs are intertwined with production choices and may shape efficiency,

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reputation, risk, and longer-term competitive position. Earlier work on environmentally oriented management accounting and management innovation already emphasized that accounting and control systems can help organizations translate environmental concerns into managerial action (Di Vaio & Varriale, 2018; Nartey & van der Poll, 2021). More recent evidence similarly shows that green management systems, environmental accounting practices, and environmental information can support sustainability-oriented decision-making and performance improvement (Lutfi et al., 2023; Huynh & Nguyen, 2024).

Against this background, green innovation (GI) can be viewed as a strategically relevant organizational capability. In this study, GI encompasses changes in products, processes, technologies, and managerial practices intended to lessen environmental impacts while also creating economic value. Green product innovation can improve materials, packaging, product design, and life-cycle characteristics, whereas green process innovation can reduce energy use, waste, emissions, and raw-material consumption. Evidence from manufacturing settings shows that environmental and green innovation can contribute to performance through efficiency, differentiation, improved resource use, and market positioning (Chaudhry et al., 2020; Somjai et al., 2020; Namazi & Khorramdel Masouleh, 2022). Gelmez et al. (2024) provide particularly direct evidence by showing that green innovation positively affects competitive advantage among manufacturing firms. Recent studies also report positive effects of GI on sustainability performance (Masri et al., 2026), although the financial consequences of different types of GI are not uniformly positive; for example, Sumayyah et al. (2025) document non-significant or negative financial effects for some innovation dimensions. These mixed findings suggest that the competitive value of GI may depend on complementary organizational systems that help firms select, evaluate, and exploit environmentally oriented innovations.

Environmental Management Accounting (EMA) represents a related capability that can support this strategic response. Rather than relying solely on conventional accounting information, EMA integrates monetary and physical environmental data into planning, control, investment evaluation, performance assessment, and resource allocation. Through information on environmental costs, material flows, energy consumption, waste, emissions, and environmental investments, EMA can reveal inefficiencies that conventional accounting systems may obscure. Empirical research increasingly treats EMA not merely as a compliance tool, but as a strategic information and control system. Salim et al. (2023) find a direct and significant relationship between EMA and sustainability competitive advantage among manufacturing SMEs. Vo and Nguyen (2024) likewise show that EMA implementation contributes to green competitive advantage in manufacturing firms, while Jiao et al. (2023) identify EMA as a relevant contributor to business sustainability and competitive advantage. Gerged et al. (2024) further demonstrate a significant direct relationship between EMA and firm performance, and Asiaei et al. (2026) provide explicit evidence that EMA contributes to competitive advantage when green resources are effectively orchestrated.

Recent studies increasingly portray GI and EMA as interconnected rather than isolated organizational practices. Environmental accounting information can identify environmental cost drivers, resource losses, and opportunities for cleaner production, thereby informing innovation priorities. At the same time, the strategic value of EMA increases when managers use its information to redesign processes, introduce cleaner technologies, or develop environmentally differentiated products. A growing stream of studies therefore models GI as a mechanism connecting EMA to performance or, conversely, EMA as a mechanism through which environmental innovation creates value. Agustia et al. (2019) show that EMA mediates the relationship between green innovation and firm value, and Hidayat et al. (2024) also identify EMA as a mediator between GI and firm value. In the opposite direction, Hasan et al. (2024), Hang (2025), Saputra et al. (2023), and Widati et al. (2026) show that GI can transmit part of EMA's effect to environmental or financial outcomes. Huy and Phuc (2025) similarly demonstrate that the management of green innovation complexity mediates the relationship between EMA practices and strategic resilience. Collectively, these studies suggest that environmental information and green innovation are not independent practices; rather, they can function as mutually reinforcing capabilities.

A newer stream of research has extended the discussion beyond mediation by considering interactions and contextual boundary conditions. Acar et al. (2025) find that EMA strengthens the effect of green dynamic capabilities on eco-innovation, positioning EMA as an enabling internal infrastructure. Asiaei et al. (2026) show that green ambidexterity strengthens the positive effect of EMA on competitive advantage, indicating that firms capable of simultaneously exploiting existing green practices and exploring new green innovations derive greater

strategic value from EMA. However, this interaction logic is not universally supported. Saribu et al. (2024) find that green innovation does not strengthen the effect of EMA on hospital performance, while Sinuraya and Sudibyo (2026) report that GI does not significantly mediate the EMA-competitive advantage relationship in their hospital sample, despite significant direct effects of EMA and GI on competitive advantage. These contrasting findings reinforce the need to test the integration effect directly rather than assuming that complementarity automatically produces superior outcomes.

The Basic Materials sector in Saudi Arabia provides an appropriate empirical context for examining these relationships. The Saudi Main Market (TASI) comprises 22 main sectors, and the present study focuses specifically on companies listed in the Basic Materials sector. Companies in this sector operate in environmentally intensive activities, including petrochemicals, mining, cement, packaging, and related basic-material industries, where production depends heavily on raw materials, energy, water, and other natural resources and may generate substantial emissions, waste, and environmental costs. The Kingdom's ongoing industrial transformation places increasing emphasis on productivity, innovation, efficient resource use, and environmental sustainability. These priorities make the relationship between environmental information systems and green innovation strategically important for Saudi listed Basic Materials companies. Direct evidence from Saudi evidence is still limited, but Metwally and Hasanein (2026) provide an important recent contribution to the Saudi oil and natural-gas sector. Using 558 responses, they find that EMA positively affects corporate environmental performance and that green process innovation partially mediates this relationship. Their results confirm that EMA and green innovation are empirically relevant and interconnected capabilities in Saudi industry. Nevertheless, their dependent variable is environmental performance rather than competitive advantage, and their model focuses on mediation rather than the incremental value created by the simultaneous deployment of EMA and GI.

The pursuit of sustainable competitive advantage in Saudi Arabia's industrial sector requires a deeper understanding of how firms respond to economic and environmental challenges. In this context, Alanazi (2025) highlights the interdependence of economic sectors and their implications for manufacturing performance in Saudi Arabia, emphasizing the importance of the broader economic environment in which industrial firms operate. From an environmental perspective, Barbary and Aldallal (2026) demonstrate the value of statistical analysis for monitoring environmental conditions and supporting sustainability-related planning in Saudi Arabia. Together, these studies provide relevant contextual insights into the economic and environmental challenges facing Saudi industries, reinforcing the need to examine how firm-level practices, particularly green innovation (GI) and environmental management accounting (EMA), relate to competitive advantage.

Furthermore, achieving competitive advantage may depend not only on individual strategic decisions but also on how different organizational practices are combined. In a distinct competitive context, Bazyari (2025) examines the optimization of investment and reinsurance strategies among competing insurance companies, illustrating the importance of jointly considering strategic decisions when evaluating competitive outcomes. Building on this broader perspective, the present study focuses on Saudi-listed Basic Materials companies and investigates whether GI and EMA individually contribute to competitive advantage and whether their interaction generates additional competitive benefits. In doing so, the study extends the discussion from broader economic, environmental, and competitive considerations to the firm-level relationship between sustainability-oriented practices and competitive advantage.

Accordingly, this research evaluates how GI, EMA, and their interaction are associated with competitive advantage among Basic Materials companies listed on the Saudi Exchange. The study shifts attention from predominantly environmental, financial, firm-value, and sustainability outcomes toward competitive advantage as the focal strategic outcome. It also examines joint deployment via a multiplicative GI $\times$ EMA interaction, rather than treating integration solely as a mediation pathway. Specifically, the study tests whether the association of one environmental capability with competitive advantage changes as the other capability increases. This perspective is consistent with the Natural Resource-Based View and resource-orchestration logic, which emphasize that strategically valuable outcomes depend on how environmentally relevant resources and capabilities are coordinated, mobilized, and deployed.

1.1. Research Gap and Study Contribution

Reviewing the relevant evidence points to four connected gaps that motivate the present investigation. The first concerns the outcome examined in prior work. A substantial portion of the literature evaluates environmental performance, financial performance, firm value, strategic resilience, or sustainable performance rather than competitive advantage itself.

The second gap concerns the mechanism by which GI and EMA are linked. Most studies that combine EMA and GI conceptualize one variable as a mediator of the other variable's relationship with performance. Mediation models explain how one capability may mediate the relationship between another and an outcome, but they do not directly test whether the association between GI and competitive advantage varies across levels of EMA, or vice versa. This unresolved issue provides a clear basis for directly testing the GI $\times$ EMA interaction.

A third limitation in the literature concerns empirical context. The reviewed empirical evidence is concentrated in countries such as Pakistan, Vietnam, Indonesia, Iran, Türkiye, Kenya, and Yemen. Although these emerging-economy settings are informative, their institutional arrangements, industrial structures, sustainability pressures, and management accounting practices differ from those in Saudi Arabia. Metwally and Hasanein (2026) provide important evidence from Saudi evidence, but the focus is on the oil and natural gas sector and environmental performance. Evidence on the integrated effect of GI and EMA on competitive advantage among companies listed in the Saudi Basic Materials sector, therefore, remains limited.

The fourth gap concerns theoretical integration. The literature applies several perspectives, including the Resource-Based View, Natural Resource-Based View, stakeholder theory, upper echelons theory, institutional theory, dynamic capabilities theory, and resource-orchestration approaches. These perspectives are often applied to isolated relationships rather than to a unified explanation of how environmental information and green innovation may operate jointly. The present study addresses this gap by conceptualizing GI and EMA as strategically relevant environmental capabilities and by empirically testing whether their joint configuration is associated with competitive advantage beyond their separate associations.

The study addresses these gaps through three related contributions. Empirically, it extends the limited Saudi evidence by focusing on competitive advantage among companies listed in the Basic Materials sector of the Saudi Exchange. Conceptually, it distinguishes the direct associations of GI and EMA from their multiplicative interaction. Theoretically, it evaluates, rather than assumes, the proposition that environmental information and green innovation operate as complementary capabilities. This approach responds to recent calls to investigate how environmental accounting systems interact with innovation and organizational capabilities (Hasan et al., 2024; Acar et al., 2025; Asiaei et al., 2026).

2. Literature Review and Hypotheses Development

2.1. Green Innovation and Competitive Advantage

Green innovation refers to developing or materially improving products, processes, technologies, or managerial practices in ways that lower environmental impacts and generate economic or strategic benefits. Product-oriented GI can improve materials, product design, packaging, recyclability, and life-cycle performance, whereas process-oriented GI can reduce resource consumption, energy use, pollution, waste, and production inefficiencies. In competitive terms, these innovations can support both cost leadership and differentiation. Cleaner and more efficient processes may reduce operating costs and environmental risks, while environmentally differentiated products may strengthen reputation, improve customer acceptance, open new markets, and enhance stakeholder relationships.

Most empirical findings reviewed here indicate that GI can play a favorable strategic role. Chaudhry et al. (2020) report positive effects of environmental product and process innovation on financial performance in manufacturing firms. Somjai et al. (2020) likewise find a positive and significant relationship between green innovation and firm performance. Namazi and Khorramdel Masouleh (2022) show that green product and process innovations influence financial and economic performance both directly and through EMA. Most importantly for the present study,

Gelmez et al. (2024) find that GI positively affects competitive advantage. Rachmawati (2023) also positions GI as an important factor in the formation of green competitive advantage, while Masri et al. (2026) find a positive and significant effect of GI on sustainability performance.

The evidence, however, is not consistently positive across all innovation types or performance outcomes. Sumayyah et al. (2025) find that green process innovation does not significantly improve financial performance, whereas green product innovation has a negative financial effect, despite positive environmental consequences. Such findings suggest that GI can impose short-term costs, require substantial investment, or generate benefits that are not immediately captured in accounting returns. They do not, however, negate its potential competitive value. Competitive advantage is broader than short-term financial performance and can arise through reputation, differentiation, market access, operational learning, and environmental responsiveness. Consistent with this distinction, Gelmez et al. (2024) provide direct evidence that GI strengthens competitive advantage even when other environmental outcomes do not necessarily translate directly into it.

Among Saudi-listed Basic Materials companies, GI is expected to be especially relevant because operations in this sector are closely tied to material use, energy intensity, production efficiency, emissions, and waste. Firms that introduce cleaner processes and environmentally improved products may be better positioned to reduce resource costs, adapt to changing sustainability expectations, and differentiate themselves from competitors. On this basis, the study proposes:

H1. Green innovation is positively and significantly associated with the competitive advantage of Saudi listed Basic Materials companies.

2.2. Environmental Management Accounting and Competitive Advantage

EMA can be understood as an internal information and control approach through which organizations identify, quantify, analyze, and apply both monetary and physical environmental information in managerial decisions. Monetary information includes environmental expenditures, waste costs, energy costs, environmental investments, and potential liabilities, while physical information includes material flows, water and energy consumption, emissions, and waste generation. By making these costs and flows visible, EMA can improve planning, budgeting, investment appraisal, operational control, and environmental performance evaluation.

EMA becomes strategically relevant when the information it generates improves resource productivity and the quality of managerial choices. Environmental information can reveal hidden costs, identify inefficient processes, improve capital allocation, support investment in cleaner technologies, and provide a stronger basis for evaluating environmental projects. Nartey and van der Poll (2021) argue that innovative management accounting practices, including environmental costing, can be integrated into manufacturing strategies to improve efficiency and sustainability. Di Vaio and Varriale (2018) similarly emphasize the role of managerial accounting instruments in monitoring, measuring, controlling, and reporting environmental initiatives for competitive green development. More recent studies show that green accounting and related environmental accounting practices can enhance financial or sustainability outcomes, although results vary by context (Setyawati & Rochmatullah, 2025; Zakaria & Hani, 2026).

A number of studies provide direct evidence connecting EMA with competitive outcomes. Salim et al. (2023) find a significant direct relationship between EMA and sustainability competitive advantage among Kenyan manufacturing SMEs. Vo and Nguyen (2024) show that EMA implementation contributes to green competitive advantage in Vietnamese manufacturing firms. Jiao et al. (2023) identify EMA as a relevant driver of business sustainability and competitive advantage. Sinuraya and Sudibyo (2026) report that EMA directly contributes to competitive advantage, even though the indirect EMA-GI-competitive advantage pathway is not significant. Asiaei et al. (2026) also demonstrate a positive relationship between EMA and competitive advantage, showing that EMA can function as a structured control system that aligns environmental goals with competitive objectives.

Supporting evidence from performance-oriented studies further explains the mechanisms through which EMA can create competitive value. Gerged et al. (2024) find a significant direct relationship between EMA and firm performance. Huynh and Nguyen (2024) show that EMA adoption improves environmental performance, while Nguyen et al. (2025) document a strong positive effect of EMA on corporate environmental performance. Hanif et al. (2023) similarly report a significant impact of EMA on corporate environmental performance. These outcomes

can strengthen competitiveness when improved environmental management reduces costs, supports innovation, improves stakeholder confidence, and protects the firm's strategic position. Khan and Ahmad (2025) also show that EMA operates within a broader green strategic system that contributes to green competitive advantage.

Accordingly, EMA is expected to serve as more than an accounting technique for Saudi-listed Basic Materials companies. By integrating environmental cost and physical resource information into managerial decisions, EMA may support cost efficiency, better investment selection, operational improvement, stakeholder responsiveness, and strategic differentiation. Therefore:

H2. Environmental management accounting is positively and significantly associated with the competitive advantage of Saudi listed Basic Materials companies.

2.3. Integration between Green Innovation and Environmental Management Accounting and Competitive Advantage

The study is built on the proposition that GI and EMA may operate as complementary capabilities, such that their joint deployment could be associated with competitive value beyond their separate contributions. EMA provides environmental information, while GI provides technological, operational, and managerial means through which firms can respond to that information. EMA may identify excessive energy costs, material losses, waste streams, or environmental liabilities, but competitive value may arise when managers translate those signals into cleaner processes, redesigned products, improved technologies, or other green innovations. Conversely, a GI undertaken without reliable information on environmental costs and resource flows may be poorly targeted, difficult to evaluate, or disconnected from strategic priorities.

Prior empirical work provides considerable evidence that the two capabilities are closely connected. Agustia et al. (2019) find that EMA mediates the relationship between GI and firm value. Chaudhry et al. (2020) similarly show that EMA mediates the effects of product and process environmental innovation on financial performance. Namazi and Khorramdel Masouleh (2022) report on the direct and indirect effects of green product and process innovation using EMA. Hidayat et al. (2024) also identify EMA as a mediating mechanism in the GI-firm value relationship. These studies suggest that innovation is more economically meaningful when it is linked to environmental accounting information.

Evidence also supports influence in the opposite direction. Hasan et al. (2024) find that EMA positively affects GI and environmental performance, with GI partially mediating the EMA-performance relationship. Hang (2025) reports that EMA directly improves financial performance and indirectly affects it through green process innovation, while Widati et al. (2026) find that GI partially mediates the EMA-financial performance relationship. Gerged et al. (2024) similarly show that environmental innovation mediates the effect of EMA on firm performance. Huy and Phuc (2025) extend this argument by showing that the management of green innovation complexity mediates the relationship between EMA practices and strategic resilience. These findings consistently indicate that accounting information and environmental innovation are mutually connected components of value creation.

More recent interaction-based studies provide additional evidence for the complementarity proposition. Acar et al. (2025) show that EMA strengthens the positive effect of green dynamic capabilities on eco-innovation, suggesting that EMA acts as enabling organizational infrastructure. Asiaei et al. (2026) find that green ambidexterity significantly strengthens EMA's positive effect on competitive advantage. At high levels of green ambidexterity, the effect of EMA on competitive advantage is stronger than at lower levels, demonstrating that the strategic return from EMA depends partly on a firm's ability to exploit existing green practices while exploring new green innovations. This evidence is closely aligned with the proposed GI $\times$ EMA interaction.

Even so, complementarity is an empirical proposition that requires direct testing rather than an assumption. Saribu et al. (2024) find that GI does not strengthen the relationship between EMA and hospital performance. Sinuraya and Sudibyo (2026) similarly report that although EMA and GI each contribute directly to competitive advantage, the indirect effect of EMA on GI on competitive advantage is not significant. Romadhon et al. (2025) also find that GI does not significantly moderate the relationship between green intellectual capital and performance. Lasau et al. (2025) report additional evidence that environmental relationships can vary depending on the role assigned to EMA and the outcome considered. Such inconsistencies indicate that the benefits of integration

may be context-dependent, thereby strengthening the rationale for direct testing among Saudi-listed Basic Materials companies.

Metwally and Hasanein (2026) provide the most relevant contextual evidence. In Saudi oil and natural gas companies, EMA positively affects corporate environmental performance, and green process innovation partially mediates this relationship. Their results demonstrate that the two capabilities are interconnected in Saudi industry and that managers are encouraged to integrate EMA and green process innovation. Yet the study does not examine competitive advantage as the final dependent variable and does not estimate a multiplicative GI $\times$ EMA interaction. The present study therefore extends this Saudi evidence by testing whether the association between GI and competitive advantage varies with EMA, and vice versa.

Accordingly:

> ***H3. The interaction between green innovation and environmental management accounting is positively and significantly associated with the competitive advantage of Saudi listed Basic Materials companies.***

3. Research Methodology

3.1. Research Design and Approach

The study employed a quantitative cross-sectional survey design to examine the associations between green innovation (GI) and environmental management accounting (EMA) and competitive advantage (CA), as well as the interaction between GI and EMA, among companies listed in the Basic Materials sector of the Saudi Exchange. This sector provides an appropriate empirical setting because its operations are typically characterized by intensive use of raw materials, energy, and other natural resources, making environmental innovation and environmental information particularly relevant to operational and strategic decision-making.

Individual managers and professionals constituted the observational units, while the questionnaire used the company as the organizational referent for assessing green innovation, environmental management accounting, and competitive advantage. Multiple respondents could represent the same listed company; therefore, the responses reflect individual key-informant assessments of organization-level practices and outcomes. The analytical model included GI and EMA as the two focal predictors, CA as the outcome variable, and the standardized GI $\times$ EMA interaction term to assess whether the association of one environmental capability with competitive advantage varied according to the level of the other. Given the cross-sectional nature of the research design, the estimated relationships were interpreted as statistical associations rather than definitive causal effects. The absence of retained company identifiers also precluded firm-clustered standard errors; accordingly, the respondent-level estimates should not be interpreted as independent firm-level observations.

3.2. Population, Sampling, and Respondent Selection

The population comprised companies classified in the Basic Materials sector of the Saudi Exchange (Tadawul). This sector was selected because its activities are resource- and environmentally intensive, involving substantial use of raw materials, energy, and water and exposure to waste, emissions, and environmental costs. A purposive key-informant sampling approach was used to reach managers and professionals knowledgeable about their companies' environmental practices, accounting information, green product or process initiatives, and competitive position. Eligible respondents included general and senior managers, finance and accounting managers, management accountants, operations or production managers, and sustainability or environmental managers. Respondent suitability was subsequently incorporated into data screening so that cases reporting low or very low knowledge of the focal environmental and innovation practices were not retained in the final analytical sample.

3.3. Questionnaire Development and Data Collection Procedure

Data were collected using a structured questionnaire based on established measures from prior research and contextualized for Saudi listed Basic Materials companies. The questionnaire contained respondent and

organizational characteristics followed by 19 substantive measurement items covering GI, EMA, and CA. All substantive items were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire was administered electronically to eligible respondents during August–September 2026. Participation was voluntary, and respondents were informed of the study's academic purpose and the confidentiality of individual and company information. A total of 304 questionnaires were received. Before analysis, responses were screened for completeness, key-informant suitability, patterned responding, and values outside the specified response scale. After applying the screening criteria at the respondent level, 46 unique cases were excluded and 258 valid responses were retained for the final analysis.

3.4. Measurement of Constructs

Construct measurement drew on established scales and recent empirical applications. GI was represented by Green Product Innovation (GPI) and Green Process Innovation (GPrI), with three and four items, respectively. EMA comprised Physical Environmental Management Accounting (PEMA) and Monetary Environmental Management Accounting (MEMA), with three items for each dimension. Competitive Advantage (CA) was measured using six items reflecting cost efficiency, differentiation, innovative capability, environmental management capability, reputation, and long-term competitive positioning. The joint relationship of GI and EMA with CA was not measured by separate questionnaire items; instead, it was evaluated statistically through the multiplicative GI $\times$ EMA term.

Table 1. Operationalization and Measurement of the Study Constructs

Construct	Dimensions / coverage	Items	Principal empirical basis	Scale / treatment
Green Innovation (GI)	Green Product Innovation (3 items); Green Process Innovation (4 items)	7	Agustia et al. (2019); Hanif et al. (2023); Gelmez et al. (2024); Hang (2025); Metwally & Hasanein (2026)	5-point Likert
Environmental Management Accounting (EMA)	Physical environmental information (3 items); Monetary environmental information (3 items)	6	Vo & Nguyen (2024); Metwally & Hasanein (2026)	5-point Likert
Competitive Advantage (CA)	Cost/efficiency, differentiation, innovation capability, environmental-management capability, reputation, long-term competitive position	6	Gelmez et al. (2024); Vo & Nguyen (2024); Asiaei et al. (2026)	5-point Likert
GI $\times$ EMA	Multiplicative interaction between standardized GI and EMA composite scores	—	Estimated statistically; no separate questionnaire items	Standardized product term

Green Innovation. Green product innovation captured the use of lower-emission and energy-efficient materials, reductions in polluting or toxic materials, and product or packaging designs that facilitate reuse or recycling. Green process innovation captured reductions in hazardous waste, recycling or reuse of waste and emissions, reductions in water and energy consumption, and reductions in raw material consumption. Composite GI scores were derived from the GPI and GPrI dimensions after evaluating the measurement properties of their indicators.

Environmental Management Accounting. EMA was measured using physical and monetary environmental information dimensions. PEMA assessed the recording and use of environmental inputs and outputs, environmental impacts, and performance targets for managing physical resource flows. MEMA assessed the identification and

classification of environmental costs and liabilities, environmental-related cost accounts, and the allocation of environmental costs to products, processes, or activities. A composite EMA score was derived from these two dimensions.

Competitive Advantage. CA was assessed relative to principal competitors using six items covering environmental and green cost efficiency, environmentally differentiated products and services, capability to develop green ideas and solutions, environmental management capability, reputation benefits, and the strengthening of long-term competitive position. The six items were combined to obtain the composite CA score used in the structural analysis.

The analysis proceeded in two stages. First, the quality of the multi-item scales was assessed using standardized indicator loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and the heterotrait-monotrait ratio (HTMT). Indicator loadings were evaluated against the preferred 0.70 reference level; alpha and CR values of at least 0.70 were treated as evidence of satisfactory internal consistency; AVE values above 0.50 were used to assess convergent validity; and HTMT values below 0.90 were used as the principal criterion for discriminant validity.

Second, composite scores were calculated for GI, EMA, and CA and used in multiple regression analysis. GI and EMA were standardized before constructing the multiplicative interaction term (GI $\times$ EMA). The estimated specification was:

$$CA = \beta_0 + \beta_1 GI + \beta_2 EMA + \beta_3 (GI \times EMA) + \varepsilon.$$

Predictor collinearity was examined using variance inflation factors (VIFs). Standardized regression coefficients (β), t-statistics, p-values, bootstrap confidence intervals, and f^2 effect sizes were used to evaluate the hypotheses. Overall explanatory power was summarized using R, R^2, and adjusted R^2. H1 was supported when β_1 was positive and statistically significant, H2 when β_2 was positive and statistically significant, and H3 when β_3 was positive and statistically significant.

Because H3 concerned whether the association between one environmental capability and CA changed with the level of the other capability, a simple-slope analysis was conducted for the statistically significant interaction. Conditional GI $\rightarrow$ CA slopes were examined at low (-1 SD), mean, and high (+1 SD) levels of EMA. In addition, common method variance was examined as a diagnostic consideration because all focal variables were collected from the same respondents in a cross-sectional questionnaire. Harman's single-factor diagnostic and full-collinearity VIF values were used as supplementary indicators, and the evidence was interpreted cautiously rather than as proof that common method bias was absent. These diagnostics do not identify or remove common method variance, and no temporal separation of measurements was implemented.

As supplementary sensitivity analyses, observed item-mean composite scores were examined using ordinary least squares (OLS) with HC3 heteroskedasticity-robust standard errors. These analyses included respondent-reported company size, age, ownership, and activity categories as controls and were kept separate from the primary hypothesis tests. They do not constitute latent-variable SEM estimates.

4. Results

4.1. Data Screening and Final Analytical Sample

A total of 304 questionnaires were received from respondents in companies operating in the Basic Materials sector of the Saudi Exchange. Before estimating the measurement and regression models, the responses were screened for completeness, respondent suitability, and patterned responding. No general missing-data problem was identified in the raw questionnaire fields. Responses were excluded when the respondent reported low or very low knowledge of environmental practices and green innovation, when the same response category was selected across all 19 substantive measurement items (complete straight-lining), or when a response fell outside the specified five-point Likert scale. Because some exclusion criteria overlapped, exclusions were counted at the respondent level rather than summed mechanically across criteria.

Table 2. Data Screening Criteria and Final Analytical Sample

Screening criterion	Cases
Initial questionnaires received	304
Low/very low key-informant knowledge	36
Complete straight-lining across 19 items	9
Invalid/non-Likert response	2
Less: Overlapping exclusion (counted twice)	−1
Total unique cases excluded	46
Final analytical sample	258

After screening, 258 valid responses were retained, representing 84.9% of the questionnaires initially received. The retained sample was used in the subsequent measurement-scale and regression analyses. The screening procedure is consistent with the study's key-informant design and with the stated requirement to remove patterned responses or cases that provide evidence that the respondent does not satisfy the knowledge criterion.

4.2. Respondent and Company Profile

The profile of the final analytical sample $(N = 258)$ indicates that respondents were drawn from relevant managerial and functional roles across the four activity groups covered by the study. Finance and accounting personnel constituted the largest group (48.4%), followed by production and operations personnel (24.8%), senior or general management (23.3%), and sustainability or environmental personnel (3.5%). The sample was also professionally experienced: 53.9% of respondents reported 10 to less than 15 years of experience and 16.7% reported 15 years or more. Following the screening procedure, all retained respondents reported at least a moderate level of knowledge of the environmental and green-innovation practices examined in the questionnaire, with 46.5% reporting high knowledge and 20.5% very high knowledge.

Regarding the organizational characteristics reported by respondents, the sample covered the four activity groups included in the survey: petrochemicals/chemicals (32.9%), packaging/basic-material products (27.1%), cement (21.7%), and mining/metals (18.2%). Most respondents were associated with medium-to-large employers: 45.0% reported companies with 1,000–4,999 employees and 37.2% reported companies with 250–999 employees. In terms of organizational age, 44.6% reported companies operating for 20 to less than 30 years, while 31.0% reported companies operating for 10 to less than 20 years. The reported ownership profile comprised Saudi private ownership (43.4%), Saudi government ownership (37.6%), and foreign or joint-venture ownership (19.0%). Finally, 96.9% of retained respondents indicated that their companies currently used environmental management accounting practices or environmental information in planning, control, or decision-making. Table 3 summarizes the respondent and organizational characteristics of the final analytical sample.

Table 3. Respondent and Organizational Characteristics of the Final Analytical Sample $(N = 258)$

Characteristic	Category	N	%
Job position	Finance/Accounting	125	48.4
	Production/Operations	64	24.8
	Senior/General Management	60	23.3
	Sustainability/Environment	9	3.5
Professional experience	$<$ 5 years	10	3.9
	5–<10 years	66	25.6
	10–<15 years	139	53.9
	$\geq$15 years	43	16.7

Characteristic	Category	N	%
Knowledge level	Moderate	85	32.9
	High	120	46.5
	Very high	53	20.5
Company activity	Petrochemicals/Chemicals	85	32.9
	Mining/Metals	47	18.2
	Cement	56	21.7
	Packaging/Basic-material products	70	27.1
Company size	<250 employees	30	11.6
	250–999 employees	96	37.2
	1,000–4,999 employees	116	45.0
	≥5,000 employees	16	6.2
Company age	<10 years	38	14.7
	10–<20 years	80	31.0
	20–<30 years	115	44.6
	≥30 years	25	9.7
Ownership	Saudi private	112	43.4
	Saudi government	97	37.6
	Foreign/joint venture	49	19.0
Current EMA use	Yes	250	96.9
	Unsure	6	2.3
	No	2	0.8

4.3. Measurement-Scale Assessment

The measurement scales were assessed before estimating the regression relationships. The evaluation covered indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Green innovation was represented by Green Product Innovation (GPI) and Green Process Innovation (GPrI), EMA by its physical (PEMA) and monetary (MEMA) dimensions, and competitive advantage (CA) by six indicators. The assessment used standardized indicator loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and the heterotrait-monotrait ratio (HTMT).

4.3.1. Indicator Reliability All 19 measurement indicators showed satisfactory indicator reliability. The standardized loadings ranged from 0.832 to 0.911, and therefore all indicators exceeded the preferred 0.70 benchmark specified in the methodology. The lowest loading was observed for GPI3 (0.832), while the highest loading was observed for GPrI3 (0.911). Since none of the indicators showed weak loadings, all items were retained.

Table 4. Standardized Indicator Loadings and Indicator Reliability Assessment

Construct	Indicator	Standardized loading	Decision
GPI	GPI1	0.853	Retain
GPI	GPI2	0.894	Retain
GPI	GPI3	0.832	Retain
GPrI	GPrI1	0.858	Retain
GPrI	GPrI2	0.881	Retain
GPrI	GPrI3	0.911	Retain
GPrI	GPrI4	0.893	Retain
PEMA	PEMA1	0.867	Retain

Construct	Indicator	Standardized loading	Decision
PEMA	PEMA2	0.881	Retain
PEMA	PEMA3	0.860	Retain
MEMA	MEMA1	0.887	Retain
MEMA	MEMA2	0.908	Retain
MEMA	MEMA3	0.897	Retain
CA	CA1	0.868	Retain
CA	CA2	0.858	Retain
CA	CA3	0.883	Retain
CA	CA4	0.880	Retain
CA	CA5	0.903	Retain
CA	CA6	0.877	Retain

4.3.2. Internal Consistency Reliability and Convergent Validity Internal consistency was evaluated using Cronbach's alpha and composite reliability. Cronbach's alpha ranged from 0.820 for GPI to 0.940 for CA, while composite reliability ranged from 0.895 to 0.953. Thus, all constructs exceeded the 0.70 criterion and demonstrated satisfactory internal consistency. Convergent validity was assessed through AVE. The AVE values ranged from 0.740 to 0.805, well above the 0.50 threshold, indicating that each construct explained more than half of the variance in its indicators. Taken together, these results support the reliability and convergent validity of the measurement model.

Table 5. Internal Consistency Reliability and Convergent Validity Assessment

Construct	Cronbach's α	Composite reliability (CR)	AVE	Assessment
GPI	0.820	0.895	0.740	Satisfactory
GPrI	0.908	0.936	0.785	Satisfactory
PEMA	0.838	0.903	0.756	Satisfactory
MEMA	0.879	0.925	0.805	Satisfactory
CA	0.940	0.953	0.771	Satisfactory

4.3.3. Discriminant Validity Discriminant validity was examined using HTMT. All pairwise HTMT ratios were below 0.90. Values ranged from 0.747 to 0.875. The largest value was between GPI and GPrI (0.875), which is theoretically plausible because these constructs represent the two first-order dimensions of green innovation. The HTMT value between PEMA and MEMA was 0.868, also remaining below the 0.90 criterion. Accordingly, the first-order constructs exhibited acceptable empirical distinctiveness for the subsequent structural analysis.

Table 6. Discriminant Validity Assessment Using the Heterotrait–Monotrait Ratio (HTMT)

Construct	GPI	GPrI	PEMA	MEMA	CA
GPI	—				
GPrI	0.875	—			
PEMA	0.753	0.871	—		
MEMA	0.747	0.794	0.868	—	
CA	0.747	0.826	0.837	0.831	—

Note. HTMT values below 0.90 indicate acceptable discriminant validity.

4.4. Regression Model Assessment

Following assessment of the measurement scales, the multiple regression model was examined to test the associations of GI and EMA, as well as the GI $\times$ EMA interaction, with competitive advantage. Prior to interpreting

the standardized coefficients, predictor collinearity was assessed using VIF. The VIF values were 2.789 for GI, 2.588 for EMA, and 1.384 for the interaction term. These values do not indicate severe multicollinearity and therefore support interpretation of the estimated regression coefficients.

Table 7. Multicollinearity Assessment Using Variance Inflation Factors (VIFs)

Predictor	VIF
GI	2.789
EMA	2.588
GI × EMA	1.384

Note. VIF = Variance Inflation Factor. The reported VIF values indicate no severe multicollinearity among the predictors.

The model showed substantial explanatory power for competitive advantage. The coefficient of determination was $R^2 = 0.697$, with an adjusted R^2 of 0.693. Thus, GI, EMA, and their interaction jointly explained approximately 69.7% of the variance in competitive advantage in the analyzed sample. This result indicates that the model accounts for a considerable proportion of variation in the focal strategic outcome, although the cross-sectional design does not by itself establish causal effects.

4.5. Hypothesis Testing

The regression coefficients were evaluated using standardized coefficients and bootstrap inference. H1 proposed a positive association between green innovation and competitive advantage. The GI $\rightarrow$ CA coefficient was positive and statistically significant ($\beta = 0.288,\ t = 4.901,\ p < 0.001;\ 95\%\ CI[0.150, 0.429]$). Its effect size was $f^2 = 0.095$. Accordingly, H1 was supported.

Table 8. Hypothesis Testing Results for the Relationship Between Green Innovation and Competitive Advantage (H1)

Statistic	Result
Relationship	GI $\rightarrow$ CA
Standardized coefficient (β)	0.288
t-value	4.901
p-value	$<$ .001
95% CI	[0.150, 0.429]
Effect size (f^2)	0.095
R	0.835
R^2	0.697
Adjusted R^2	0.693
Decision	Supported

Note. R, R^2, and adjusted R^2 refer to the overall regression model in which GI, EMA, and GI × EMA jointly predict competitive advantage.

H2 proposed a positive association between environmental management accounting and competitive advantage. The EMA $\rightarrow$ CA coefficient was also positive and statistically significant ($\beta = 0.518,\ t = 9.305,\ p < 0.001;\ 95\%\ CI[0.383, 0.647]$). The corresponding effect size was $f^2 = 0.341$. Therefore, H2 was supported. In the estimated model, the standardized coefficient for EMA was larger than that for GI; however, these coefficients should be interpreted as model-specific associations rather than causal rankings.

Table 9. Hypothesis Testing Results for the Relationship Between Environmental Management Accounting and Competitive Advantage (H2)

Statistic	Result
Relationship	EMA $\rightarrow$ CA
Standardized coefficient (β)	0.518
t-value	9.305
p-value	$< .001$
95% CI	[0.383, 0.647]
Effect size (f^2)	0.341
R	0.835
R^2	0.697
Adjusted R^2	0.693
Decision	Supported

Note. R, R^2, and adjusted R^2 refer to the overall regression model in which GI, EMA, and GI $\times$ EMA jointly predict competitive advantage.

H3 proposed that the GI $\times$ EMA interaction would be positively and significantly associated with competitive advantage. The interaction coefficient was statistically significant but negative (β =-0.078, t =-2.604, $p = 0.010$; $95\%\ CI[-0.144, -0.025]$), with a relatively small effect size ($f^2 = 0.027$). Because the estimated sign is opposite to the positive direction stated in H3, the hypothesis was not supported in its hypothesized direction. Statistical significance of the interaction alone does not support H3 because the hypothesis explicitly predicted positive complementarity.

Table 10. Hypothesis Testing Results for the Interaction Effect of Green Innovation and Environmental Management Accounting on Competitive Advantage (H3)

Statistic	Result
Relationship	GI $\times$ EMA $\rightarrow$ CA
Standardized coefficient (β)	-0.078
t-value	-2.604
p-value	.010
95% CI	[-0.144, -0.025]
Effect size (f^2)	0.027
R	0.835
R^2	0.697
Adjusted R^2	0.693
Decision	Not supported in hypothesized direction

Note:

- R, R^2, and adjusted R^2 refer to the overall regression model in which GI, EMA, and GI $\times$ EMA jointly predict competitive advantage.

- Although the interaction effect is statistically significant, H3 is not supported because the estimated coefficient is negative, contrary to the hypothesized positive direction.

Table 11. Summary of Hypothesis Testing Results

Hypothesis	Relationship	β	t-value	p-value	95% CI	f^2	Decision
H1	GI $\rightarrow$ CA	0.288	4.901	$< .001$	[0.150, 0.429]	0.095	Supported
H2	EMA $\rightarrow$ CA	0.518	9.305	$< .001$	[0.383, 0.647]	0.341	Supported

Hypothesis	Relationship	β	t-value	p-value	95% CI	f^2	Decision
H3	GI × EMA → CA	−0.078	−2.604	.010	[−0.144, −0.025]	0.027	Not supported in hypothesized direction

Note. β = standardized coefficient; CI = confidence interval; f^2 = effect size. H3 was not supported in the hypothesized direction because the GI × EMA interaction was statistically significant but negative, contrary to the predicted positive relationship.

4.6. Interaction and Simple-Slope Analysis

Because the interaction coefficient was negative and significant, a simple-slope analysis was conducted to clarify its substantive meaning. The association between GI and competitive advantage remained positive and statistically significant at low (−1 SD), mean, and high (+1 SD) levels of EMA. At low EMA, the conditional slope of GI was $0.366 (t = 6.512, p < 0.001)$. At the mean level of EMA, the slope was $0.288 (t = 4.901, p < 0.001)$. At high EMA, the slope declined to 0.211 but remained statistically significant $(t = 2.832, p = 0.005)$.

Table 12. Simple-Slope Analysis of the GI–CA Relationship at Different Levels of EMA

Level of EMA	Conditional GI → CA slope	t-value	p-value
Low EMA (−1 SD)	0.366	6.512	< .001
Mean EMA	0.288	4.901	< .001
High EMA (+1 SD)	0.211	2.832	.005

Note. Low and high EMA represent one standard deviation below (−1 SD) and above (+1 SD) the mean, respectively. The positive association between GI and CA remains statistically significant across all three EMA levels but weakens as EMA increases.

The pattern therefore does not indicate that green innovation becomes detrimental when EMA is high. Instead, the positive association between GI and competitive advantage becomes progressively weaker as EMA increases. In other words, the interaction is consistent with a diminishing incremental association rather than the strengthening or synergistic pattern predicted by H3. This result is particularly relevant to the study's central integration argument and is examined further in the Discussion section.

4.7. Additional Diagnostic Analysis: Common Method Variance

Because the focal constructs were obtained from the same respondents through a cross-sectional questionnaire, common method variance (CMV) was examined as an additional diagnostic consideration. Harman's single-factor diagnostic indicated that the first factor accounted for 60.69% of the total variance. Since this percentage exceeds the commonly used 50% reference point, common method variance cannot be ruled out based on this diagnostic.

A supplementary full-collinearity assessment produced VIF values of 2.931 for GI, 3.484 for EMA, and 3.212 for CA. GI and CA were below the conservative 3.3 reference value, whereas EMA was slightly above it. Consequently, the evidence does not justify claiming that common method bias is absent. Rather, potential CMV should be acknowledged when interpreting the regression relationships. This caution is also consistent with the cross-sectional nature of the research design; therefore, the findings are interpreted as statistically significant relationships within the estimated model rather than definitive causal effects. The elevated first-factor share and the EMA VIF warrant particular caution when interpreting the interaction estimate.

Table 13. Full-Collinearity VIF Assessment for Common Method Variance

Construct	Full-collinearity VIF
GI	2.931
EMA	3.484
CA	3.212

Note. Full-collinearity VIF values were examined as a supplementary diagnostic for potential common method variance (CMV). The results should be interpreted with caution and not as definitive evidence of common method bias.

4.8. Supplementary Robustness and Sensitivity Analyses

To assess the sensitivity of the interaction result, supplementary OLS regressions were estimated using observed composite scores and HC3 robust standard errors. The unadjusted interaction remained negative and statistically significant $(B = -0.132, p = 0.010)$. After controlling for respondent-reported company characteristics, its coefficient remained negative but was not significant at the 5% level $(B = -0.107, p = 0.066)$. The results of selected additional specifications are summarized in Table 14.

Table 14. Supplementary Robustness Checks for the GI × EMA Interaction

Specification	Interaction B	HC3 p-value	R^2
Unadjusted composite OLS	−0.132	.010	.698
With company controls	−0.107	.066	.722
Winsorized (1st–99th pct.) with controls	−0.146	.022	.723
Rank-based model with controls	−0.265	.035	.684
Green product innovation × EMA, controls	−0.130	.022	.705
Green process innovation × EMA, controls	−0.101	.078	.722
GI × monetary EMA, controls	−0.117	.037	.708
GI × physical EMA, controls	−0.078	.323	.679

Note. B denotes an unstandardized interaction coefficient; coefficients are not directly comparable with the standardized β reported in the primary model. All models use N = 258 respondent-level observations and HC3 robust inference. Controls comprise company size, age, ownership, and activity categories. Dimension-level tests are exploratory and do not establish distinct causal mechanisms. Company identifiers were unavailable, so within-company clustering could not be assessed.

Overall, the negative interaction is directionally consistent across several specifications, but its statistical significance depends on model choice. Consequently, the interaction should be interpreted cautiously rather than as conclusive evidence of capability substitution.

4.9. Summary of Empirical Findings

Overall, the empirical analysis supports the positive associations proposed in H1 and H2. Both green innovation and environmental management accounting were positively and significantly associated with competitive advantage, and the regression model explained 69.7% of the variance in CA. The measurement-scale results also showed

satisfactory indicator reliability, internal consistency, convergent validity, and discriminant validity for the first-order dimensions. In contrast, the GI $\times$ EMA interaction was significant but negative. The simple-slope results confirmed that GI retained a positive association with competitive advantage at all examined levels of EMA, but that this association weakened as EMA increased. Consequently, the expected positive interaction specified in H3 was not supported. These findings provide the basis for the theoretical and empirical interpretation developed in the following Discussion section.

5. Discussion

This study examined the individual and interactive relationships between green innovation (GI) and environmental management accounting (EMA) and competitive advantage (CA) among Saudi-listed Basic Materials companies. The findings support the direct strategic relevance of both environmental capabilities, while revealing a more nuanced pattern regarding their joint effect. GI and EMA were positively and significantly associated with competitive advantage, supporting H1 and H2. However, the GI $\times$ EMA interaction was statistically significant but negative, and H3 was therefore not supported in the hypothesized positive direction.

The positive relationship between GI and competitive advantage ($\beta = 0.288, p < 0.001$) suggests that firms with stronger green product and process innovation tend to achieve better competitive positioning. Green innovation can contribute to competitiveness by improving resource efficiency, reducing environmental impacts, supporting product differentiation, and strengthening organizational responsiveness to environmental pressures. This result is consistent with Gelmez et al. (2024), who report a positive effect of green innovation on competitive advantage, as well as Somjai et al. (2020) and Chaudhry et al. (2020), who document favorable performance consequences of environmentally oriented innovation. From the Natural Resource-Based View perspective, the finding supports the view that environmental capabilities can become strategically valuable when they improve resource productivity and differentiation. This relationship is particularly relevant to Saudi Basic Materials companies, whose operations are characterized by intensive use of materials, energy, and other natural resources.

EMA also exhibited a positive and significant relationship with competitive advantage ($\beta = 0.518, p < 0.001$), supporting H2. This finding indicates that the use of physical and monetary environmental information can strengthen competitive positioning by improving the visibility of environmental costs and resource flows and supporting planning, resource allocation, investment appraisal, and operational control. The result is consistent with Salim et al. (2023), Vo and Nguyen (2024), Jiao et al. (2023), and Asiaei et al. (2026), who similarly associate EMA with competitive or sustainability-related outcomes. From a resource-orchestration perspective, EMA can be regarded as an information-and-control capability that helps managers identify inefficiencies and direct organizational resources toward environmentally and strategically valuable activities.

The interaction result provides the study's most distinctive finding. Contrary to H3, the GI $\times$ EMA interaction was significant but negative ($\beta = -0.078, p = 0.010$). This result does not imply that either GI or EMA adversely affects competitive advantage, since both direct relationships are positive. Rather, it indicates that the incremental positive association between one capability and competitive advantage weakens as the other increases. The simple-slope analysis supports this interpretation: the positive association between GI and CA declined from $\beta = 0.366$ at low EMA to $\beta = 0.288$ at the mean level and $\beta = 0.211$ at high EMA, while remaining statistically significant at all three levels.

This pattern is more consistent with diminishing incremental returns or capability overlap than with the originally hypothesized reinforcing synergy. Firms with relatively low levels of EMA may gain substantial additional benefits from increasing GI, whereas firms with highly developed EMA practices may already capture some efficiency and decision-making benefits that overlap with those from additional green innovation. Simultaneously maintaining sophisticated EMA systems and intensive green innovation may also entail coordination, information-processing, financial, and managerial costs that partially offset expected complementarities. These explanations remain theoretically informed interpretations rather than mechanisms directly tested in this study. Alternative explanations include organizational implementation constraints and timing differences between accounting-system adoption and the realization of innovation benefits; the present data cannot distinguish among these mechanisms.

The supplementary controlled specification attenuates the interaction to $p = 0.066$, indicating that this interpretation is sensitive to covariate adjustment and should not be viewed as a robustly established organizational mechanism.

The finding adds nuance to previous evidence on environmental capability complementarity. Acar et al. (2025) and Asiaei et al. (2026) provide evidence of reinforcing relationships under particular organizational configurations, whereas Saribu et al. (2024) and Sinuraya and Sudibyo (2026) report less supportive evidence regarding complementary or indirect effects. The present results, therefore, suggest that the competitive consequences of combining environmental accounting and innovation capabilities may depend on how those capabilities are configured and deployed rather than simply on their simultaneous presence. This interpretation is consistent with resource-orchestration logic, which emphasizes that strategic value depends on how resources and capabilities are structured, bundled, and leveraged.

Overall, GI, EMA, and their interaction explained a substantial proportion of the variance in competitive advantage ($R^2 = 0.697$). Nevertheless, the interaction effect was relatively small ($f^2 = 0.027$), and its practical importance should therefore not be overstated. The findings indicate that GI and EMA are individually valuable environmental capabilities, but higher levels of both do not automatically generate additional synergistic competitive benefits. Instead, the results highlight the importance of effective alignment and orchestration of environmental information and innovation capabilities. Given the cross-sectional, key-informant survey design, however, the relationships should be interpreted as associations rather than definitive causal effects, and the potential influence of common method variance should also be recognized.

6. Theoretical and Practical Implications

The study adds to the literature by showing positive associations between green innovation (GI) and environmental management accounting (EMA) and competitive advantage, alongside an interaction pattern that is less straightforward than the anticipated positive synergy. The negative interaction effect suggests that the simultaneous presence of valuable environmental capabilities does not necessarily generate additional competitive benefits, thereby extending the NRBV and resource-orchestration perspectives by emphasizing the importance of effective capability configuration and coordination.

From a practical perspective, managers in Saudi Basic Materials companies should view GI and EMA as interconnected strategic capabilities whose competitive benefits depend on careful alignment and coordination. EMA information can be used to identify environmental inefficiencies, prioritize green investments, and evaluate innovation outcomes. Therefore, firms should focus not only on increasing GI and EMA independently but also on effectively integrating environmental information into innovation and strategic decision-making.

7. Limitations and Future Research

Several limitations should be considered when interpreting the findings. First, the cross-sectional design limits causal interpretation of the relationships among GI, EMA, and competitive advantage. Second, the use of self-reported questionnaire data from key informants may introduce perceptual and common method bias, which cannot be completely ruled out based on the diagnostic results. Future studies could employ longitudinal and multi-source designs and incorporate objective financial, environmental, and innovation indicators. Competitive advantage was measured perceptually rather than using archival performance indicators, and unobserved firm characteristics may influence the estimated associations.

Third, multiple respondents could represent the same listed company, but company identifiers were not collected to preserve respondent and organizational confidentiality. Consequently, within-company clustering could not be explicitly modeled. Future studies should retain anonymized company identifiers to enable cluster-robust or multilevel analyses.

Fourth, the study focuses exclusively on Saudi listed Basic Materials companies, which may limit the generalizability of the findings to other industries and institutional settings. Future research could replicate the

model across different sectors and countries. Further research is needed to investigate the unexpected negative GI $\times$ EMA interaction and to examine potential explanations, such as capability overlap, coordination costs, organizational maturity, and other organizational or contextual moderators.

8. Conclusion

This research investigated the associations between green innovation, environmental management accounting, and their interaction with competitive advantage in Saudi-listed Basic Materials companies. Drawing on the Natural Resource-Based View and resource-orchestration logic, the study proposed that GI and EMA represent strategically relevant environmental capabilities and tested whether their joint configuration was associated with competitive advantage beyond their separate relationships.

The direct relationships received clear empirical support. Green innovation was positively and significantly associated with competitive advantage, supporting H1. Environmental management accounting was also positively and significantly associated with competitive advantage, supporting H2. Together with the interaction term, the regression model explained 69.7% of the variance in competitive advantage, indicating substantial explanatory power within the analyzed sample.

The evidence for the integration effect is more qualified. Contrary to H3, the GI $\times$ EMA interaction was statistically significant but negative ($\beta = -0.078, p = 0.010$), and therefore the hypothesized positive synergy was not supported. Simple-slope analysis further showed that the association between GI and competitive advantage remained positive and statistically significant at low, mean, and high levels of EMA, but became progressively weaker as EMA increased.

The results therefore indicate that GI and EMA can each be valuable, while higher levels of both do not necessarily translate into additional synergistic competitive gains. The findings, therefore, extend the literature beyond a simple complementarity assumption and highlight the importance of how environmental capabilities are coordinated and orchestrated within organizations.

For Saudi Basic Materials companies, the central implication is that environmental accounting and green innovation should be treated as interconnected strategic capabilities. Firms may benefit from using EMA data to identify environmental inefficiencies, prioritize green innovation investments, evaluate their outcomes, and integrate environmental considerations into operational and strategic decision-making. However, the effectiveness of this approach appears to depend on how GI and EMA are aligned and deployed, rather than merely on achieving high levels of both practices independently.

Overall, this research contributes to the emerging intersection of management accounting, green innovation, and strategic management by providing evidence from an environmentally intensive Saudi context and directly testing the incremental interaction between GI and EMA. The unexpected interaction result further demonstrates that environmental capability complementarity is not necessarily automatic and provides a foundation for future research into the organizational conditions under which environmental information and green innovation can be transformed into sustained competitive advantage.

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A. Survey Questionnaire

The questionnaire contained eight background/screening questions and 19 construct-measurement statements. The substantive statements used a five-point Likert scale (1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree).

Section A. Respondent and Organizational Profile

A1. Current position

Response options: Senior/general management; Finance/accounting employee; Production operations employee; Sustainability/environment employee

A2. Years of professional experience

Response options: Less than 5 years; 5 to less than 10 years; 10 to less than 15 years; 15 years or more

A3. How would you rate your knowledge of environmental practices and green innovation activities in the company?

Response options: Very low; Low; Moderate; High; Very high

A4. Company's main activity within the Basic Materials sector

Response options: Petrochemicals/chemicals; Cement; Mining/metals; Packaging and basic-material products

A5. Company size (number of employees)

Response options: Fewer than 250; 250–999; 1,000–4,999; 5,000 or more

A6. Company age

Response options: Less than 10 years; 10 to less than 20 years; 20 to less than 30 years; 30 years or more

A7. Ownership type

Response options: Private Saudi ownership; Saudi government ownership; Foreign ownership or joint venture

A8. To your knowledge, does the company currently use environmental management accounting practices or physical and/or monetary environmental information in planning, control, and decision-making?

Response options: Yes; No; Not sure

Section B. Construct Measurement Items

Please indicate your agreement with each statement based on your knowledge of the company.

Green Product Innovation (GPI)

GPI1. Our company uses materials in its products that help reduce emissions and/or improve energy-use efficiency.

GPI2. Our company works to reduce or replace polluting, hazardous, or toxic materials used in its products.

GPI3. Our company designs products and/or packaging materials to facilitate reuse, recycling, or recovery.

Green Process Innovation (GPrI)

GPrI1. Our company modifies production processes to reduce hazardous waste and environmental pollution.

GPrI2. Our company recycles, reuses, or recovers waste and emissions generated by production processes.

GPrI3. Our company improves production processes to reduce water and energy consumption.

GPrI4. Our company improves production processes to reduce raw-material consumption.

Physical Environmental Management Accounting (PEMA)

PEMA1. Our company's accounting/management information system records information on physical environmental inputs and outputs, such as materials, energy, water, waste, and emissions.

PEMA2. Our company analyzes environmental impacts associated with products and production processes using physical environmental information.

PEMA3. Our company uses environmental performance targets or indicators to monitor and manage physical resource flows and environmental outputs.

Monetary Environmental Management Accounting (MEMA)

MEMA1. Our company's accounting system identifies and classifies environmental costs and environmental liabilities.

MEMA2. Our company maintains records or accounts specifically for environment-related costs and expenditures.

MEMA3. Our company allocates environmental costs to relevant products, processes, activities, or responsibility centers.

Competitive Advantage (CA)

CA1. Compared with its main competitors, our company achieves better cost efficiency.

CA2. Compared with its main competitors, our company's products and/or services are more differentiated in the market.

CA3. Compared with its main competitors, our company has a greater ability to develop and implement innovative ideas and solutions.

CA4. Compared with its main competitors, our company is better able to respond to market requirements and changes in the business environment.

CA5. Compared with its main competitors, our company has a better market reputation.

CA6. Compared with its main competitors, our company has a stronger long-term competitive position.