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The Effect of Life Cycle Assessment on Performance Sustainability: The Moderating Roles of Bioaccounting and Smart Environmental

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ABSTRACT

This study examines the effect of Life Cycle Assessment (LCA) on performance sustainability and investigates the moderating roles of bioaccounting and smart environmental capabilities. Using a quantitative approach, data were collected from managers and decision-makers in broiler production companies and analysed using Partial Least Squares–Structural Equation Modeling (PLS-SEM). The results indicate that LCA has a significant positive effect on performance sustainability, while bioaccounting and smart environmental significantly strengthen this relationship. This study contributes to sustainability accounting literature by demonstrating how organisational capabilities enhance the effectiveness of LCA in achieving sustainable performance

ABSTRAK

Penelitian ini mengkaji pengaruh Life Cycle Assessment (LCA) terhadap keberlanjutan kinerja serta menganalisis peran moderasi bioaccounting dan kapabilitas smart environmental. Dengan menggunakan pendekatan kuantitatif, data dikumpulkan dari manajer dan pengambil keputusan pada perusahaan produksi ayam broiler, kemudian dianalisis menggunakan metode Partial Least Squares–Structural Equation Modeling (PLS-SEM). Hasil penelitian menunjukkan bahwa Life Cycle Assessment berpengaruh positif dan signifikan terhadap keberlanjutan kinerja, sementara bioaccounting dan smart environmental terbukti secara signifikan memperkuat hubungan tersebut. Penelitian ini berkontribusi pada literatur akuntansi keberlanjutan dengan menunjukkan bahwa kapabilitas organisasi berperan penting dalam meningkatkan efektivitas penerapan Life Cycle Assessment untuk mencapai kinerja yang berkelanjutan

INTRODUCTION

The increasing urgency of environmental degradation and climate change has prompted a global shift towards sustainability in various sectors, particularly in business and agriculture(Kariyasa & Dewi, 2011; Xu & Zhang, 2025). The concept of sustainability is multifaceted, encompassing environmental, social, and economic dimensions. As industries strive to enhance their sustainability profiles, the integration of life cycle assessment (LCA) and performance sustainability has emerged as a critical area of research(Kadawo et al., 2023; Ošlovnik & Denac, 2025; Präger et al., 2025; Wehner et al., 2022).

Despite growing pressure to adopt sustainability strategies, many firms face significant

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challenges in translating environmental initiatives into measurable performance outcomes. Companies often implement sustainability practices in a fragmented manner, lacking integrated systems that connect environmental assessments with managerial decision-making and performance evaluation. As a result, sustainability efforts frequently remain symbolic rather than performance-oriented.Therefore, this study aims to examine the effect of Life Cycle Assessment on performance sustainability and to investigate the moderating roles of bioaccounting and smart environmental capabilities in strengthening this relationship

This integration not only facilitates a comprehensive understanding of the environmental impacts associated with products and processes but also aligns corporate strategies with sustainable practices. The need for robust frameworks that incorporate bioaccounting and smart environmental as dual moderating factors in sustainability assessments has become increasingly apparent.(Abrol, 2025; Doifode et al., 2024; Farfan-Lievano et al., 2024; Sugiharto et al., 2024b, 2024a; Zeynali et al., 2025) .

Research in this domain is driven by the recognition that traditional accounting practices often overlook the environmental costs associated with production and consumption. Bioaccounting, which extends beyond conventional accounting to include ecological considerations, offers a pathway to quantify and manage these costs effectively. By integrating bioaccounting with LCA, organisations can better understand the ecological footprint of their operations, thereby enabling more informed decision-making. Furthermore, the role of smart environmental —defined as the ability to gather, analyse, and interpret environmental data—serves as a crucial complement to bioaccounting. Together, these frameworks can enhance the accuracy of sustainability assessments and improve organisational performance in terms of environmental responsibility.

The formulation of this research is anchored in the observation that many organisations struggle to implement effective sustainability strategies due to a lack of integrated approaches. While LCA provides a systematic method for evaluating the environmental impacts of products throughout their life cycles, the absence of a cohesive strategy that incorporates financial and ecological considerations often leads to suboptimal outcomes.

This research aims to address this gap by exploring how bioaccounting and smart environmental can function as moderating factors in the relationship between life cycle sustainability and performance sustainability. By examining existing literature and case studies, this study will elucidate the potential benefits of this integration, thereby contributing to the broader discourse on sustainable development. The purpose of this research is to evaluate the roles of bioaccounting and smart environmental in enhancing the effectiveness of sustainability assessments. Specifically, this study seeks to identify the mechanisms through which these factors influence the relationship between life cycle assessment and performance sustainability. Through a comprehensive analysis of relevant case studies and empirical data, this research aims to provide actionable insights for practitioners and policymakers seeking to implement more effective sustainability strategies. Ultimately, the findings will contribute to the development of a more integrated framework for sustainability that aligns environmental goals with organisational performance.

Finally, the integration of life cycle and performance sustainability represents a critical frontier in the quest for sustainable development. By leveraging the dual moderating factors of bioaccounting and smart environmental , organisations can enhance their understanding of the environmental impacts of their operations and make more informed decisions that align with sustainability goals. This research not only addresses a significant gap in the literature but also provides a foundation for future studies aimed at advancing the integration of sustainability practices across various sectors. As the urgency for sustainable solutions continues to grow, the insights derived from this research will be invaluable in guiding organisations towards more responsible and effective environmental stewardship

This study is grounded in Stakeholder Theory**,** Natural Resource-Based View (NRBV)**, and** Sustainability Accounting Theory. Stakeholder Theory posits that organisational performance sustainability is influenced by the firm's ability to respond to environmental and social expectations from multiple stakeholders. In parallel, the Natural Resource-Based View emphasises that competitive advantage can be achieved through effective management of environmental resources and ecological capabilities. Sustainability Accounting Theory further extends this perspective by arguing that environmental and biological resources must be recognised, measured, and integrated into organisational decision-making systems.

Within this theoretical context, Life Cycle Assessment (LCA) functions as a strategic tool to identify environmental impacts across production stages, while bioaccounting and smart environmental act as organisational capabilities that translate environmental information into performance-oriented decisions. Therefore, this research empirically tests how LCA influences performance sustainability and how bioaccounting and smart environmental strengthen this relationship as moderating mechanisms This study is based on the essential concept that Life Cycle Assessment alone is insufficient to ensure performance sustainability unless environmental information is effectively internalised into organisational systems. Therefore, bioaccounting and smart environmental capabilities are positioned as critical organisational mechanisms that determine the effectiveness of LCA in achieving sustainable performance outcomes.

THEORETICAL FRAMEWORK AND HYPOTHESES

A. Life Cycle Assessment and Performance Sustainability

In recent years, the concept of sustainability has garnered significant attention across various sectors, particularly in the context of environmental management and corporate responsibility. Life Cycle Assessment (LCA) serves as a critical tool in this domain, enabling organisations to evaluate the environmental impacts associated with all stages of a product's life, from raw material extraction through to disposal (Alhumoudi et al., 2024). The importance of LCA lies in its comprehensive approach, which not only assesses direct emissions but also considers indirect effects, thereby providing a holistic view of sustainability performance. For instance, a study by (H. Ahmed et al., 2025; N. Ahmed et al., 2025; Arvandi et al., 2025; Einas Azher et al., 2025a, 2025b) highlighted that leading agricultural economies that implemented LCA methodologies significantly reduced their soil emissions, demonstrating the potential for LCA to drive sustainable practices. Previous studies suggest that Life Cycle Assessment alone may not be sufficient to improve sustainability performance unless supported by organisational mechanisms that internalise environmental information. Bioaccounting and smart environmental capabilities therefore play a critical role in strengthening the relationship between LCA and performance sustainability by enabling the effective utilisation of environmental information in organisational decision-making processes.

Moreover, performance sustainability extends beyond environmental metrics to encompass economic and social dimensions, creating a multi-faceted framework for evaluating corporate performance (Iqbal Chaudhry et al., 2020). This integration is vital as businesses face increasing pressure from stakeholders to demonstrate not just profitability but also a commitment to sustainable practices. The dual focus on environmental and performance sustainability is exemplified by organisations that have adopted comprehensive sustainability reporting frameworks, which incorporate LCA findings alongside financial performance metrics (Aureli et al., 2023).

However, the integration of LCA into performance sustainability is not without challenges. Companies often struggle with data collection and analysis, which can hinder the effective implementation of sustainability initiatives(Almasyhari et al., 2025). Furthermore, the lack of standardisation in LCA methodologies can lead to inconsistencies in reporting and benchmarking, making it difficult for organisations to compare their performance against industry standards. This underscores the need for robust moderating factors, such as bioaccounting and smart environmental , to enhance the effectiveness of LCA in driving sustainability. From a theoretical standpoint, Life Cycle Assessment provides a systematic evaluation of environmental impacts throughout the product life cycle. However, LCA alone does not automatically lead to performance sustainability unless its information is internalised into organisational systems. This implies that the effect of LCA on sustainability performance is contingent upon the organisation's accounting and environmental intelligence capabilities, which justifies the inclusion of moderating variables in this study.

H1: *Life Cycle Assessment has a positive and significant effect on performance sustainability.*

B. Bioaccounting as a Moderator between LCA and Performance Sustainability

Bioaccounting refers to an accounting approach that incorporates biological and environmental information into organisational accounting systems to support sustainability-oriented decision-making. Unlike traditional accounting, bioaccounting emphasises the measurement, recording, and reporting of environmental impacts and resource use. In the context of Life Cycle Assessment, bioaccounting functions as a mechanism that translates LCA results into managerial and financial information, thereby enhancing their relevance for sustainability performance.

Bioaccounting, which involves the integration of biological and ecological metrics into accounting practices, offers a promising avenue for addressing these challenges. By incorporating ecological data into financial assessments, organisations can gain a more nuanced understanding of their environmental impacts and make informed decisions that align with sustainability goals (Farfan-Lievano et al., 2024). Similarly, smart environmental —defined as the ability to collect, analyse, and interpret environmental data—can provide organisations with the insights needed to optimise their sustainability strategies (Xia et al., 2025). Together, these factors can serve as vital tools in bridging the gap between LCA and performance sustainability. Finally, the integration of life cycle assessment and performance sustainability is crucial for organisations aiming to enhance their environmental stewardship while maintaining competitive advantage. The roles of bioaccounting and smart environmental as dual moderating factors present a unique opportunity to strengthen this integration, enabling companies to navigate the complexities of sustainability in a rapidly evolving landscape.

Bioaccounting plays a pivotal role in advancing sustainability metrics by incorporating ecological considerations into traditional accounting practices. This innovative approach allows organisations to quantify their environmental impacts in financial terms, thereby facilitating informed decision-making and strategic planning (Alhumoudi et al., 2024). For instance, companies that have adopted bioaccounting frameworks can effectively track their resource utilisation, emissions, and waste generation, leading to improved sustainability performance. A notable example is the poultry industry, where bioaccounting has been employed to assess the environmental impacts of various production methods, revealing significant opportunities for reducing nitrogen utilisation and improving overall efficiency (Alfonso-Avila et al., 2022).

One of the most compelling aspects of bioaccounting is its ability to foster transparency and accountability. By integrating ecological metrics into financial reporting, organisations can provide stakeholders with a clearer picture of their environmental performance(Farfan-Lievano et al., 2024). This transparency is increasingly demanded by consumers and investors alike, who are seeking assurance that their choices are contributing to sustainable practices. A study by (Iqbal Chaudhry et al., 2020) found that firms employing environmental management accounting techniques reported enhanced financial performance, indicating a positive correlation between sustainability and profitability. Moreover, bioaccounting can drive innovation by encouraging organisations to explore alternative production methods and resource management strategies. For example, the adoption of low-protein feed in poultry production has been linked to reduced nitrogen emissions and improved litter quality. By quantifying the environmental benefits of such innovations, bioaccounting can motivate companies to invest in sustainable technologies and practices that align with their long-term goals.

Despite its advantages, the implementation of bioaccounting is not without challenges. Many organisations face difficulties in collecting and analysing the necessary ecological data, which can complicate the integration of bioaccounting into existing accounting frameworks (Almasyhari et al., 2025). Additionally, the lack of standardised metrics for ecological accounting can lead to inconsistencies in reporting, making it challenging for stakeholders to evaluate performance across different organisations. Addressing these challenges will require collaboration between industry stakeholders, regulatory bodies, and academia to develop robust bioaccounting standards and methodologies. In conclusion, bioaccounting represents a transformative approach to enhancing sustainability metrics within organisations. By integrating ecological considerations into financial assessments, companies can improve their environmental performance, foster transparency, and drive innovation. As the demand for sustainable practices continues to rise, the role of bioaccounting will be increasingly critical in shaping the future of corporate sustainability. Bioaccounting strengthens the relationship between Life Cycle Assessment and performance sustainability by translating environmental impact data into measurable economic and managerial information. While LCA identifies environmental burdens across production stages, bioaccounting enables organisations to monetise and internalise these impacts into cost structures, performance evaluation, and strategic decision-making. In organisations with strong bioaccounting practices, LCA results are more likely to influence sustainability-oriented investments, resource efficiency initiatives, and long-term performance outcomes. Conversely, in organisations with weak bioaccounting systems, LCA findings may remain symbolic and fail to generate tangible performance improvements. Thus, bioaccounting is expected to **moderate** the effect of LCA on performance sustainability.

H2: Bioaccounting positively moderates the relationship between Life Cycle Assessment and performance sustainability.

C. Smart Environmental as a Moderating Variable

Smart environmental capability refers to the use of digital technologies, data analytics, and intelligent systems to monitor, analyse, and manage environmental performance in real time. This capability enables organisations to respond more effectively to environmental information generated by tools such as Life Cycle Assessment. By integrating smart environmental systems, firms can improve the accuracy, timeliness, and strategic use of environmental data, which ultimately strengthens sustainability performance.

Smart environmental encompasses the processes, technologies, and methodologies used to collect, analyse, and interpret environmental data to inform decision-making (Xia et al., 2025). Its significance in the realm of sustainability cannot be overstated, as it provides organisations with the insights necessary to understand their environmental impacts and develop effective strategies for improvement. For instance, the integration of deep learning models in predicting vehicle CO2 emissions has demonstrated the potential of smart environmental to enhance the accuracy of emissions assessments and inform policy decisions(Alam et al., 2025).

One of the primary benefits of smart environmental is its ability to facilitate real-time monitoring and reporting of environmental performance. By leveraging advanced data analytics and IoT technologies, organisations can track their resource consumption, emissions, and waste generation in real-time, allowing for timely interventions and adjustments to operations (Sugiharto et al., 2024a, 2024b). this proactive approach not only enhances sustainability performance but also contributes to cost savings and operational efficiency. Furthermore, smart environmental can support organisations in identifying trends and patterns in their environmental data, enabling them to make data-driven decisions that align with their sustainability goals. For example, a study by (Boiger et al., 2025) highlighted how multi-objective optimisation approaches can be employed to maximise greenhouse gas emission reductions in the bioeconomy. By utilising smart environmental , organisations can identify the most effective strategies for minimising their environmental footprint while maximising economic benefits.

Despite its potential, the adoption of smart environmental is often hindered by challenges related to data integration and analysis. Many organisations struggle with siloed data systems, which can impede their ability to gain a comprehensive understanding of their environmental impacts (Nair et al., 2022). Additionally, the complexity of environmental data can pose challenges in terms of interpretation and application, necessitating the development of user-friendly tools and frameworks that facilitate data-driven decision-making. Smart environmental serves as a key enabler of sustainability by providing organisations with the insights needed to understand and manage their environmental impacts. By leveraging advanced data analytics and real-time monitoring, companies can enhance their sustainability performance and drive innovation. As the demand for sustainable practices continues to grow, the role of smart environmental will be increasingly vital in shaping the future of corporate responsibility.

Smart environmental refers to the organisational capability to collect, analyse, and utilise environmental data through intelligent systems and digital technologies. In the context of LCA, smart environmental enhances the timeliness, accuracy, and usability of life cycle information for operational and strategic decisions. Organisations with advanced smart environmental capabilities are better positioned to transform LCA outputs into adaptive environmental strategies, predictive risk management, and continuous performance improvements. Therefore, smart environmental does not act as a direct determinant of sustainability performance but rather amplifies the effectiveness of LCA in improving **pe**rformance sustainability.

H3: Smart environmental positively moderates the relationship between Life Cycle Assessment and performance sustainability.

D. The Synergistic Relationship Between Bioaccounting and Smart environmental

The integration of bioaccounting and smart environmental presents a unique opportunity for organisations to enhance their sustainability practices. By combining ecological accounting metrics with advanced data analytics, companies can gain a comprehensive understanding of their environmental impacts and make informed decisions that align with their sustainability goals. This synergistic relationship enables organisations to not only quantify their ecological footprint but also to optimise their resource utilisation and emissions management. One of the key advantages of this integration is the ability to create more accurate and comprehensive sustainability reports. Traditional sustainability reporting often relies on fragmented data sources, which can lead to inconsistencies and inaccuracies in reporting.

However, by employing bioaccounting methodologies alongside smart environmental tools, organisations can develop a more cohesive and reliable reporting framework that reflects their true environmental performance. This enhanced transparency is essential for building trust with stakeholders and demonstrating a commitment to sustainability. Moreover, the combination of bioaccounting and smart environmental can drive innovation by uncovering new opportunities for resource efficiency and waste reduction. For instance, the application of life cycle costing in conjunction with environmental data analysis can help organisations identify cost-effective strategies for minimising their environmental impacts while maximising economic returns (Ippolito et al., 2024) . This approach not only supports sustainability goals but also contributes to the overall competitiveness of organisations in the marketplace. Despite the potential benefits, the integration of bioaccounting and smart environmental requires a cultural shift within organisations. Many companies still operate within traditional accounting frameworks that prioritise financial metrics over ecological considerations (Kazancoglu et al., 2021)To fully leverage the advantages of this integration, organisations must foster a culture of sustainability that values ecological performance alongside financial success. This may involve training staff, investing in new technologies, and developing cross-functional teams that can drive sustainability initiatives forward. The synergistic relationship between bioaccounting and smart environmental offers a powerful framework for enhancing sustainability practices within organisations. By integrating ecological accounting metrics with advanced data analytics, companies can gain a comprehensive understanding of their environmental impacts and drive innovation in resource management. As the demand for sustainable practices continues to rise, the integration of these two approaches will be critical in shaping the future of corporate sustainability.

H4: *Bioaccounting has a positive and significant effect on smart environmental capability.*

RESEARCH METHOD

The main materials employed in this research to evaluate the sustainability of broiler chicken production comprise feed components, water, and litter. The feed consisted of low-protein corn and soybean meal, chosen for their nutritional value and availability (Alfonso-Avila et al. 2022). This selection is vital for comprehending the environmental ramifications of waste management in poultry farming (Guðjónsdóttir et al., 2025). The system is capable of delivering real-time data, which is essential for ensuring optimal conditions for broiler chickens while minimising environmental effects. Additionally, a climate-controlled poultry facility fitted with automated feeding and watering systems was used to maintain consistent environmental conditions for the birds throughout the research.

Methodology

The approach for this study incorporated a thorough life cycle assessment framework that encompassed several crucial phases: defining the goal and scope, conducting inventory analysis, performing impact assessment, and interpreting results. The objective was to analyse the environmental effects of broiler chicken production from feed sourcing to waste management, with an emphasis on integrating bioaccounting principles to evaluate the economic implications of environmental costs. Data collection occurred over a 12-week timeframe, during which broiler chickens were reared under regulated conditions. Throughout this duration, daily feed intake, water usage, and growth rates were carefully documented. Alongside quantitative data, qualitative evaluations were carried out through farmer surveys to collect insights on best practices and obstacles in sustainable broiler production. These surveys provided context for the quantitative results and assisted in pinpointing areas for enhancement in environmental management strategies. The integration of both quantitative and qualitative data guarantees a comprehensive understanding of the sustainability challenges encountered in broiler chicken production, thereby aiding informed decision-making for future advancements

Operational Definition and Measurement of Variables

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) refers to a systematic evaluation of environmental impacts associated with all stages of a product’s life cycle, from raw material acquisition to waste management. In this study, LCA is measured using indicators adapted from prior sustainability and environmental management literature, including feed efficiency, water consumption, waste generation, and emission management across production stages. Respondents assessed each indicator using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Bioaccounting

Bioaccounting is defined as the integration of biological and ecological information into accounting and managerial decision-making processes. This variable captures the organisation's ability to identify, measure, record, and report environmental and biological costs. Bioaccounting is measured through indicators reflecting environmental cost identification, ecological asset measurement, sustainability-oriented accounting reporting, and the use of environmental information in strategic decisions. Measurement items were adapted from sustainability accounting and environmental management accounting studies and evaluated using a five-point Likert scale

Smart Environmental

Smart environmental refers to the organisational capability to collect, process, and utilise environmental data through intelligent systems and digital technologies to support sustainability management. This construct is operationalised using indicators such as real-time environmental monitoring, data analytics utilisation, integration of environmental information systems, and adaptive environmental decision-making. All indicators were measured using a five-point Likert scale

Performance Sustainability

Performance sustainability represents the organisation's ability to achieve long-term economic, environmental, and operational performance while maintaining ecological responsibility. This variable is measured using indicators related to resource efficiency, environmental performance improvement, cost reduction through sustainability initiatives, and long-term organisational resilience. Respondents evaluated performance sustainability using a five-point Likert scale based on their organisational experience

Data Collection

Data collection is a critical component of research, particularly in the field of agricultural production, where understanding the perspectives of key stakeholders can lead to more informed decision-making. In this study, data were meticulously gathered through a structured questionnaire that was distributed to managers and decision-makers within broiler production companies. The significance of targeting these individuals cannot be overstated; they play a pivotal role in shaping the operational strategies and policies of their organisations. By focusing on this demographic, the research aims to capture insights that are not only relevant but also actionable, providing a comprehensive overview of current practices and challenges faced in the broiler industry.

The questionnaire itself was designed with precision, ensuring that it addressed a wide array of topics pertinent to broiler production. It was administered over a three-month period, utilising both online and offline methods to maximise reach and inclusivity. This dual approach was intentional, recognising that while many managers are increasingly tech-savvy and comfortable with digital platforms, others may prefer traditional methods of communication. For instance, conducting face-to-face interviews at industry conferences or local agricultural fairs provided opportunities for deeper engagement and richer data collection. This methodological diversity not only enhanced the reliability of the data but also allowed for a more nuanced understanding of the respondents' perspectives.

Each measurement item within the questionnaire was assessed using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). This scale was carefully chosen to facilitate a clear and quantifiable analysis of responses. By employing this method, the research team could not only gauge the intensity of agreement or disagreement on specific statements but also identify trends and patterns within the data. For example, if a significant number of respondents indicated strong agreement with a statement regarding the importance of biosecurity measures, it would suggest a collective recognition of its critical role in maintaining the health and productivity of broiler flocks. Such insights are invaluable for both academic analysis and practical application within the industry.

Moreover, the data collected through this structured approach can be subjected to various statistical analyses, allowing researchers to draw meaningful conclusions. For instance, correlational analyses could reveal relationships between management practices and production outcomes, while regression analyses could help predict the impact of specific variables on overall performance. This analytical depth is essential for translating raw data into actionable insights. Additionally, the findings can serve as a benchmark for industry standards, enabling companies to evaluate their practices against those of their peers and identify areas for improvement.

The structured questionnaire method employed in this research represents a robust approach to data collection within the broiler production sector. By targeting key decision-makers and utilising a mixed-methods strategy, the study is poised to uncover valuable insights that can enhance operational efficiencies and drive innovation. The analytical potential of the data, coupled with the descriptive richness of the responses, underscores the importance of this research in contributing to the broader discourse on agricultural production practices. Ultimately, the findings will not only inform individual companies but also shape industry standards, fostering a more resilient and sustainable broiler production landscape.

Data Analysis (PLS-SEM)

The collected data were analysed using Partial Least Squares–Structural Equation Modeling (PLS-SEM) with SmartPLS software. This method is particularly favoured in research settings where the objectives include exploring complex relationships between variables, as it allows for the simultaneous examination of multiple relationships in a single model. The analysis followed a two-stage approach, consisting of the evaluation of the measurement model, which assesses validity and reliability, and the structural model, which focuses on hypothesis testing.

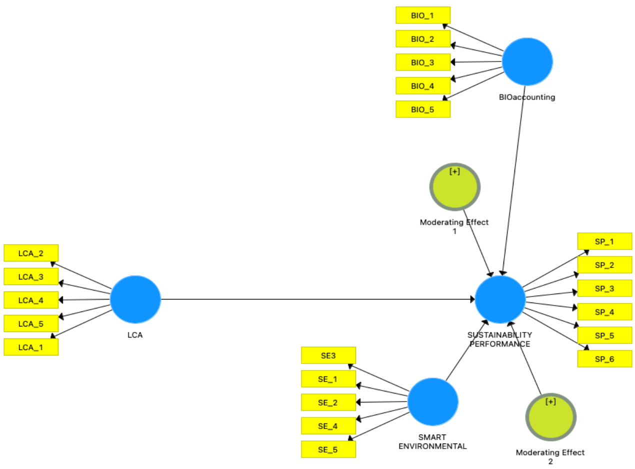
In the first stage of the analysis, the measurement model was evaluated to ensure that the constructs were both valid and reliable. Validity refers to the extent to which a tool measures what it is intended to measure, while reliability pertains to the consistency of the measurement across different instances. In PLS-SEM, validity can be examined through convergent validity and discriminant validity. Convergent validity indicates that items intended to measure the same construct correlate highly, while discriminant validity ensures that constructs that are supposed to be different are indeed distinct from one another. For instance, if we were measuring customer satisfaction and brand loyalty, we would expect these two constructs to show high convergent validity within their respective measures but low correlation with each other. By employing techniques such as the Average Variance Extracted (AVE) and the Fornell-Larcker criterion, we can substantiate the validity of the constructs, thereby strengthening the overall integrity of the research findings.

Reliability was assessed using composite reliability and Cronbach's alpha, both of which provide insights into the internal consistency of the constructs. A composite reliability score above 0.7 is generally considered acceptable, indicating that the items within each construct are measuring the same underlying concept consistently.

Following the evaluation of the measurement model, the analysis proceeded to the structural model, which involved hypothesis testing. This stage is critical as it allows researchers to examine the relationships proposed in their theoretical framework. The structural model assesses the strength and significance of the paths between the constructs, which can be visualised through path coefficients. For instance, if we hypothesise that employee engagement positively influences organisational performance, the path coefficient should demonstrate a significant positive value. Bootstrapping techniques can be employed to determine the statistical significance of these path coefficients, providing a robust method for hypothesis testing. This process not only helps in confirming or refuting the proposed relationships but also offers insights into the magnitude of these effects, which can be vital for practitioners looking to implement changes based on the findings.

Moreover, the results from the structural model can be further analysed using R-squared values, which indicate the amount of variance explained by the model. A higher R-squared value suggests that the model explains a significant proportion of the variance in the dependent variable, thus enhancing the model's predictive power. This statistic is invaluable for stakeholders, as it highlights the importance of fostering employee engagement initiatives to drive organisational success.

The analysis of the collected data using PLS-SEM with SmartPLS software through a two-stage approach provides a comprehensive understanding of the relationships between constructs. The rigorous evaluation of the measurement model ensures that the constructs are both valid and reliable, while the structural model facilitates hypothesis testing and provides insights into the strength and significance of the relationships. By employing these methodologies, researchers can draw meaningful conclusions that not only contribute to academic literature but also offer practical implications for organisations seeking to enhance their performance through informed decision-making. The integration of these analytical techniques ultimately reinforces the reliability of the findings and underscores the importance of a methodical approach in research.



PROSES ANALISIS PLS-SEM

The process of analysing data using Partial Least Squares–Structural Equation Modeling (PLS-SEM) is a sophisticated methodology that has gained significant traction in various fields of research, particularly where predictive analysis and complex variable relationships are paramount. This approach, facilitated by software tools such as SmartPLS, allows researchers to delve into intricate models that incorporate both direct and indirect relationships among variables. The decision to employ PLS-SEM stems from its unique capabilities, particularly in handling data that may not meet the stringent assumptions required by traditional covariance-based structural equation modelling techniques. At its core, PLS-SEM is particularly advantageous for predictive research. This is largely due to its ability to model complex relationships involving moderating variables, which can significantly influence the dynamics of the study. For instance, consider a scenario in marketing research where the impact of customer satisfaction on brand loyalty is being examined.

The analysis process in PLS-SEM typically unfolds in a two-step procedure, which is crucial for ensuring the robustness of the findings. The first step involves the assessment of the measurement model, which serves to evaluate the reliability and validity of the constructs involved in the study. This phase is essential as it establishes whether the variables accurately represent the theoretical concepts they are intended to measure.

Once the measurement model has been validated, the next step is to evaluate the structural model. This aspect focuses on the relationships between the constructs, assessing the strength and significance of these connections. For instance, in the earlier example of customer satisfaction and brand loyalty, the structural model would quantify how significantly customer satisfaction predicts brand loyalty while accounting for any moderating variables identified. This analysis not only reveals direct relationships but also uncovers indirect effects, offering a holistic view of the interplay between various constructs. Researchers often employ bootstrapping techniques within SmartPLS to derive t-values and p-values, which help determine the statistical significance of the hypothesised relationships.

EVALUASI STRUCTURAL MODEL

The evaluation of a structural model is a critical aspect of quantitative research, particularly in the fields of social sciences, marketing, and behavioural studies. This process involves a systematic assessment of the relationships between variables, aiming to ascertain the validity and reliability of the proposed theoretical framework. In this context, the structural model serves as a blueprint that illustrates how various constructs interact with one another, and the evaluation of this model can provide invaluable insights into the underlying dynamics of the phenomena being studied. By delving deeper into the evaluation process, we can uncover the significance of path coefficients, the coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2), while also considering the implications of bootstrapping techniques in validating these relationships. Path coefficients are fundamental in understanding the strength and direction of relationships between constructs within the model. Each path coefficient quantifies the effect of one variable on another, providing a numerical representation of the hypothesised relationships.

The coefficient of determination, or R^2, is another critical metric that reflects the proportion of variance in the dependent variable that can be explained by the independent variables in the model. A higher R^2 value indicates that the model accounts for a significant amount of variance, thereby enhancing its explanatory power. However, it is essential to approach R^2 with caution, as a high value does not inherently imply that the model is valid or that the relationships are causal.

Researchers must critically evaluate the context and theoretical underpinnings of their models to ensure that the interpretations drawn from R^2 are meaningful.

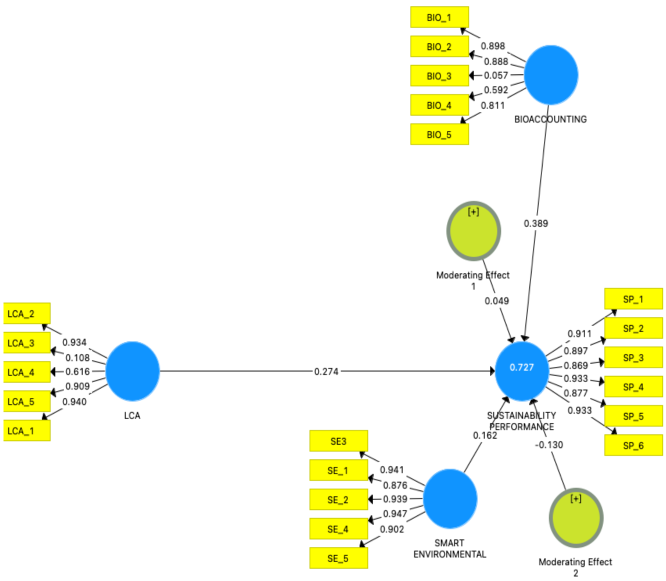
Effect size, denoted as f^2, provides further insight into the practical significance of the relationships identified in the structural model. While path coefficients indicate the strength of relationships, effect size quantifies the impact of a particular independent variable on the dependent variable, relative to the overall model. For instance, an f^2 value of 0.35 would suggest a large effect, indicating that changes in the independent variable have a substantial impact on the dependent variable. This metric is particularly valuable when comparing the relative importance of different predictors within the model. By assessing effect sizes, researchers can prioritise which variables warrant further investigation or intervention based on their practical implications. For instance, in a marketing context, understanding which advertising strategies yield the largest effect sizes can inform resource allocation and strategic planning.

Predictive relevance, represented by Q^2, assesses the model's ability to predict new data points. This is particularly important in applied research, where the ultimate goal is often to make predictions or inform decision-making. A Q^2 value greater than zero indicates that the model has predictive relevance, meaning it can generalise well to new datasets. For example, if a structural model developed to predict consumer behaviour achieves a Q^2 of 0.25, it suggests that the model can effectively predict outcomes for 25% of new cases. This predictive capability is crucial for businesses and organisations seeking to apply research findings to real-world scenarios, as it underscores the model's utility beyond the original sample. However, it is vital to recognise that predictive relevance should not be viewed in isolation; it must be considered alongside other metrics such as R^2 and effect size to provide a comprehensive assessment of the model's overall performance.

The evaluation of a structural model is a multifaceted process that demands careful consideration of various statistical metrics, including path coefficients, R^2, f^2, Q^2, and the application of bootstrapping techniques. Each of these elements contributes to a deeper understanding of the relationships between constructs, allowing researchers to assess both the theoretical and practical implications of their findings. By integrating these insights, scholars can develop more robust models that not only explain existing phenomena but also predict future outcomes, ultimately enhancing the relevance and applicability of their research. As the landscape of quantitative research continues to evolve, the importance of thorough model evaluation remains paramount, ensuring that the conclusions drawn are both reliable and actionable.

Data Analysis And Discussion

Outer model testing is a crucial analytical process in research that evaluates the quality of respondents' answers and ensures the validity and reliability of each variable indicator. This stage confirms whether the research instrument accurately captures the intended constructs, allowing the collected data to reflect actual conditions rather than random outcomes. In assessing convergent validity, the loading factor serves as a key indicator, where a value above 0.7 signifies that the instrument is consistent and appropriate for further analysis. High validity and reliability significantly enhance the credibility of research findings, particularly in fields where the results may influence policy or practical decision-making, such as education or healthcare. Conversely, low values raise concerns about the adequacy of the measurement tools and may hinder the implementation of research outcomes. Therefore, outer model testing is not merely a technical step, but a foundational component that strengthens empirical evidence and supports sound, data-driven decision-making



The value of convergent validity is represented by the loading factor associated with the latent variable and its manifest. In accordance with the convergent validity of all indicators, a loading factor exceeding 0.7 is deemed acceptable. This loading factor serves as the cross-loading value, which is instrumental in assessing whether the construct possesses sufficient discriminant validity. This is determined by ensuring that the loading value for the relevant construct is greater than that of the other constructs. In this section, we will summarise the results of the discriminant validity evaluation. The assessment of discriminant validity utilises the cross-loading values. A reflective manifest is regarded as having achieved discriminant validity when its cross-loading value is the highest in relation to other variables. Below, we present the cross-loading values associated with each manifest.

Fornell-Larcke... | Cross Loadings | »2 | Copy to Clipboard: | Excel Format | R F

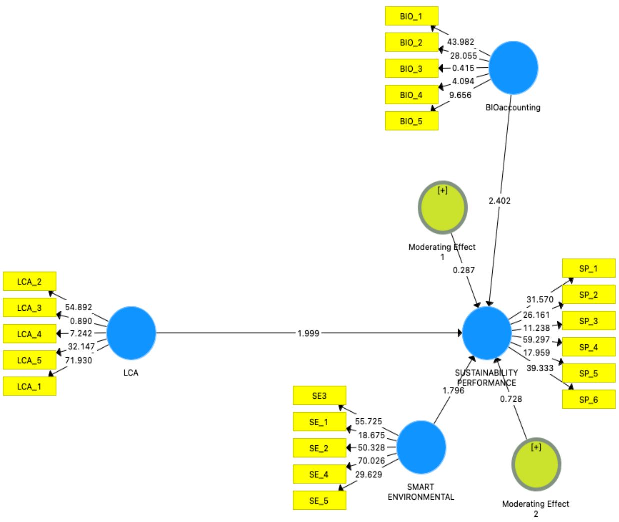
	BIOACCOUNTING	LCA	Moderating Effect	Moderating Effect	SMART ENVIRONM	SUSTAINABILIT
BIOACCOUNTING	0.722					
LCA	0.808	0.771				
Moderating Effe...	-0.648	-0.653	0.722			
Moderating Effe...	-0.673	-0.647	0.962	0.813		
SMART ENVIRO...	0.758	0.765	-0.547	-0.557	0.921	
SUSTAINABILIT...	0.813	0.787	-0.628	-0.648	0.732	0.9

The findings are considered reliable and valid when the metrics for Cronbach alpha, rho_A, composite reliability, and average variance extracted exceed 0.5. Consequently, such data processing outcomes suggest that the data is both reliable and valid. Testing the inner model assesses the suitability of the data for further analysis and provides insights into the optimisation results among the variables involved.

	Cronbach's Alpha	rho_A	Composite Reliabil	Average Vari
BIOACCOUNTING	0.727	0.875	0.815	(
LCA	0.790	0.935	0.859	(
Moderating Effe...	0.954	1.000	0.959	(
Moderating Effe...	0.976	1.000	0.978	(
SMART ENVIRO...	0.955	0.960	0.966	(
SUSTAINABILIT...	0.955	0.956	0.964	(

Inner Model

To assess the importance of accepting a hypothesis, the P-Value is utilised. A research hypothesis can be accepted if the P-Value is below 0.05. To ascertain the P-Value using SmartPLS, a bootstrapping procedure is performed on a model that is both valid and reliable, whilst also fulfilling the feasibility criteria of the model. The results from the bootstrapping process are displayed in the table below. Based on the outcomes of the hypothesis testing, the impact of critical attitudes on balance has been confirmed (see the illustration below).



PATH COEFECIENT

Mean, STDEV, T-Values, P-Values | Confidence Intervals | Confidence Intervals Bias Corrected | Samples

	Original Sample (C	Sample Mean (M)	Standard Deviatio	T Statistics (|O/ST	P Values
BIOaccounting -> SUSTAINABILITY PERFORMANCE	0.389	0.361	0.162	2.402	0.017
LCA -> SUSTAINABILITY PERFORMANCE	0.274	0.284	0.137	1.999	0.046
Moderating Effect 1 -> SUSTAINABILITY PERFORMANCE	0.049	0.008	0.170	0.287	0.774
Moderating Effect 2 -> SUSTAINABILITY PERFORMANCE	-0.130	-0.089	0.178	0.728	0.467
SMART ENVIRONMENTAL -> SUSTAINABILITY PERFORMANCE	0.162	0.177	0.090	1.796	0.073

Interpretation

Life Cycle Assessment and Performance Sustainability

The significant effect of Life Cycle Assessment on performance sustainability indicates that LCA functions not merely as an environmental assessment tool but as a strategic mechanism that enhances organisational efficiency and long-term performance. This finding supports the Natural Resource-Based View, which posits that environmental capabilities contribute to sustainable competitive advantage. The result is consistent with previous studies that emphasise the role of life cycle-based approaches in improving sustainability outcomes.

Life Cycle Assessment (LCA) serves as a comprehensive framework that evaluates the environmental impacts of a product or service throughout its entire life cycle, from raw material extraction to production, distribution, use, and disposal. This holistic approach allows organisations to identify critical stages where environmental impacts can be minimised, thereby fostering a culture of sustainability. For instance, consider a manufacturing company that utilises LCA to analyse the carbon footprint of its products. By identifying that a significant portion of emissions occurs during the production phase, the company can implement energy-efficient technologies or switch to renewable energy sources, thereby reducing its overall environmental impact. This example illustrates how LCA not only highlights areas for improvement but also drives innovation and efficiency within the organisation.

Moreover, the strategic implications of LCA extend beyond mere compliance with environmental regulations. By integrating LCA into their decision-making processes, organisations can gain valuable insights that inform product design, supply chain management, and marketing strategies. For example, a company that discovers through LCA that a particular material has a high environmental impact may choose to invest in alternative materials that are more sustainable. This proactive approach not only mitigates potential risks associated with environmental legislation but also positions the company as a leader in sustainability, enhancing its brand reputation and customer loyalty. The transition from reactive compliance to proactive strategy underscores the transformative potential of LCA in shaping organisational practices.

In addition to enhancing operational efficiency, the insights gained from LCA can significantly contribute to financial performance. By identifying inefficiencies and waste within the production process, organisations can reduce costs associated with resource consumption and waste management. For instance, a beverage company that conducts an LCA may find that optimising its water usage during production can lead to substantial cost savings while simultaneously reducing its environmental footprint. Such financial benefits reinforce the argument that sustainability and profitability are not mutually exclusive but can be mutually reinforcing when approached strategically. This alignment of environmental and economic goals is crucial for fostering a sustainable business model that can withstand the pressures of a rapidly changing market landscape.

Furthermore, the role of LCA in promoting sustainable competitive advantage aligns with the principles of the Natural Resource-Based View (NRBV). According to the NRBV, organisations that effectively leverage their environmental capabilities can differentiate themselves from competitors. By adopting LCA, companies can not only enhance their operational efficiencies but also develop unique offerings that resonate with environmentally conscious consumers. For example, a fashion brand that utilises LCA to ensure its products are made from sustainably sourced materials can attract a growing segment of consumers who prioritise ethical consumption. This differentiation strategy, rooted in environmental stewardship, can lead to increased market share and customer loyalty, thereby solidifying the organisation's competitive position in the market.

Life Cycle Assessment emerges as a pivotal tool that transcends its role as an environmental assessment mechanism, evolving into a strategic asset that underpins organisational efficiency and long-term performance sustainability. By adopting LCA, organisations can not only identify and mitigate environmental impacts but also drive innovation, enhance financial performance, and cultivate a competitive advantage rooted in sustainability. The interconnectedness of these factors highlights the importance of integrating LCA into the broader strategic framework of organisations, ensuring that sustainability becomes a core aspect of business operations rather than a peripheral concern. As the global emphasis on sustainability intensifies, those organisations that embrace LCA as a foundational element of their strategy will be better positioned to thrive in an increasingly eco-conscious marketplace.

Bioaccounting as a Moderator between LCA and Performance Sustainability

The moderating effects of bioaccounting suggest that the effectiveness of Life Cycle Assessment (LCA) depends significantly on organisational capabilities that facilitate the translation of environmental information into actionable managerial strategies. This finding not only extends the existing literature on sustainability accounting but also underscores the pivotal role that accounting systems and intelligent environmental capabilities play in transforming environmental assessments into tangible performance improvements. To delve deeper into this subject, it is essential to explore the intricate relationship between bioaccounting, organisational capabilities, and the practical implications for sustainability.

Bioaccounting, as an emerging field, integrates traditional accounting practices with ecological considerations, thereby providing organisations with a robust framework for evaluating their environmental impact. This integration is particularly vital in the context of LCA, which assesses the environmental aspects of a product or service throughout its entire life cycle—from raw material extraction to disposal. For instance, a company producing biodegradable packaging can utilise LCA to identify not only the environmental burdens associated with each stage of production but also potential areas for improvement. However, the mere application of LCA is insufficient; it necessitates the organisational capacity to interpret and act upon the data generated. This is where bioaccounting becomes instrumental, as it equips managers with the tools to make informed decisions that align with sustainability goals.

The effectiveness of LCA is inherently tied to the organisational capabilities that support it. These capabilities encompass a range of factors, including technological infrastructure, employee expertise, and a culture that prioritises sustainability. For example, an organisation that invests in advanced data analytics tools can better analyse the complex data generated by LCA, leading to more informed decision-making. Furthermore, a workforce that is well-versed in sustainability practices can facilitate the implementation of changes identified through LCA findings. This synergy between technological and human capabilities is crucial in ensuring that environmental assessments lead to meaningful organisational change. The challenge lies in fostering an environment where these capabilities can flourish, as this often requires a shift in organisational culture and values.

Moreover, the role of intelligent environmental capabilities cannot be overstated. These capabilities refer to the ability of an organisation to not only gather and analyse environmental data but also to integrate this information into strategic planning and operational processes. For instance, a manufacturing company that utilises predictive analytics to forecast the environmental impact of different production methods can make proactive decisions that reduce their carbon footprint. This proactive approach is essential in today's competitive landscape, where consumers are increasingly demanding transparency and sustainability from the brands they support. By leveraging intelligent environmental capabilities, organisations can not only improve their environmental performance but also enhance their market position.

The transition from environmental assessment to performance improvement is not merely a technical challenge; it is also a strategic imperative. Organisations must recognise that sustainability is not just a regulatory requirement but a critical component of their long-term viability. For example, companies that have successfully integrated sustainability into their core business strategies often experience enhanced brand loyalty and customer satisfaction. This is particularly evident in sectors such as food and beverage, where consumers are increasingly inclined to support brands that demonstrate a commitment to sustainable practices. Therefore, the ability to translate environmental assessments into effective managerial actions is essential for organisations seeking to thrive in an increasingly sustainability-conscious market.

The moderating effects of bioaccounting highlight the intricate relationship between organisational capabilities and the effectiveness of LCA. By understanding and developing these capabilities, organisations can transform environmental assessments into actionable strategies that lead to significant performance improvements. This transformation not only contributes to sustainability goals but also enhances competitive advantage in the marketplace. As the field of sustainability accounting continues to evolve, it is imperative for organisations to embrace bioaccounting as a vital tool in their pursuit of environmental stewardship. Ultimately, the integration of accounting systems and intelligent environmental capabilities will be critical in shaping a more sustainable future for businesses and the planet alike.

Smart Environmental as a Moderating Variable

The moderating effects of smart environmental capabilities suggest that the effectiveness of Life Cycle Assessment (LCA) is not merely a function of the assessment itself but is significantly influenced by the organisational capabilities that enable the translation of environmental information into actionable managerial decisions. This insight is crucial as it highlights a dynamic interplay between environmental accounting systems and the competencies within organisations that facilitate the effective use of environmental data. In essence, the findings underscore the importance of integrating advanced environmental capabilities with accounting practices to achieve substantial improvements in sustainability performance.

To elaborate further, it is essential to understand what is meant by smart environmental capabilities. These capabilities encompass a range of technologies and processes that allow organisations to collect, analyse, and utilise environmental data effectively. For instance, companies equipped with sophisticated data analytics tools can monitor their carbon emissions in real-time, enabling them to make informed decisions quickly. This contrasts sharply with organisations that rely on outdated methods, which may only provide periodic assessments. The ability to leverage such technologies not only enhances the accuracy of environmental assessments but also empowers managers to implement strategies that reduce environmental impact more effectively. Therefore, the integration of smart capabilities is not a mere enhancement; it is a fundamental requirement for organisations aiming to improve their sustainability profiles.

Moreover, the relationship between accounting systems and environmental performance cannot be overstated. Traditional accounting practices often focus on financial metrics, leaving little room for environmental considerations. However, the integration of environmental factors into accounting systems allows for a more holistic view of organisational performance. For example, when companies adopt green accounting practices, they can quantify the costs associated with environmental degradation and incorporate these figures into their financial reports. This practice not only raises awareness among stakeholders but also drives organisations to pursue sustainability initiatives that may have previously been overlooked. By aligning financial and environmental objectives, organisations can foster a culture of sustainability that permeates all levels of decision-making.

Transitioning from theory to practice, it is vital to consider real-world examples that illustrate the successful application of these concepts. A notable case is that of Unilever, which has embedded sustainability deeply into its corporate strategy. By employing advanced analytics and integrating sustainability metrics into its accounting systems, Unilever has been able to track the environmental impact of its products throughout their life cycles. This approach has led to significant reductions in waste and emissions, demonstrating how smart environmental capabilities can translate into tangible performance improvements. The success of such initiatives serves as a powerful illustration of how organisations can leverage environmental assessments to drive strategic actions, thereby enhancing their overall sustainability performance.

Furthermore, the implications of these findings extend beyond individual organisations. As more companies recognise the importance of integrating smart environmental capabilities with their accounting systems, a broader shift in industry standards may emerge. This shift could lead to the development of new benchmarks for sustainability performance, where companies are evaluated not only on their financial success but also on their environmental stewardship. Consequently, as organisations adopt these practices, they contribute to a collective movement towards more sustainable business models. This transformation is not merely beneficial for the environment; it also presents opportunities for innovation and competitive advantage in an increasingly eco-conscious market.

In conclusion, the moderating effects of smart environmental capabilities on the effectiveness of LCA underscore the critical role that organisational capabilities play in translating environmental information into actionable managerial decisions. By integrating advanced environmental capabilities with accounting practices, organisations can enhance their sustainability performance in meaningful ways. The examples of companies like Unilever illustrate the practical applications of these concepts, demonstrating that the alignment of financial and environmental objectives is not only possible but essential. As the business landscape continues to evolve, the integration of sustainability into core organisational strategies will likely become a defining characteristic of successful enterprises. Ultimately, the findings presented here contribute significantly to the sustainability accounting literature and highlight the need for a paradigm shift in how organisations approach environmental assessments and performance improvements.

The Relationship Between Bioaccounting and Sustainability Performance: An In-Depth Exploration

Bioaccounting has emerged as an essential framework for evaluating the sustainability performance of organisations, particularly in light of the increasing urgency surrounding environmental and economic impacts. This innovative approach integrates traditional accounting methodologies with environmental considerations, thereby enabling firms to quantify their ecological footprints and resource consumption with a higher degree of accuracy. For example, a pivotal study conducted by Alhumoudi et al. (2024) underscores the significant role of carbon management accounting in facilitating corporate strategies aimed at reducing carbon emissions. By merging life cycle assessment (LCA) with material flow cost accounting, organisations can attain a holistic understanding of their carbon emissions. This understanding not only aids in the identification of key areas for improvement but also enhances the implementation of more effective sustainability measures.

To illustrate this point further, consider a manufacturing company that has adopted bioaccounting practices. By applying LCA, the firm can trace the environmental impact of its products from raw material extraction through to disposal. This comprehensive analysis allows the company to identify stages in the production process that contribute disproportionately to carbon emissions. Consequently, the firm can implement targeted interventions, such as optimising energy usage or switching to renewable energy sources, thereby effectively reducing its overall carbon footprint.

The significance of bioaccounting is further emphasised by its capacity to provide actionable insights into resource utilisation. A thorough analysis conducted by Ahmed et al. (2025) on sustainable technology and resource utilisation within leading agricultural economies revealed that the implementation of bioaccounting practices can lead to substantial reductions in soil emissions. Their findings indicate that organisations adopting bioaccounting do not merely enhance their sustainability performance; they also optimise operational efficiency through improved resource allocation. For instance, a farm that utilises bioaccounting techniques can monitor soil health and nutrient levels more effectively, allowing for precise application of fertilisers and water. This not only conserves resources but also minimises negative environmental impacts, showcasing the dual benefits of bioaccounting.

Moreover, bioaccounting plays a pivotal role in fostering transparency and accountability in sustainability reporting. The adoption of environmental management accounting (EMA) practices enables firms to disclose their environmental impacts more comprehensively, thereby building trust with stakeholders. A study by Nair et al. (2022) highlights that manufacturing firms in Malaysia that embraced EMA reported enhanced stakeholder engagement and improved corporate reputation. This finding demonstrates that the integration of bioaccounting into corporate strategies can yield better sustainability outcomes while simultaneously enhancing competitive advantage. For example, a company that transparently reports its environmental performance metrics may attract environmentally-conscious consumers, leading to increased sales and brand loyalty.

In addition to enhancing transparency, bioaccounting supports the development of sustainability metrics that align with corporate goals. For instance, Indriani et al. (2025) explored the innovative concept of circular accounting for carbon emissions measurement, proposing a framework that allows organisations to track their carbon footprints with greater precision. By establishing clear and measurable metrics, businesses can set tangible sustainability targets and monitor their progress over time. This process fosters a culture of continuous improvement in sustainability performance, as organisations are held accountable for their commitments. An illustrative case can be seen in a tech company that sets a goal to reduce its carbon emissions by 20% over five years. By employing bioaccounting metrics, the company can track its progress quarterly, making necessary adjustments to its operations to ensure it remains on target.

Furthermore, the role of bioaccounting in decision-making processes cannot be overstated. By providing relevant data concerning environmental impacts and resource utilisation, bioaccounting informs strategic choices that align with sustainability objectives. As highlighted by Almasyhari et al. (2025), firms that incorporate bioaccounting into their strategic decision-making processes are better positioned to tackle environmental challenges while simultaneously achieving financial objectives. This dual focus on environmental and economic performance underscores the transformative potential of bioaccounting in cultivating a more sustainable business landscape. For example, a retail company that uses bioaccounting data to inform its supply chain decisions may choose to source materials from suppliers that utilise sustainable practices, thereby enhancing both its environmental performance and its brand image.

The Relationship Between Life Cycle Assessment (LCA) and Performance Sustainability

Life Cycle Assessment (LCA) has emerged as a critical tool in evaluating the environmental impacts associated with all stages of a product's life, from raw material extraction through production, use, and disposal. This method not only aids in identifying areas for improvement in sustainability practices but also supports businesses in achieving performance sustainability by aligning operational processes with environmental objectives. The integration of LCA into corporate strategies is increasingly recognised as essential for companies aiming to enhance their sustainability performance while maintaining competitive advantage in an evolving marketplace.

One of the most significant advantages of implementing LCA is its ability to provide quantitative data that informs decision-making. This data is not merely numbers on a page; it represents a comprehensive analysis of the environmental impacts associated with each phase of a product's life cycle. For instance, a meta-analysis conducted by Alfonso-Avila et al. (2022) demonstrated that low-protein diets in broiler chicken production significantly improve nitrogen utilisation and reduce water consumption. This finding underscores the potential of LCA in optimising resource use and minimising waste, particularly in industries with substantial environmental footprints. By utilising LCA, companies can highlight inefficiencies that may otherwise go unnoticed, allowing for targeted interventions that lead to more sustainable practices.

Moreover, LCA facilitates transparency in reporting environmental impacts, which is increasingly demanded by stakeholders. In today's market, consumers and investors alike are becoming more discerning, seeking out companies that prioritise sustainability. According to Ahmed et al. (2025), leading agricultural economies are now utilising sustainable technologies to mitigate soil emissions, showcasing how LCA can help track progress towards sustainability goals. This transparency not only enhances corporate accountability but also builds trust with consumers and investors who are increasingly prioritising sustainability in their purchasing and investment decisions. When companies disclose their LCA findings, they not only comply with regulatory demands but also engage in a form of storytelling that resonates with a growing audience concerned about environmental issues.

The role of LCA in performance sustainability extends beyond mere compliance and risk management; it also drives innovation. Companies that adopt LCA methodologies often discover new opportunities for product development and process optimisation. For example, the integration of LCA with circular economy principles has led to innovative approaches in waste management and resource recovery, as evidenced by research from Kamali Saraji et al. (2025). By rethinking product design and end-of-life strategies, businesses can create value while reducing their environmental impact. This innovation is not just about creating new products; it involves rethinking existing processes to enhance efficiency and sustainability. For instance, a company may find that redesigning its packaging can significantly reduce waste and improve recyclability, thereby aligning with both consumer preferences and regulatory requirements.

Despite the clear advantages, the adoption of LCA is not without challenges. Many companies face barriers such as high implementation costs, lack of expertise, and difficulties in data collection and analysis. Alhumoudi et al. (2024) highlight the limitations of integrating LCA with carbon management accounting, suggesting that without proper frameworks and support, the potential benefits of LCA may not be fully realised. The complexity of LCA methodologies can be daunting for organisations, particularly smaller enterprises that may lack the resources to conduct thorough assessments. Therefore, it is crucial for organisations to invest in training and resources to effectively leverage LCA in their sustainability strategies. This investment not only equips employees with the necessary skills but also fosters a culture of sustainability within the organisation, ensuring that sustainability becomes a core value rather than an afterthought.

In addition to training, companies must also consider the importance of collaboration in overcoming the challenges associated with LCA implementation. Engaging with external experts, industry groups, and academic institutions can provide valuable insights and resources that enhance the effectiveness of LCA practices. Collaborative efforts can lead to the development of best practices and standardised methodologies that simplify the LCA process, making it more accessible to a broader range of businesses. Furthermore, such partnerships can facilitate knowledge sharing, enabling companies to learn from one another's experiences and successes in implementing LCA.

The integration of LCA into corporate strategies is not merely a trend; it represents a fundamental shift in how businesses approach sustainability. As the global landscape becomes increasingly complex, with rising consumer expectations and stringent regulatory requirements, the need for robust sustainability frameworks has never been more pressing. LCA serves as a cornerstone of this framework, providing a systematic approach to understanding and mitigating environmental impacts. By embedding LCA into their operations, companies can not only enhance their environmental performance but also position themselves as leaders in sustainability within their respective industries.

Conclusion

The integration of life cycle assessment and performance sustainability, supported by the roles of bioaccounting and smart environmental , represents a promising avenue for advancing corporate sustainability practices. As organisations navigate the complexities of environmental stewardship, the need for robust methodologies that encompass both ecological and economic considerations becomes increasingly critical (Almasyhari et al., 2025). The findings from this research underscore the importance of adopting comprehensive frameworks that integrate LCA, bioaccounting, and smart environmental to drive sustainability performance.

Implication

The findings of this study provide significant insights for companies aiming to develop robust sustainability strategies that are not only effective but also practical. The research highlights the critical role of Life Cycle Assessment (LCA) as an essential environmental evaluation tool. However, the implications extend far beyond mere implementation. Companies are encouraged to weave LCA outputs into their bioaccounting systems and smart environmental technologies. This integration is not merely a recommendation; it is a strategic necessity in today's competitive landscape. For instance, when a company utilises LCA to assess the environmental impact of a product from raw material extraction to disposal, it gains a comprehensive understanding of its ecological footprint. By integrating these findings into bioaccounting systems, firms can quantify the environmental costs associated with their operations, leading to more informed financial decisions that reflect both economic and environmental realities.

Moreover, the incorporation of smart environmental technologies can further enhance the utility of LCA data. Technologies such as artificial intelligence and data analytics can process vast amounts of environmental data, providing real-time insights into sustainability performance. For instance, a manufacturing firm could employ predictive analytics to forecast the environmental impact of different production methods, allowing them to choose the most sustainable option. This not only aids in improving decision-making quality but also positions the company as a leader in sustainability within its industry. The synergy between LCA, bioaccounting, and smart technologies creates a dynamic framework that empowers businesses to translate environmental information into actionable strategies. By fostering a culture of sustainability, companies can enhance their overall performance, leading to long-term benefits such as increased customer loyalty, improved regulatory compliance, and a stronger brand reputation.

In addition, the integration of LCA outputs into corporate strategies can facilitate cross-departmental collaboration, which is often a challenge in large organisations. By breaking down silos and encouraging departments such as marketing, production, and finance to work together on sustainability initiatives, companies can create a more cohesive approach to environmental stewardship. For example, a marketing team that understands the sustainability metrics derived from LCA can effectively communicate a product's eco-friendly attributes to consumers, thereby enhancing its marketability. This not only drives sales but also reinforces the company's commitment to sustainability, creating a positive feedback loop that benefits all stakeholders involved. Furthermore, such collaboration can lead to innovative solutions that might not have emerged in a more fragmented organisational structure.

The integration of Life Cycle Assessment into bioaccounting systems and smart environmental technologies is not just a progressive step; it is an essential strategy for companies aiming to thrive in an environmentally conscious market. By utilising LCA effectively, companies can gain valuable insights that inform their sustainability strategies, improve decision-making processes, and foster a culture of collaboration across departments. The result is a comprehensive approach to sustainability that not only mitigates environmental impact but also drives business success. As organisations continue to navigate the complexities of sustainability, those that prioritise integration and innovation will undoubtedly lead the way towards a more sustainable future.

Suggestion

Moreover, further studies should investigate the impact of regulatory frameworks and stakeholder expectations on the adoption of bioaccounting and smart environmental . Understanding the drivers and barriers to integration will provide valuable insights for organisations seeking to enhance their sustainability practices (Kazancoglu et al., 2021). Engaging with stakeholders, including consumers, investors, and policymakers, will be essential for fostering a culture of sustainability that prioritises ecological performance alongside financial success.

Limitation

Despite its contributions, this study has several limitations. First, the research focuses on broiler production companies, which may limit the generalisability of the findings to other industries. Second, the study relies on cross-sectional data, which restricts the ability to capture dynamic changes in sustainability practices over time. Future research could address these limitations by applying longitudinal designs or examining different industrial contexts.

Acknowledgement

The steadfast support from the management and the rector of Universitas Sains Indonesia has been fundamental to the institution's achievements. Their dedication to cultivating an environment characterised by academic excellence, community involvement, and innovation has profoundly influenced students, faculty, and the wider community. As we progress, it is crucial to consistently recognise and value the contributions of those in leadership roles, as their vision and commitment are essential in shaping the future of higher education in Indonesia. Recognising their efforts not only nurtures a culture of appreciation but also motivates ongoing excellence and engagement within the university community.

Conflict of Interest

The authors affirm that there are no conflicts of interest to disclose. This study received funding from Universitas Sains Indonesia. The funding body did not influence the study's design, the gathering, analysis, or interpretation of data, the composition of the manuscript, or the decision-making process regarding the publication of the findings.

Use of Artificial Intelligence Technology

In the ever-evolving landscape of academic writing, the integration of artificial intelligence (AI) has emerged as a prominent topic of discussion. A crucial aspect that warrants attention is the transparency surrounding the utilisation of AI tools within the writing process. When employing such technology, it is essential to clearly disclose this in the Acknowledgment section, specifying the AI tools used and their intended purposes.

Furthermore, disclosing the use of AI in writing transcends mere administrative compliance, reflecting a high standard of academic ethics. In this context, AI can assist writers in organising their thoughts and constructing more robust arguments.. Nonetheless, it is vital to remember that despite AI's potential contributions, the ultimate responsibility lies with the writer. Writers must ensure that the final output embodies their own thoughts and analyses, thereby upholding academic integrity. In this regard, AI should be perceived as a supportive tool that enhances the creative process rather than a substitute for the critical thinking essential to academic writing.

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