

THE RELATIONSHIP OF GREEN LOGISTICS AND GREEN MANUFACTURING TO SUPPLY CHAIN SUSTAINABILITY

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Abstract: This study explores the impact of Green Logistics and Green Manufacturing on Supply Chain Sustainability in the Deltamas Industrial Area, Bekasi, Indonesia. The research highlights the growing importance of sustainable practices in supply chains to reduce environmental impacts such as emissions and waste. Data were collected through surveys, Focus Group Discussions (FGD), and expert interviews with company managers, government representatives, and industry professionals. The findings, analyzed using Structural Equation Modeling (SEM), reveal that both Green Logistics and Green Manufacturing significantly positively influence Supply Chain Sustainability. These results align with qualitative insights from experts, which emphasize the importance of green practices in reducing carbon footprints, enhancing operational efficiency, and improving corporate image. The study concludes that implementing Green Logistics and Green Manufacturing in the industrial sector is essential for achieving sustainable supply chain goals.

Keywords: Green Logistics, Green Manufacturing, Supply Chain, Sustainability

Introduction

Today's global supply chains are facing increasingly complex challenges due to the acceleration of industrial activities and rapid technological advancements. This complexity has driven the emergence of sustainability paradigms, particularly in response to growing environmental vulnerabilities (Joshi, 2022). Emissions originating from supply chain activities have been proven to contribute significantly to environmental instability, leading to ecosystem disruption, global supply interruptions, extreme weather patterns, and threats to species extinction. Over the past five decades, the average global temperature has risen by more than 1.5°C, accompanied by a global increase in sea levels (V. et al., 2021). These environmental issues are further exacerbated by social problems within the supply chain, such as unsafe working conditions, poor workplace hygiene, and risks to both the physical and mental health of workers (Oliveira, 2018). In this context, sustainable supply chains have become a critical and urgent approach to be implemented. This concept aims to reduce the negative environmental and social impacts of supply chain activities while maintaining economic efficiency (Fan, Pintarič, & Klemeš, 2020). One of the major challenges in implementing supply chain sustainability is the integration of green logistics and green manufacturing practices (Strandhagen, 2022). Green logistics requires technological and infrastructural investments that support sustainability, such as transportation route efficiency, reusable packaging, and more efficient logistics operations (Islam, 2021). Meanwhile, green manufacturing faces obstacles such as high initial investments for adopting environmentally friendly technologies, the need to update infrastructure, and the sourcing of more sustainable raw materials (Afum, 2020). Overcoming these challenges requires management commitment, adequate financial resources, and a shift in organizational culture (Ghadimi, 2020).

The implementation of green logistics is a crucial step in building supply chain sustainability. This practice includes route optimization, the use of eco-friendly fuels, efficient waste management, and the application of information technology to improve visibility and logistics efficiency (Trivellas, 2020). For example, PT Unilever Indonesia Tbk has implemented a low-emission vehicle fleet and optimized distribution routes as part of its green logistics strategy (WEF, 2022). As a result, the company successfully reduced its carbon footprint, enhanced operational efficiency, and significantly lowered logistics costs. Accordingly, key indicators of green logistics that contribute to supply chain sustainability include waste management, emission and energy consumption reduction, the use of non-hazardous materials, and the implementation of reverse logistics (Zimon, 2019). Other studies also identify green logistics as involving the use of alternative fuels, environmentally friendly packaging materials, and its influence on corporate image (Trivellas, 2020). On the other hand, the application of green manufacturing plays a vital role in shaping environmentally friendly supply chains, particularly in industrial areas. This practice includes energy efficiency, the use of renewable resources, waste and emission reduction, as well as the design of sustainable and recyclable products. Sensor technologies and real-time monitoring enable the identification of potential inefficiencies in the production process. PT Indofood Sukses Makmur Tbk has demonstrated the successful integration of green manufacturing practices through the use of energy-saving technologies, raw material efficiency, and eco-friendly packaging design (Indofood CBD, 2022). Key indicators of green manufacturing include pollution emissions, energy consumption, green production, and the lean and green approach that contributes to building a sustainable supply chain (Bendig, 2023).

The benefit of this research is to provide a practical and comprehensive understanding of how green logistics and green manufacturing can be implemented to enhance supply chain sustainability, particularly in industrial zones such as Deltamas. The findings are expected to offer concrete recommendations to companies and policymakers in developing applicable and impactful sustainability strategies. The state of the art of this research lies in its integrative approach to two key elements of sustainability—green logistics and green manufacturing—whose impacts on supply chain sustainability in industrial zones are simultaneously analyzed. While many previous studies have focused on either aspect separately, this research addresses the gap by presenting a unified study based on practical indicators that have been tested by leading companies in Indonesia. Therefore, understanding and strengthening the roles of green logistics and green manufacturing have become increasingly important to ensure the resilience and competitiveness of industrial supply chains in the future, while also meeting the growing environmental and social demands of stakeholders.

Method

1. Research Location

This study was conducted in the Deltamas Industrial Estate, located in Bekasi Regency, encompassing all users of logistics transportation services and the transportation infrastructure within the area. Deltamas is an industrial zone designed as a self-contained city covering 3,200 hectares, integrating residential, commercial, and international-standard industrial areas, with direct access to the Jakarta–Cikampek Toll Road at Km 37. Of this total area, approximately 1,700 hectares are designated as an industrial estate that accommodates 82 companies.

The selection of the Deltamas Industrial Estate as the research location is based on several considerations: first, the area forms a unified zone with controlled industrial activity access points via the Km 37 toll gate and Jalan Raya Tegaldanas; second, it is one of six industrial estates in Indonesia designated as a pilot project for the Global Eco-Industrial Park Programme by the United Nations Industrial Development Organization (UNIDO), a specialized agency under the

United Nations; and third, the ease of data collection facilitated by support from the industrial estate management.



Figure 1. Research Location Layout

2. Population and Sample

The research population consists of company executives or management in the Deltamas Industrial Area. The sample was selected using both probability and non-probability sampling methods to anticipate attendance in the Focus Group Discussion (FGD). Using the Slovin formula with a 95% confidence level, the required sample size is 69 out of a total of 82 companies.

3. Data Collection

Secondary data was obtained from industrial estate managers, government agencies, and relevant companies, covering company information, waste management, and freight transportation data.

Table 1. Secondary Data

Numb.	Data Needs	Data Source	Data Usage
1	Number, name, and PIC of companies, company characteristics	Industrial Estate Manager (PT. Puradelta Lestari)	Population data, Company characteristics, Contact point for FGD planning, In-depth data from company website, Waste treatment tariff, Renewable PLN tariff
2	Industrial waste management companies	PPLI	Industrial waste management tariff

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3	Freight transport data report	UPTD Dishub Bekasi	PKB Kab.	Number of owned vehicles, Vehicle characteristics per company (if available)
4	Roadside Interview Survey Report on Freight Transport in Deltamas	PTDI-STTD		Types of owned vehicles, Types of transported goods, Origin-destination of goods, Cost per kg/km, Type of fuel used, Alternative routes, Traffic volume and V/C ratio in the area

4. Company Interview

This survey was conducted by gathering company management through routine meetings between PT. Puradelta Lestari (estate manager) and all tenants in the Deltamas Industrial Area. These meetings were designed as Focus Group Discussions (FGDs) with engaging topics to encourage high attendance. The selected topic was “Implementation of Green Logistics to Enhance Branding and Productivity in the Industrial Area”, held on February 21, 2024, at Le Premier Hotel, Deltamas City.

Table 2. Respondent Data Recapitulation

Numb.	Form Content	Respondents	Notes
1	General company description	70	Matches the number of attending companies
2	Economic field description	42	28 respondents stated they were not in positions handling the required data, so they did not provide input
3	Environmental field description	42	
4	Social field description	42	
5	Questionnaire A	137	70 companies were present, represented by 137 individuals. 67 companies sent 2 representatives, while 3 companies sent only 1 representative
6	Questionnaire B	137	
7	Questionnaire C	137	
8	Questionnaire D	137	

5. Expert Interview

A follow-up Focus Group Discussion (FGD) was conducted at the Market Office in Deltamas City on Friday, November 1, 2024. This session included experts and academics in addition to the initial FGD participants. The discussion involved interviews and questionnaire filling. The experts selected as respondents are experienced in supply chain sustainability, green logistics, and green manufacturing.

Table 3. Expert Profile

Numb.	Expert Code	Position	Experience
1	A	Operational Director, PT. Puradelta Lestari, Deltamas (Estate Operator)	28 years
2	B	Head of Transportation Agency, Bekasi Regency (Regulator)	14 years
3	C	Logistics Practitioner and/or Professional (ALI Expert Council)	30 years
4	D	General Manager and/or Operations Manager at a company in Deltamas (Tenant/Operator)	14 years
5	E	Logistics Lecturer at PTDI-STTD Bekasi (Academia)	11 years

6. Data Analysis Method

This study employs a mixed-method approach combining qualitative and quantitative analysis. Quantitative analysis is conducted using Structural Equation Modeling (SEM) with Lisrel 8.80 to examine the relationships between variables and indicators. Qualitative analysis is based on expert insights to understand the impacts and experiences of green logistics and green manufacturing on supply chain sustainability.

Discussion

1. General Characteristics of Companies in the Deltamas Industrial Area

The characteristics of companies in the Deltamas Industrial Area can be identified as a general overview of the businesses operating within the area. A total of 76% of the companies have Foreign Direct Investment (FDI) status, while 24% are classified as Domestic Investment

(DI) companies. Given the higher percentage of Foreign Direct Investment (FDI) companies, businesses in the Deltamas Industrial Area are engaged in trade activities involving global or foreign companies. Therefore, the concept of Supply Chain Sustainability modeling through the implementation of Green Logistics and Green Manufacturing is highly suitable for industrial areas in general and the Deltamas industrial Area in particular.

Companies in the Deltamas Industrial Area have been established since the inception of the industrial zone in 1946 and have grown significantly from 2012 to 2021. This indicates that companies in the area are relatively new and modern. Based on data classification, there are two main proportions of companies: 69% are large enterprises, while 31% are medium-sized enterprises. The information regarding the year of establishment and classification is essential for discussing the relevance of Green Logistics, Green Manufacturing, and Supply Chain Sustainability, making the Deltamas Industrial Area a highly suitable location for such initiatives. The largest business sector in the area is Automotive Spare Parts, accounting for 21%, followed by Automotive Manufacturing Industry at 19%. The smallest sector is the Oil and Natural Gas Industry, with a share of 2%.

2. Validity and Reliability Testing

The validity test aims to assess whether the data can be considered valid and reliable. The criteria for determining validity and reliability. If the Average Variance Extracted (AVE) value is greater than 0.5 (> 0.5), the data is considered valid. If the Cronbach's Alpha value is greater than 0.60 (> 0.60), the data is considered reliable. Survey data that has been collected and input into the computer must undergo validity and reliability testing before it can be used. The test results for the collected data are as follows:

Table 4. Validity and Reliability Testing

Numb.	Variable Data	Code	Validity (AVE>0,5)	Reliability (Cronbach Alpha>0,7)	Result
1	Green logistic	GL	0,822	0,989	Valid and reliable
2	Green manufacturing	GM	0,742	0,981	Valid and reliable
3	Supply chain sustainability	SCS	0,671	0,974	Valid and reliable

Based on the validity and reliability tests, all variables Green Logistics (GL), Green Manufacturing (GM), and Supply Chain Sustainability (SCS) meet the criteria for validity and reliability testing. Therefore, all variables are considered significantly valid and reliable.

3. SEM Model Estimation Results

The direct relationship model represents the relationship between variables without the involvement of an intervening variable. The relationships between variables can be seen in the following table:

Table 5. Direct Relationship Model Between Variables

Relationship	Original Sample	Sample Mean	Std. Deviation	Statistics	P Values
GL -> SCS	0,394	0,392	0,073	5,376	0,000
GM -> SCS	0,171	0,173	0,069	2,489	0,007

From the direct relationship table, both Green Logistics (GL) and Green Manufacturing (GM) have a significant impact on changes in the Supply Chain Sustainability (SCS) variable. The positive original sample values indicate that the influence and changes occur in the same direction.

4. Hypotheses

a. Hypothesis Testing: The Direct Influence of Green Logistics on Supply Chain Sustainability

- Null Hypothesis (H_{01}): $\alpha = 0$, meaning Green Logistics has no effect on Supply Chain Sustainability.
- Alternative Hypothesis (H_{a1}): $\alpha \neq 0$, meaning Green Logistics has an effect on Supply Chain Sustainability.

This hypothesis has a p-value of 0.000 (< 0.05) and a t-statistic of 5.376 (> 1.96) at a 95% confidence level. The original sample value is positive (0.394), indicating that Green Logistics positively and directly influences Supply Chain Sustainability. This means that an increase of 0.394 in Green Logistics leads to a corresponding increase of 0.394 in Supply Chain Sustainability.

Conclusion: Thus, H_{01} is rejected, and H_{a1} is accepted, meaning that Green Logistics has a positive effect on Supply Chain Sustainability.

b. Hypothesis Testing: The Direct Influence of Green Manufacturing on Supply Chain Sustainability

- Null Hypothesis (H_{02}): $\alpha = 0$, meaning Green Manufacturing has no effect on Supply Chain Sustainability.
- Alternative Hypothesis (H_{a2}): $\alpha \neq 0$, meaning Green Manufacturing has an effect on Supply Chain Sustainability.

This hypothesis has a p-value of 0.007 (< 0.05) and a t-statistic of 2.489 (> 1.96) at a 95% confidence level. The original sample value is positive (0.171), indicating that Green Manufacturing positively and directly influences Supply Chain Sustainability. This means that an increase of 0.171 in Green Manufacturing leads to a corresponding increase of 0.171 in Supply Chain Sustainability.

Conclusion: Thus, H_{02} is rejected, and H_{a2} is accepted, meaning that Green Manufacturing has a positive effect on Supply Chain Sustainability.

5. Expert Opinions

Through a follow-up Focus Group Discussion (FGD) using interviews and questionnaire completion, expert feedback, inputs, and corrections were obtained regarding the research variables in the supply chain sustainability modeling through green logistics and green manufacturing. The discussion clarified that each variable has a significant influence on supply chain sustainability. The details of expert responses are presented in the following table:

Table 6. Quantitative and Qualitative Data on Inter-Variable Relationships

Relationship	P-Val	Expert A	Expert B	Expert C	Expert D	Expert E	Conclusion
Influence of Green Logistics on Supply Chain Sustainability	0.000	The industrial area strives to encourage company operators to use electric vehicles/low-carbon emission vehicles for internal operations	The government supports better transportation processes by implementing IoT-based Vehicle Testing Equipment updates in collaboration with stakeholders and establishing	Sustainable supply chain processes are implemented by regulating sustainable transportation activities, focusing on minimizing	Some operational transport modes within the company have already adopted renewable and low-emission energy sources, and companies	Several studies indicate that green logistics can mitigate environmental impacts caused by logistics activities, leading to better supply	Supports expanding, deepening, and incorporating quantitative data.

		, applying the green transportation concept.	Green Open Spaces along several transportation routes in Bekasi Regency.	g the negative impacts of logistics activities.	expect transportation costs to be reduced.	chain optimization.	
Influence of Green Manufacturing on Supply Chain Sustainability	0.007	The industrial area implements a zero-waste system to maximize raw material reuse, minimize waste, and reduce raw material demand within the supply chain, thus enhancing overall sustainability.	The government urges companies to ensure that storage and transport containers remain sealed and intact to prevent raw materials from spilling on roads in Bekasi Regency.	Green manufacturing improves efficiency and reduces the carbon footprint in production and distribution processes, reinforcing supply chain sustainability from raw material selection to final product delivery.	Raw materials and finished products are stored in eco-friendly warehouses utilizing solar panels for power and lighting.	Many studies confirm a mutually supportive relationship between supply chain sustainability and green manufacturing.	Supports expanding and deepening quantitative data.

6. The Direct Influence of the Green Logistics Variable on Supply Chain Sustainability

The results of the analysis in this study indicate that Green Logistics has a significant positive influence on Supply Chain Sustainability. In other words, the higher the level of Green Logistics implementation, the better the Supply Chain Sustainability, and vice versa. The impact of green logistics practices on supply chain sustainability in the automotive sector. The findings revealed that the implementation of green logistics, such as optimizing delivery routes and utilizing green fleets, contributed positively to reducing carbon emissions and improving overall supply chain efficiency (Sarkis, Zhu, & Lai, 2012). Supply Chain Sustainability refers to the management and integration of economic, social, and environmental performance across the entire supply chain to create shared value for all stakeholders, optimize efficiency and profitability, and reduce costs by considering environmental, economic, and social impacts throughout the production and distribution processes (Carter & Easton, 2011).

Green Logistics has a significantly positive impact on Supply Chain Sustainability by supporting efforts to reduce environmental impact and enhance overall efficiency (Zhu & Geng, 2013). A strong influence of green logistics aligns with the goals of supply chain sustainability, reinforcing the concept of sustainability within a company's supply chain. This influence can be described through several economic, social, and environmental indicators (Wu & Pagell, 2011). These influential indicators include:

- a. In its implementation, green logistics supports sustainable productivity through a supply chain that meets customer needs by determining strategic alternative routes. This improves delivery time effectiveness and reduces logistics costs for the company (McKinnon, 2010).

- b. Corporate image is a crucial aspect in building partnerships with other companies or stakeholders. In practice, assessments of reliability, integrity, and corporate social responsibility serve as parameters to enhance trust and foster collaboration with other firms, thereby creating sustainable performance that adheres to green logistics principles (Klassen & Vereecke, 2012).
- c. In selecting suitable suppliers for production, information regarding product quality control standards and the strategic aspect of logistics is necessary. This is essential to maintain product quality and minimize waste generation to preserve sustainability within the company's environment. Companies ensure the selection of environmentally friendly fuels to reduce total waste output (Lee, 2008).

7. The Direct Influence of the Green Manufacturing Variable on Supply Chain Sustainability

The analysis results in this study indicate that Green Manufacturing has a significant positive influence on Supply Chain Sustainability. In other words, the higher the level of Green Manufacturing, the better the Supply Chain Sustainability, and vice versa. The impact of Green Manufacturing on supply chain sustainability in the manufacturing sector. The study found that green manufacturing practices including energy efficiency, waste management, and the use of sustainable raw materials can enhance supply chain sustainability performance by reducing environmental footprints and improving operational efficiency (Zhu, Sarkis, & Lai, 2018). Supply Chain Sustainability refers to the management of the flow of materials, information, and capital, as well as collaboration among companies along the supply chain, while considering the objectives of the three dimensions of sustainable development—economic, environmental, and social. These objectives are derived from the needs of customers and stakeholders, referring to the ability of an organization or individual to achieve consistent and positive long-term outcomes (Seuring & Müller, 2008).

Green Manufacturing has a significant positive influence on Supply Chain Sustainability, supporting efforts to reduce environmental impacts and enhance overall efficiency (Sarkis, Zhu, & Lai, 2017). A strong influence of green manufacturing aligns with the concept of sustainability in corporate supply chains. Its impact can be elaborated through several economic, social, and environmental indicators. These include:

- a. The implementation of green manufacturing reflects a commitment to building stronger partnerships and improving corporate performance. This focus on sustainability drives innovation, creates more environmentally friendly products, and enhances market competitiveness. It also increases consumer appeal, improves corporate image, and ensures reliable procurement of production materials according to customer needs (Porter & Kramer, 2011).
- b. Companies that adopt green manufacturing concepts produce goods in compliance with regulations related to occupational health and safety, as well as employee welfare, while reducing legal risks. Additionally, these companies often have strong collaborations or partnerships with other firms and stakeholders. This leads to increased consumer demand for sustainable products, encouraging companies to integrate green manufacturing practices into their strategic planning (Chiou, Chan, Lettice, & Chung, 2011).
- c. Green manufacturing adopts environmentally friendly technologies in the manufacturing innovation process by using raw materials that reduce emissions and waste, aiming for environmental sustainability. Companies also implement waste management practices in accordance with applicable environmental regulations to achieve the concepts of zero emission and zero waste. This approach contributes to shaping a corporate image that demonstrates environmental responsibility.

Conclusion

The companies located in the Deltamas Industrial Area are global companies, so the concepts related to the modeling of Supply Chain Sustainability with the implementation of Green Logistics and Green Manufacturing are highly applicable. Green Logistics has a significant positive impact on Supply Chain Sustainability, as does Green Manufacturing, which also has a significant positive impact on Supply Chain Sustainability. The results of the qualitative analysis, which include the views of experts and specialists, align with the quantitative research findings regarding the relationships between the variables obtained through SEM testing. This qualitative analysis clarifies the relationships between the variables with relevant evidence and deepens the understanding with several concrete examples of the application of Green Logistics and Green Manufacturing. From the quantitative analysis results, the relationship between Green Logistics and Supply Chain Sustainability shows a high direct value, as does the relationship between Green Manufacturing and Supply Chain Sustainability, which also shows a high direct value.

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