SUSTAINABILITY ANALYTICS FRAMEWORK FOR ESG PERFORMANCE AND CIRCULAR ECONOMY IN INDONESIA'S ELECTRIC VEHICLE INDUSTRY

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Abstract

The rapid growth of Indonesia's electric vehicle (EV) industry highlights the urgency of integrating sustainability into business strategies. However, many companies still face challenges in translating Environmental, Social, and Governance (ESG) commitments into operational practices that can strengthen long-term competitiveness. This study aims to develop and test a Sustainability Analytics Framework that links ESG Performance, Circular Economy Practices, Sustainability Analytics, and Sustainable Competitiveness. Using a quantitative approach, data were collected from 225 respondents representing managers and staff in EV-related industries, including automotive, battery production, and nickel mining. The data were analyzed using Structural Equation Modeling with Partial Least Squares (SEM-PLS) through SmartPLS 4.0. Results indicate that ESG Performance significantly influences both Circular Economy and Sustainability Analytics. Furthermore, Circular Economy and Sustainability Analytics serve as mediators that strengthen the effect of ESG on Sustainable Competitiveness. Among the tested relationships, Sustainability Analytics shows the strongest effect on competitiveness, emphasizing the role of data-driven decision-making in the global EV ecosystem. This study contributes by offering an integrated framework that guides Indonesian industries in meeting international sustainability standards such as the EU Battery Passport while enhancing long-term competitive advantage.

Keywords: ESG Performance, Circular Economy, Sustainability Analytics, Sustainable Competitiveness, Electric Vehicle.

JEL Classification: F43, O14, O18

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INTRODUCTION

The electric vehicle (EV) industry has become a central pillar in the global transition toward sustainable transportation. Governments, industries, and international institutions increasingly promote EV development as a strategic response to climate change, fossil fuel dependency, and environmental degradation (Pandey, 2025; Zaino et al., 2024). The electrification of transportation is widely regarded as a key pathway to reducing greenhouse gas emissions and supporting

long-term sustainable economic growth (Zhang & Fujimori, 2020).

In Indonesia, the EV industry holds strategic importance due to the country's abundant natural resources, particularly nickel, which is a critical component of lithium-ion batteries (Mubarok & Kartini, 2024; Pandyaswargo et al., 2021). Indonesia's ambition to become a global EV manufacturing and battery production hub has accelerated investments across mining, battery processing, and automotive manufacturing sectors. However, alongside these opportunities, the rapid growth of the EV industry raises significant environmental, social, and governance challenges that must be addressed to ensure sustainable development.

Environmental challenges include land degradation, biodiversity loss, and carbon emissions associated with nickel mining and battery manufacturing (Joseph, 2025; Mangani et al., 2025). Social challenges involve labor conditions, occupational safety, community displacement, and social conflicts in mining regions. Governance challenges arise from regulatory compliance, transparency, supply chain traceability, and alignment with international sustainability standards. As global markets increasingly demand responsible and traceable production processes, Indonesian EV firms face mounting pressure to demonstrate credible sustainability performance (Rosada, 2025).

Environmental, Social, and Governance (ESG) performance has emerged as a widely adopted framework for evaluating corporate sustainability and non-financial performance. ESG integrates environmental responsibility, social equity, and governance quality into a comprehensive assessment of how firms manage sustainability-related risks and opportunities. While ESG disclosure has gained prominence, particularly in capital markets, concerns remain regarding the extent to which ESG performance translates into tangible competitive advantages, especially in emerging industries such as electric vehicles.

Furthermore, sustainability is a crucial issue in the EV industry. While electric vehicles reduce emissions during use, their production processes, from nickel mining to battery disposal, pose new environmental challenges. The European Union (2023), through its Battery Regulation (Regulation (EU) 2023/1542), has set strict standards: starting in 2027, all EV batteries entering the European market must be equipped with a digital battery passport. This passport contains information on the origin of the raw materials, their carbon footprint, and the content of recycled materials. This means that EVs from Indonesia must meet international standards if they want to compete in the export market.

The Global Sustainable Investment Alliance (2022) noted that global sustainnable investment assets reached US$30.3 trillion. Investors are increasingly paying attention to ESG performance when channeling capital. Therefore, EV companies in Indonesia need to strengthen transparency and accountability to access competitive financing sources.

Geissdoerfer et al. (2017) asserted that the circular economy is a new paradigm that emphasizes the regeneration of production systems through the reuse, repair, and recycling of materials. Harper et al. (2019) in Nature showed that battery recycling strategies, through both hydrometallurgy and pyrometallurgy, can recover up to 90% of critical materials and reduce the need for new mining by up to 30%.

However, Indonesian literature still shows limitations. Kamarudin et al. (2025) examined the impact of electric vehicle adoption on national energy consumption, while Tangkudung and Kaseger (2024) focused more on the potential for nickel down streaming. These studies are important, but they fail to integrate ESG aspects with data analytics approaches. Marr (2021) highlights that data-driven sustainability analytics for managing

sustainability can improve energy efficiency by up to 15% compared to manual reporting.

By examining global trends, national policies, and existing literature, several research questions can be formulated: What is the current sustainability status of the Indonesian EV industry? How can a circular economy be applied to EV battery management? How can a sustainability analytics framework help Indonesian EV companies make proactive decisions that support global competitiveness?

This study aims to empirically examine the relationships among ESG Performance, Circular Economy practices, Sustainability Analytics, and Sustainable Competitiveness within Indonesia's electric vehicle industry. By integrating governance, operational sustainability, and data-driven capabilities, this research contributes to sustainability and operations management literature and provides practical insights for managers and policymakers seeking to enhance the global competitiveness of Indonesia's EV sector

Based on the problem formulation, the objective of this research is to design a Sustainability Analytics Framework that: (1) integrates cross-functional and supply chain ESG indicators, (2) utilizes descriptive, predictive, and prescriptive analytics in sustainability management, and (3) connects circular economy principles with EV industry strategies.

To address this gap, this study proposes a Sustainability Analytics Framework that integrates ESG Performance, Circular Economy practices, and Sustainability Analytics to explain Sustainable Competitiveness. Circular economy principles emphasize resource efficiency, waste reduction, recycling, and closed-loop systems, which are particularly relevant for battery lifecycle management. Sustainability analytics enables firms to collect, analyze, and utilize sustainability-related data to support decision-making, regulatory compliance, and strategic alignment.

LITERATURE REVIEW

This section reviews relevant theories and empirical studies related to ESG Performance, Circular Economy practices, Sustainability Analytics, and Sustainable Competitiveness. The review aims to establish a conceptual foundation for examining how sustainability governance, operational practices, and data-driven capabilities interact to shape long-term competitiveness in the electric vehicle industry. By synthesizing prior research, this section identifies key relationships and gaps that inform the development of the proposed research framework.

ESG Performance

In the electric vehicle industry, ESG performance is particularly critical due to complex and resource-intensive supply chains. Mining activities, battery production, and manufacturing processes expose firms to environmental risks and social scrutiny. Strong ESG governance enables firms to manage these risks more effectively, enhance transparency, and maintain legitimacy in global markets. Empirical studies consistently show that firms with superior ESG performance tend to benefit from improved reputation, reduced risk exposure, and enhanced access to capital (Dauerer et al., 2025).

The circular economy concept offers a practical mechanism for operationalizing ESG principles. Circular economy practices challenge the traditional linear production model by promoting recycling, reuse, remanufacturing, and lifecycle optimization (Arı et al., 2025). In the EV industry, circular strategies are especially important for battery recycling and second-life applications, which reduce environmental impact and dependence on virgin materials such as nickel and cobalt (Gizem Arı et al., 2025).

Sustainability analytics refers to the use of data analytics, digital technologies, and information systems to support sustainability management. From a resource-based view, sustainability analytics

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capability constitutes a strategic asset that enhances decision-making quality, operational efficiency, and regulatory compliance (Dauerer et al., 2025). Analytics enables firms to monitor ESG performance, assess lifecycle impacts, and provide verifiable sustainnability data demanded by international markets.

ESG Performance and Sustainability Analytics

Several recent studies support the link between ESG, CE, sustainability analytics, and sustainable competitiveness. Geissdoerfer et al. (2018) emphasize that the circular economy is closely linked to ESG practices, particularly in creating sustainable business models. Harper et al. (2019) show that implementing a circular economy in the electric vehicle industry, particularly battery recycling, can reduce dependence on new mining by up to 30% while opening up opportunities for innovation.

In terms of analytics, Lee et al. (2020) demonstrated that sustainability analytics plays a crucial role in a company's digital transformation, enabling more accurate, data-driven decision-making. Det Udomsap & Hallinger (2020) and Li et al. (2021) also emphasized that big data analytics has a significant contribution to creating sustainable competitive advantage. Albareda et al. (2022) added that ESG will only have a significant impact if translated operationally through the circular economy and sustainability analytics.

Furthermore, recent regulations, such as the EU Battery Passport released by the European Commission (2023), demonstrate that supply chain transparency and data-driven sustainability are now legal obligations, not simply strategic options. These findings suggest that the integration of ESG, CE, and analytics is becoming increasingly important, particularly in a rapidly growing industry like electric vehicles. However, research in the Indonesian context is still limited, so this study seeks to fill this gap by exploring the application of this framework to the national EV industry.

Based on these arguments, this study posits that ESG performance positively influences circular economy practices and sustainability analytics, which in turn enhance sustainable competitiveness. Circular economy practices and sustainability analytics are expected to mediate the relationship between ESG performance and sustainable competitiveness. First, ESG performance serves as the foundation that drives the implementation of a circular economy and the development of sustainability analytics. Second, a circular economy has a direct impact on competitiveness through material efficiency and process innovation. Third, sustainability analytics strengthens competitiveness through the ability to measure, control, and continuously improve ESG performance. Thus, the circular economy and sustainability analytics serve as mediators connecting ESG performance with sustainnable competitiveness. This means that companies cannot simply declare ESG commitments; they must also be able to implement them through circular practices and sustainnability analytics to truly achieve long-term competitiveness.

H1: ESG Performance has a positive impact on the Circular Economy.
H2: ESG Performance has a positive impact on Sustainability Analytics.
H3: Circular Economy has a positive impact on Sustainable Competitiveness.
H4: Sustainability Analytics has a positive impact on Sustainable Competitiveness.
H5: ESG Performance has a positive impact on Sustainable Competitiveness.
H6: Circular Economy has a positive impact on Sustainability Analytics.

RESEARCH METHODS

The research approach used in this study is an explanatory one with a causal associative design, which aims to explore and test the relationships between variables within the framework of a proposed

research model. This approach was chosen because the study seeks to explain how ESG performance, circular economy implementation, and sustainability analytics readiness can influence the competitive advantage of the electric vehicle industry in Indonesia.

The population consists of firms operating across the EV value chain, including automotive manufacturing, battery production, and nickel mining. Purposive sampling was applied to select respondents with at least two years of experience in sustainability management, operations, supply chain management, or strategic planning. A total of 225 valid responses were collected, meeting the requirements for Structural Equation Modeling with Partial Least Squares (SEM-PLS). The sampling technique used purposive sampling, where respondents were selected based on certain criteria, including working for a company involved in EV development, having at least two years of experience in sustainability, operations, or the supply chain, and being willing to complete the research questionnaire.

The research instrument was a questionnaire consisting of four main variables. The ESG performance variable was measured using 15 indicators adapted from the Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB) standards. The circular economy variable consisted of 10 indicators adapted from research by Harper et al. (2019) and Geissdoerfer et al. (2017). The sustainability analytics readiness variable included 12 indicators measuring a company's ability to integrate ESG data with descriptive, predictive, and prescriptive analytics, adapted from Marr (2021). Meanwhile, the EV industry competitive advantage variable was measured using eight indicators emphasizing cost efficiency, regulatory compliance, and investor attractiveness.

Respondents were asked to complete a statement-based questionnaire with a five-point Likert scale, ranging from "1 = strongly disagree" to "5 = strongly agree." Data were collected using a structured questionnaire measured on a five-point Likert scale. ESG Performance was measured through indicators related to environmental management, social responsibility, and governance quality. Circular Economy practices were measured through indicators capturing recycling, waste reduction, and lifecycle management. Sustainability Analytics was measured through indicators reflecting data collection, integration, and analytical capability. Sustainable Competitiveness was measured through indicators related to long-term efficiency, compliance, reputation, and market performance.

Before the questionnaire was widely distributed, a pilot test of the instrument was conducted on 30 initial respondents to test its validity and reliability. Validity testing was conducted using Corrected Item-Total Correlation analysis, where instrument items with correlation values greater than 0.30 were declared valid. Reliability testing used the Cronbach's Alpha coefficient, with values above 0.70 indicating the instrument's reliability. The pilot test results showed that all indicators met validity criteria, with correlation values ranging from 0.35 to 0.72, and Cronbach's Alpha values for all variables ranging from 0.78 to 0.91. This proves that the research instrument is suitable for primary data collection.

The Data analysis was conducted using SEM-PLS with SmartPLS 4.0. The analysis included measurement model evaluation to assess reliability and validity, followed by structural model evaluation to test hypothesized relationships and mediation effects. Ethical considerations were addressed by ensuring voluntary participation and respondent confidentiality. This analysis included Exploratory Factor Analysis (EFA) to determine the factor structure, Confirmatory Factor Analysis (CFA) to test the fit of the measurement model, and hypothesis

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testing of the structural model to assess the relationships between variables. Additional qualitative analysis was conducted on the expert interview data using thematic analysis techniques to strengthen the interpretation of the quantitative results.

With this research method, it is hoped that the study results will be able to provide a comprehensive explanation regarding the role of ESG, circular economy, and sustainability analytics in increasing the competitive advantage of the electric vehicle industry in Indonesia.

RESULT AND DISCUSSION

This study used 225 respondents from the electric vehicle industry, including automotive companies, battery manufacturers, and nickel mining companies that are part of the global supply chain. The analysis was conducted using the Structural Equation Modeling – Partial Least Squares (SEM-PLS) approach using SmartPLS 4.0. The analysis phase began with an evaluation of the measurement model (outer model) to test the validity and reliability of the instrument, followed by an evaluation of the structural model (inner model) to test the proposed hypotheses.

This study demonstrates that ESG Performance contributes to Sustainable Competitiveness primarily through Circular Economy practices and Sustainability Analytics. Firms that integrate ESG governance with operational sustainability and data-driven capabilities are better positioned to achieve long-term competitive advantage. SEM-PLS analysis conducted on data from 225 respondents showed that the research instrument was valid and reliable, as indicated by outer loadings values in Figure 1 mostly above 0.70 and AVE values above 0.50 (Hair et al., 2021). All constructs also met reliability criteria with Cronbach's Alpha and Composite Reliability values above 0.70. This confirms that the studied variables can consistently measure the phenomenon.

The research results in Table 1 show that ESG performance significantly impacts the circular economy and sustainability analytics. This finding indicates that strong sustainability governance encourages companies to adopt circular practices while building a more mature data infrastructure. A previous study by Geissdoerfer et al. (2018) also showed that ESG integration is a key driver in the transition to a circular economy. Furthermore, Marr (2021) stated that companies that develop ESG-based analytics systems are able to increase operational efficiency while improving their global reputation.

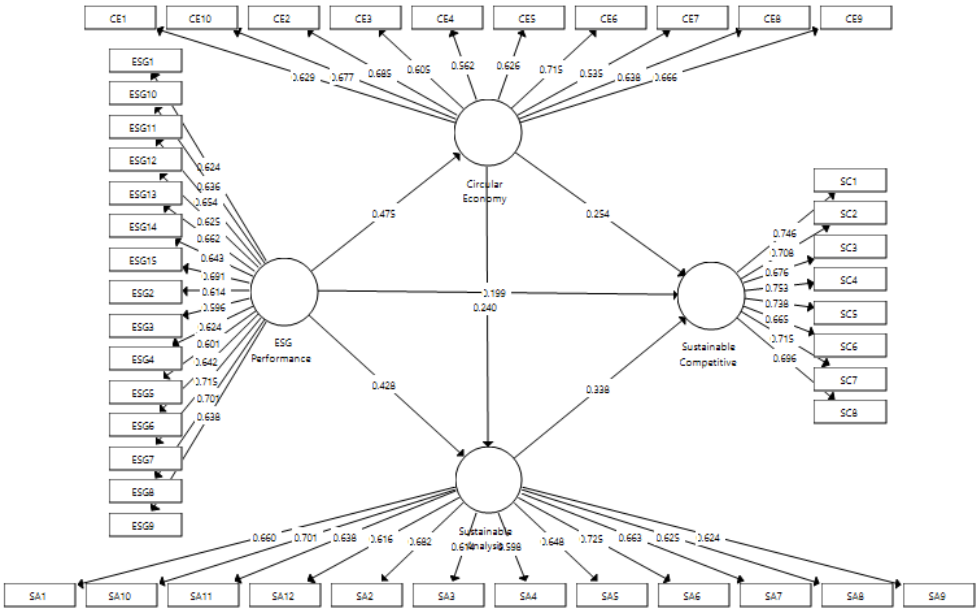

Figure 1. Results of SEM-PLS

Table 1. Results of Hypothesis-testing

Hypothesis	Relationship	Coefficient	T-stat	P-value	Conclusion
H_1	ESG → Circular Economy	0.475	10.292	0.000	Accepted
H_2	ESG → Sustainability Analytics	0.428	7.407	0.000	Accepted
H_3	Circular Economy → Sustainable Competitiveness	0.254	4.155	0.000	Accepted
H_4	Sustainability Analytics → Sustainable Competitiveness	0.338	6.405	0.000	Accepted
H_5	ESG → Sustainable Competitiveness	0.199	3.505	0.000	Accepted
H_6	Circular Economy → Sustainability Analytics)	0.240	4.439	0.000	Accepted

Furthermore, Circular Economy Practices and Sustainability Analytics have been shown to be key links between ESG and Sustainable Competitiveness. Circular economy contributes through material efficiency, recycling, and product innovation, as explained by Harper et al. (2019) who found that circular practices in the battery industry not only impact the environment but also increase economic opportunities. Furthermore, sustainability analytics has been shown to have the strongest impact on competitiveness, as companies that utilize data analytics are better able to forecast market needs, optimize supply chains, and comply with global regulations (Sun et al., 2022). These findings support Lee et al.'s (2020) argument that the success of sustainability strategies in the digital age is largely determined by a company's ability to transform data into actionable decisions.

From a Managerially, firms should embed ESG principles into core operations rather than treating them as symbolic or compliance-oriented activities. Investment in sustainability analytics is critical for meeting international market demands and enhancing strategic decision-making. Circular economy initiatives should be aligned with business objectives to deliver both sustainability and economic benefits. In the Indonesian context, this is particularly relevant given that international regulations such as the EU Battery Passport 2023 require transparency of nickel and battery supply chain data. If Indonesian companies can simultaneously integrate ESG, the circular economy, and sustainability analytics, they will not only be able to survive but also gain a competitive advantage in the global market (European Commission, 2023; Albareda et al., 2022).

The results of the study indicate that "ESG Performance" significantly influences "Circular Economy Practices." This means that companies with more ESG maturity tend to more consistently adopt circular economy practices, such as waste management, energy efficiency, and material recycling. This finding supports the research of Geissdoerfer et al. (2018), which explains that the success of the transition to a circular economy is highly dependent on the integration of ESG aspects into corporate strategy. In Indonesia, this is relevant given that the nickel and battery industries are facing pressure from the EU Battery Passport regulation, which requires transparency of material origins (European Commission, 2023).

Furthermore, this study also demonstrates that ESG performance positively impacts sustainability analytics. Companies that seriously implement ESG typically develop digital reporting systems and data infrastructure to monitor carbon emissions, energy use, and social performance. This finding aligns with Marr (2021), who emphasized that integrating ESG with analytics can increase operational efficiency by up to 15% through sustainability-based data management. This finding is further supported by

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research by Sun et al. (2022), which shows that companies with mature sustainability analytics systems are better able to meet international standards and attract green investment.

Other findings show that Circular Economy Practices have a positive impact on Sustainable Competitiveness. This means that adopting circular economy practices can strengthen a company's competitive position through cost savings, product innovation, and an enhanced eco-friendly brand image. Harper et al. (2019) in their study of the battery supply chain stated that the circular economy not only provides environmental benefits but also opens up new business opportunities such as processing waste into secondary raw materials. This context is relevant to Indonesia as the world's largest nickel producer, where battery recycling can be a long-term strategy to maintain global competitiveness.

Furthermore, Sustainability Analytics has the strongest influence on Sustainable Competitiveness. By utilizing data analytics, companies can forecast market needs, optimize supply chains, and design faster product innovations. These results are consistent with Lee et al.'s (2020) opinion, which states that the success of a sustainability strategy is largely determined by a company's ability to transform data into actionable insights. In the electric vehicle industry, the application of analytics allows companies to monitor the battery life cycle, from nickel extraction, production, use, to recycling.

Although ESG performance also directly impacts sustainable competitiveness, this study's results show that its impact is smaller than when mediated by the circular economy and sustainability analytics. This means that ESG performance serves as a foundation, but competitive value is only achieved when ESG is translated into concrete operational practices. This reinforces the view of Albareda et al. (2022), who emphasize that sustainability is not just about compliance but rather a measurable and integrated business strategy.

Finally, this study found that Circular Economy Practices influence Sustainability Analytics. The implementation of recycling systems and closed-loop supply chains encourages companies to build analytics platforms that can digitally track material flows. This aligns with the provisions of the EU Battery Regulation 2023, which emphasizes the use of digital product passports to ensure transparency throughout the product lifecycle. Thus, the circular economy and sustainability analytics are not two separate entities, but rather mutually reinforcing in creating sustainable competitiveness.

Discussion

In terms of current conditions, Indonesia’s electric vehicle industry is experiencing rapid growth while facing increasing demands for sustainability compliance, supply chain transparency, and alignment with international market standards. The findings of this study indicate that the integration of ESG performance, circular economy practices, and sustainability analytics is no longer optional, but has become a structural requirement for firms operating within global EV value chains. The enforcement of regulations such as the EU Battery Regulation reflects a broader global shift in which sustainability performance is increasingly embedded in trade access, investment decisions, and industrial competitiveness.

From an economic policy perspective, these results suggest that national EV and industrial development policies should move beyond resource-based and production-oriented strategies toward frameworks that actively support data-driven sustainability and circular economy integration. Policymakers can facilitate this transition by promoting standardized ESG data reporting, supporting investments in sustainability analytics infrastructure, and providing incentives for circular economy

initiatives across the EV ecosystem. Aligning industrial, environmental, and digital transformation policies will strengthen Indonesia's position in global EV markets, enhance value creation from nickel and battery industries, and reduce long-term economic and environmental risks. In this context, the integration of ESG, circular economy practices, and sustainability analytics emerges not only as a firm-level strategy but also as a key pillar of sustainable economic policy for the development of a competitive and low-carbon EV industry.

CONCLUSION AND RECOMMENDATION

Based on these conclusions, several recommendations can be proposed. Firms in Indonesia's electric vehicle industry should prioritize the integration of ESG principles into core operational and strategic decision-making rather than treating them as compliance-oriented activities. Investment in sustainability analytics infrastructure is essential to ensure accurate measurement, monitoring, and reporting of ESG and circular economy performance, particularly in response to increasing global requirements for supply chain transparency. In parallel, policymakers should support the development of standardized ESG data frameworks and provide incentives for circular economy initiatives across the EV value chain. Such coordinated efforts between industry and government can strengthen Indonesia's position in global EV markets while ensuring long-term economic resilience and sustainability.

This study concludes that ESG performance plays a fundamental role in enhancing sustainable competitiveness in Indonesia's electric vehicle industry. The research objectives are achieved by demonstrating that ESG performance positively drives the implementation of circular economy practices and the development of sustainability analytics capabilities. The findings confirm that circular economy practices strengthen competitiveness by improving resource efficiency, innovation, and long-term operational sustainability. In addition, sustainability analytics emerges as a critical mechanism that enables firms to measure, control, and continuously improve ESG and circular economy performance in a systematic manner. The results further indicate that ESG performance alone is insufficient to generate sustainable competitiveness unless it is operationalized through circular economy strategies and supported by data-driven analytics. From a managerial perspective, companies should integrate ESG into core business processes, invest in sustainability analytics systems, and align circular economy initiatives with strategic objectives to meet global market demands and achieve long-term competitive advantage.

The practical implication is that companies in the electric vehicle sector need to allocate investment in sustainability analytics systems and build strategic partnerships within the circular economy ecosystem to meet the increasingly stringent global market demands for sustainability.

Limitation and future studies

Despite its contributions, this study has several limitations that should be acknowledged, as they may influence the interpretation of the results and the generalizability of the conclusions. First, the scope of the research is limited to the electric vehicle industry in Indonesia, which may restrict the applicability of the findings to other industries or national contexts with different regulatory environments and levels of sustainability maturity. Second, the study relies on cross-sectional survey data, which captures respondents' perceptions at a single point in time and does not fully reflect dynamic changes in ESG practices, circular economy implementation, or sustainability analytics capabilities. Third, the use of self-reported data may introduce subjective bias, as

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respondents may overestimate their firms' sustainability performance or analytical readiness.

These limitations suggest several directions for future research. Future studies could expand the scope by conducting cross-country or cross-industry comparesons to enhance external validity and deepen understanding of contextual differences. Longitudinal research designs are also recommended to examine how ESG performance, circular economy practices, and sustainability analytics evolve over time and affect sustainable competitiveness in the long run. In addition, future research may incorporate objective secondary data, qualitative case studies, or mixed-method approaches to reduce perceptual bias and provide richer insights into managerial decision-making processes related to sustainability-driven competitiveness.

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