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Green Supply Chain Management Innovation in Promoting Sustainability in Indonesia's Palm Oil Industry

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Abstract: The palm oil industry is vital to Indonesia's economy but faces regulatory, environmental, and cost challenges, driving the need for sustainable supply chains. This study examines the impact of Green Supply Chain Management (GSCM) on corporate sustainability performance and the mediating role of Green Innovation. It focuses on Green Procurement, Manufacturing, Logistics, and Packaging. This study a quantitative approach, data was collected from industry specialists through structured questionnaires. The research follows a structured process: problem identification, literature review, hypothesis development, data collection, and analysis using Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was chosen for its suitability in handling complex models, formative constructs, and non-normal data, making it ideal for predicting GSCM's impact on CSP Data from 100 managers across more than 20 companies were analyzed using PLS-SEM with WarpPLS 6.0, which handles non-linear and complex relationships. Findings show GSCM significantly improves economic, environmental, and social sustainability, with Green Innovation mediating economic and social impacts but not environmental ones. The study underscores the need to align GSCM with SDGs for long-term sustainability and offers strategic insights for academics and practitioners.

Keywords: Green innovation; Green supply chain management; Indonesia; Palm oil; SDGs; Sustainability performance

Introduction

The plantation sector is a key driver of Indonesia's economy, employing millions and contributing significantly to GDP and exports. As the world's largest palm oil producer, Indonesia benefits from a favorable climate, technological advancements, government support, and strong global demand. Palm oil production has become a crucial element of the country's agricultural landscape, supporting both large-scale plantations and smallholder farmers. The sector's rapid growth has spurred economic development, providing livelihoods for millions of Indonesians and generating substantial foreign exchange earnings. However, this growth has also raised concerns due to its environmental and social impacts, such as deforestation, habitat destruction, and exploitation of workers. These challenges have prompted calls for a more sustainable approach to palm oil production, one that balances economic benefits with environmental protection and social responsibility (Jenderal, 2020). However, the industry faces major environmental and social challenges, including deforestation, biodiversity loss, land conflicts, and high carbon emissions (Meijaard et al., 2020; Olivier et al., 1994). Palm oil plantations contribute around 20% of global GHG emissions, prompting increased regulatory pressure for sustainability. To address these concerns, Indonesia

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introduced sustainability policies, such as Indonesian Sustainable Palm Oil (ISPO) certification under Minister of Agriculture Regulation No. 38/2020 and Presidential Regulation No. 44/2020, focusing on environmental and social responsibility. However, implementation remains inconsistent, with only a fraction of producers certified. Green Supply Chain Management (GSCM) presents a solution by integrating sustainability principles across the supply chain, reducing waste, optimizing resources, and enhancing business performance (Tseng et al., 2019). Strategies like eco-design, green procurement, reverse logistics, and green manufacturing can reduce environmental impact while maintaining profitability. Additionally, recent studies suggest that utilizing palm oil industry waste for high-value products can significantly contribute to sustainability efforts. For instance, research by Maryam et al. (2024) demonstrates the feasibility of producing nanocrystalline cellulose (NCC) from oil palm empty fruit bunch (OPEFB) fiber using bioprocess technology. This approach aligns with GSCM principles by promoting resource efficiency and waste reduction, ultimately reducing the environmental footprint of palm oil production. Similarly, integrating lean and green manufacturing practices can enhance efficiency and sustainability. A study by Ulfah et al. (2024) highlights how the application of the Green Lean Six Sigma and factorial experiments approach in the bottled drinking water industry led to quality improvements and process optimization. These insights suggest that applying similar methodologies in the palm oil industry could improve sustainability performance by minimizing waste and increasing operational efficiency. However, GSCM adoption in Indonesia's palm oil sector remains low, with limited data on implementation. Further research and strategic interventions are needed to encourage wider adoption and ensure a sustainable future for the industry. With growing environmental concerns, stricter global sustainability standards, and economic pressures, research on Green Supply Chain Management (GSCM) in the palm oil industry is essential. Understanding barriers, costs, and regulatory impacts can help develop effective policies and strategies for a more sustainable and competitive sector. Without action, Indonesia risks losing global market access due to increasing sustainability demands. This study aims to bridge knowledge gaps and accelerate GSCM adoption in the industry. GSCM covers green procurement, manufacturing, logistics, and packaging, all aimed at reducing environmental impact (Novitasari et al., 2021; Renaldo et al., 2022). These practices align with UN SDGs and benefit business performance, particularly when supported by institutional forces (Nazir et al., 2024). In Saudi Arabia, GSCM enhances business sustainability (Hejazi et al., 2023), while Green Human Capital (GHC) and Environmental Management Systems (EMS) promote GSCM adoption and corporate success (S. Ali et al., 2022; Murad et al., 2023). Green innovation is a key mediator, strengthening the link between GSCM and business performance (Novitasari et al., 2021), while regulations and consumer expectations moderate its success (Hashmi et al., 2021). In palm oil, Green SCOR-based KPIs measure sustainability (Primadasa et al., 2020), and Green Intellectual Capital (GIC) and Green Information Systems (GIS) further enhance financial outcomes (Renaldo et al., 2022). Despite extensive research, gaps remain in Indonesia's palm oil sector, particularly in green procurement, manufacturing, and logistics. While green innovation's mediating role is recognized, its specific impact on palm oil is underexplored. Future studies should examine institutional pressures, human capital, and innovation dynamics in palm oil supply chains (Hejazi et al., 2023; Nazir et al., 2024). This study seeks to fill these gaps by examining the adoption of GSCM techniques in Indonesia's palm oil sector, with a particular emphasis on their impact on corporate sustainability performance and the mediating role of green innovation. The study aims to provide valuable insights for both practitioners and academics by delving into important dimensions and their relationship to sustainable outcome.

Method

This study examines the impact of Green Supply Chain Management (GSCM) on Corporate Sustainability Performance (CSP) in Indonesia's palm oil sector, a key industry facing environmental and social challenges. It evaluates Green Procurement, Manufacturing, Logistics, and Packaging in relation to economic, environmental, and social sustainability. Using a quantitative approach, data was collected from industry specialists through structured questionnaires. The research follows a structured process: problem identification, literature review, hypothesis development, data collection, and analysis using Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was chosen for its suitability in handling complex models, formative constructs, and non-normal data, making it ideal for predicting GSCM's impact on CSP (Hair et al., 2019; Singh et al., 2024). It also assesses indirect effects, allowing evaluation of green innovation's mediating role in this relationship (F. Ali et al., 2018; Fauzi, 2022). The inclusion of WarpPLS version 6.0 in the analysis further enhances the study's ability to handle non-linear relationships and provide robust statistical insights. Furthermore, the questionnaire design includes precise metrics to capture subtle aspects of GSCM implementation, which strengthens data quality. To improve data reliability, the survey instrument was pretested to fine-tune measurement scales and eliminate biases. The research framework builds on well-established sustainability and supply chain concepts, providing a solid theoretical foundation. Each stage of the research process is carefully structured following best practices in supply chain and sustainability research, ensuring the validity and reliability of findings. Additionally, the study integrates institutional and regulatory considerations, recognizing the influence of policies such as Indonesia Sustainable Palm Oil (ISPO) certification on GSCM adoption and sustainability performance. This study aims to offer empirical insights and practical implications for sustainable supply chain management, particularly in the unique context of Indonesia's palm oil industry.

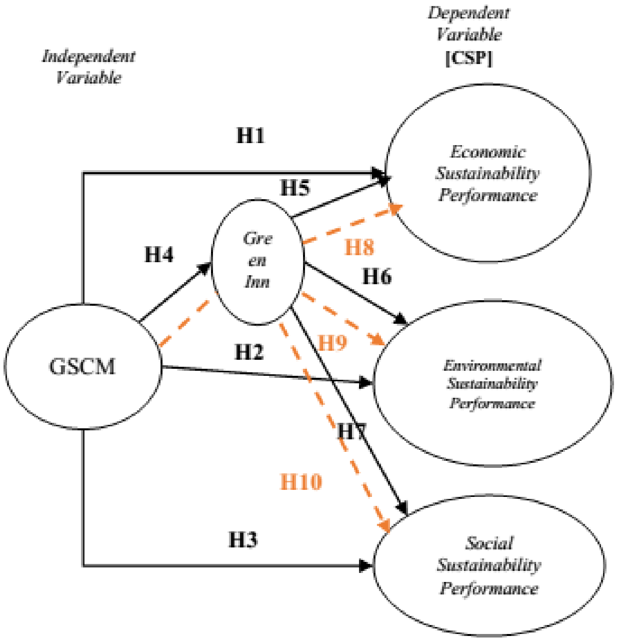

Figure 1. Research hypotheses

This study begins by examining the complexities and constraints in Indonesia's palm oil supply chain. As a key contributor to the national economy, the palm oil industry faces global scrutiny for its environmental and social impacts, such as deforestation and greenhouse gas (GHG) emissions (Fekete et al., 2021). These challenges highlight the urgent need for sustainable practices, with Green Supply Chain Management (GSCM) emerging as a critical solution. The study assumes that implementing GSCM improves Corporate Sustainability Performance (CSP) by addressing economic, environmental, and social sustainability (Tseng et al., 2019). This stage also helped in formulating hypotheses and designing a structured questionnaire, ensuring alignment with previous research and industry practices. Based on the literature review, ten hypotheses on GSCM's impact on corporate sustainability performance have been developed, as shown in Figure 1. To further strengthen its practical contribution, this study also considers barriers to GSCM adoption, such as high implementation costs, lack of awareness, and regulatory challenges. Identifying these challenges can help policymakers and industry leaders develop more effective strategies for accelerating sustainable transformation in Indonesia's palm oil sector.

Based on the outlined framework above, the hypotheses generated are as follows:
H1: GSCM has a positive impact on Economic Sustainability Performance.
H2: GSCM positively influences Environmental Sustainability Performance.
H3: GSCM positively affects Social Sustainability Performance.
H4: GSCM contributes positively to Green Innovation.
H5: Green Innovation positively impacts Economic Sustainability Performance.
H6: Green Innovation has a positive effect on Environmental Sustainability Performance.
H7: Green Innovation positively influences Social Sustainability Performance.
H8: GSCM positively affects Economic Sustainability Performance through the mediation of Green Innovation.
H9: GSCM positively influences Environmental Sustainability Performance through the mediation of Green Innovation.
H10: GSCM positively impacts Social Sustainability Performance through the mediation of Green Innovation.

Data were collected through standardized questionnaires from supply chain managers, sustainability officers, and operational managers in 20 palm oil firms across Indonesia's western and central provinces. Using the Slovin formula, a minimum of 96 respondents was required, allowing a 10% error margin. Companies of various sizes and functions (manufacturing, procurement, logistics, sustainability) were included for diverse insights (Matsuo, 2022). The questionnaire, based on established studies, mapped GSCM variables like Green Procurement (eco-friendly materials, supplier partnerships) and Green Logistics (carbon emissions reduction) to ensure validity (Hair et al., 2019). PLS-SEM analysis was used due to its strength in handling complex models with small samples (Henseler et al., 2016), with WarpPLS software selected for its ability to process non-linear relationships (Henseler et al., 2015). Validity and reliability were confirmed through factor loadings (>0.7), AVE (>0.5), Fornell-Larcker Criterion, HTMT (<0.85), Composite Reliability (>0.7), and Cronbach's Alpha (>0.6) (Hair et al., 2019; Henseler et al., 2016). This study tested 10 hypotheses to assess direct and mediated relationships between GSCM practices and Corporate Sustainability

Performance (CSP). The analysis explored how Green Procurement, Manufacturing, Logistics, and Packaging impact economic, environmental, and social sustainability, with Green Innovation examined as a mediator. PLS-SEM identified significant pathways, evaluating direct effects of GSCM on CSP and indirect effects through Green Innovation. This systematic approach provided a comprehensive understanding of how GSCM and Green Innovation contribute to corporate sustainability in the palm oil industry while ensuring model validity and reliability.

Result and Discussion

The respondents involved are experienced practitioners in the palm oil industry, possessing sufficient capability and insight to assess the implementation of Green Supply Chain Management (GSCM) on Corporate Sustainability Performance (CSP) within their respective companies, representing more than 20 companies in Indonesia. The respondents were selected based on their professional backgrounds to ensure they provide objective and substantial perspectives on green supply chain strategies in the context of corporate sustainability. The 100 respondents were predominantly male (76%) and held bachelor's (61%) or master's degrees (21%). Most were in the productive age range of 36-45 years (36%) and above 45 years (62%), reflecting their professional maturity. A significant portion held strategic roles, including Senior Managers (63%) and General Managers (18%), with over 10 years of work experience (77%). Geographically, respondents were distributed across Western and Central Indonesia, with proportions of 39% and 61%, respectively. This diverse and experienced profile ensures that the study captures well-rounded insights into GSCM implementation challenges and best practices in the palm oil industry. Many respondents have first-hand experience in sustainability initiatives, regulatory compliance, and supply chain optimization, strengthening the credibility of their perspectives. Additionally, their high-level roles enable them to provide strategic viewpoints on corporate sustainability policies, investment decisions, and the long-term benefits of adopting sustainable supply chain practices. This rich respondent profile enhances the study's practical relevance, offering valuable recommendations for industry stakeholders, policymakers, and researchers seeking to drive sustainable transformation in Indonesia's palm oil sector.

Data Validity and Reliability Test

After identifying the demographic distribution of respondents, validity and reliability tests were conducted to ensure that the research instrument accurately and consistently measures the intended constructs. Validity refers to how well indicators represent latent constructs, while reliability ensures consistent measurement results under the same conditions (Hair et al., 2019; Kock, 2017). In this study, validity and reliability testing was performed by evaluating the outer model, assessed through factor loading values derived from pattern loadings and cross-loadings, as well as the Average Variance Extracted (AVE). Additionally, construct reliability was examined using Composite Reliability (CR) and Cronbach's Alpha (CA), as generated by the WarpPLS application. Table 1 presents the factor loading values for each indicator within its respective construct. An indicator meets convergent validity if it has a factor loading of ≥ 0.70. These comprehensive assessments confirm the robustness of the measurement model, ensuring that the research findings are credible and generalizable.

Table 1. Factor Loading Evaluation

Indicator	Factor Loading	Result
Green Procurement (X1.1)	0.711	Valid (≥ 0.70)
Green Manufacturing (X1.2)	0.854	Valid (≥ 0.70)
Green Packaging (X1.3)	0.863	Valid (≥ 0.70)
Green Logistics (X1.4)	0.712	Valid (≥ 0.70)
Green Distribution (X1.5)	0.812	Valid (≥ 0.70)
Green Product Innovation (Y1.1)	0.892	Valid (≥ 0.70)
Green Process Innovation (Y1.2)	0.938	Valid (≥ 0.70)
Eco – Design (Y1.3)	0.899	Valid (≥ 0.70)
Green Technology Adoption (Y1.4)	0.914	Valid (≥ 0.70)
Cost Reduction (Y2.1)	0.859	Valid (≥ 0.70)
Profitability (Y2.2)	1.060	Valid (≥ 0.70)
Market Competitiveness (Y2.3)	1.691	Valid (≥ 0.70)
Resource Efficiency (Y2.4)	0.757	Valid (≥ 0.70)
Energy Efficiency (Y3.1)	1.006	Valid (≥ 0.70)
Waste Management (Y3.2)	0.851	Valid (≥ 0.70)
Emission Reduction (Y3.3)	0.971	Valid (≥ 0.70)
Resource Conservation (Y3.4)	0.742	Valid (≥ 0.70)
Employee Well-Being (Y4.1)	0.727	Valid (≥ 0.70)
Community Impact (Y4.2)	0.909	Valid (≥ 0.70)
Health and Safety (Y4.3)	1.291	Valid (≥ 0.70)
Stakeholder Engagement (Y4.4)	1.205	Valid (≥ 0.70)

In addition, convergent validity is also tested using the Average Variance Extracted (AVE) value. The AVE value indicates the extent to which a construct can explain the variance of its indicators. An AVE value greater than 0.50 suggests that more than 50% of the variance in the indicators is explained by the construct, thereby confirming convergent validity. Table 2 presents the AVE results for each construct in this study.

Table 2. Average Variance Extracted (AVE)

Construct	AVE	Result
Green Supply Chain Management	0.621	Valid (≥ 0.50)
Green Innovation	0.824	Valid (≥ 0.50)
Economic Sustainability Performance	0.956	Valid (≥ 0.50)
Environmental Sustainability Performance	0.848	Valid (≥ 0.50)
Social Sustainability Performance	0.912	Valid (≥ 0.50)

Table 3. Composite Reliability and Cronbach's Alpha

Construct	CR	CA	Result
Green Supply Chain Management	0.889	0.842	Reliable (≥ 0.70)
Green Innovation	0.949	0.927	Reliable (≥ 0.70)
Economic Sustainability Performance	0.834	0.728	Reliable (≥ 0.70)
Environmental Sustainability Performance	0.911	0.869	Reliable (≥ 0.70)
Social Sustainability Performance	0.874	0.803	Reliable (≥ 0.70)

Meanwhile, reliability is tested using Composite Reliability (CR) and Cronbach's Alpha (CA), which measure the internal consistency of indicators within a construct. A CR value of ≥ 0,70 and CA value of ≥ 0,60 indicate that the construct is reliable and stable across measurements (Hair et al., 2019). Table 3 presents the reliability results, demonstrating the consistency and robustness of the research instrument. These measures confirm that the research instrument effectively reflects the underlying theoretical constructs, enhancing the validity and reliability of the study's conclusions.

Based on the results of the validity and reliability tests, it can be concluded that all indicators and constructs meet the criteria for high validity and reliability. Therefore, this research instrument can be used for further analysis with a high level of confidence.

Indicator Exploration for Each Variable

The first step in doing SEM analysis using the PLS technique is to look at the indicators that reflect the latent variables. This method guarantees that only the most relevant and valid indicators are chosen to appropriately represent the model's structures. Indicators are regarded valid if they show strong and consistent connections with their respective latent variables. Only indicators with positive factor loadings or component weights are preserved for a clearer interpretation of variable relationships. Factor loadings are used in reflecting indicator models, where the indicators represent the latent variable, and component weights are used in formative indicator models, where the indicators define the construct.

Table 4. Results of Indicator Exploration for Each Variable

Indicator	Weight	P value	Notes
Green Procurement (X1.1)	0.567	<0.001	Used in the model
Green Manufacturing (X1.2)	0.843	<0.001	Used in the model
Green Packaging (X1.3)	0.808	<0.001	Used in the model
Green Logistics (X1.4)	0.826	<0.001	Used in the model
Green Distribution (X1.5)	0.860	<0.001	Used in the model
Green Product Innovation (Y1.1)	0.956	<0.001	Used in the model
Green Process Innovation (Y1.2)	0.813	<0.001	Used in the model
Eco – Design (Y1.3)	0.954	<0.001	Used in the model
Green Technology Adoption (Y1.4)	0.899	<0.001	Used in the model
Cost Reduction (Y2.1)	0.443	<0.001	Used in the model
Profitability (Y2.2)	0.893	<0.001	Used in the model
Market Competitiveness (Y2.3)	0.866	<0.001	Used in the model
Resource Efficiency (Y2.4)	0.734	<0.001	Used in the model
Energy Efficiency (Y3.1)	0.864	<0.001	Used in the model
Waste Management (Y3.2)	0.867	<0.001	Used in the model
Emission Reduction (Y3.3)	0.861	<0.001	Used in the model
Resource Conservation (Y3.4)	0.797	<0.001	Used in the model
Employee Well-Being (Y4.1)	0.800	<0.001	Used in the model
Community Impact (Y4.2)	0.884	<0.001	Used in the model
Health and Safety (Y4.3)	0.587	<0.001	Used in the model
Stakeholder Engagement (Y4.4)	0.891	<0.001	Used in the model

In this study, all indicators were thoroughly assessed for significance and directionality. The model's robustness and validity were maintained by excluding indicators with insignificant or negative loadings or weights. However, an exploratory study of indicators for each variable found that all indicators matched the necessary statistical criteria, such as significance, reliability, and positive loading or weight values. As a result, all of the indications were kept and incorporated into the final model, ensuring a thorough representation of the constructs being studied. Table 4 displays the study's findings, including factor loadings and component weights for each indicator, and provides a detailed description of the indicators included in the model. This technique ensures that the model accurately represents the interactions between factors and provides useful insights on GSCM dynamics and company sustainability performance.

Model Fit and Quality Indices

Before interpreting hypothesis testing results, the model's Goodness of Fit must be confirmed. In PLS analysis, ten Model Fit and Quality Indices assess the structural model's adequacy (Saragih et al., 2024). Key metrics include SRMR, NFI, and Chi-Square/df to validate fit, while R^2 and Q^2 measure explanatory and predictive power. These indices ensure the model aligns with theoretical assumptions and empirical data, confirming its reliability and predictive strength. Table 5 presents a detailed overview of these indices, evaluating the model's structural quality and research compatibility.

Table 5. Model Fit and Quality Indices

Model Fit/ Quality Indices	Value	Fit Criteria	Result
Average block VIF	AVIF = 1.261	Acceptable if AVIF ≤ 5 ; Ideal if AVIF ≤ 3.30	Ideal
Average full collinearity VIF	AFVIF = 3.549	Acceptable if AFVIF ≤ 5 ; Ideal if AFVIF ≤ 3.30	Acceptable
Average path coefficient	APC = 0.339 P < 0.001	P < 0.05	Significant
Average R-squared	ARS = 0.281 P < 0.001	P < 0.05	Significant
Average adjusted R-squared	AARS = 0.268 P < 0.001	P < 0.05	Significant
Tenenhaus GoF	GoF = 0.435	Small if GoF ≥ 0.10 ; Medium if GoF ≥ 0.25 ; Large if GoF ≥ 0.36	Large
Sympson's paradox ratio	SPR = 1.000	Acceptable if SPR ≥ 0.70 ; Ideal if SPR = 1	Ideal
R-squared contribution ratio	RSCR = 0.984	Acceptable if RSCR ≥ 0.90 ; Ideal RSCR = 1	Acceptable
Statistical suppression ratio	SSR = 1.000	Acceptable if SSR ≥ 0.70	Acceptable
Nonlinear bivariate causality direction ratio	NLBCDR = 1.000	Acceptable if NLBCDR ≥ 0.70	Acceptable

This study used PLS-SEM with WarpPLS to analyze the relationship between GSCM practices and Corporate Sustainability Performance (CSP). PLS-SEM was chosen for its ability to handle complex models, small samples, and non-normal data (Hair et al., 2019). This method provides reliable estimates for direct and indirect relationships, including moderating and mediating effects. Figure 2 illustrates the structural model, depicting GSCM's impact on Green Innovation ($\beta = 0.31$, $p < 0.01$) and CSP dimensions (ECO, EV, SOC) to varying degrees. Green Innovation moderates sustainability outcomes, with R^2 values of 0.42 (ECO), 0.28 (EV), and 0.33 (SOC), indicating strong explanatory power.

This model confirms Green Innovation as a key mediator, strengthening the link between GSCM and sustainability outcomes. GSCM positively impacts economic, environmental, and social performance, reinforcing its role in corporate sustainability. Integrating innovation into supply chains enhances sustainability benefits and long-term resilience, particularly in resource-intensive industries like palm oil. Green Innovation helps bridge gaps in achieving sustainability by promoting eco-friendly technologies and practices. The findings highlight the need for businesses to align strategies with global sustainability goals and environmental regulations, offering practical insights for optimizing GSCM implementation in the palm oil sector.

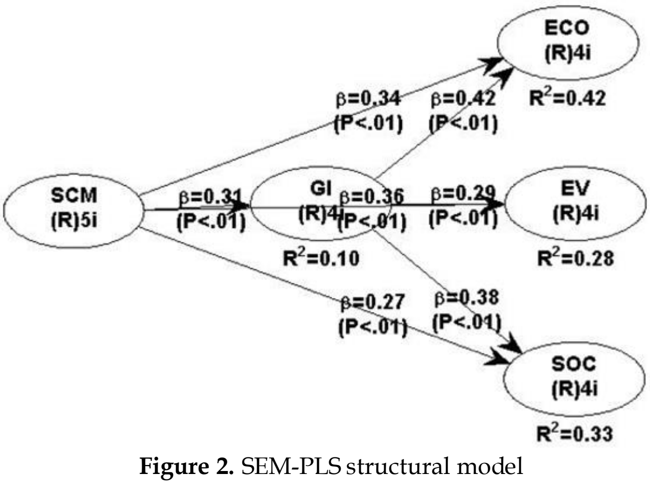

Figure 2. SEM-PLS structural model

Result of Direct Effect Testing

The structural model illustrates relationships between variables using path coefficients for direct effects and p-values for significance. Path coefficients indicate relationship strength and direction (positive or negative), while p-values < 0.05 confirm statistical significance. Direct effects show immediate impacts, whereas indirect effects involve mediation by other factors, offering deeper insights into variable interactions. Table 6 presents PLS analysis results, highlighting seven significant direct correlations ($p < 0.05$), confirming the model's robustness in capturing key interactions.

Table 6. Hypothesis Testing on Direct Effects in PLS Analysis

Variable		Path Coefficient	P-value	Test Results
Predictor	Response			
SCM (X1)	ECO (Y2)	0.336	<0.001**	Significant
SCM (X1)	EV (Y3)	0.362	<0.001**	Significant
SCM (X1)	SOC (Y4)	0.273	<0.001**	Significant
SCM (X1)	GI (Y1)	0.313	<0.001**	Significant
GI (Y1)	ECO (Y2)	0.416	<0.001**	Significant
GI (Y1)	EV (Y3)	0.293	<0.001**	Significant
GI (Y1)	SOC (Y4)	0.376	<0.001**	Significant

The results strongly support the adoption of all seven direct effect hypotheses proposed in this study. These findings emphasise the importance of Green Supply Chain Management (GSCM) characteristics such as Green Procurement, Green Manufacturing, Green Logistics, and Green Packaging in shaping key aspects of Corporate Sustainability Performance. The statistically significant relationships underscore the validity of the theoretical framework and its application within the context of Indonesia's palm oil industry. These insights lay a strong foundation for further discussion on the implications of these direct effects for both academic and practical perspectives, particularly in the design and implementation of sustainability strategies.

Result of Indirect Effect Testing

SEM distinguishes between direct and indirect effects, with indirect effects revealing how variables interact through mediators. This study examined Green Innovation as a mediator between GSCM practices and Corporate Sustainability Performance (CSP) using PLS analysis. The results highlight Green Innovation's strong mediating role in economic and social sustainability, while its effect on environmental sustainability is weaker (Table 7). These findings underscore the importance of Green Innovation in enhancing GSCM's impact and achieving sustainability goals.

Table 7. Hypothesis Testing on Indirect Effects with Two Segments in PLS Analysis

Variable			Path Coefficient	P-value	Test Results
Predictor	Mediating	Response		Predictor	Mediating
SCM (X1)	GI (Y1)	ECO (Y2)	0.130	0.030*	Significant
SCM (X1)	GI (Y1)	EV (Y3)	0.092	0.093ns	Not Significant
SCM (X1)	GI (Y1)	SOC (Y4)	0.118	0.044*	Significant

Table 7 shows the indirect effects of Green Innovation (GI) in the GSCM-CSP relationship. The results confirm that GI significantly mediates economic (ECO) and social (SOC) sustainability ($\beta = 0.130$, $p = 0.030$; $\beta = 0.118$, $p = 0.044$), indicating that Green Innovation enhances financial efficiency and social responsibility in GSCM implementation. However, GI's effect on environmental sustainability (EV) is not significant ($\beta = 0.092$, $p = 0.093$), suggesting limited adoption of eco-friendly technologies or regulatory challenges in the palm oil sector. This implies that while GSCM strengthens corporate sustainability, its environmental impact requires further improvements. These findings highlight the need to integrate Green Innovation into GSCM strategies to maximize sustainability benefits. Future research should explore factors like government policies and technological advancements to enhance environmental sustainability outcomes.

Practical Implications for Industry

Indonesia's palm oil industry is a vital economic sector, contributing significantly to the country's GDP, but it faces substantial environmental and social challenges, including deforestation, biodiversity loss, and human rights violations. As the global demand for palm oil increases, the urgency to adopt sustainable practices has never been greater. One promising approach to addressing these challenges is the implementation of Green Supply Chain Management (GSCM). GSCM integrates environmentally friendly practices into every stage of the supply chain, from sourcing raw materials to the final product, promoting eco-efficient production and minimizing waste, emissions, and energy consumption. In the context of Indonesia's palm oil industry, adopting GSCM practices can mitigate the adverse effects of conventional palm oil production, such as deforestation and soil degradation, while enhancing corporate sustainability. By shifting to more sustainable sourcing methods, utilizing renewable energy, and improving manufacturing processes, palm oil companies can improve both their environmental impact and economic viability. Furthermore, GSCM has the potential to enhance corporate reputation, improve compliance with international sustainability certifications, and foster stronger relationships with stakeholders, including consumers and investors increasingly focused on sustainability.

The implementation of GSCM in Indonesia's palm oil sector faces significant barriers, including high upfront costs, lack of awareness, weak enforcement of regulations, and the complexity of coordinating a vast and fragmented supply chain. Despite these challenges, there are considerable opportunities for innovation. Technological advancements, such as satellite monitoring for land management and blockchain for traceability, can provide solutions to many of the industry's sustainability issues. The novelty of exploring GSCM in the palm oil industry lies in its potential to reshape the sector by linking environmental sustainability with economic growth through innovative, scalable, and cost-effective solutions. Furthermore, it offers a unique opportunity to integrate multiple stakeholders, from smallholder farmers to large corporations, into a unified, green supply chain model that enhances transparency, reduces negative environmental impacts, and boosts long-term profitability. By harnessing such opportunities, Indonesia's palm oil industry could become a global leader in sustainable agricultural practices, demonstrating that economic success and environmental responsibility can go hand in hand.

To enhance environmental sustainability, companies should adopt eco-friendly raw materials through ISO 14001-certified suppliers and green procurement policies (Parmar et al., 2019; Zhu et al., 2020). Cleaner production technologies, such as energy-efficient machinery and recycling, help reduce waste and costs (Nguyen et al., 2022; Vyas et al., 2020). Low-emission transport (electric/biofuel vehicles) and route optimization (TMS) minimize carbon footprints (Chen et al., 2020; Zhao et al., 2023). Biodegradable packaging and minimalist designs boost eco-friendliness (Huang et al., 2020; Kim et al., 2018). Integrating GSCM into long-term strategies with transparent reporting attracts green investors (Rahman et al., 2023). For social sustainability, expanding CSR programs, improving workplace safety, and engaging employees strengthen commitment (Rahman et al., 2023). Collaborations with research institutions can drive waste management innovations, while IoT-based monitoring improves risk management (Chen et al., 2020; Zhao et al., 2023). Case studies in Indonesia's palm oil sector show successful GSCM adoption, including zero-residue processing, Bio-CNG energy from waste, and automation for higher extraction efficiency, reducing emissions and ensuring sustainable operations.

Conclusion

This study examines the impact of Green Supply Chain Management (GSCM) practices on Corporate Sustainability Performance (CSP) in Indonesia's palm oil industry, highlighting Green Innovation as a mediator. Using PLS-SEM analysis on 100 respondents, the findings support 9 out of 10 hypotheses, confirming that GSCM significantly improves economic, environmental, and social sustainability, both directly and through Green Innovation. Key GSCM components—procurement, manufacturing, logistics, and packaging—positively influence CSP. However, Green Innovation's impact on environmental sustainability is limited, suggesting the need for greater eco-friendly technology adoption. Aligning GSCM with the Sustainable Development Goals (SDGs) is crucial for competitiveness and long-term sustainability. To enhance GSCM implementation, companies should invest in green technologies, collaborate with research institutions, and strengthen internal policies through regular audits and sustainability-aligned operations. Training programs can enhance employee competencies, while partnerships with global sustainability organizations can accelerate best practice adoption. Digital tools and analytics should be integrated to optimize resource use and decision-making. Future research should explore GSCM applicability in other industries and regions for broader insights. Incorporating moderators like government support and stakeholder pressure, as well as qualitative methods (case studies, interviews), can deepen understanding. A longitudinal approach can assess long-term GSCM effectiveness. Expanding automation, biofuel use, and zero-waste initiatives will boost sustainability, cost efficiency, and Indonesia's global competitiveness in responsible palm oil production. Future studies should focus on scalability and best practices for broader industry adoption.

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Conceptualization, D.A.P and S; methodology, D.A.P and S; validation D.A.P and S.; formal analysis, D.A.P and S; investigation, D.A.P and S; resources, D.A.P and S; data curation, D.A.P and S; writing—original draft preparation, D.A.P and S.; writing—review and editing, D.A.P and S; visualization, M.S.R and N.M; supervision, M.S.R and N.M; project administration D.A.P and S, funding acquisition, M.S.R and N.M. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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