International Journal of
Economic, Business, Accounting, Agriculture
Management and Sharia Administration (IJEBAS)

International Journal of Economics, Business, Accounting,
Agriculture Management and Sharia Administration
(IJEBAS Journal) | ISSN (e): 2808-4713
Volumes 6 No. 3 (2026)

MULTI-OBJECTIVE OPTIMIZATION MODEL APPROACH FOR SUSTAINABLE MSME SUPPLY CHAINS: A BALANCE APPROACH BETWEEN ECONOMIC, ENVIRONMENTAL AND OPERATIONAL PERFORMANCE IN DEVELOPING COUNTRIES

Indra Welly Arifin[1], Hastuti Handayani Harahap[2], Frederick Rudy Sentosa Rajagukguk[3]
Sekolah Tinggi Ilmu Ekonomi Bina Karya Tebing Tinggi[1,2,3]
E-mail: indrawellyarifin66@gmail.com[1], harahaphastutyhandayani@gmail.com[2],
rudyrajagukguk00241@gmail.com[3]
*Korespondensi: indrawellyarifin66@gmail.com

Received : 05 April 2026 Accepted : 14 May 2026
Revised : 15 April 2026 Published : 24 May 2026

Abstract

This study aims to analyze the influence of supply chain strategy on sustainable supply chain performance in Micro, Small, and Medium Enterprises (MSMEs), considering the role of operational efficiency and integration as intervening variables. The approach used is quantitative with the Partial Least Squares–Structural Equation Modeling (PLS-SEM) method using SmartPLS software. Data were obtained through distributing questionnaires to MSMEs in developing countries. The results of the study indicate that supply chain strategy does not have a significant direct effect on sustainable supply chain performance. However, supply chain strategy has a positive and significant effect on operational efficiency and integration, and operational efficiency and integration have a positive and significant effect on sustainable supply chain performance. In addition, the results of the mediation test indicate that operational efficiency and integration fully mediate the relationship between supply chain strategy and sustainable supply chain performance. The R-square value is in the moderate to strong category and the high Goodness of Fit value indicates that the research model has good predictive ability. These findings confirm that improving sustainable supply chain performance in MSMEs depends not only on strategy selection but also on the effectiveness of strategy implementation through increased operational efficiency and integration. This research provides theoretical contributions in the development of multi-objective optimization models as well as practical implications for MSMEs and policy makers in designing more efficient, integrated, and sustainable supply chain strategies.

Keywords: Supply Chain Strategy, Sustainable Supply Chain Performance, Operational Efficiency, Supply Chain Integration and MSMEs

1. Background

Micro, Small, and Medium Enterprises (MSMEs) play a central role in the economies of developing countries, creating jobs, absorbing local labor, and contributing significantly to Gross Domestic Product. However, MSMEs often face limitations in resources, managerial capacity, access to technology, and financing, which limit their ability to grow sustainably. Furthermore, regulatory pressures, consumer demands for environmentally friendly practices, and market fluctuations require MSMEs to optimize their supply chains to remain competitive and resilient. MSME supply chains in developing countries are typically fragmented, informal, and poorly integrated. This leads to operational inefficiencies such as long lead times, suboptimal inventory levels, and high product damage rates, ultimately reducing economic performance. Furthermore, environmentally unfriendly production and distribution practices (e.g., fossil fuel use, solid waste generation, and hazardous materials) impact the local environment and contribute to climate change. Limited infrastructure and a lack of incentives for green practices exacerbate this dilemma in many communities in developing countries. In this context, decision-making in the design and operation of MSME supply chains becomes a multidimensional issue: entrepreneurs need to balance economic objectives (profitability, costs, customer service), environmental objectives (emissions, waste, resource use), and operational objectives (supply reliability, production time, flexibility). Traditional approaches that focus solely on cost minimization often ignore long-term environmental impacts and operational risks. Conversely, solutions that focus solely on environmental sustainability without considering the economic constraints of MSMEs may be unimplementable. Multi-objective optimization models offer an analytical framework for addressing these conflicting objectives by exploring trade-offs and providing balanced solutions that meet stakeholder priorities. However, implementing such models in MSMEs in developing countries faces several challenges: limited and inaccurate data, heterogeneity of production processes, limited technical capabilities of business actors, and the need for models that are simple, operable, and adaptable to local conditions. Furthermore, consideration must be given to the policies and incentives that encourage the adoption of optimal practices generated by the models.

Table 1.1 MSME Supply Chain Performance Data (Baseline)

No	MSME sector	Operational Costs (Rp/month)	Lead Time (days)	Inventory Level (units)	Damage Level (%)	CO_2 emissions (kg/month)	Waste (kg/month)
1	Processed Foods	25,000,000	7	1,200	8.5	520	75
2	Craft	18,500,000	10	800	6.2	430	60
3	Textiles	32,000,000	12	1,500	10.1	680	95
4	Agriculture	20,000,000	5	1,000	7.8	390	85
5	Drink	22,500,000	6	1,100	9.0	510	70

The data in the table shows variations in supply chain performance across five MSME sectors: processed food, crafts, textiles, agriculture, and beverages. These differences reflect the heterogeneity of operational characteristics and the challenges each sector faces in managing its supply chain. In terms of operational costs, the textile sector has the highest costs at IDR 32,000,000 per month, followed by processed food and beverages. The high costs in the textile sector can be attributed to the use of large quantities of raw materials, complex production processes, and relatively high dependence on energy. Conversely, the crafts sector shows the lowest operational costs, indicating a smaller production scale and the use of simpler technology. This is in line with the characteristics of MSMEs in developing countries, which tend to be labor-intensive but low in technology.

In terms of lead time, the textile sector again performed the worst, with a lead time of 12 days, while the agricultural sector had the shortest lead time (5 days). Long lead times in certain sectors indicate inefficiencies in production and distribution processes, such as delays in raw material supplies or a lack of integration between actors in the supply chain. This condition strengthens the research argument that MSME supply chains remain fragmented and poorly coordinated. Furthermore, at the inventory level, the textile sector has the highest inventory level (1,500 units), which has the potential to increase storage costs and the risk of stock buildup. On the other hand, the crafts sector has the lowest inventory level, which, while efficient in terms of storage costs, potentially poses a risk of stockouts when demand increases. This indicates a classic trade-off in inventory management that needs to be optimized.

From a quality and production efficiency perspective, the highest product damage rates were found in the textile (10.1%) and beverage (9.0%) sectors. These high damage rates indicate inefficiencies in the production and distribution processes, which ultimately increase costs and reduce competitiveness. In the context of multi-objective optimization, this indicator is important because it is directly related to operational efficiency and customer satisfaction. Furthermore, from an environmental perspective, the textile sector again contributed the highest CO_2 emissions (680 kg/month) and the largest amount of waste (95 kg/month). This indicates that this sector has a significant environmental impact compared to other sectors. Conversely, the agricultural sector had the lowest emissions (390 kg/month) but produced relatively high levels of waste (85 kg), likely originating from organic waste. These findings reinforce the need to consider not only economic aspects but also environmental impacts when improving supply chain performance.

Table 1.2 Alternative Supply Chain Optimization Strategies

Alternative	Strategy Description	Cost (Rp)	Lead Time (days)	CO_2 emissions (kg)	Waste (kg)	Service Level (%)
A1	Conventional system	100%	100%	100%	100%	85
A2	Simple digitalization	110%	80%	90%	85%	90
A3	Green supply chain	120%	85%	70%	60%	88
A4	Local supplier integration	95%	75%	85%	80%	87
A5	Combination (digital + green)	130%	70%	60%	50%	92

The alternative strategy table shows various approaches that MSMEs can implement to improve their supply chain performance, considering economic, operational, and environmental aspects. Each alternative reflects the consequences of trade-offs between variables, so strategy selection cannot be done partially but must consider all objectives simultaneously. Alternative A1 (conventional system) is used as the baseline, with all indicators at 100% and a service level of 85%. This condition reflects the common practice of MSMEs that are still not integrated and have not adopted innovation, thus tending to be less efficient from both operational and environmental perspectives.

Alternative A2 (simple digitalization) demonstrated a significant improvement in operational performance, marked by an 80% reduction in lead times and a 90% increase in service levels. Furthermore, digitalization contributed to a reduction in emissions and waste, although not optimal. However, this improvement was accompanied by a 110% increase in costs, reflecting the need for initial investment in technology. This indicates that digitalization is an effective strategy for improving efficiency and service, but requires financial readiness from MSMEs. Alternative A3 (green supply chain) focuses on environmental sustainability. This is evident in the significant reduction in CO_2 emissions by up to 70% and waste by up to 60%. However, the impact on lead times and service levels was not as positive as digitalization, and costs increased by up to 120%. This situation demonstrates that implementing environmentally friendly practices often requires additional costs and process changes that do not directly improve operational efficiency.

Alternative A4 (integration of local suppliers) offers a relatively balanced solution with lower costs (95%) compared to conventional systems, as well as a 75% improvement in lead times. Using local suppliers reduces distribution time and increases supply chain flexibility. Furthermore, there is a reduction in emissions and waste, although not as significant as a green supply chain strategy. This suggests that a locally based approach can be a practical and economical solution for MSMEs in developing countries. Alternative A5 (a combination of digital and green) provides the best overall performance, with the fastest lead time (70%), lowest emissions (60%), lowest waste (50%), and highest service level (92%). However, this strategy also has the highest cost (130%), which is a major obstacle to its implementation. Therefore, this alternative represents a technically optimal solution (Pareto superior), but may not be feasible for all MSMEs due to resource constraints.

Overall, this analysis shows that no single strategy is absolutely best without considering the preferences and limitations of MSMEs. The lowest-cost alternatives do not necessarily have the best environmental impact, while the most environmentally friendly and efficient strategies often require high investment. Therefore, a multi-objective optimization approach is needed to determine the combination of strategies that best aligns with priorities in terms of cost, service, and environmental sustainability.

Formulation of the problem

Based on the background and conceptual framework of the research, the problem formulation in this research is as follows:

1. How does supply chain strategy (X) influence sustainable supply chain performance (Y) in MSMEs?
2. How does supply chain strategy (X) affect operational efficiency and supply chain integration (Z) in MSMEs?
3. How do operational efficiency and supply chain integration (Z) affect sustainable supply chain performance (Y) in MSMEs?
4. Are operational efficiency and supply chain integration (Z) able to mediate the relationship between supply chain strategy (X) and sustainable supply chain performance (Y)?

5. Which supply chain strategy is most optimal in improving sustainable supply chain performance considering cost, time, and environmental impact aspects?

2. Theoretical Basis

2.1 Supply Chain Management Concept

A supply chain is an integrated system that connects various activities, from raw material procurement to product distribution to the end consumer. In the modern context, the supply chain is no longer viewed as a linear activity, but rather as a complex network involving various interacting actors and processes. According to Jamwal and Hussain (2020), the supply chain is part of a complex global business network and requires optimal management to simultaneously improve service performance and reduce costs. In MSMEs, supply chain management is often traditional and poorly integrated, leading to various problems such as distribution inefficiencies, inventory imbalances, and delivery delays. Therefore, a more systematic approach to supply chain management is needed to increase business competitiveness.

2.2 Sustainable Supply Chain

Sustainable supply chains are an extension of traditional supply chain concepts that integrate economic, environmental, and social aspects into decision-making. According to Jayarathna et al. (2021), sustainable supply chain models aim to simultaneously optimize multiple dimensions, including costs, environmental impacts, and social aspects. Furthermore, Tautenhain et al. (2019) state that sustainability in supply chains often creates conflicts between objectives, particularly between economic profitability and environmental responsibility. Therefore, an approach capable of balancing these dimensions in an integrated manner is needed. However, research shows that most models still emphasize economic and environmental aspects, while social aspects receive less attention (Jayarathna et al., 2021). This suggests a research opportunity to develop a more comprehensive model.

2.3 MSMEs and Supply Chain Challenges in Developing Countries

MSMEs play a crucial role in the economy, particularly in creating jobs and driving economic growth. However, in implementing supply chains, MSMEs face various obstacles, such as limited capital, technology, and managerial capacity. In the context of developing countries, these challenges are further complicated by limited infrastructure and low integration between business actors. This leads to MSME supply chains being inefficient and difficult to adapt to market changes. Therefore, a simple yet effective model is needed to assist MSMEs in optimal supply chain management.

2.4 Multi-Objective Optimization

Multi-objective optimization is a mathematical approach used to solve problems with more than one conflicting objective. According to Jayarathna et al. (2021), multi-objective optimization has become a primary method in modeling sustainable supply chains because it can accommodate multiple objectives such as economic, environmental, and social simultaneously. Furthermore, Chanchaichujit et al. (2020) explain that multi-objective optimization models in supply chains can be used to minimize costs and emissions simultaneously through a linear programming approach. Furthermore, Jamwal and Hussain (2020) emphasize that the solution in multi-objective optimization is not a single one, but rather a set of optimal solutions (Pareto optimal) that provide a balance between different objectives. Thus, this approach is highly relevant for addressing the complexity of MSME supply chain decision-making involving multiple conflicting objectives.

2.5 Operational Efficiency and Supply Chain Integration

Operational efficiency is a system's ability to produce maximum output with minimal resource usage. In the supply chain, operational efficiency is reflected in indicators such as lead time, product damage rate, and inventory management. Meanwhile, supply chain integration refers to the level of coordination between actors in the supply chain. According to Jayarathna et al. (2021), good integration can improve information flow and reduce uncertainty within the supply chain system, thereby enhancing overall performance. Furthermore, research shows that increased efficiency and integration can be key factors in achieving sustainable supply chain performance, especially in the context of resource-constrained MSMEs.

2.6 Sustainable Supply Chain Performance

Sustainable supply chain performance measures a system's success in achieving a balance between economic, environmental, and operational objectives. Commonly used indicators include operational costs, lead time, service levels, carbon emissions, and waste. According to Jayarathna et al. (2021), a sustainable supply chain model must be able to integrate these various indicators within a comprehensive evaluation framework. Furthermore, Wang et al. (2020) state that sustainable supply chain performance evaluation must consider the entire supply chain network, including efficiency, environmental, and social aspects simultaneously. Thus, performance measurement focuses not only on economic aspects but also encompasses environmental impacts and operational efficiency as a whole.

3. Research Methods

3.1 Types and Approaches of Research

This study uses a quantitative approach to test the causal relationships between variables formulated in the conceptual framework. This quantitative approach was chosen because it provides objective measurements and allows for statistical hypothesis testing. In data analysis, this study employed the Partial Least Squares-based Structural Equation Modeling (PLS-SEM) method with the aid of SmartPLS software. According to Hair et al. (2019), PLS-SEM is a highly suitable analytical method for use when research aims to develop theory, has a complex model, and involves many latent variables and indicators. Furthermore, this method is also suitable for research with relatively small sample sizes and non-normally distributed data, making it highly relevant for research on MSMEs in developing countries.

3.2 Population and Sample

The population in this study were MSMEs involved in supply chain activities, such as producers, distributors, and suppliers. The sampling technique used purposive sampling, which is the selection of samples based on certain criteria, such as MSMEs that have actively carried out production and distribution activities. According to Cepeda-Carrion et al. (2019), in PLS-SEM-based research, the sample size does not have to be large, but it must meet minimum rules such as the 10-times rule, namely the number of samples at least 10 times the number of indicators or paths in the model.

3.3 Data Types and Sources

The data used in this study are primary data obtained through the distribution of questionnaires to MSMEs. The research instrument uses a Likert scale (1–5), which measures respondents' perceptions of the variables: Supply chain strategy (X), Operational efficiency and integration (Z) and Sustainable supply chain performance (Y). According to Shiau, Sarstedt, and Hair (2019), perception-based survey data is very commonly used in PLS-SEM research because it is able to measure latent constructs that cannot be observed directly.

3.4 Data Analysis Techniques (SmartPLS)

Data analysis was carried out using SmartPLS with the PLS-SEM approach which consists of two main stages, namely:

3.4.1 Evaluation of the Measurement Model (Outer Model)

Measurement models are used to test the validity and reliability of constructs. According to Wijaya (2019), outer model evaluation includes:

1. Convergent validity (factor loading ≥ 0.70)
2. Discriminant validity (AVE ≥ 0.50)
3. Reliability (Cronbach's Alpha ≥ 0.60 and Composite Reliability ≥ 0.70)

This stage aims to ensure that the indicators used are able to measure latent variables accurately.

3.4.2 Structural Model Evaluation (Inner Model)

Structural models are used to test the relationships between variables in research. According to Bido and Silva (2019), evaluation of the inner model in PLS-SEM includes:

1. R-square (R^2) to measure the model's ability to explain the dependent variable
2. Path coefficient to see the strength of the relationship between variables
3. Effect size (f^2) to measure the influence of each variable
4. Predictive relevance (Q^2) to test the predictive ability of the model

In addition, hypothesis testing was carried out using the bootstrapping method to obtain t-statistic and p-value values.

3.4.3 Mediation Test (Intervening)

Intervening variable testing was conducted to determine whether operational efficiency and integration (Z) variables were able to mediate the relationship between supply chain strategy (X) and performance (Y). According to Cheah et al. (2019), PLS-SEM is very effective for testing mediation relationships because it can analyze direct and indirect relationships simultaneously.

4. Results and Discussion

4.1 Evaluation of the Measurement Model (Outer Model)

The measurement model (outer model) is a confirmatory factor analysis (CFA) that tests the validity and reliability of the latent constructs. The following are the results of the outer model evaluation in this study.

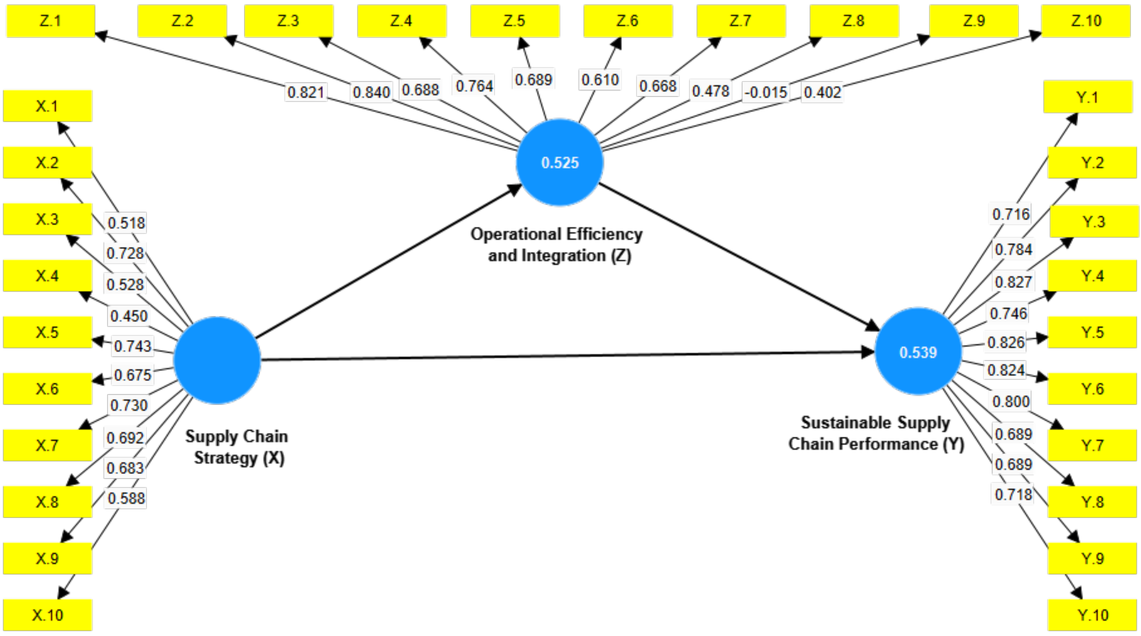

Figure 4.1. Outer Model

Convergent Validity

The convergent validity of the measurement model with the reflective indicator model is assessed based on the correlation between the item score/component score and the construct score calculated using PLS. The following are the results of the convergent validity measurement model test using loading factors:

Table 4.1
Results of Instrument Validity Test Using Loading Factor

	Operational Efficiency _and Integration (Z)	Supply Chain Strategy (X)	Sustainable Supply _Chain Performance (Y)
X.1		0.718	
X.2		0.788	
X.3		0.728	
X.4		0.728	
X.5		0.750	
X.6		0.743	
X.7		0.875	
X.8		0.730	
X.9		0.792	
X.10		0.783	
Y.1			0.716
Y.2			0.718
Y.3			0.784
Y.4			0.827
Y.5			0.746
Y.6			0.826
Y.7			0.824
Y.8			0.800
Y.9			0.889

Y.10			0.889
Z.1	0.821		
Z.2	0.702		
Z.3	0.840		
Z.4	0.788		
Z.5	0.764		
Z.6	0.789		
Z.7	0.710		
Z.8	0.768		
Z.9	0.778		
Z.10	0.815		

Source :Primary data processed (2026)

Based on Table 4.1 above, all loading factor values have exceeded the 0.7 threshold, thus concluding that each indicator in this study is valid. Therefore, these indicators can be used to measure the research variables.

Reliability Test

An instrument can be considered reliable if its Average Variance Extracted value is greater than 0.5, Cronbach's Alpha value is greater than 0.6, and Composite Reliability value is greater than 0.7. The following table shows the results of the reliability calculations using Average Variance Extracted (AVE), Cronbach's Alpha, and Composite Reliability:

Table 4.2 Calculation of AVE, Cronbach Alpha, and Composite Reliability

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Operational Efficiency _and Integration (Z)	0.836	0.896	0.857	0.512
Supply Chain Strategy (X)	0.875	0.881	0.872	0.511
Sustainable Supply _Chain Performance (Y)	0.932	0.935	0.933	0.583

Source :Primary data processed (2026)

The results of the measurement model (outer model) testing indicate that all constructs in this study meet the reliability and convergent validity criteria required for PLS-SEM analysis. This evaluation was conducted using three main indicators: Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE). In the Operational Efficiency and Integration (Z) variable, a Cronbach's Alpha value of 0.836 was obtained, indicating a good level of internal consistency because it has exceeded the minimum limit of 0.70. The Composite Reliability (rho_c) value of 0.857 also indicates that this construct has high reliability in measuring latent variables. In addition, the AVE value of 0.512 indicates that more than 50% of the indicator variance can be explained by the construct, thus meeting the criteria for convergent validity. Thus, the indicators in this variable are declared valid and reliable in representing operational efficiency and supply chain integration.

Furthermore, for the Supply Chain Strategy (X) variable, the Cronbach's Alpha value of 0.875 indicates an excellent level of reliability. The Composite Reliability value of 0.872 confirms that this construct is consistent in measuring the concept of supply chain strategy. The AVE value of 0.511 also meets the required threshold, thus concluding that the indicators used are able to adequately explain the variable. This indicates that the supply chain strategy construct has good measurement quality and is worthy of use in further analysis.

The Sustainable Supply Chain Performance (Y) variable obtained a Cronbach's Alpha value of 0.932, indicating very high reliability. The Composite Reliability value of 0.933 also strengthens the internal consistency of this construct. Furthermore, the AVE value of 0.583 indicates a strong level of convergent validity, as the variable is able to explain more than 58% of the indicator's variance. These results indicate that the sustainable supply chain performance construct has excellent measurement quality compared to other variables. Overall, all variables in this study met the criteria for reliability (Cronbach's Alpha and Composite Reliability > 0.70) and convergent validity (AVE > 0.50). Therefore, it can be concluded that the measurement model used is appropriate and can proceed to the structural model evaluation stage (inner model). These results also indicate that the research instrument is able to measure the constructs consistently and accurately, thus supporting the reliability of subsequent analysis results in examining the relationships between variables.

Structural Model Evaluation (Inner Model)

Evaluation of the inner model can be seen from several indicators, including the coefficient of determination (R2), Predictive Relevance (Q2), and Goodness of Fit Index (GoF) (Hussein, 2015). The results of the structural model displayed by Smart PLS 3.0 in this study are as follows:

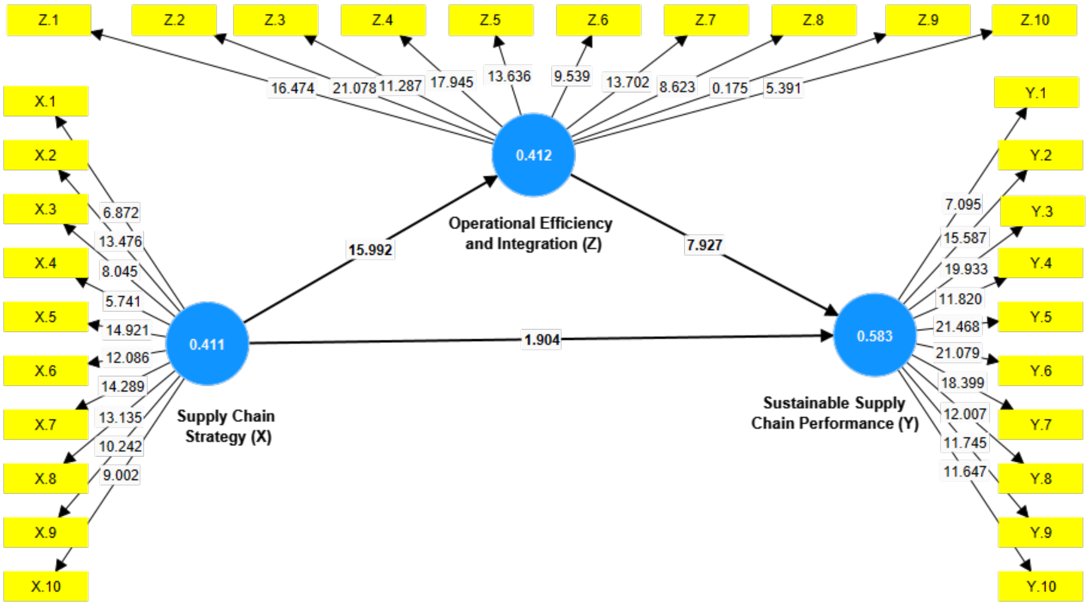

Figure 4.2 Structural Model (Inner Model)

R2 (R-square) results

In assessing a model using PLS, we begin by looking at the R-square for each dependent latent variable. The results of the r2 calculation in this study are as follows:

Table 4.3
Correlation Value (r2)

	R-square	R-square adjusted
Operational Efficiency _and Integration (Z)	0.625	0.623
Sustainable Supply _Chain Performance (Y)	0.639	0.636

Source :Primary data processed (2026)

The evaluation results of the structural model (inner model) through the R-square (R²) value indicate the ability of the independent variables to explain the dependent variables in the research model. The R-square value illustrates how much variation in endogenous constructs can be explained by the exogenous constructs that influence them. In the Operational Efficiency and Integration (Z) variable, the R-square value was obtained at 0.625 and the adjusted R-square was at 0.623. This indicates that 62.5% of the variation in operational efficiency and integration can be explained by the Supply Chain Strategy (X) variable, while the remaining 37.5% is influenced by other factors outside the research model. This value is considered strong (moderate to substantial), indicating that supply chain strategy has a significant role in improving operational efficiency and integration in the context of MSMEs.

Furthermore, the Sustainable Supply Chain Performance (Y) variable obtained an R-square value of 0.639 and an adjusted R-square of 0.636. These results indicate that 63.9% of the variation in sustainable supply chain performance can be explained by the Supply Chain Strategy (X) and Operational Efficiency and Integration (Z) variables simultaneously. Meanwhile, 36.1% is influenced by other variables not included in the model, such as external factors (government policies, market conditions, or technology). Based on general criteria in PLS-SEM, an R-square value of 0.67 is categorized as strong, 0.33 as moderate, and 0.19 as weak. Thus, the R-square values for both endogenous variables in this study are in the moderate to strong category, indicating that the model has quite good explanatory power. Overall, these results indicate that supply chain strategy not only directly influences sustainable supply chain performance but also indirectly through increased operational efficiency and integration. This strengthens the role of intervening variables in the research model and demonstrates that a multi-objective optimization approach that considers multiple performance aspects can explain the phenomenon more comprehensively.

Goodness of Fit Model

Goodness of Fit (GoF) in PLS-SEM is used to evaluate the overall model fit by combining the quality of the measurement model (outer model) and the structural model (inner model).

The GoF formula is as follows:

$$GoF = \sqrt{AVE \times R^2}$$

1. Calculating Average AVE

$$AVE = \frac{0{,}512 + 0{,}511 + 0{,}583}{3} = 0{,}535$$

2. Calculating the Average R-square

$$R^2 = \frac{0{,}625 + 0{,}639}{2} = 0{,}632$$

3. Calculating GoF

$$GoF = \sqrt{0{,}535 \times 0{,}632} = \sqrt{0{,}338} = 0{,}581$$

Interpretation of Goodness of Fit

The GoF value obtained was 0.581. Based on the criteria:

a) Small GoF = 0.10
b) Medium GoF = 0.25
c) GoF large = 0.36

So the value of 0.581 is included in the large category (strong fit).

The Goodness of Fit (GoF) calculation showed a value of 0.581, which is in the strong (large fit) category. This indicates that the developed research model has a very good level of fit in explaining the relationship between the studied variables. A high GoF value indicates that the combination of construct validity (represented by AVE) and model predictive ability (represented by R-square) has been optimally met. Thus, the model is not only able to measure the construct accurately but also has a good ability to explain the endogenous variables in the study. Substantively, these results strengthen that the model that integrates Supply Chain Strategy (X), Operational Efficiency and Integration (Z), and Sustainable Supply Chain Performance (Y) is able to explain the phenomenon of the MSME supply chain comprehensively. This is in line with the multi-objective optimization approach, where the balance between economic, operational, and environmental aspects can be analyzed simultaneously.

Furthermore, the high GoF value also indicates that the intervening variables, namely operational efficiency and integration, play a significant role in strengthening the relationship between supply chain strategy and sustainable performance. In other words, the developed model is not only statistically valid but also theoretically and practically relevant in the context of MSMEs in developing countries. Therefore, it can be concluded that this research model is suitable for further analysis, including hypothesis testing and interpretation of relationships between variables.

Hypothesis Testing

Based on the results of the inner model, all tested hypotheses met the requirements and could therefore be used as an analysis model in this study. Hypothesis testing in this study used a 5% alpha, meaning that if the t-statistic value is ≥ 1.96 or the probability value is ≤ the level of significance (α = 5%), the analysis in this study continued by testing the direct and indirect effects between variables in the structural model. This test was conducted to determine the extent of each independent variable's contribution to the dependent variable, both directly and through mediating variables.

Table 4.4 Direct Effect

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Operational Efficiency _and Integration (Z) -> Sustainable Supply _Chain Performance (Y)	0.597	0.605	0.075	7,927	0,000
Supply Chain _Strategy (X) -> Operational Efficiency _and Integration (Z)	0.725	0.730	0.045	15,992	0,000
Supply Chain _Strategy (X) -> Sustainable Supply _Chain Performance (Y)	0.176	0.177	0.092	1,904	0.057

Source :Primary data processed (2026)

Hypothesis testing in this study was conducted using the bootstrapping method in PLS-SEM, with a significance level (α) of 5%. The testing criteria used were if the t-statistic value ≥ 1.96 or p-value ≤ 0.05, then the hypothesis is declared accepted.

1. Based on the analysis results, the relationship between Supply Chain Strategy (X) and Operational Efficiency and Integration (Z) shows a t-statistic value of 15.992 and a p-value of 0.000. A t-statistic value that is much greater than 1.96 and a p-value smaller than 0.05 indicates that the relationship is statistically significant. Thus, the hypothesis that supply chain strategy has a positive and significant effect on operational efficiency and supply chain integration can be accepted. The results of this study indicate that supply chain strategy has a very strong influence on increasing operational efficiency and integration in the MSME supply chain. The high t-statistic value (15.992) indicates that changes in supply chain strategy will significantly affect the ability of MSMEs to manage operational processes more efficiently and improve coordination between actors in the supply chain.

   In the context of this research, strategies such as digitalization, integration of local suppliers, and the implementation of green supply chain concepts have been shown to accelerate information flow, reduce lead times, and improve synchronization between production and distribution. This indicates that supply chain strategy impacts not only technical aspects but also the quality of relationships between actors in the supply chain system. This finding aligns with the research objective, which emphasizes the importance of a multi-objective optimization approach, where improving operational efficiency and integration are crucial initial steps in achieving sustainable supply chain performance. In other words, an appropriate supply chain strategy will create a more coordinated and efficient system, ultimately contributing to improved economic, operational, and environmental performance. Furthermore, these results also reinforce the role of the intervening variable (Z) in the research model, where operational efficiency and integration act as mechanisms that bridge the influence of strategy on sustainable supply chain performance. Therefore, improving strategy without being accompanied by improvements in efficiency and integration is unlikely to produce optimal results.
2. Hypothesis testing was conducted using a significance level (α) of 5%, with the criteria that the hypothesis is accepted if the t-statistic value ≥ 1.96 or p-value ≤ 0.05. Based on the analysis results, the relationship between Supply Chain Strategy (X) and Sustainable Supply Chain Performance (Y) shows a t-statistic value of 1.904 and a p-value of 0.057. The t-statistic value is smaller than 1.96 and the p-value is greater than 0.05, so statistically it shows that the relationship is not significant. Thus, the hypothesis stating that supply chain strategy has a direct effect on sustainable supply chain performance cannot be accepted (rejected).

   Hypothesis testing was conducted using a significance level (α) of 5%, with the criteria that the hypothesis is accepted if the t-statistic value ≥ 1.96 or p-value ≤ 0.05. Based on the analysis results, the relationship between Supply Chain Strategy (X) and Sustainable Supply Chain Performance (Y) shows a t-statistic value of 1.904 and a p-value of 0.057. The t-statistic value is smaller than 1.96 and the p-value is greater than 0.05, so statistically it shows that the relationship is not significant. Thus, the hypothesis stating that supply chain strategy has a direct effect on sustainable supply chain performance cannot be accepted (rejected).

The results of this study indicate that supply chain strategies do not have a significant direct impact on sustainable supply chain performance in MSMEs. Although conceptually, strategies such as digitalization, green supply chains, and supplier integration are believed to improve performance, in practice, these impacts are not directly evident. This condition indicates that the implementation of supply chain strategies does not automatically result in improved economic, environmental, and operational performance. This may be due to several factors, such as limited resources, lack of technological readiness, and low managerial capacity in MSMEs in developing countries.

Furthermore, these results reinforce the important role of intervening variables, namely Operational Efficiency and Integration (Z). Supply chain strategies tend to primarily influence operational efficiency and the level of integration within the system, which then impact sustainable supply chain performance. In other words, the influence of strategy on performance is indirect. In the context of a multi-objective optimization approach, these findings suggest that performance improvement depends not only on strategy selection but also on how effectively it is implemented through increased efficiency and integration. Without improvements in operational aspects, the implemented strategy has the potential to fail to deliver optimal results.

3. Hypothesis testing was conducted with a significance level (α) of 5%, with the criteria that the hypothesis is accepted if the t-statistic value ≥ 1.96 or p-value ≤ 0.05. Based on the analysis results, the relationship between Operational Efficiency and Integration (Z) on Sustainable Supply Chain Performance (Y) shows a t-statistic value of 7.927 and a p-value of 0.000. A t-statistic value that is much greater than 1.96 and a p-value smaller than 0.05 indicates that the relationship is statistically significant. Thus, the hypothesis that operational efficiency and integration have a positive and significant effect on sustainable supply chain performance can be accepted.

The results of this study indicate that operational efficiency and supply chain integration have a strong influence on improving sustainable supply chain performance in MSMEs. A high t-statistic value (7.927) indicates that the better the level of operational efficiency and integration between actors in the supply chain, the higher the resulting performance, both from an economic, operational, and environmental perspective. Good operational efficiency is reflected in the ability of MSMEs to manage production time (lead time), reduce waste, and optimize resource use. Meanwhile, supply chain integration allows for better coordination between suppliers, producers, and distributors, resulting in a smoother flow of goods and information. The combination of these two aspects has been proven to reduce operational costs, reduce emissions and waste, and improve service levels to customers.

In the context of this study, these findings reinforce the role of the intervening variable (Z) as a key factor in bridging the relationship between supply chain strategy and sustainable performance. Although supply chain strategy does not have a significant direct effect on performance (as previously found), through increased efficiency and integration, it can have a significant indirect impact. These findings are also in line with the multi-objective optimization approach, where achieving optimal performance depends not only on the chosen strategy but also on the effectiveness of its implementation in improving overall system efficiency. In other words, operational efficiency and integration are the main mechanisms that enable the achievement of a balance between economic, environmental, and operational objectives in the MSME supply chain.

Table 4.5 Indirect Effect

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Supply Chain _Strategy (X) -> Operational Efficiency _and Integration (Z) -> Sustainable Supply _Chain Performance (Y)	0.432	0.442	0.068	6,392	0,000

Source :Primary data processed (2026)

The mediation hypothesis testing was conducted to determine whether the Operational Efficiency and Integration (Z) variables were able to mediate the relationship between Supply Chain Strategy (X) and Sustainable Supply Chain Performance (Y). The testing criteria used a significance level (α) of 5%, that is, if the t-statistic value ≥ 1.96 or p-value ≤ 0.05, then the mediation effect was declared significant. Based on the analysis results, the indirect relationship between Supply Chain Strategy (X) → Operational Efficiency and Integration (Z) → Sustainable Supply Chain Performance (Y) showed a t-statistic value of 6.392 and a p-value of 0.000. These values indicate that the indirect effect is statistically significant. Thus, the hypothesis stating that operational efficiency and integration mediate the relationship between supply chain strategy and sustainable supply chain performance can be accepted.

The results of this study indicate that Operational Efficiency and Integration (Z) act as significant intervening variables in the relationship between supply chain strategy and sustainable supply chain performance. Although the previous test found that the direct effect of Supply Chain Strategy (X) → Sustainable Supply Chain Performance (Y) was not significant, through the indirect path (mediation), the effect becomes significant. This indicates that supply chain strategy does not directly improve performance, but first improves operational efficiency and integration within the supply chain system. After efficiency and integration increase, then there is an overall improvement in performance, both from the economic, operational, and environmental aspects.

In other words, operational efficiency and integration act as key mechanisms explaining how supply chain strategies can generate sustainable performance. Strategies such as digitalization, local supplier integration, and the implementation of a green supply chain will only be effective if they improve coordination between actors, accelerate information flow, and optimize resource utilization. In the context of MSMEs in developing countries, these findings are highly relevant because resource constraints often hinder the direct implementation of strategies. Therefore, increasing efficiency and integration is a more realistic and impactful strategic step in boosting supply chain performance. Furthermore, these results reinforce the multi-objective optimization approach, where performance achievement is not determined by a single factor but is the result of the interaction of various interrelated variables. Operational efficiency and integration serve as a bridge connecting strategy to the desired end result.

Discussion of Research Results on the Most Optimal Supply Chain Strategy

The results of this study indicate that the relationship between Supply Chain Strategy (X), Operational Efficiency and Integration (Z), and Sustainable Supply Chain Performance (Y) has an indirect pattern, where intervening variables play a very important role in explaining the mechanism of the relationship between variables. Partially, the results of the hypothesis test indicate that Supply Chain Strategy (X) does not have a significant direct effect on Sustainable Supply Chain Performance (Y). This finding indicates that the implementation of supply chain strategies, such as digitalization, supplier integration, and green supply chains, does not automatically improve sustainable supply chain performance. This reflects the real conditions of MSMEs in developing countries that still face various limitations in implementing strategies, both in terms of resources, technology, and managerial capacity.

However, the results of the study indicate that Supply Chain Strategy (X) has a significant effect on Operational Efficiency and Integration (Z), and Operational Efficiency and Integration (Z) have a significant effect on Sustainable Supply Chain Performance (Y). Furthermore, the results of the mediation test indicate that Z is able to fully mediate the relationship between X and Y. This means that a new supply chain strategy will have an impact on performance if it is able to improve operational efficiency and integration in the supply chain. This finding reinforces that operational efficiency and integration are key factors (critical success factors) in improving sustainable supply chain performance. In other words, a good strategy must be implemented effectively through increased coordination, reduced waste, and optimized information flow and distribution.

The results of this study align with those of Arifin, Harahap, and Rajagukguk (2023) in their study titled "The Impact of Green Marketing Techniques on Consumer Purchasing Decisions in Organic Product Companies in North Sumatra through Product Quality Perception as an Intervening Variable," which found that intervening variables play a significant role in mediating the influence of strategy on outcomes. In this study, green marketing does not directly influence purchasing decisions, but rather through product quality perception as a mediating variable. Furthermore, Arifin et al.'s (2022) study on the influence of green marketing techniques on consumer loyalty through green pricing as a mediating variable also shows that environmentally-based marketing strategies require intermediary mechanisms to impact consumer loyalty. This is consistent with the findings of this study, where supply chain strategies require efficiency and integration as mediators to improve performance.

Furthermore, in a study by Arifin et al. (2023) on digital marketing and public awareness of blue economy products, it was found that implementing digital strategies does not have an immediate impact, but requires a process of adaptation and increased system capacity to produce optimal output. This is in line with the results of this study, which show that digitalization as part of a supply chain strategy must be accompanied by increased operational efficiency. Another study by Arifin et al. (2024) on digital transformation and packaging innovation in MSMEs also emphasized that the success of a strategy is highly dependent on the ability of business actors to integrate innovation into operational processes. Without proper integration, the implemented strategy will not have a significant impact on competitiveness or business performance. Thus, the overall results of this study confirm that a multi-objective optimization approach in the MSME supply chain depends not only on strategy selection but also on the effectiveness of its implementation through increased efficiency and integration. This is especially important in the context of developing countries, where resource constraints demand a more adaptive and integrated approach.

Determining the most optimal supply chain strategy to improve sustainable supply chain performance cannot be done by considering only one aspect, but must integrate various dimensions, namely cost, time (lead time), and environmental impact. In the context of this research, a multi-objective optimization approach is used to identify the strategy that can provide the best balance between these three aspects. Based on the alternative strategy data that has been analyzed, each strategy shows different advantages and disadvantages. The conventional system strategy (A1) has a relatively standard cost, but shows less than optimal performance in terms of time and environmental impact. This indicates that the traditional approach is no longer relevant to meet the demands of efficiency and sustainability.

A simple digitalization strategy (A2) provides significant improvements in time and service levels, and can reduce emissions and waste, although not drastically. However, this strategy requires additional costs, so its implementation must be tailored to the financial capabilities of MSMEs. Meanwhile, a green supply chain strategy (A3) demonstrates key environmental advantages, with significant reductions in emissions and waste. However, this strategy tends to increase costs and is not fully optimal in improving time efficiency. This indicates a trade-off between environmental sustainability and economic efficiency. The local supplier integration strategy (A4) emerges as a fairly balanced alternative, with lower costs than the other strategies and improvements in lead times and environmental impact. This approach is particularly relevant for MSMEs in developing countries because it is easier to implement and does not require significant investment.

However, the combined digitalization and green supply chain strategy (A5) demonstrated the best overall performance. This strategy was able to provide the fastest lead times, the lowest emissions and waste, and the highest service levels. This indicates that the integration of digital technology and environmentally friendly practices is the most comprehensive solution for improving sustainable supply chain performance. However, the A5 strategy also has the highest implementation costs, so not all MSMEs can readily adopt it. Therefore, in a practical context, selecting the optimal strategy must consider the limited resources available to MSMEs. In relation to the results of the research model analysis, the optimal strategy is not only the one with the best performance value, but also the one that can improve operational efficiency and supply chain integration. This is in line with the finding that operational efficiency and integration are key variables mediating the relationship between strategy and performance.

5. Conclusion

Based on the results of the analysis and discussion regarding the Multi-Objective Optimization Model Approach for Sustainable MSME Supply Chains, the following conclusions can be drawn:

1. Supply Chain Strategy does not have a direct impact on Sustainable Supply Chain Performance.
   The test results show that the direct relationship between supply chain strategy and performance is insignificant. This indicates that the implementation of strategies such as digitalization, green supply chains, and supplier integration cannot directly improve the economic, environmental, and operational performance of MSMEs without supporting factors.
2. Supply Chain Strategy has a positive and significant impact on Operational Efficiency and Integration.
   These findings indicate that the implemented strategies are able to increase the efficiency of operational processes and strengthen coordination in the supply chain, such as reducing lead times, increasing information flow, and synchronizing between business actors.
3. Operational Efficiency and Integration have a positive and significant impact on Sustainable Supply Chain Performance.
   These results confirm that increased efficiency and integration are key factors in driving improved MSME performance, both in terms of costs, services, and environmental impact.
4. Operational Efficiency and Integration fully mediate the relationship between Supply Chain Strategy and Sustainable Supply Chain Performance.

This shows that the influence of strategy on performance is not direct, but rather through increased operational efficiency and integration as intermediary variables. Thus, the success of a strategy depends heavily on the effectiveness of its implementation within the operational system.

5. The research model has a good level of suitability and predictive ability.
   This is evidenced by the moderate to strong R-squared value and the high Goodness of Fit (GoF) value. Thus, the developed model is able to comprehensively explain the relationships between variables.

REFERENCES

Arifin, IW, Harahap, HH, & Rajagukguk, FRS (2023). The impact of green marketing techniques on consumer purchasing decisions in organic product companies in North Sumatra through product quality perception as an intervening variable. International Journal of Economics, Management and Accounting (IJEMA).

Arifin, IW, Harahap, HH, & Rajagukguk, FRS (2022). The influence of green marketing techniques on consumer loyalty to environmentally friendly products with an evaluation of green pricing techniques as a mediating variable. Accounting Progress, 3(2), 123–132.

Arifin, IW, Harahap, HH, & Rajagukguk, FRS (2023). Analysis of the influence of digital marketing on increasing public awareness of blue economy products in coastal areas of North Sumatra. SIBATIK Journal.

Arifin, IW, Masyitah, E., Harahap, HH, Rajagukguk, FRS, & Rusmewahni, R. (2024). Digital transformation and packaging innovation: Strategies to increase the competitiveness of brown sugar and chip MSMEs in Pelanggiran Laut Tador Village. Community Service Progress, 4(2), 71–76.

Bido, D. S., & Silva, D. (2019). SmartPLS 3: Specification, estimation, evaluation and reporting.

Cepeda-Carrion, G., Cegarra-Navarro, J. G., & Cillo, V. (2019). Tips for using PLS-SEM in knowledge management. Journal of Knowledge Management.

Cheah, J.-H., Ting, H., Ramayah, T., et al. (2019). Reflective-formative estimation approaches in PLS-SEM.

Chanchaichujit, J., Balasubramanian, S., Shukla, V., & Rosas, J. (2020). Multi-objective decision model for green supply chain management. Cogent Business & Management.

Hair, J.F., Risher, J.J., Sarstedt, M., & Ringle, C.M. (2019). When to use and how to report PLS-SEM. European Business Review.

Jamwal, P. K., & Hussain, S. (2020). A fuzzy based multi-objective optimization of multi-echelon supply chain network. Journal of Intelligent & Fuzzy Systems.

Jayarathna, C. P., Agdas, D., Dawes, L., & Yigitcanlar, T. (2021). Multi-objective optimization for sustainable supply chains and logistics: A review. Sustainability, 13(24), 13617.

Shiau, W.-L., Sarstedt, M., & Hair, J.F. (2019). Internet research using PLS-SEM. Internet Research.

Tautenhain, C.P.S., Barbosa-Povoa, A.P., Mota, B., & Nascimento, M.C.V. (2019). Multi-objective sustainable supply chain optimization.

Wang, et al. (2020). An efficient sorting multi-objective optimization framework for sustainable supply networks. Journal of Cleaner Production.

Wijaya, A. (2019). Research Methods Using SmartPLS 3.