



Research article

The impact of environmental management accounting practices on corporate sustainability dimensions: evidence from Saudi petrochemical companies

BILEL JARRAYA

Department of Accounting, College of Business and Economics, Qassim University, Saudi Arabia

* **Correspondence:** Email: b.jarraya@qu.edu.sa.

Abstract: This study examines the relationships among Environmental Management Accounting (EMA), Sustainability Reporting Quality (SRQ), and Corporate Sustainability Performance (CSP) in Saudi petrochemical companies. These companies are facing increasing pressures related to sustainability and ESG. We studied data from 13 listed companies from 2017 to 2024 and explored how eco-efficiency and emission efficiency affect environmental and economic sustainability performance, directly and through the quality of sustainability reporting. A quantitative research design was used, applying Partial Least Squares Structural Equation Modeling (PLS-SEM). Eco-efficiency was measured using asset-based energy efficiency. Emission efficiency assesses the ability to generate economic value in relation to greenhouse gas emissions. SRQ was measured using a multidimensional disclosure index that meets Global Reporting Initiative (GRI) standards. The findings showed that EMA practices have a greater impact on sustainability performance than sustainability disclosure mechanisms alone. Emission efficiency positively influences environmental and economic sustainability outcomes. In contrast, eco-efficiency shows negative short-term effects, indicating costs associated with sustainability transitions and pressures for organizational adjustments. The results also suggest that SRQ acts as a selective mediator, benefiting environmental sustainability outcomes more than economic performance. This study adds to the literature on sustainability accounting and environmental management. It highlights the need to integrate EMA practices with sustainability reporting to advance industrial sustainability transformation and ensure environmental accountability, in line with Saudi Vision 2030.

Keywords: environmental management accounting; sustainability reporting quality; corporate sustainability performance; eco-efficiency; emission efficiency

1. Introduction

In the past, industrial development and economic progress frequently depended on heavy energy use, higher greenhouse gas emissions, and greater pressure on natural resources. Over the last twenty years, rising environmental issues and international sustainability efforts have changed how companies define success. Today, companies are evaluated not only by their profits but also by how responsibly they operate, how much they lower their environmental impact, and how they support enduring sustainability. International agreements like the Paris Climate Agreement, global decarbonization plans, and the growth of ESG-focused investments have pushed industrial companies to make sustainability central to their operations and strategies.

These problems are especially clear in energy-intensive industries like petrochemicals, where operations consume considerable energy and produce high carbon emissions. The petrochemical sector remains vital to industrial and economic growth, especially in oil-dependent countries, but it now faces greater scrutiny of its environmental effects and sustainability efforts. Today, these companies must do more than stay competitive; they need to improve environmental efficiency, cut emissions, and exhibit accountability for sustainability. Studies indicate that companies need to balance economic goals with environmental management by adopting cleaner production methods, making more efficient use of resources, and being more transparent in their sustainability practices [1–3].

In this context, Environmental Management Accounting (EMA) has become a key tool for helping companies make sustainability-focused decisions. EMA combines environmental and financial information, allowing companies to spot environmental costs, use resources more efficiently, manage emissions, and improve their operations. Rather than viewing environmental issues as mere external constraints, EMA helps companies integrate environmental aspects directly into their management and investment decisions. Research shows that effective use of EMA can improve environmental performance, improve operations, and help companies compete on sustainability, especially in resource-intensive industries facing major environmental problems [4–7].

Furthermore, sustainability reporting has become an important way for companies to share information about their environmental and sustainability efforts with stakeholders. In recent years, this reporting has moved from being optional to becoming a tactical tool that builds transparency, accountability, and trust. Studies show that strong sustainability reporting improves a company's reputation and shows its pledge to sustainable development goals [8–10]. As a result, companies are now expected to act on sustainability and clearly report their efforts using well-known frameworks, including the Global Reporting Initiative (GRI).

The Global Reporting Initiative is now one of the most widely used frameworks for sustainability reporting, especially in industries with large environmental and social impacts. The updated GRI Universal Standards provide global guidance for measuring and reporting on environmental, economic, and governance issues [11]. Using the GRI Standards helps companies make their reports

more consistent and comparable, build confidence with stakeholders, and measure their sustainability performance against international benchmarks.

Saudi Arabia provides a relevant context for examining issues related to environmental management and corporate sustainability. Through its Vision 2030 initiative, the country has implemented significant reforms aimed at economic diversification, industrial modernization, environmental protection, and the transition to more sustainable growth patterns. The petrochemical industry plays a strategic role in this transformation due to its substantial contribution to the national economy and its centrality to the Kingdom's industrial development.

However, the sector is characterized by energy-intensive and resource-intensive operations that create significant environmental pressures. As a result, there are increasing expectations for companies to enhance resource efficiency, reduce emissions, and improve the transparency of their environmental reporting. Leading firms, such as SABIC, have launched initiatives to boost energy efficiency, cut emissions, and progressively incorporate sustainability considerations into their operations [12,13].

These developments position the Saudi petrochemical industry at the intersection of economic significance and environmental transformation, making it an important setting for assessing whether environmentally oriented accounting practices lead to measurable sustainability outcomes. The sector also presents a distinctive empirical setting due to its relatively concentrated industrial structure, where production is predominantly conducted by large, capital-intensive, and resource-intensive firms operating within the same national regulatory and sustainability framework.

This combination of industrial concentration, environmental intensity, and heightened sustainability expectations creates an appropriate environment for investigating the relationships among EMA, Sustainability Reporting Quality (SRQ), and Corporate Sustainability Performance (CSP). It allows these relationships to be examined within a strategically important industry where environmental management and sustainability disclosure are increasingly relevant to corporate decision-making and national sustainability objectives.

Although global interest in EMA and sustainability reporting is growing, there remains little research on these topics in Gulf countries, particularly in Saudi Arabia's petrochemical sector. Most researchers have examined environmental accounting, sustainability reporting, or sustainability performance separately, and few have explored how these areas interrelate within a single framework. Much of the research has focused on Asia and other emerging markets, leaving the Saudi industrial sector with less attention [14,15]. This gap matters because Saudi petrochemicals are important to the economy, and there is a strong policy push for a sustainable industry under Vision 2030.

Given this background, we consider how EMA practices, the quality of sustainability reporting, and CSP are linked in Saudi petrochemical companies. we use two major EMA efficiency measures. The first is eco-efficiency, the ratio of total assets to total energy use, which indicates how effectively a company uses resources while conserving energy. The second is emission efficiency, the ratio of total sales to total GHG emissions, which indicates how much economic value is created per unit of emissions. Using several measures of these indicators helps me examine different facets of environmental efficiency and avoid issues with overlapping or related ratios.

The study also includes SRQ to link environmental management practices to sustainability outcomes. SRQ covers how much information is shared, how transparent, complete, and credible the sustainability disclosures are, and whether they follow the GRI Standards. Rather than assuming that

sustainability reporting fully explains the link between EMA practices and CSP, we examine the direct and indirect effects of sustainability reporting on sustainability outcomes. This approach gives a fuller picture of how internal environmental accounting and external reporting work together to shape sustainability performance.

My goals of this study are as follows: First, we look at how eco-efficiency and emission efficiency directly affect sustainability performance in Saudi petrochemical companies. Second, we examine the link between EMA practices and the quality of sustainability reporting. Third, we examine the direct and indirect roles of reporting quality in shaping sustainability outcomes. Finally, we attempt to offer real-world evidence on the effectiveness of EMA practices as tools for managing sustainability in one of the Gulf region's most environmentally sensitive industries.

This study adds to research in several important ways. First, it brings together EMA practices, the quality of sustainability reporting, and CSP within a single framework. Second, it provides new data on Saudi Arabia's petrochemical sector, which is important to the economy but has been understudied in this area. Third, I use several sustainability performance measures aligned with the GRI Standards, permitting a detailed look at environmental and economic outcomes. Fourth, I use Partial Least Squares Structural Equation Modeling (PLS-SEM) to simultaneously analyze direct and indirect relationships among sustainability factors. Managers, policymakers, and regulators can decide whether investing in EMA and sustainability reporting yields better sustainability outcomes. The results may also support efforts to improve sustainability reporting standards and to include environmental accounting in company sustainability assessments, in line with Saudi Vision 2030.

The rest of the paper is organized as follows: In the next section, we review the main theories and previous research and present my hypotheses. Afterward, we explain the research methods and the measurement model. Then, we present and discuss the findings. The paper ends with practical outcomes and suggestions for future research.

2. Theoretical foundation and literature review

This research is grounded in three complementary theoretical perspectives: the Natural Resource-Based View (NRBV), Stakeholder Theory, and Legitimacy Theory. Collectively, these perspectives offer a thorough framework for examining how EMA practices and SRQ contribute to CSP.

The Natural Resource-Based View (NRBV), introduced by Hart et al. [16], builds on the traditional resource-based view by stressing the strategic significance of environmental capabilities in achieving sustainable competitive advantage. This perspective suggests that organizations that effectively manage environmental resources, improve energy efficiency, and cut emissions may improve environmental and economic performance. Within the scope of this research, eco-efficiency and emission efficiency are considered key environmental capabilities that may strengthen sustainability outcomes through improved resource utilization and environmental management.

Stakeholder Theory [17] asserts that organizations must address the expectations of diverse stakeholder groups, including investors, regulators, customers, and local communities. As sustainability concerns intensify, firms are expected to demonstrate responsible environmental behavior and transparent sustainability practices. EMA systems support this objective by generating reliable environmental information that supports decision-making and enhances accountability.

Legitimacy Theory delivers additional insight into the motivations for organizational disclosure of sustainability information. This perspective holds that firms seek to preserve social legitimacy by aligning their actions and disclosures with public norms. High-quality sustainability reporting serves as a mechanism for organizations to communicate their environmental commitment and reinforce partner trust.

The above three theoretical perspectives together explain distinct yet complementary mechanisms within the proposed research model. The Natural Resource-Based View (NRBV) provides the primary rationale for the direct relationship between EMA practices and CSP. Eco-efficiency and emission efficiency represent environmental management capabilities that allow firms to improve resource utilization, control environmental impacts, and achieve sustainability-related economic and environmental outcomes.

Stakeholder Theory builds on this logic by explaining that internally generated environmental information must respond to the expectations of various stakeholders, including investors, regulators, and customers. From this perspective, stronger environmental management capabilities can lead to more transparent and comprehensive sustainability reporting. In turn, higher-quality disclosures may enhance organizational accountability and improve sustainability performance.

Legitimacy Theory further explains the disclosure mechanism, suggesting that firms use SRQ to demonstrate alignment between their environmental actions and broader societal expectations. These mechanisms are particularly relevant to Saudi petrochemical companies, which operate in an environmentally sensitive industry and face increasing demands for environmental accountability, industrial sustainability, and transparent reporting, particularly in the context of the sustainability transformation associated with Saudi Vision 2030.

Therefore, the integrated application of NRBV, Stakeholder Theory, and Legitimacy Theory provides a robust theoretical foundation for examining both the direct effects of EMA on CSP and the complementary role of SRQ within the proposed model.

2.1. EMA and CSP

Corporate sustainability has become a strategic priority for industrial firms operating in increasingly competitive and environmentally sensitive markets. Beyond traditional financial objectives, firms are now expected to improve resource efficiency, reduce environmental impacts, and maintain long-term operational resilience. In this context, EMA has emerged as an important managerial mechanism that integrates environmental and financial information to support sustainability-oriented decision-making. EMA enables firms to identify environmental costs, optimize resource utilization, improve operational efficiency, and support environmentally responsible business practices. Recent sustainability literature increasingly emphasizes that environmentally oriented accounting systems are no longer limited to compliance purposes but are becoming strategic tools for enhancing sustainability performance and competitive advantage [5–7,18].

One of the most important dimensions of EMA is eco-efficiency, which reflects the firm's ability to generate value while minimizing resource consumption and environmental pressure. Eco-efficiency has become central to sustainability-oriented operational management because it links environmental performance directly with economic productivity. According to the World Business Council for

Sustainable Development (WBCSD), eco-efficiency contributes to sustainability by promoting cleaner production, efficient resource use, and reduced environmental intensity throughout operational processes [19]. Empirical evidence further suggests that firms adopting eco-efficiency practices tend to improve operational performance, reduce environmental costs, and strengthen sustainability competitiveness [1,2,4].

Similarly, emission efficiency has become increasingly important in sustainability research, particularly for carbon-intensive industries facing growing regulatory and stakeholder pressure. Emission efficiency reflects the firm's ability to generate economic output while controlling greenhouse gas emissions intensity. Studies suggest that firms with stronger carbon-efficiency practices often demonstrate better environmental responsiveness, stronger operational sustainability, and improved long-term economic performance [20,21]. In energy-intensive industries such as petrochemicals, improving emission efficiency is particularly critical because carbon management has become closely linked to investment attractiveness, sustainability legitimacy, and future competitiveness.

Nevertheless, empirical findings concerning the relationship between EMA practices and sustainability performance remain somewhat mixed. While many studies report positive associations between environmental accounting practices and sustainability outcomes, others argue that the effectiveness of EMA depends on managerial commitment, regulatory pressure, industry characteristics, and firms' sustainability maturity levels [22,23]. These inconsistencies appear particularly relevant in emerging economies, where sustainability-oriented accounting systems are evolving, and institutional sustainability pressures differ from those observed in developed countries.

Despite these mixed findings, the growing sustainability literature generally supports the view that environmentally oriented accounting practices contribute positively to corporate sustainability outcomes by improving operational efficiency, resource management, and environmental responsiveness. Based on this discussion, the following hypotheses are proposed:

H₁. Eco-Efficiency positively influences CSP.

H_{1a}. Eco-Efficiency positively influences Environmental CSP.

H_{1b}. Eco-Efficiency positively influences Economic CSP.

H₂. Emission Efficiency positively influences CSP.

H_{2a}. Emission Efficiency positively influences Environmental CSP.

H_{2b}. Emission Efficiency positively influences Economic CSP.

2.2. SRQ and CSP

Over recent years, sustainability reporting has evolved from a voluntary disclosure practice into a strategic governance and accountability mechanism. Stakeholders increasingly expect firms to disclose reliable and transparent information regarding environmental impacts, sustainability initiatives, and long-term sustainability commitments. Consequently, SRQ has become an important

indicator of corporate transparency, sustainability accountability, and legitimacy. High-quality sustainability reporting improves information credibility, reduces information asymmetry, and strengthens stakeholder confidence in corporate sustainability practices [8].

The Global Reporting Initiative (GRI) has emerged as one of the most widely adopted frameworks for sustainability disclosure worldwide. The GRI standards provide internationally recognized guidance for reporting environmental, economic, and governance-related information, thereby improving reporting comparability and disclosure consistency across firms and industries [11]. Firms adopting GRI-based disclosures are often perceived as more transparent and more committed to sustainability-oriented governance mechanisms.

Empirical studies suggest that SRQ may contribute positively to sustainability performance in several ways. First, transparent sustainability disclosures may increase stakeholder pressure on firms to improve environmental practices and sustainability outcomes. Second, higher reporting quality may encourage internal sustainability monitoring and improve managerial accountability regarding sustainability objectives [9,10]. Third, firms with stronger sustainability reporting systems often demonstrate better environmental governance structures and more effective sustainability-oriented strategic alignment [20].

However, empirical evidence regarding the effect of SRQ on sustainability performance remains inconclusive. Some researchers argue that sustainability reporting improves environmental and operational performance through enhanced transparency and stakeholder engagement, whereas others suggest that sustainability disclosures may sometimes function symbolically without necessarily generating substantial operational sustainability improvements [24,25]. These inconsistencies suggest that the effectiveness of sustainability reporting may vary depending on industry context, disclosure quality, and firms' sustainability integration capabilities.

Despite these debates, SRQ continues to play an increasingly important role in shaping corporate sustainability governance and accountability. Accordingly, the following hypotheses are proposed:

H₃. SRQ positively influences CSP.

H_{3a}. SRQ positively influences Environmental CSP.

H_{3b}. SRQ positively influences Economic CSP.

2.3. EMA and SRQ

EMA practices are closely associated with the production of sustainability-related information and environmental disclosure quality. EMA systems generate detailed environmental and operational data concerning energy use, resource efficiency, emissions management, and environmental costs. Such information forms an important foundation for sustainability reporting and environmental transparency. Firms implementing stronger EMA practices are therefore generally better positioned to produce comprehensive, credible, and transparent sustainability disclosures [5–7].

Sustainability accounting literature increasingly emphasizes that internal environmental accounting systems play a central role in improving external sustainability reporting practices. Environmental accounting mechanisms facilitate data collection, environmental performance

monitoring, and sustainability measurement, thereby enhancing the quality and reliability of sustainability disclosures [22]. Firms with stronger environmental accounting capabilities are often more capable of aligning sustainability reporting with internationally recognized frameworks such as GRI standards.

Empirical studies further indicate that sustainability-oriented operational practices may positively influence reporting transparency and disclosure comprehensiveness. Ahmad et al. [4] argued that environmentally responsible firms tend to disclose more extensive sustainability information to strengthen legitimacy and stakeholder confidence. Similarly, evidence suggests that firms demonstrating stronger environmental efficiency often provide more credible and higher-quality sustainability disclosures due to increased stakeholder scrutiny and regulatory expectations [1,2].

Nevertheless, the relationship between EMA practices and SRQ may vary across institutional and industrial settings. In some contexts, firms may implement sustainability-oriented operational practices without fully reflecting these efforts in external disclosures. In other cases, sustainability reporting may exceed actual sustainability performance, leading to concerns regarding symbolic disclosure practices or greenwashing behavior [25]. These mixed findings highlight the importance of further empirical investigation, particularly within environmentally sensitive industries operating in emerging economies.

Given the increasing importance of sustainability, transparency, and environmental accountability, we expect environmentally oriented accounting practices to positively contribute to SRQ. Therefore, the following hypotheses are proposed:

H4. Eco-efficiency positively influences SRQ.

H5. Emission efficiency positively influences SRQ.

2.4. The complementary role of SRQ

The growing sustainability literature increasingly recognizes that sustainability reporting may play a complementary role in linking internal sustainability practices with broader sustainability outcomes. From a legitimacy theory perspective, sustainability disclosures help firms communicate environmental commitment, strengthen stakeholder trust, and improve corporate reputation [26]. Similarly, stakeholder theory suggests that transparent sustainability communication enhances firms' responsiveness to external sustainability expectations and may indirectly encourage stronger sustainability-oriented practices [17].

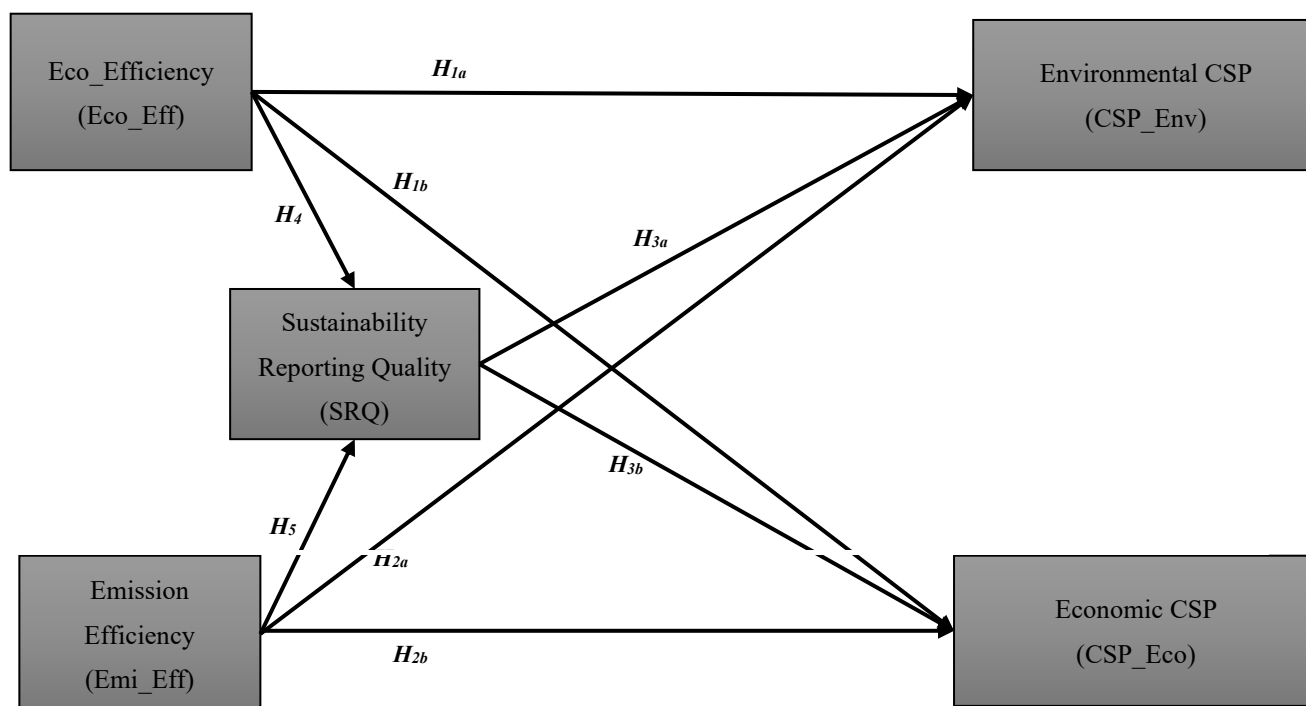
Empirical evidence indicates that sustainability reporting may reinforce the effectiveness of sustainability-oriented operational practices by improving transparency, accountability, and sustainability governance mechanisms [9,10]. In this context, firms implementing effective EMA practices may benefit not only from direct operational sustainability improvements but also from enhanced sustainability legitimacy through higher-quality disclosures.

However, findings regarding the indirect role of sustainability reporting remain fragmented and inconclusive. While some studies report that sustainability reporting strengthens the relationship between sustainability practices and sustainability performance, others argue that operational sustainability practices exert stronger direct effects than disclosure mechanisms alone [24,25]. This

suggests that sustainability reporting may function more as a complementary governance mechanism rather than a fully independent driver of sustainability outcomes.

Within environmentally sensitive sectors such as petrochemicals, sustainability reporting may therefore support sustainability performance by improving environmental transparency and reinforcing stakeholder accountability, while operational sustainability improvements continue to depend primarily on firms' internal environmental management capabilities. Based on this perspective, the present study proposes the following hypothesis:

H6. SRQ complements the relationship between EMA practices (Eco_Efficiency and Emission Efficiency) and CSP (Environmental and Economic).



2.5. Research gap and study contribution

Despite the growing body of literature examining EMA, sustainability reporting, and CSP, several important research gaps remain. First, researchers have frequently investigated these relationships separately rather than within an integrated analytical framework uniting environmental accounting practices, SRQ, and multidimensional sustainability performance indicators. Consequently, limited empirical evidence exists on how these factors interact to shape sustainability outcomes.

Second, empirical findings concerning the role of sustainability reporting in improving sustainability performance are inconclusive. While some studies report that high-quality sustainability disclosures add positively to sustainability outcomes through heightened transparency and stakeholder accountability, other studies suggest that sustainability reporting may function symbolically without necessarily creating substantial operational improvements. This variation indicates the need for further empirical investigation concerning the direct and complementary roles of SRQ within sustainability-oriented management systems.

Third, although environmental efficiency and carbon management have received increasing scholarly attention, relatively few studies have simultaneously examined eco-efficiency and emission efficiency inside a single integrated sustainability framework. Existing studies often focus either on active environmental performance or on sustainability disclosure practices independently, leaving the interaction between these dimensions underexplored.

Fourth, empirical evidence from Gulf countries remains limited, especially in Saudi Arabia's petrochemical industry, despite its crucial economic and environmental importance. Most prior sustainability accounting studies have concentrated on developed economies or Asian emerging markets, while relatively little attention has been devoted to ecologically sensitive industries operating within the Gulf region. This gap is especially relevant under Saudi Vision 2030, which emphasizes sustainability-oriented industrial transformation, environmental accountability, and improved corporate transparency.

Finally, limited research has adopted GRI-aligned multidimensional sustainability indicators and examined the relationships among EMA practices, SRQ, and CSP using cutting-edge analytical approaches such as Partial Least Squares Structural Equation Modeling (PLS-SEM). Therefore, we intend to remedy these gaps by developing an integrated framework that examines how eco-efficiency, emission efficiency, and SRQ jointly influence CSP among Saudi petrochemical firms.

To address these gaps, we develop and test an integrated framework that links EMA practices, SRQ, and CSP in Saudi petrochemical companies. Specifically, the study adds to the literature in four ways. First, it extends sustainability accounting research through integrating environmental management practices, SRQ, and multidimensional sustainability performance within a single model. Second, it offers empirical evidence from a strategically important, still underexplored industrial context. Third, it distinguishes eco-efficiency and emission efficiency, enabling a subtler understanding of environmental management capabilities. Fourth, it illustrates the selective mediating role of SRQ, showing that its contribution is stronger for green sustainability outcomes than for economic sustainability performance.

3. Data and methodology

3.1. Research design

I adopt a quantitative, explanatory research design to examine the relationships among EMA practices, SRQ, and CSP in Saudi petrochemical firms. The quantitative approach is considered appropriate because the study intends to empirically investigate the direct and complementary relationships among multiple sustainability-related constructs using measurable environmental, reporting, and financial indicators. In addition, the interpretative nature of the research enables a better understanding of how environmentally oriented accounting practices contribute to sustainability outcomes in environmentally sensitive industrial areas.

I concentrate on the Saudi petrochemical industry because of its strategic economic importance and major environmental impact. As one of the most energy-demanding and carbon-sensitive sectors, the petrochemical industry provides a suitable context for examining the effectiveness of EMA practices in improving sustainability performance. Furthermore, the sector has faced growing

sustainability pressures in recent years due to Saudi Vision 2030 initiatives that emphasize environmental accountability, industrial sustainability, energy efficiency, and corporate transparency.

To achieve my objectives of the study, secondary data are collected from publicly available corporate documents, including annual reports, sustainability reports, environmental disclosures, and GRI-based sustainability reports issued by Saudi petrochemical firms. We adopt a longitudinal perspective by analyzing sustainability-related indicators across reporting periods, thereby enabling a more thorough assessment of sustainability practices and performance over time.

The conceptual framework of the study merges two EMA efficiency indicators, namely eco-efficiency and emission efficiency, with SRQ and CSP dimensions. Eco-efficiency is operationalized as the ratio of total assets to total energy consumption, reflecting firms' ability to utilize resources efficiently while limiting energy use. Emission efficiency is measured as the ratio of total sales to total greenhouse-gas emissions, reflecting operational carbon productivity and firms' capacity to generate economic value with lower emissions intensity. SRQ is evaluated using GRI-based disclosure indicators measuring the extent, completeness, transparency, and credibility of sustainability reporting practices.

To empirically examine the proposed relationships, this study uses Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS software. PLS-SEM is considered appropriate for this study for several reasons. First, we consider complex direct and complementary relationships among latent constructs simultaneously. Second, the method is well-suited to sustainability-oriented exploratory models across operational, environmental, and reporting dimensions. Third, PLS-SEM performs effectively with relatively moderate sample sizes and does not require strict assumptions of normality compared with covariance-based structural equation modeling methods. Finally, the method enables the simultaneous assessment of the measurement and structural models, allowing an extensive analysis of reliability, validity, and predictive relationships among the study variables.

Accordingly, the adopted research design provides a suitable empirical framework for examining how EMA practices and the quality of sustainability reporting interact to shape CSP within Saudi petrochemical firms.

3.2. Sample and data collection

The empirical analysis focuses on Saudi petrochemical firms due to the sector's strategic economic importance and substantial environmental footprint, particularly in terms of energy consumption, greenhouse gas emissions, and resource utilization. This setting provides a relevant context for examining the relationships among environmental management practices, sustainability reporting, and CSP within the broader sustainability transformation associated with Saudi Vision 2030.

This study relies on longitudinal firm-level data collected from publicly available corporate disclosures issued by Saudi petrochemical companies listed on the Saudi Stock Exchange (Tadawul). Data were obtained from multiple official sources, including annual reports, sustainability reports, ESG disclosures, corporate governance reports, and GRI-based sustainability reports published on firms' official websites and financial reporting platforms. Additional environmental and operational

information related to energy consumption and greenhouse gas emissions was manually extracted from sustainability disclosures whenever available.

The sample selection process followed several criteria to ensure consistency, comparability, and reliability of the dataset. First, only listed Saudi petrochemical firms were included in the analysis. Second, firms were required to disclose sufficient environmental, financial, and sustainability-related information necessary for constructing the study variables. Third, companies with substantial missing sustainability or environmental disclosure data during the observation period were excluded to maintain analytical consistency and measurement reliability.

Following the application of these criteria, the final sample comprised 13 listed Saudi petrochemical firms observed over the 2017–2024 period, yielding a balanced panel of 104 firm-year observations. The observation window was selected for both methodological and contextual reasons. The starting year, 2017, coincides with the mandatory adoption of International Financial Reporting Standards (IFRS) by Saudi listed companies, providing a more consistent and comparable financial reporting environment for constructing the accounting and economic indicators used in the study. It also marks the early post-Vision 2030 period, during which environmental sustainability, resource efficiency, corporate transparency, and sustainability reporting received increasing institutional and corporate attention. Extending the analysis through 2024 captures the progressive development of these practices and initiatives, while representing the most recent year for which sufficiently complete and comparable financial, environmental, and sustainability data were available at the time of data collection. Thus, the selected period provides a consistent longitudinal window for examining the proposed relationships during an important phase of sustainability transformation in the Saudi petrochemical sector.

The statistical adequacy of the final sample was further assessed using an a priori power analysis following Faul et al. [27]. Based on the maximum number of predictors directed toward any endogenous construct in the structural model (three predictors), a conventional medium effect size ($f^2 = 0.15$), a significance level of $\alpha = 0.10$, and a statistical power of 0.80, the minimum required sample size was estimated at 62 observations. The available 104 firm-year observations exceeded this requirement, supporting the statistical adequacy of the sample for estimating the proposed structural relationships using PLS-SEM.

Sustainability-related indicators were manually collected and verified to improve measurement accuracy and ensure alignment with the Global Reporting Initiative (GRI) framework. SRQ was operationalized as a multidimensional GRI-based measure encompassing economic, environmental, and social dimensions. The SRQ measure was developed through content analysis of sustainability and annual reports using GRI-aligned disclosure items reflecting the extent and completeness of reported sustainability information. The detailed procedure used to translate these disclosure items into the overall SRQ measure is presented in Section 3.3.3.

EMA indicators were constructed using environmental and financial data extracted directly from firms' reports and disclosures. Eco-efficiency was measured as the ratio of total assets to total energy consumption, reflecting the relationship between the firm's asset base and its energy use. Emission efficiency was measured as the ratio of total sales to total greenhouse-gas emissions, capturing the economic value generated relative to emissions. The methodological rationale and detailed operationalization of these indicators are presented in Section 3.3.1.

The use of multiple corporate reporting sources, together with manually collected financial and environmental indicators, supported data consistency and enables an integrated assessment of EMA, SRQ, and CSP within the Saudi petrochemical sector.

3.3. Measurement of variables

3.3.1. Measurement of corporate sustainability performance

CSP reflects a firm's ability to achieve long-term economic success while improving environmental responsibility and operational sustainability. Consistent with the sustainability accounting literature, we adopted a multidimensional approach to measuring CSP to capture economic and environmental sustainability outcomes, rather than relying on a single aggregated performance indicator. Researchers argue that multidimensional sustainability measures provide a more comprehensive evaluation of firms' sustainability performance because sustainability outcomes are inherently complex and extend beyond traditional financial profitability measures alone [28,29].

In this study, CSP was operationalized using two major dimensions: economic sustainability performance and environmental sustainability performance. The economic sustainability dimension reflects firms' ability to generate sustainable financial and operational outcomes, whereas the environmental dimension captures improvements in environmental efficiency and emissions management.

The economic sustainability dimension (CSP_Eco) was operationalized as a composite construct using three commonly adopted financial and operational indicators: Return on Assets (ROA), Return on Equity (ROE), and sales growth rate. Return on Assets reflects firms' efficiency in using assets to generate profits and was calculated as follows:

$$ROA = \frac{Net\ Incomes}{Total\ Assets} \times 100 \quad (1)$$

Return on Equity measures firms' ability to generate sustainable value for shareholders and was computed as:

$$ROE = \frac{Net\ Incomes}{Shareholders' Equity} \times 100 \quad (2)$$

In addition, the sales growth rate was included to capture market growth and operational resilience through the annual percentage change in total sales:

$$Sales\ Growth = \frac{Sales_t - Sales_{t-1}}{Sales_{t-1}} \times 100 \quad (3)$$

These indicators are widely used in sustainability and corporate performance literature as proxies for economic sustainability and long-term financial viability [8,21].

The environmental sustainability dimension was measured using two dynamic environmental performance indicators related to greenhouse gas emissions and energy consumption. Environmental performance was assessed through the annual change rate of total greenhouse gas emissions:

$$CSP_{Env} = \frac{GHG_t - GHG_{t-1}}{GHG_{t-1}} \times 100 \quad (4)$$

Greenhouse gas emissions were measured using Scope 1 and Scope 2 emissions disclosures, reflecting direct emissions generated from firms' operations as well as indirect emissions associated with purchased energy consumption. Scope 3 emissions were excluded due to limitations in disclosure consistency and data availability across the sampled firms. The use of Scope 1 and Scope 2 emissions is consistent with prior sustainability and environmental accounting studies focusing on operational carbon efficiency and industrial environmental performance.

Similarly, energy sustainability performance was measured using the annual change rate of total energy consumption:

$$CSP_{Enr} = \frac{Energy_t - Energy_{t-1}}{Energy_{t-1}} \times 100 \quad (5)$$

Negative values for both indicators indicate improvements in environmental sustainability performance because they reflect reductions in greenhouse gas emissions and energy consumption relative to the previous reporting period. This dynamic measurement approach is consistent with other sustainability studies emphasizing the importance of continuous environmental improvement rather than static environmental levels alone [5–7].

Accordingly, the five individual performance indicators were organized into two CSP dimensions for the structural model. The economic dimension (CSP_Eco) comprises ROA, ROE, and Sales Growth. The environmental dimension was initially represented by two separate dynamic indicators: the annual change in greenhouse-gas emissions (CSP_Env) and the annual change in energy consumption (CSP_Enr). Because these two environmental indicators exhibited high empirical overlap during measurement assessment, they were subsequently integrated into a unified environmental sustainability performance construct (CSP_Env). Thus, the final structural model distinguishes between two complementary CSP dimensions: economic sustainability performance (CSP_Eco) and environmental sustainability performance (CSP_Env). This structure preserves the multidimensional nature of CSP while providing a clearer and more parsimonious representation of economic and environmental sustainability outcomes.

Adopting multidimensional CSP indicators provides several methodological and theoretical advantages. First, it allows simultaneous assessment of both financial sustainability and environmental sustainability outcomes. Second, it improves the comprehensiveness of sustainability evaluation within environmentally sensitive industries such as petrochemicals. Third, it aligns the study with the multidimensional sustainability perspective emphasized by the Global Reporting Initiative (GRI) framework, which emphasizes the integration of economic, environmental, and governance-related sustainability dimensions.

Overall, the multidimensional operationalization of CSP adopted in this study enables a more comprehensive understanding of how EMA practices and SRQ contribute to sustainability-oriented organizational outcomes within Saudi petrochemical firms.

3.3.2. *Measurement of environmental management accounting*

EMA refers to the integration of environmental and financial information to support sustainability-oriented managerial decision-making, resource optimization, environmental cost management, and operational efficiency improvement. EMA has increasingly evolved from a

compliance-oriented accounting practice into a strategic sustainability management tool that assists firms in improving environmental performance while maintaining long-term economic competitiveness [5–7,22]. Within environmentally sensitive industries such as petrochemicals, EMA practices play a particularly important role because firms operate under substantial pressure related to energy consumption, emissions intensity, environmental accountability, and sustainability governance.

Consistent with prior sustainability and environmental accounting literature, we operationalized EMA using two efficiency-oriented indicators: eco-efficiency and emission efficiency. These indicators were selected because they capture firms' ability to generate economic value while minimizing environmental pressure and resource consumption. Furthermore, efficiency-based measures are considered particularly suitable for evaluating sustainability-oriented operational performance within industrial sectors characterized by intensive environmental impacts.

The first EMA construct, eco-efficiency (*Eco_Eff*), reflects firms' ability to utilize organizational resources efficiently while minimizing energy consumption. In the present study, eco-efficiency was measured as the ratio of total assets to total energy consumption:

$$Eco_Eff = \frac{Total\ Assets}{Total\ Energy\ Consumption} \times 100 \quad (6)$$

This operationalization reflects the extent to which firms are capable of generating and utilizing resource capacity with lower energy intensity. Unlike traditional productivity indicators based solely on sales or profitability, the use of total assets as the scaling factor provides a broader representation of organizational operational capacity and long-term resource utilization efficiency. This measurement approach is particularly relevant in capital-intensive industries such as petrochemicals, where operational sustainability is strongly associated with efficient utilization of large-scale industrial assets and infrastructure.

The second EMA construct, emission efficiency (*Emi_Eff*), captures firms' ability to generate economic output while controlling greenhouse gas emissions intensity. Emission efficiency was measured as the ratio of total sales to total greenhouse-gas emissions:

$$Emi_Eff = \frac{Total\ Sales}{Total\ GHG\ Emissions} \times 100 \quad (7)$$

This indicator reflects operational carbon productivity by evaluating how efficiently firms generate revenues relative to emissions produced during operational activities. Similar to the environmental sustainability indicators adopted in the study, greenhouse-gas emissions were measured using Scope 1 and Scope 2 emission disclosures. Scope 1 emissions represent direct emissions generated from firms' operational activities, whereas Scope 2 emissions reflect indirect emissions associated with purchased energy consumption. Scope 3 emissions were excluded due to limitations in disclosure consistency and data availability across the sampled firms.

I intentionally adopted different scaling bases for the two EMA indicators in order to capture distinct dimensions of environmental management efficiency while reducing ratio redundancy and potential multi-collinearity concerns between sustainability-related variables. Specifically, eco-efficiency focuses on resource utilization efficiency relative to firms' operational asset base, whereas emission efficiency emphasizes firms' ability to generate economic value with lower carbon intensity.

This differentiated operationalization improves construct distinctiveness and provides a more comprehensive evaluation of EMA practices within Saudi petrochemical firms.

It is important to distinguish conceptually between the EMA efficiency indicators and the CSP outcome measures. Although both rely partly on environmental and operational firm-level information, they serve different analytical purposes. *Eco_Eff* and *Emi_Eff* capture efficiency-oriented managerial measures linking economic resources or outputs to environmental inputs and pressures, whereas *CSP_Eco* and *CSP_Env* capture realized economic and environmental sustainability outcomes. This distinction separates the efficiency of environmental resource management from the sustainability performance outcomes associated with such practices.

The selection of these indicators is consistent with sustainability accounting and environmental management studies emphasizing the importance of efficiency-oriented environmental accounting measures for evaluating sustainability performance in industrial sectors [4,21]. More specifically, asset-based eco-efficiency relates the firm's productive asset base to energy consumption, thereby capturing resource efficiency in a capital- and energy-intensive industry such as petrochemicals. Sales-based emission efficiency, in turn, relates economic output to greenhouse-gas emissions, reflecting the firm's ability to generate economic value relative to its carbon footprint. The use of different financial denominators therefore captures two complementary dimensions of EMA: Resource utilization efficiency and carbon productivity while providing greater conceptual distinction between the two indicators. Overall, the adopted EMA measurement framework enables a more comprehensive assessment of how environmentally oriented managerial practices contribute to sustainability performance and SRQ within environmentally intensive industrial settings.

3.3.3. *Measurement of SRQ*

SRQ reflects the extent to which firms provide transparent, comprehensive, credible, and decision-useful sustainability-related disclosures to stakeholders. In recent years, sustainability reporting has evolved beyond a voluntary communication practice into an important governance and accountability mechanism that supports corporate legitimacy, stakeholder engagement, and sustainability-oriented decision-making [8–10]. High-quality sustainability reporting enhances information transparency, improves stakeholder confidence, and strengthens firms' ability to demonstrate commitment to sustainable development objectives.

Consistent with sustainability reporting literature, we operationalized SRQ using a multidimensional disclosure index aligned with the Global Reporting Initiative (GRI) framework. The GRI standards were selected because they represent one of the most internationally recognized sustainability reporting frameworks and provide comprehensive disclosure guidelines covering environmental, social, economic, and governance-related sustainability dimensions [11]. The use of the GRI framework also improves reporting comparability and consistency across firms and reporting periods.

In this study, SRQ was measured through a structured content analysis of firms' annual reports, sustainability reports, ESG disclosures, and corporate governance reports. The analysis focused on three major sustainability disclosure dimensions: environmental disclosure quality, social disclosure quality, and governance/economic disclosure quality. The three disclosure dimensions were initially

assessed separately to improve the comprehensiveness of sustainability reporting evaluation. Subsequently, the scores were aggregated into a single SRQ index representing the overall quality of sustainability disclosures across the sampled firms.

The construction of the SRQ measure followed a systematic process. First, the selected disclosure items aligned with the GRI were categorized into three sustainability dimensions: Economic, Environmental, and Social, based on their respective reporting categories. Each disclosure item was assigned a binary score, with a value of 1 given when relevant information was disclosed and 0 otherwise.

Next, the coded items were aggregated within each dimension, and a dimension-specific score was calculated as the proportion of disclosed items to the total applicable items in that dimension. To derive the overall SRQ measure used in the empirical analysis, the scores from the Economic, Environmental, and Social dimensions were equally weighted and combined. This equal weighting ensures that each sustainability dimension contributes equally to the overall SRQ measure, regardless of the differences in the number of disclosure items within each dimension.

Consequently, the three dimensions serve as complementary components of a comprehensive SRQ measure rather than as separate constructs in the structural model. This sequential approach provides a transparent and replicable link between the individual GRI-aligned disclosure items, the dimension-specific scores, and the overall SRQ measure.

The SRQ index was calculated as follows:

$$SRQ = \frac{\text{Disclosed GRI Indicators}}{\text{Total Applicable GRI Indicators}} \times 100 \quad (8)$$

The environmental disclosure dimension includes disclosures related to energy consumption, greenhouse-gas emissions, environmental initiatives, resource management, waste management, and climate-related sustainability practices. The social disclosure dimension covers disclosures concerning employee welfare, diversity, occupational health and safety, training and development, community engagement, and social responsibility initiatives. Finally, the governance/economic disclosure dimension includes disclosures related to sustainability governance structures, ethical practices, economic sustainability initiatives, compliance mechanisms, and sustainability-related strategic policies.

Each disclosure item was evaluated based on its presence and reporting completeness within firms' published disclosures. A binary scoring procedure was adopted, whereby a score of "1" was assigned if the required disclosure item was reported and "0" otherwise. The scores obtained for all applicable GRI indicators were subsequently aggregated into a unified SRQ index representing the overall SRQ of the sampled firms.

To improve consistency and reduce subjectivity in the disclosure assessment process, we utilized a structured disclosure extraction framework developed for GRI-based sustainability reporting analysis. The framework was designed to identify and quantify sustainability-related disclosure items from firms' reports using predefined GRI-aligned terminology and disclosure categories covering environmental, social, and governance/economic dimensions. The extracted disclosures were subsequently reviewed and validated manually to ensure contextual relevance, reporting accuracy, and consistency with the study objectives. This semi-structured approach enhanced the reliability,

reproducibility, and comprehensiveness of the SRQ measurement process while reducing potential coding inconsistencies commonly associated with manual sustainability disclosure analysis.

The content analysis process, therefore, combined systematic disclosure extraction procedures with manual verification to improve measurement accuracy and strengthen the methodological rigor of the disclosure evaluation process. This approach is consistent with prior sustainability reporting studies employing GRI-based disclosure indices to evaluate sustainability reporting practices and disclosure quality [25,30].

The adoption of a multidimensional GRI-based SRQ construct provides several methodological advantages. First, it captures multiple dimensions of sustainability disclosure rather than focusing solely on environmental reporting. Second, it improves the comprehensiveness of sustainability transparency assessment within environmentally sensitive industries. Third, it aligns the study with international sustainability reporting standards and recent sustainability governance literature, emphasizing the strategic role of high-quality sustainability disclosures in supporting stakeholder accountability and corporate legitimacy.

Overall, the adopted SRQ measurement framework enables a more comprehensive evaluation of sustainability reporting practices and their relationship with EMA practices and CSP within Saudi petrochemical firms.

3.4. Data analysis technique

To empirically examine the proposed relationships among EMA practices, SRQ, and Corporate Sustainability Performance (CSP), we employed Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS software. PLS-SEM is considered particularly appropriate for this study because it enables the simultaneous estimation of complex relationships among multiple sustainability-related constructs while accommodating both direct and complementary effects within an integrated analytical framework.

The selection of PLS-SEM is supported by several methodological considerations. First, we investigated a relatively complex sustainability-oriented model integrating EMA practices, SRQ, and multidimensional sustainability performance indicators. PLS-SEM is widely recognized as suitable for exploratory and predictive sustainability research involving complex structural relationships among multiple sustainability-related constructs [31].

Second, we incorporated multidimensional sustainability-oriented indicators integrating environmental, economic, and sustainability reporting dimensions within a unified analytical framework. PLS-SEM provides substantial flexibility for estimating complex sustainability-related relationships involving composite indicators and multidimensional performance measures commonly used in sustainability and accounting research contexts.

Third, we relied on firm-level longitudinal observations collected from Saudi petrochemical firms, generating a moderate sample size of 104 firm-year observations. Compared with covariance-based structural equation modeling techniques, PLS-SEM is considered more appropriate for studies involving moderate sample sizes and does not require strict multivariate normality assumptions [29,32]. This characteristic is particularly important in sustainability and ESG-related research, where environmental and disclosure variables frequently exhibit non-normal distributions.

PLS-SEM was selected instead of covariance-based SEM (CB-SEM) because it is well aligned with my objectives and characteristics of this study. The analysis emphasizes the estimation and prediction of relationships among EMA, SRQ, and CSP, including direct and indirect effects, rather than primarily focusing on reproducing the observed covariance matrix and assessing overall model fit. PLS-SEM is also suitable for the proposed model structure, which includes multiple endogenous relationships and mediation effects, while accommodating the study's moderate sample of 104 firm-year observations. Furthermore, its emphasis on explained variance and predictive relevance is consistent with the study's evaluation of R^2 , f^2 , and Q^2 . Taken together, these considerations support the selection of PLS-SEM as an appropriate analytical approach for the proposed research model.

The empirical analysis was conducted in two major stages. The first stage focused on evaluating construct validity, discriminant validity, and multi-collinearity among the sustainability related constructs included in the model. Discriminant validity was assessed using the Heterotrait-Monotrait Ratio (HTMT), which is considered one of the most reliable approaches for evaluating construct distinctiveness in PLS-SEM models [32]. In addition, multi-collinearity diagnostics were examined using the Variance Inflation Factor (VIF) values to ensure the absence of significant collinearity problems among predictor constructs. Following PLS-SEM recommendations, VIF values below the commonly accepted threshold indicate that multi-collinearity does not pose a serious concern within the structural model.

The second stage focused on evaluating the structural model and testing the proposed hypotheses. The statistical significance of the structural relationships was assessed using a nonparametric bootstrapping procedure in SmartPLS with 10,000 bootstrap subsamples. Percentile bootstrap confidence intervals were estimated at the 90% confidence level, and the no-sign-change option was applied during resampling. This procedure was used to obtain robust estimates of the path coefficients, t-values, p-values, and confidence intervals for the direct and indirect effects examined in the structural model.

Furthermore, the predictive and explanatory capabilities of the model were evaluated using the coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). The coefficient of determination (R^2) assesses the explanatory power of the endogenous sustainability-related constructs, whereas the effect size (f^2) evaluates the relative contribution of each exogenous construct to the structural model. Predictive relevance (Q^2) was assessed using the blindfolding procedure to examine the model's predictive capability for endogenous sustainability-related constructs.

Overall, the use of PLS-SEM provides a robust and flexible analytical framework suitable for evaluating the complex interrelationships among EMA practices, SRQ, and CSP within Saudi petrochemical firms.

4. Results and discussion

4.1. Descriptive statistics and correlation analysis

Table 1 presents the descriptive statistics for the major variables included in the study. Overall, the results indicate noticeable variability across the sampled Saudi petrochemical firms regarding sustainability performance, EMA practices, and SRQ. Such variability is expected within

environmentally intensive industries characterized by differences in operational scale, environmental efficiency, disclosure practices, and sustainability integration levels.

Regarding the economic sustainability indicators, the results show moderate variability in firms' financial and operational sustainability performance. The mean values of CSP_ROA, CSP_ROE, and CSP_SC indicate heterogeneous economic performance across firms during the observation period. In particular, the relatively high standard deviation and kurtosis observed for CSP_SC suggest substantial variation in sales growth dynamics among the sampled firms. Similarly, positive skewness values for CSP_ROA and CSP_SC indicate that several firms achieved comparatively higher economic sustainability outcomes relative to the sample average.

The environmental sustainability indicators also reveal observable differences across firms. CSP_Env and CSP_Enr exhibit relatively moderate dispersion levels, reflecting differences in firms' greenhouse-gas emissions performance and energy-consumption efficiency. The relatively low skewness and kurtosis values associated with these variables suggest more stable environmental performance distributions compared with the economic sustainability indicators.

Concerning the EMA indicators, Eco_Eff and Emi_Eff display noticeable variability across firms, indicating differences in resource utilization efficiency and carbon-efficiency performance within the Saudi petrochemical sector. The positive skewness observed for both variables suggests that a limited number of firms demonstrate substantially stronger environmental efficiency performance compared with the rest of the sample.

The descriptive statistics further indicate that SRQ exhibits substantial variability across firms, with scores ranging from 0.031 to 0.969. This variation reflects differences in sustainability disclosure practices, reporting maturity, and alignment with GRI-based reporting standards among the sampled firms.

Overall, the descriptive statistics reveal moderate non-normality across several sustainability-related variables, particularly the EMA indicators and economic sustainability measures, as reflected by skewness and kurtosis statistics. These distributional characteristics further support the suitability of PLS-SEM, which does not require strict multivariate normality assumptions.

Table 1. Descriptive statistics.

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
CSP_ROA	0.052	0.095	-0.160	0.418	1.440	3.432
CSP_ROE	0.070	0.164	-0.439	0.569	-0.080	1.876
CSP_SC	0.077	0.365	-0.737	1.882	1.783	5.764
CSP_Env	0.036	0.085	-0.132	0.228	0.172	0.365
CSP_Enr	0.032	0.079	-0.132	0.228	0.283	0.605
Eco_Eff	20.150	0.652	19.037	22.314	1.271	2.180
Emi_Eff	2.955	0.820	1.712	5.566	1.522	2.367
SRQ	0.311	0.293	0.031	0.969	1.191	-0.089

Note: CSP_ROA = Return on Assets; CSP_ROE = Return on Equity; CSP_SC = Sales Growth; CSP_Env = annual change in greenhouse gas emissions; CSP_Enr = annual change in energy consumption; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; Std. Dev. = Standard Deviation.

Table 2 presents the correlation matrix among the study variables. The correlation analysis provides preliminary insights into the direction and strength of the relationships among EMA practices, SRQ, and CSP indicators.

The results indicate positive associations between the EMA indicators and several economic sustainability measures. In particular, emission efficiency (Emi_Eff) demonstrates relatively stronger positive correlations with CSP_ROA and CSP_ROE, suggesting that firms exhibiting higher carbon-efficiency performance tend to achieve stronger economic sustainability outcomes. Eco-efficiency (Eco_Eff) also shows positive, although relatively moderate, correlations with economic sustainability indicators.

The findings further reveal a strong positive correlation between CSP_Env and CSP_Enr, reflecting the close relationship between greenhouse-gas emissions performance and energy-consumption efficiency within petrochemical firms. This result is theoretically expected because improvements in energy efficiency are commonly associated with reductions in operational emissions in environmentally intensive industries.

In addition, SRQ demonstrates relatively weak correlations with most sustainability performance indicators, although it exhibits a moderate positive relationship with Eco_Eff. These preliminary findings suggest that operational environmental management practices may exert stronger direct sustainability effects than sustainability disclosure practices alone.

Importantly, the correlation coefficients among the predictor variables remained below commonly accepted critical multi-collinearity thresholds, indicating the absence of severe bivariate collinearity concerns that could substantially distort the subsequent structural model estimation. Overall, the correlation analysis provides preliminary empirical support for the proposed relationships in the conceptual framework and justifies proceeding with the subsequent PLS-SEM analysis.

Table 2. Correlation matrix.

Variables	CSP ROA	CSP ROE	CSP SC	CSP Env	CSP Enr	Eco Eff	Emi Eff	SRQ
CSP_ROA	1.000							
CSP_ROE	0.924	1.000						
CSP_SC	0.521	0.551	1.000					
CSP_Env	0.311	0.398	0.560	1.000				
CSP_Enr	0.294	0.383	0.585	0.963	1.000			
Eco_Eff	0.245	0.234	0.035	-0.149	-0.181	1.000		
Emi_Eff	0.484	0.439	0.242	-0.037	-0.043	0.751	1.000	
SRQ	-0.077	-0.023	-0.080	0.060	-0.005	0.374	-0.065	1.000

Note: Values represent pairwise correlation coefficients. CSP_ROA = Return on Assets; CSP_ROE = Return on Equity; CSP_SC = Sales Growth; CSP_Env = annual change in greenhouse gas emissions; CSP_Enr = annual change in energy consumption; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ.

4.2. Measurement model assessment

The measurement model assessment was conducted before testing the structural relationships to evaluate construct validity, discriminant validity, and potential multi-collinearity issues among the sustainability-related constructs included in the model. Consistent with PLS-SEM guidelines, the

assessment focused on ensuring that the measurement structure exhibited acceptable levels of construct distinctiveness and statistical stability before proceeding to hypothesis testing [31,32]. While the descriptive statistics and correlation analysis were initially conducted using the original sustainability indicators, the final PLS-SEM estimation relied on integrated sustainability performance constructs to improve model parsimony and theoretical coherence.

Discriminant validity was primarily assessed using the Heterotrait–Monotrait Ratio (HTMT), which is widely recognized as one of the most reliable approaches for evaluating construct distinctiveness in PLS-SEM models. As presented in Table 3, all HTMT values remained below the commonly recommended threshold, indicating satisfactory discriminant validity among the study constructs. The results, therefore, confirm that the constructs included in the model measure conceptually distinct sustainability-related dimensions.

During the initial assessment stage, the environmental sustainability indicators related to greenhouse gas emissions and energy performance exhibited a high degree of empirical overlap. Specifically, the separate environmental and energy sustainability measures demonstrated substantial conceptual and statistical similarity, which created discriminant validity concerns within the measurement model. To improve construct distinctiveness and enhance model stability, the two indicators were subsequently integrated into a unified environmental sustainability performance construct (CSP_Env). This refinement was considered theoretically appropriate because both indicators capture closely related dimensions of environmental operational sustainability within petrochemical firms. Similarly, the economic sustainability indicators related to profitability and operational growth were integrated into a unified economic sustainability construct (CSP_Eco), combining return on assets, return on equity, and sales growth indicators. This integration enabled a more comprehensive representation of firms' economic sustainability performance within the structural model.

Table 3. Discriminant validity assessment using HTMT.

Constructs	CSP_Eco	CSP_Env	Eco_Eff	Emi_Eff	SRQ
CSP_Eco	-				
CSP_Env	0.527	-			
Eco_Eff	0.210	0.168	-		
Emi_Eff	0.476	0.041	0.751	-	
SRQ	0.073	0.034	0.374	0.065	-

Note: HTMT = Heterotrait–Monotrait ratio; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ. HTMT values below 0.85 indicate adequate discriminant validity.

In addition to discriminant validity assessment, multi-collinearity diagnostics were examined using the Variance Inflation Factor (VIF) values. As shown in Table 4, all VIF values remained below the commonly accepted threshold of 5, indicating that multi-collinearity did not pose a significant concern within the structural model. These results suggest that the predictor constructs included in the model do not exhibit excessive collinearity that could distort the estimation of structural relationships.

Table 4. Collinearity assessment using VIF.

Structural Path	VIF
Eco_Eff → CSP_Eco	3.891
Eco_Eff → CSP_Env	3.891
Emi_Eff → CSP_Eco	3.362
Emi_Eff → CSP_Env	3.362
SRQ → CSP_Eco	1.706
SRQ → CSP_Env	1.706

Note: VIF = Variance Inflation Factor; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP. VIF values below 5 indicate the absence of critical multicollinearity concerns.

The measurement assessment process also involved evaluating the overall adequacy and coherence of the sustainability-related constructs included in the study. Table 5 summarizes the major measurement model assessment results. Overall, the final measurement structure demonstrated satisfactory construct distinctiveness, acceptable collinearity levels, and adequate statistical stability, thereby supporting the suitability of the model for subsequent structural analysis and hypothesis testing.

Overall, the measurement model assessment confirmed that the adopted operationalization of EMA practices, SRQ, and CSP provided an adequate and statistically stable basis for evaluating the proposed relationships within the Saudi petrochemical sector.

Table 5. Summary of a measurement model assessment.

Assessment Criterion	Result	Interpretation
HTMT	Below recommended threshold	Discriminant validity established
VIF	Below threshold value of 5	No significant multi-collinearity issue
Measurement Refinement	CSP_Env and CSP_Enr integrated construct	Improved construct distinctiveness and model stability
Overall Assessment	Acceptable	Measurement model suitable for structural analysis

Note: HTMT = Heterotrait–Monotrait ratio; VIF = Variance Inflation Factor; CSP_Env = annual change in greenhouse gas emissions; CSP_Enr = annual change in energy consumption; CSP_Env = integrated Environmental CSP construct. HTMT values below 0.85 indicate adequate discriminant validity, while VIF values below 5 indicate the absence of critical multicollinearity concerns.

4.3. Structural model assessment

Following the assessment of the measurement model, the structural model was evaluated to examine the proposed relationships among EMA practices, SRQ, CSP. The structural assessment focused on evaluating the significance, direction, explanatory capability, and predictive relevance of the hypothesized relationships within the proposed conceptual framework.

The structural relationships were estimated using the bootstrapping procedure implemented in SmartPLS. Path coefficients (β), t-values, and p-values were used to assess the statistical significance of the proposed hypotheses. Following prior exploratory sustainability and ESG-related studies, we considered significance levels up to 10% for marginally significant relationships [31,32].

Table 6 presents the structural path assessment results. The findings reveal that both EMA indicators exert significant effects on CSP and SRQ. Specifically, Eco_Eff demonstrated significant negative relationships with CSP_Eco ($\beta = -0.448$, $p < 0.05$) and CSP_Env ($\beta = -0.570$, $p < 0.01$), while exhibiting a strong positive effect on SRQ ($\beta = 0.969$, $p < 0.01$). Similarly, Emi_Eff exerted significant positive effects on CSP_Eco ($\beta = 0.801$, $p < 0.01$) and CSP_Env ($\beta = 0.405$, $p < 0.05$), whereas its relationship with SRQ was negative but highly significant ($\beta = -0.792$, $p < 0.01$). These findings highlight the substantial influence of operational environmental management practices for sustainability performance and disclosure quality within Saudi petrochemical firms, supporting prior sustainability accounting studies emphasizing the strategic role of environmental management systems in improving sustainability outcomes [5–7,18].

The results further indicate that SRQ exerts relatively weaker direct effects on sustainability performance dimensions. Although SRQ demonstrated a positive relationship with CSP_Env ($\beta = 0.267$, $p < 0.05$), its effect on CSP_Eco remained only marginally significant at the 10% level ($\beta = 0.155$, $p < 0.10$). These findings suggest that SRQ alone may not necessarily generate immediate economic sustainability improvements unless accompanied by effective operational environmental management practices. This interpretation is consistent with prior ESG and sustainability disclosure literature arguing that disclosure quality does not automatically translate into substantive sustainability performance improvements in the absence of genuine operational sustainability integration [25,30].

Table 6. Structural path assessment and hypotheses testing.

Hypothesis	Structural path	β	t-value	p-value	Significance
H_{1a}	Eco_Eff $\rightarrow$ CSP_Env	-0.570	2.685	0.004	***
H_{1b}	Eco_Eff $\rightarrow$ CSP_Eco	-0.448	2.261	0.012	**
H_{2a}	Emi_Eff $\rightarrow$ CSP_Env	0.405	2.093	0.018	**
H_{2b}	Emi_Eff $\rightarrow$ CSP_Eco	0.801	4.397	<0.001	***
H_{3a}	SRQ $\rightarrow$ CSP_Env	0.267	2.031	0.021	**
H_{3b}	SRQ $\rightarrow$ CSP_Eco	0.155	1.365	0.086	*
H_4	Eco_Eff $\rightarrow$ SRQ	0.969	6.923	<0.001	***
H_5	Emi_Eff $\rightarrow$ SRQ	-0.792	5.526	<0.001	***

Note: β = standardized path coefficient; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP. Statistical significance was assessed using bootstrapping with 10,000 subsamples and 90% percentile confidence intervals. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The model's explanatory power was assessed using the coefficient of determination (R^2). As presented in Table 7, the model demonstrated moderate explanatory capability for CSP_Eco and SRQ, with R^2 values of 0.260 and 0.414, respectively. By contrast, CSP_Env exhibited a relatively lower R^2

value of 0.086, suggesting that environmental sustainability performance is influenced by additional operational, technological, and regulatory factors beyond the variables incorporated in this model. Similar observations have been reported in prior sustainability and ESG-related studies, where environmental sustainability outcomes were found to depend on broader institutional, technological, and industry-specific determinants beyond internal management practices alone [8].

Nevertheless, such explanatory levels remain acceptable within sustainability and ESG-related research contexts characterized by inherently complex and multidimensional sustainability phenomena [31,33].

Table 7. Predictive power assessment (R^2).

Endogenous Construct	R^2	Interpretation
CSP_Eco	0.260	Moderate explanatory power
CSP_Env	0.086	Weak but acceptable explanatory power
SRQ	0.414	Moderate explanatory power

Note: R^2 = coefficient of determination, indicating the proportion of variance in each endogenous construct explained by its predictors; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP; SRQ = SRQ. Higher R^2 values indicate greater explanatory power of the structural model.

To further evaluate the relative contribution of the exogenous constructs, effect size analysis (f^2) was conducted. The results reported in Table 8 reveal that EMA practices exert substantially stronger effects on SRQ compared with their direct effects on sustainability performance dimensions. In particular, Eco_Eff and Emi_Eff demonstrated large effect sizes on SRQ, highlighting the important role of operational environmental management practices in improving SRQ. These findings support EMA literature emphasizing that firms with more developed environmental operational systems tend to exhibit stronger sustainability disclosure practices and higher sustainability transparency levels [5–7,34].

Table 8. Effect size assessment (f^2).

Structural Relationship	f^2	Effect Size
Eco_Eff → CSP_Eco	0.070	Small
Eco_Eff → CSP_Env	0.091	Small
Eco_Eff → SRQ	0.698	Large
Emi_Eff → CSP_Eco	0.258	Medium
Emi_Eff → CSP_Env	0.053	Small
Emi_Eff → SRQ	0.467	Large
SRQ → CSP_Eco	0.019	Very small
SRQ → CSP_Env	0.046	Small

Note: f^2 = effect size, indicating the contribution of each predictor to the explanatory power of the endogenous construct; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP. Effect sizes are interpreted as very small (< 0.02), small (≥ 0.02), medium (≥ 0.15), and large (≥ 0.35).

By contrast, SRQ exhibited relatively weak direct effect sizes on sustainability performance outcomes, suggesting that sustainability reporting alone may not be sufficient to generate substantial sustainability improvements without effective environmental operational practices. This result is consistent with ESG and sustainability disclosure studies arguing that disclosure-oriented sustainability initiatives may produce limited organizational sustainability impact unless supported by substantive operational environmental practices and sustainability integration mechanisms [25,30].

Finally, the predictive relevance of the model was evaluated using Q^2 predict statistics. As shown in Table 9, the model demonstrates stronger predictive capability for SRQ and economic sustainability performance compared with environmental sustainability performance. SRQ exhibited the highest predictive relevance (Q^2 predict = 0.394), followed by CSP_Eco (Q^2 predict = 0.213). By contrast, CSP_Env demonstrated relatively weak predictive relevance (Q^2 predict = 0.011), indicating that environmental sustainability outcomes may also depend on external operational, technological, and regulatory factors beyond the variables incorporated in the present model. Similar observations have been highlighted in prior sustainability and ESG-related studies emphasizing the multidimensional and context-dependent nature of environmental sustainability performance within environmentally intensive industries [33].

Moreover, the predictive relevance results reinforce the argument that operational environmental management practices appear to contribute more effectively to sustainability disclosure quality and economic sustainability outcomes than to broader environmental sustainability performance, which is frequently influenced by external institutional and industry-related sustainability pressures [8,31].

Taken together, the R^2 , f^2 , and Q^2 results provide complementary evidence of the model's explanatory and predictive performance. Notably, Eco_Eff and Emi_Eff exhibit large effect sizes on SRQ (f^2 = 0.698 and 0.467, respectively), indicating that both EMA-related indicators make substantial contributions to explaining variation in SRQ. These effects are considerably stronger than most of those observed for the CSP dimensions, suggesting that EMA-related practices are particularly relevant to the reporting dimension of corporate sustainability. Furthermore, the smaller effect sizes observed for several relationships with CSP indicate that sustainability performance is likely shaped by a broader set of organizational and contextual factors. The positive Q^2 values further confirm that the model has predictive relevance for the endogenous constructs, complementing the explanatory evidence provided by R^2 .

Table 9. Predictive relevance assessment (Q^2 predict).

Endogenous Construct	Q^2 predict	RMSE	MAE	Interpretation
SRQ	0.394	0.796	0.604	Large predictive relevance
CSP_Eco	0.213	0.929	0.664	Moderate predictive relevance
CSP_Env	0.011	1.018	0.724	Small predictive relevance

Note: Q^2 predict = out-of-sample predictive relevance; RMSE = Root Mean Squared Error; MAE = Mean Absolute Error; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP. Positive Q^2 predict values indicate that the model has predictive relevance for the corresponding endogenous construct, with higher values indicating stronger predictive performance. Lower RMSE and MAE values indicate smaller prediction errors.

To further examine the mediating role of SRQ, indirect effects were assessed using the bootstrapping procedure in SmartPLS. The results presented in Table 10 reveal that SRQ exerts selective mediation effects within the proposed conceptual framework.

Specifically, the indirect effect of Eco_Eff on CSP_Env through SRQ was positive and statistically significant ($\beta = 0.259$, $p < 0.05$), indicating that SRQ partially mediates the relationship between eco-efficiency practices and environmental sustainability performance. This finding suggests that firms implementing stronger resource-efficiency practices tend to enhance the quality of sustainability disclosures, which subsequently contributes to improved environmental sustainability outcomes. Similar relationships have been highlighted in prior sustainability accounting studies emphasizing the complementary role of sustainability disclosure mechanisms in reinforcing environmental accountability and sustainability integration processes [5–7,18].

Similarly, the indirect relationship between Emi_Eff and CSP_Env through SRQ was statistically significant ($\beta = -0.212$, $p < 0.05$), confirming the existence of a mediating role of SRQ in the relationship between emission-efficiency practices and environmental sustainability performance. These findings imply that sustainability disclosure mechanisms may reinforce the environmental impact of operational environmental management practices by improving environmental transparency, accountability, and sustainability monitoring processes. This interpretation is consistent with prior ESG literature suggesting that sustainability reporting practices contribute more directly to environmentally oriented organizational outcomes than to short-term financial sustainability outcomes [30].

By contrast, the indirect effects associated with CSP_Eco were not statistically significant. Specifically, the mediation effects of SRQ in the relationships between Eco_Eff and CSP_Eco, as well as between Emi_Eff and CSP_Eco, remained insignificant. This result suggests that SRQ may play a more influential role in environmentally oriented sustainability outcomes than in directly improving firms' economic sustainability performance. Similar findings have been reported in prior studies arguing that sustainability disclosure quality alone does not necessarily generate immediate economic benefits unless supported by substantive environmental operational practices and broader organizational sustainability capabilities [8,25].

Overall, the indirect effects analysis indicates that SRQ acts as a partial and environmentally oriented mediating mechanism within the proposed model. While operational EMA practices exert substantial direct effects on sustainability performance, SRQ appears to strengthen environmental sustainability outcomes more effectively than economic sustainability outcomes.

Table 10. Indirect effects assessment.

Indirect Relationship	β	t-value	p-value	Result
Eco_Eff $\rightarrow$ SRQ $\rightarrow$ CSP_Eco	0.150	1.255	0.105	n.s.
Eco_Eff $\rightarrow$ SRQ $\rightarrow$ CSP_Env	0.259	1.886	0.030	**
Emi_Eff $\rightarrow$ SRQ $\rightarrow$ CSP_Eco	-0.123	1.199	0.115	n.s.
Emi_Eff $\rightarrow$ SRQ $\rightarrow$ CSP_Env	-0.212	1.771	0.038	**

Note: β = standardized indirect effect; CI = percentile bootstrap confidence interval; Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP.

Statistical significance was assessed using bootstrapping with 10,000 subsamples and 90% percentile confidence intervals. ** $p < 0.05$; n.s. = not significant.

The results reported in Table 11 provide deeper insights into the mediating role of SRQ within the proposed conceptual framework. More specifically, the comparison between direct, indirect, and total effects reveals that SRQ does not operate as a uniform mediating mechanism across all sustainability relationships. Instead, its mediating influence appears to be more pronounced for environmental sustainability outcomes than for economic sustainability outcomes. Similar distinctions between environmental and economic sustainability mediation mechanisms have been highlighted in prior ESG and sustainability reporting studies emphasizing the context-dependent nature of sustainability disclosure impacts [25,30]. Since several mediation relationships exhibited opposite signs between direct and indirect effects, mediation was interpreted following the competitive mediation logic proposed by Zhao et al. [35], rather than relying exclusively on Variance Accounted For (VAF) thresholds.

For the relationship between Eco_Eff and CSP_Eco, the direct effect remained negative and statistically significant ($\beta = -0.448$, $p < 0.05$), whereas the indirect effect through SRQ was positive but statistically insignificant ($\beta = 0.150$, $p > 0.10$). Consequently, the total effect remained negative and significant ($\beta = -0.298$, $p < 0.05$), indicating that the relationship is primarily driven by the direct operational influence of eco-efficiency practices rather than by sustainability disclosure mechanisms. This finding suggests that improvements in asset-based eco-efficiency may involve substantial environmental investments and operational restructuring costs that temporarily reduce observable economic sustainability outcomes. Similar sustainability transition cost effects have been discussed in prior environmental management and eco-efficiency literature [23,36].

In contrast, the relationship between Eco_Eff and CSP_Env demonstrated a different pattern. While the direct effect remained significantly negative ($\beta = -0.570$, $p < 0.01$), the indirect effect through SRQ was positive and statistically significant ($\beta = 0.259$, $p < 0.05$). As a result, the magnitude of the negative total effect decreased to $\beta = -0.311$ ($p < 0.05$). This finding indicates the presence of partial competitive mediation, suggesting that SRQ partially mitigates the negative direct impact of eco-efficiency practices on environmental sustainability performance. In other words, although eco-efficiency initiatives may initially generate operational adjustment pressures, improved sustainability reporting practices appear to strengthen environmental transparency, monitoring, and accountability mechanisms that contribute positively to environmental sustainability outcomes. This interpretation is consistent with prior sustainability accounting studies emphasizing the complementary role of sustainability disclosure practices in supporting environmental governance and accountability mechanisms [5–7].

Regarding Emi_Eff and CSP_Eco, the results indicate a strong positive direct effect ($\beta = 0.801$, $p < 0.01$) accompanied by an insignificant indirect effect through SRQ ($\beta = -0.123$, $p > 0.10$). Therefore, the total effect remained strongly positive ($\beta = 0.679$, $p < 0.01$), implying that emission-efficiency practices influence economic sustainability performance primarily through direct operational improvements rather than through SRQ. This finding supports prior environmental management literature arguing that operational carbon-efficiency improvements may generate direct

economic and operational benefits through cost reduction, efficiency enhancement, and improved resource utilization [5–7,18].

Finally, the relationship between Emi_Eff and CSP_Env also revealed evidence of partial competitive mediation. Although the direct effect of emission efficiency on environmental sustainability performance was positive and significant ($\beta = 0.405, p < 0.05$), the indirect effect through SRQ was negative and statistically significant ($\beta = -0.212, p < 0.05$). Consequently, the positive total effect declined to $\beta = 0.193$ and remained only marginally significant at the 10% level ($p < 0.10$). This finding suggests that sustainability reporting practices may partially reduce or constrain the positive operational environmental effects associated with emission-efficiency practices, possibly because disclosure-related compliance, reporting standardization, and transparency requirements introduce additional organizational and administrative pressures. Similar tensions between sustainability disclosure requirements and operational sustainability efficiency have been identified in prior ESG reporting and sustainability governance research [25,30].

Overall, the mediation analysis demonstrates that SRQ functions as a selective and environmentally oriented mediating mechanism rather than as a universally reinforcing sustainability factor. The findings therefore suggest that operational EMA practices remain the primary drivers of sustainability performance, whereas SRQ plays a complementary role that modifies or partially channels the impact of environmental management practices on sustainability outcomes.

The stronger mediating role of SRQ for environmental rather than economic sustainability outcomes may reflect the closer informational connection between sustainability reporting and environmental accountability. Environmental indicators such as energy consumption, emissions, and resource efficiency are directly incorporated into sustainability disclosure, monitoring, and accountability processes. Economic sustainability outcomes, by contrast, are affected by a broader range of financial, market, investment, and operational factors. This may explain why SRQ more clearly channels the effects of EMA practices toward environmental performance than toward short-term economic performance.

Table 11. Total effects assessment.

Relationship	Direct effect	Indirect effect	Total effect	Mediation type
Eco_Eff → CSP_Eco	-0.448**	0.150 (n.s.)	-0.298**	No mediation
Eco_Eff → CSP_Env	-0.570***	0.259**	-0.311**	Partial competitive mediation
Emi_Eff → CSP_Eco	0.801***	-0.123 (n.s.)	0.679***	No mediation
Emi_Eff → CSP_Env	0.405**	-0.212**	0.193*	Partial competitive mediation

Note: Eco_Eff = Eco-Efficiency; Emi_Eff = Emission Efficiency; SRQ = SRQ; CSP_Eco = Economic CSP; CSP_Env = Environmental CSP. Indirect effects are mediated through SRQ. Total effects represent the sum of direct and indirect effects. Partial competitive mediation indicates significant direct and indirect effects operating in opposite directions, while no mediation indicates a non-significant indirect effect. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; n.s. = not significant.

Overall, the structural model assessment provides substantial empirical evidence supporting the strategic role of EMA practices in shaping sustainability-related organizational outcomes within Saudi

petrochemical firms. The findings demonstrate that operational environmental management practices exert stronger and more consistent effects on sustainability performance and SRQ than sustainability reporting practices alone. These results are consistent with prior EMA and sustainability literature emphasizing that substantive environmental operational practices often generate stronger sustainability outcomes than disclosure-oriented sustainability initiatives alone [5–7,18].

These findings also highlight an important distinction between substantive sustainability practices and disclosure-oriented mechanisms. EMA practices are embedded in internal resource allocation, energy management, emission control, and operational decision-making and therefore influence sustainability outcomes more directly. SRQ primarily serves an external transparency and accountability function by communicating these underlying practices to stakeholders. Accordingly, sustainability reporting should be viewed as complementary to, rather than a substitute for, substantive environmental management practices.

More specifically, the results reveal that emission-efficiency and eco-efficiency practices significantly influence sustainability outcomes through direct and indirect mechanisms, although the mediating role of SRQ remains selective and more environmentally oriented than economically oriented. The mediation analysis further indicates that SRQ functions primarily as a complementary sustainability mechanism that partially channels and modifies the effects of operational environmental practices rather than fully mediating sustainability relationships. Similar selective sustainability mediation patterns have been reported in prior ESG and sustainability disclosure studies, highlighting the differentiated impacts of operational sustainability practices and disclosure mechanisms across sustainability dimensions [25,30].

The structural model results also highlight the multidimensional and complex nature of sustainability performance within environmentally intensive industries. While the model demonstrated moderate explanatory and predictive capability for economic sustainability performance and SRQ, environmental sustainability outcomes appear to be additionally influenced by broader operational, technological, and regulatory factors beyond the variables incorporated in the present framework. Such complexity has been widely emphasized in sustainability and ESG-related research, particularly within environmentally intensive sectors characterized by strong regulatory exposure and operational environmental pressures [8].

Overall, the findings support the suitability and empirical relevance of the proposed conceptual framework for examining the interrelationships among EMA practices, SRQ, and CSP within environmentally intensive industrial settings. The results further reinforce the importance of integrating substantive environmental operational practices with sustainability disclosure mechanisms to achieve more effective sustainability-oriented organizational transformation.

4.4. Discussion of findings

4.4.1. EMA as the primary sustainability driver

One of the most important findings of this study is the prominent role played by EMA practices in explaining sustainability-related organizational outcomes within Saudi petrochemical firms. The results demonstrate that substantive environmental operational practices are directly associated with

both CSP and SRQ. However, the magnitude of these relationships varies across the different pathways examined.

The effect-size analysis further clarifies this pattern. Both Eco_Eff and Emi_Eff exert large effects on SRQ ($f^2 = 0.698$ and 0.467 , respectively), while their direct effects on sustainability performance vary from small to medium across the economic and environmental dimensions. In contrast, SRQ exhibits only a very small effect on economic sustainability performance ($f^2 = 0.019$) and a small effect on environmental sustainability performance ($f^2 = 0.046$). This pattern suggests that EMA-related operational practices play a particularly substantial role in shaping SRQ. In contrast, their direct contribution to sustainability performance varies across specific economic and environmental pathways.

This result reinforces the core arguments of the EMA literature, which emphasizes that measurable sustainability improvements are more likely to emerge from substantive environmental management practices than from disclosure-oriented initiatives alone [5–7,18]. From this perspective, EMA systems provide firms with environmental and operational information that can support resource optimization, emissions control, environmental cost management, efficiency improvement, and long-term sustainability integration. Consequently, firms with stronger environmental management capabilities may be better positioned to achieve measurable sustainability improvements that extend beyond sustainability communication alone.

The medium effect size observed for emission efficiency on economic sustainability performance ($f^2 = 0.258$) further highlights the strategic relevance of operational carbon management within environmentally intensive industries such as petrochemicals. Improvements in emission efficiency may contribute to operational cost reduction, energy optimization, regulatory compliance, and more efficient resource utilization, thereby supporting firms' longer-term economic sustainability capabilities. This interpretation reflects the broader environmental management perspective that integrating environmental considerations into organizational decision-making can generate strategic and operational value [18].

Regional evidence provides an important context for interpreting these results. Abdel-Halim et al. [15], focusing on the Saudi petrochemical sector, highlighted the importance of sustainability accounting and reporting practices and stakeholder priorities in shaping corporate sustainability-related practices. The present study extends this evidence by empirically distinguishing substantive EMA practices from SRQ and by examining their respective relationships with measurable economic and environmental sustainability outcomes.

A complementary regional perspective was provided by Asiri et al. [37], who showed that organizational resources and coercive institutional pressures influence EMA adoption across the MENA region, including the six GCC countries. Whereas their study primarily examined the antecedents of EMA adoption, the present analysis shifts attention toward the organizational and sustainability-related outcomes associated with environmental management practices. The results show that EMA-related operational capabilities are significantly associated with both SRQ and CSP, thereby extending the regional discussion from the conditions supporting EMA adoption to its potential sustainability-related consequences.

These relationships are particularly relevant within the Saudi context, where Vision 2030 increasingly emphasizes industrial sustainability transformation, environmental efficiency, emissions

reduction, and ESG-oriented development. For strategically important and environmentally intensive sectors such as petrochemicals, meaningful sustainability transformation therefore appears to require integrating operational environmental management capabilities with sustainability governance and reporting practices, rather than relying on disclosure initiatives alone.

Beyond the direct influence of EMA practices, the results also reveal that SRQ plays a selective and complementary role across sustainability dimensions.

4.4.2. Selective environmental mediation of SRQ

The assessment of indirect and total effects reveals that SRQ plays a selective and predominantly environmentally oriented mediating role. Specifically, significant indirect effects through SRQ are observed for relationships involving environmental sustainability performance, whereas the corresponding indirect effects on economic sustainability performance are not statistically significant. This pattern suggests that sustainability disclosure mechanisms are more closely connected to environmental accountability, transparency, and ecological monitoring processes than to immediate economic sustainability improvements.

One possible explanation lies in the environmental orientation of sustainability reporting frameworks and ESG disclosure practices. Standards influenced by GRI and related sustainability frameworks place substantial emphasis on emissions reduction, energy efficiency, resource consumption, climate-related disclosure, and environmental governance. Consequently, firms with higher reporting quality may strengthen environmental transparency and stakeholder accountability, which can support environmentally oriented sustainability processes [30]. Other research similarly indicates that sustainability disclosure can contribute to governance primarily through enhanced transparency and accountability rather than through immediate financial performance effects [9,10].

Furthermore, the absence of statistically significant indirect effects through SRQ for economic sustainability indicates that disclosure quality alone may not translate into measurable short-term economic improvements. This interpretation is also consistent with the direct effect-size assessment, where SRQ exhibits a very small effect on economic sustainability performance ($f^2 = 0.019$), compared with a small effect on environmental sustainability performance ($f^2 = 0.046$). Economic sustainability outcomes are shaped by broader operational, strategic, market, and regulatory factors that extend beyond sustainability communication. Accordingly, while sustainability reporting may enhance corporate legitimacy, stakeholder confidence, and environmental transparency, its contribution to economic sustainability is likely to remain limited unless supported by substantive environmental operational improvements [8,25].

GCC-wide evidence provides an important regional comparison. Alruwaili and Alsulami [38], examining GRI-based sustainability disclosure and corporate performance among listed firms across GCC countries, report that the relationship between sustainability reporting and corporate performance varies across performance measures and national contexts. This study provides a more differentiated perspective within the Saudi petrochemical sector by showing that SRQ does not contribute uniformly across sustainability dimensions. Its mediating role is evident in the pathways leading to environmental sustainability outcomes, whereas the corresponding indirect effects on economic sustainability are not statistically significant.

This regional comparison highlights the importance of considering both the sustainability dimension being assessed and the operational capabilities underlying reported information. Within the present study, SRQ appears to function primarily as a complementary governance and accountability mechanism that supports environmental transparency and partially channels the effects of operational environmental practices rather than replacing them as the main driver of sustainability performance.

Taken together, this pattern reinforces the distinction between substantive sustainability integration and disclosure-oriented mechanisms. Firms may achieve relatively high levels of sustainability reporting while experiencing limited operational sustainability transformation if environmental management capabilities are insufficiently developed. In the Saudi petrochemical context, this distinction is particularly relevant as increasing sustainability expectations require firms to combine greater environmental transparency with deeper operational integration of sustainability practices.

Overall, sustainability reporting appears to be most effective when supported by substantive environmental management practices. SRQ therefore operates as a selective and complementary sustainability mechanism, with a more evident mediating role in environmental sustainability pathways than in economic sustainability pathways.

4.4.3. Interpretation of the Negative Eco_Eff Effects

One of the more unexpected results of this study is the negative direct relationship between Eco_Eff and both economic and environmental sustainability performance. Although eco-efficiency is generally expected to contribute positively to sustainability outcomes, the observed relationships suggest that its effects within Saudi petrochemical firms may be more complex and potentially shaped by transitional dynamics.

A plausible explanation relates to the transition costs associated with implementing environmentally oriented organizational improvements. Eco-efficiency initiatives often require substantial investments in cleaner technologies, process modernization, environmental monitoring systems, energy transition mechanisms, emissions-reduction technologies, and organizational restructuring. Such investments may initially impose financial and managerial burdens before their longer-term sustainability benefits become fully observable. Prior environmental management literature has similarly recognized that environmental investments may involve short-term implementation costs and organizational adjustment pressures before more stable benefits emerge [23,36]. Burritt and Christ [22] further emphasize the implementation and organizational adaptation challenges that may accompany environmental management initiatives in environmentally intensive industries.

The operational characteristics of the petrochemical industry provide an additional perspective for interpreting this pattern. Sustainability transformation in such a resource- and energy-intensive sector frequently requires large-scale industrial adjustments, technological upgrading, production-process redesign, and compliance with evolving environmental requirements. Firms pursuing substantial eco-efficiency improvements may therefore experience implementation pressures, adaptation costs, and organizational transformation challenges that can offset some of the expected benefits during the transition period.

A further consideration is the time horizon over which the benefits of eco-efficiency initiatives materialize. Such initiatives may generate stronger sustainability benefits over longer implementation periods, whereas the relationships observed during the study period may partly reflect adjustment costs and transition pressures. This interpretation is compatible with the broader environmental management literature, which recognizes that sustainability-oriented organizational transformation may involve gradual adaptation before more stable environmental and economic benefits emerge [5–7,18].

Furthermore, the positive indirect effects observed through SRQ provide an important complementary insight. SRQ partially offsets the negative direct relationship between Eco_Eff and environmental sustainability performance, indicating that reporting quality may play a supportive role in environmental accountability and transparency during sustainability transition. However, because the corresponding indirect effect on economic sustainability performance is not statistically significant, this complementary role should not be generalized across all sustainability dimensions.

Within the Saudi context, this interpretation is particularly relevant as Vision 2030 continues to encourage industrial modernization, cleaner technologies, resource efficiency, and lower-emission production. For petrochemical firms undergoing such transformation, the observed negative Eco_Eff relationships may therefore reflect, at least partly, the short-term pressures associated with environmental and operational adjustment rather than evidence that eco-efficiency is inherently detrimental to sustainability. This interpretation contributes to the sustainability transition discussion by highlighting the possibility that the benefits of eco-efficiency initiatives in environmentally intensive industries may emerge gradually rather than uniformly or immediately.

4.4.4. SRQ limitations and symbolic sustainability

The relatively limited direct contribution of SRQ to sustainability performance, particularly economic sustainability performance, provides an important basis for distinguishing sustainability disclosure and substantive sustainability integration. Although reporting quality contributes to transparency and accountability, the effect-size assessment indicates that its direct influence on economic and environmental sustainability performance remains very small and small, respectively. This pattern suggests that improvements in disclosure quality do not necessarily translate directly into equivalent improvements in measurable sustainability performance.

This distinction can be interpreted through the concepts of symbolic and substantive sustainability practices discussed in the ESG and sustainability reporting literature. Sustainability reporting may serve important functions by enhancing corporate transparency, stakeholder confidence, organizational legitimacy, and external accountability, while the underlying operational transformation may progress at a different pace. Michelon et al. and Hahn and Kühnen highlight the importance of distinguishing the quality and substantive content of sustainability disclosure from reporting practices that primarily serve communication or legitimacy purposes [25,30]. Cho et al. [24] similarly draw attention to the potential gap between sustainability communication and substantive organizational change.

Legitimacy Theory and Stakeholder Theory provide further insight into this distinction. From a legitimacy perspective, sustainability disclosure enables firms to communicate their environmental and social commitments and demonstrate alignment with broader societal expectations. Stakeholder Theory, in turn, explains how reporting responds to increasing demands from investors, regulators,

customers, and other stakeholders for greater transparency and accountability. However, these disclosure-related functions should not be assumed to produce operational sustainability improvements automatically. The value of SRQ therefore lies not only in the extent of disclosure but also in the extent to which reported information reflects and supports substantive environmental practices.

This interpretation is particularly relevant for environmentally intensive industries, where sustainability transformation often requires substantial technological investment, process redesign, resource-efficiency improvements, and organizational adaptation. In such settings, reporting practices and operational transformation may evolve at different speeds. Improvements in sustainability disclosure may become visible before the effects of deeper operational changes are fully reflected in measurable sustainability outcomes.

Within the Saudi petrochemical context, this distinction is relevant to the ongoing sustainability transformation associated with Vision 2030. Increasing expectations for ESG transparency and environmental accountability are encouraging firms to strengthen sustainability reporting. Furthermore, substantive operational transformation may require longer implementation horizons and significant investments in cleaner technologies, resource efficiency, and environmental management systems. The coexistence of these two processes highlights the importance of assessing sustainability reporting together with the underlying operational practices it is intended to represent.

Overall, the evidence supports a nuanced interpretation of SRQ: Sustainability reporting is valuable for transparency, legitimacy, and stakeholder accountability, but its contribution to measurable sustainability performance depends on its connection with substantive environmental management practices. This distinction helps explain why improvements in reporting quality and operational sustainability performance may not necessarily occur simultaneously or with the same magnitude.

4.4.5. Complexity of environmental sustainability performance

A further insight emerging from the structural model concerns the comparatively lower explanatory and predictive capability observed for environmental sustainability performance. The environmental sustainability construct (CSP_Env) exhibited relatively lower R^2 and Q^2 predict values than economic sustainability performance and SRQ. This pattern indicates that environmental sustainability outcomes may be influenced by a broader range of factors extending beyond the EMA and reporting variables incorporated in the present model.

The operational complexity of environmental sustainability within the petrochemical industry provides one explanation for this result. Environmental outcomes may depend not only on internal environmental management practices but also on technological capabilities, production intensity, energy market conditions, carbon-reduction technologies, environmental regulation, climate-related operational risks, and industry-specific environmental pressures. Such a combination of internal and external influences makes environmental sustainability more difficult to explain and predict through organizational accounting and disclosure variables alone [8]. De Villiers et al. [39] similarly emphasize that environmental sustainability outcomes in environmentally intensive sectors are shaped by evolving technological and regulatory conditions that extend beyond firms' internal sustainability management systems.

The comparatively lower predictive relevance of CSP_Env may also reflect the time required for environmental transformation to produce measurable outcomes. Investments in cleaner technologies, emissions-reduction initiatives, renewable energy integration, environmental compliance systems, and industrial restructuring may require extended implementation periods before their effects are fully reflected in environmental performance indicators. Prior environmental management research recognizes that sustainability-oriented organizational changes may generate gradual rather than immediate outcomes as firms adapt their technologies, processes, and management systems [5–7,18].

Another consideration is the multidimensional nature of environmental sustainability. Environmental performance reflects interconnected aspects such as emissions, energy use, resource efficiency, technological adaptation, environmental governance, and operational ecological performance. The interaction among these dimensions may contribute to greater variability in environmental outcomes and help explain why CSP_Env exhibits lower explanatory and predictive capability than the comparatively more stable economic sustainability indicators. This complexity highlights the importance of interpreting environmental sustainability as a context-dependent outcome that a limited set of organizational predictors cannot fully capture.

This interpretation is particularly relevant to the Saudi petrochemical sector, where sustainability transformation involves technological modernization, emissions reduction, energy-transition initiatives, and evolving environmental expectations. As firms adapt their operations to these changing conditions, environmental performance may increasingly depend on the interaction between internal management capabilities and broader technological, regulatory, and industrial developments. The strategic importance and environmental intensity of the sector therefore provide a particularly relevant context in which to observe the complexity of sustainability transformation.

Overall, the comparatively lower explanatory and predictive capability of CSP_Env should not be interpreted simply as evidence of limited model relevance. Rather, it reflects the complex and evolving nature of environmental sustainability performance, which is shaped by multiple operational, technological, institutional, and regulatory influences. This interpretation also identifies an important direction for future research: Extending the present model by incorporating additional technological, regulatory, and industry-level factors may provide a more comprehensive explanation of environmental sustainability outcomes.

5. Conclusion and implications

In this study, we investigated the interrelationships among EMA practices, SRQ, and CSP within Saudi petrochemical firms. By integrating eco-efficiency, emission-efficiency, sustainability disclosure quality, and multidimensional sustainability performance indicators into a unified conceptual framework, the study contributes to the growing sustainability accounting and ESG literature within environmentally intensive industrial contexts. The findings demonstrate that EMA practices exert stronger and more consistent effects on sustainability performance than sustainability disclosure mechanisms alone. More specifically, eco-efficiency and emission-efficiency practices were found to significantly influence SRQ and CSP through direct and indirect mechanisms, whereas SRQ exhibited comparatively weaker direct effects on economic sustainability outcomes.

The study further revealed that SRQ functions primarily as a selective and environmentally oriented mediating mechanism. While sustainability disclosure quality contributed positively to environmental sustainability performance through transparency, accountability, and environmental governance channels, its direct contribution to economic sustainability performance remained relatively limited. These findings reinforce the distinction between substantive sustainability integration and symbolic sustainability disclosure frequently emphasized within ESG and sustainability reporting literature. In addition, the negative direct effects associated with eco-efficiency practices highlighted the transitional and multidimensional nature of sustainability transformation within environmentally intensive industries, where sustainability-oriented operational improvements may initially generate adjustment costs and organizational restructuring pressures before producing stable long-term sustainability benefits.

From a theoretical perspective, the study contributes to EMA and sustainability reporting literature by demonstrating that substantive environmental operational practices remain more influential than disclosure-oriented sustainability mechanisms in driving measurable sustainability outcomes. The study also extends prior ESG and sustainability governance research by highlighting the selective mediating role of SRQ and the complexity of environmental sustainability performance within environmentally intensive sectors. Furthermore, the study contributes to the limited body of sustainability accounting research focusing on emerging sustainability transformation contexts within the Middle East and Saudi Arabia specifically.

From a practical perspective, the results have distinct implications for corporate managers, regulators and policymakers, and sustainability reporting practitioners.

For corporate managers, the results underscore the importance of integrating environmental performance information into internal accounting and decision-making rather than treating sustainability primarily as an external reporting function. Energy- and emission-efficiency indicators can be incorporated into investment evaluation, operational planning, budgeting, and performance-monitoring systems to provide managers with more systematic information on the environmental and economic consequences of operational decisions. The observed relationships involving eco-efficiency also suggest that environmental investments should be evaluated over appropriate time horizons, as implementation and adjustment costs may arise before longer-term sustainability benefits become fully observable. Managers should therefore assess environmental initiatives using short-term operational indicators and longer-term sustainability objectives.

For regulators and policymakers, the results highlight the need for stronger alignment between sustainability disclosure and measurable environmental performance. Reporting frameworks and sector-level guidance can encourage greater consistency and comparability in the disclosure of operational indicators related to energy use, emissions, and resource efficiency. Greater alignment between reported sustainability commitments and observable environmental performance can improve transparency and enable stakeholders to assess more effectively whether disclosed sustainability initiatives are supported by substantive operational improvements. In environmentally intensive sectors such as petrochemicals, this alignment can also support broader national objectives related to resource efficiency, emissions reduction, and industrial sustainability transformation.

For sustainability reporting practitioners, the selective role of SRQ indicates that improving disclosure should involve more than increasing the volume of reported information. Reporting

processes should be more closely connected to internally generated EMA information so that disclosed environmental indicators can be traced to underlying operational data and management systems. Greater attention to the relevance, consistency, comparability, and verifiability of sustainability information can strengthen reporting credibility and improve its usefulness for investors, regulators, and other stakeholders. Such integration can help sustainability reporting function as a more effective accountability mechanism while ensuring that external disclosures remain connected to substantive environmental management practices.

Despite its contributions, this study is subject to several limitations. First, the empirical analysis focused exclusively on Saudi petrochemical firms, which may limit the generalizability of the findings to other industrial sectors or geographical contexts. The sectoral characteristics of the sample also define important boundary conditions for interpreting the findings. Because petrochemical firms are highly capital-intensive, energy-intensive, and environmentally exposed, the observed relationships may be particularly relevant to other environmentally intensive industrial sectors. Caution should therefore be exercised when generalizing the results to service-oriented or less carbon-intensive industries, where environmental efficiency and emissions may have a less direct influence on organizational performance. Second, the study relied primarily on secondary sustainability disclosure and financial data, which may not fully capture the broader organizational dimensions of sustainability transformation and environmental management practices. Third, although the study incorporated multidimensional sustainability indicators, environmental sustainability performance remains a highly complex construct influenced by numerous technological, regulatory, institutional, and operational factors beyond those included in the present model.

In future studies, researchers may extend the present framework by examining additional industrial sectors, conducting cross-country comparative analyses, or integrating longitudinal sustainability transition perspectives over longer time horizons. Researchers may also incorporate governance-related variables, institutional pressures, digital sustainability technologies, or primary qualitative data to provide deeper insights into the organizational dynamics underlying sustainability transformation and EMA implementation. Finally, researchers could further explore how global ESG transformation trends, climate-related regulatory pressures, and sustainability governance developments influence EMA adoption and sustainability transformation within emerging sustainability-oriented economies.

Use of AI tools declaration

During the preparation of this work, the author used generative AI tools to assist with language editing and improvement of manuscript readability. The author reviewed and edited the content as needed and takes full responsibility for the final content of the publication.

Acknowledgments

The author(s) would like to thank Qassim University, represented by the Deanship of Graduate Studies & Scientific Research for financial support of this research (QU-ND95-2026). This research was funded by Qassim University, represented by the Deanship of Graduate Studies and Scientific Research, Grant No. QU-ND95-2026.

The data used in this study were obtained from publicly available annual reports, sustainability reports, and corporate disclosures of Saudi petrochemical companies. The datasets generated and analyzed during the current study are available from the author upon reasonable request.

Bilel Jarraya: Conceptualization, methodology, data curation, formal analysis, investigation, visualization, writing original draft, writing review and editing, project administration, and funding acquisition.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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