

Analysis of Determinant Factors of Sustainable Warehouse and their Impact on Sustainable Logistics Performance with the Moderating Role of Logistics 4.0: A Study on Tip / Rest Areas of the Trans-Java Toll Road

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ABSTRACT: This study investigates the determinant factors of sustainable warehouse and their impact on sustainable logistics performance, with Logistics 4.0 examined as a moderating variable in the context of TIP/rest areas along the Trans-Java Toll Road. The study adopts the triple bottom line perspective and positions sustainable warehouse as a second-order construct composed of economic, social, and environmental dimensions, while sustainable logistics performance is treated as the outcome variable reflecting broader logistics sustainability achievements.

The research applies a quantitative design using a structured survey distributed to business managers and decision-makers involved in warehousing, distribution, and logistics operations near the Trans-Java Toll Road corridor. A total of 191 valid responses were analyzed through Structural Equation Modeling with the Partial Least Squares approach (PLS-SEM), covering measurement model assessment and structural model testing, including the moderation effect of Logistics 4.0. The results indicate that the direct effect of sustainable warehouse on sustainable logistics performance is not significant, and the moderating role of Logistics 4.0 is also not supported. In contrast, the economic dimension positively influences sustainable logistics performance ($\beta = 0.2959$, $p < 0.05$), the social dimension positively influences sustainable logistics performance ($\beta = 0.4709$, $p < 0.05$), and the environmental dimension positively influences sustainable logistics performance ($\beta = 0.2048$, $p < 0.05$).

These findings indicate that the social dimension is the strongest contributor among the three dimensions in explaining sustainable logistics performance in the TIP/rest area context. These findings imply that sustainable warehouse practices in the toll road rest area context are still at an early stage of maturity, so the impact of integrated warehouse sustainability has not yet fully translated into system-level logistics sustainability outcomes. At the same time, the significant role of the economic, social, and environmental dimensions indicates that practical sustainability improvements at the operational level remain essential levers for strengthening logistics performance in developing logistics ecosystems. From a theoretical perspective, the study enriches the sustainable logistics and warehousing literature by integrating the triple bottom line framework with Logistics 4.0 in the context of toll road logistics infrastructure. From a managerial and policy perspective, the study highlights the need for stronger operational integration, better environmental investment, and more systematic digital adoption if sustainable warehouses are expected to produce measurable impacts on sustainable logistics performance.

The originality of this study lies in its focus on sustainable warehouse development in TIP/rest area logistics environments on the Trans-Java Toll Road and in examining Logistics 4.0 as a moderator in a relationship that has received limited empirical attention in Indonesia.

KEYWORDS: Triple bottom line, sustainable warehouse, Logistics 4.0, sustainable logistics performance, rest area logistics, Trans-Java Toll Road.

BACKGROUND

Indonesia's logistics system operates under conditions shaped by archipelagic geography, dispersed economic centers, and unequal infrastructure quality, making logistics efficiency a strategic challenge for national competitiveness. In such a context, warehousing is not merely a storage activity, but a central operational node that supports freight consolidation, transport coordination, inventory movement, and distribution continuity across supply chains (Nagendra & Gyaneshwar, 2017).

The government has attempted to address national logistics issues through a series of policy initiatives, including the National Logistics System blueprint and later the logistics ecosystem arrangement agenda. These initiatives emphasize coordination among logistics stakeholders and the need to improve infrastructure, information integration, and warehousing capability in order to reduce logistics costs and strengthen supply chain competitiveness.

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Despite these efforts, logistics costs in Indonesia remain relatively high as a share of gross domestic product, while logistics performance still lags behind several ASEAN peers. This indicates that physical infrastructure expansion alone does not automatically improve logistics competitiveness unless accompanied by better system integration, sustainability orientation, and operational capability improvements.

One strategic infrastructure setting relevant to this issue is the development of TIP/rest areas along the Trans-Java Toll Road. Initially designed to support rest and service needs for road users, these areas have gradually evolved into broader economic and logistics spaces that can function as promotional areas, transfer points, local product hubs, and potential logistics nodes. The emergence of TIP/rest areas as logistics-supporting facilities creates an opportunity to rethink the role of warehouses in toll road infrastructure ecosystems. Warehouses in this context may contribute not only to storage and delivery performance, but also to more sustainable logistics outcomes through energy efficiency, environmental management, labor protection, and digital integration.

In many conventional warehousing studies, attention has historically focused on time, cost, throughput, and profit optimization (Chen et al., 2017). While such concerns remain important, they do not fully capture the broader demands of contemporary logistics systems, especially when logistics is expected to support economic efficiency, social responsibility, and environmental stewardship at the same time. The triple bottom line approach offers a more comprehensive perspective because it evaluates organizational performance across economic, social, and environmental dimensions simultaneously (He et al., 2017). In the warehousing context, this means that an efficient warehouse should also be safe for workers, responsible toward society, and capable of reducing environmental burdens through better resource use, waste management, and emissions control.

At the same time, the discourse of Logistics 4.0 has gained increasing importance as logistics systems become more digitalized. Technologies such as Internet of Things, data analytics, automation, cloud systems, and real-time information sharing are expected to improve visibility, responsiveness, and efficiency, and potentially reinforce the sustainability benefits of warehouse operations (Strandhagen et al., 2017). However, the actual relationship between sustainable warehouse practices, digital logistics capability, and sustainable logistics performance remains insufficiently understood in the Indonesian toll road context. This gap becomes more visible when considering that many facilities may have begun to adopt sustainability narratives and digital tools, but not yet in an integrated or mature manner.

The present study addresses this gap by analyzing determinant factors of sustainable warehouse and their impact on sustainable logistics performance in business environments located around TIP/rest areas on the Trans-Java Toll Road. It also tests whether Logistics 4.0 strengthens the relationship between sustainable warehouse and sustainable logistics performance, thereby contributing both empirically and conceptually to sustainable logistics research in developing country settings.

THEORETICAL FRAMEWORK

Sustainable Development

The idea of sustainable development gained conceptual foundation through debates on long-term resource balance in the 1970s and was later formalized in the Brundtland perspective that development should meet present needs without compromising future generations (World Commission on Environment and Development, 1987). In operational terms, sustainable development requires a balance among economic growth, social equity, and environmental protection, making it highly relevant for sectors such as logistics and infrastructure that directly shape resource use and development patterns (Ulrich, 2007; Britannica, 2016). In more recent policy discourse, sustainable development has also been translated into practical agendas through the Sustainable Development Goals and national planning priorities (United Nations, 2015). This broader policy environment reinforces the expectation that logistics and infrastructure development should not only pursue efficiency and market growth, but also support environmental responsibility and inclusive welfare (Nasution et al., 2023; Jayanthi, 2025).

Warehousing

Warehousing is commonly defined as the activity of storing goods, yet in practice it encompasses a much broader set of processes including receiving, recording, storage, order selection, labelling, consolidation, and shipping of goods (Warman, 2010; Cagliano et al., 2011). Because these processes influence transport distances, picking frequency, lead time, and inventory accuracy, warehouse management becomes a critical determinant of logistics system performance and customer service quality (Chen et al., 2017; Ribino et al., 2017). Beyond its storage role, warehousing also performs functions such as movement and material handling, storage protection, consolidation, and information transfer, each of which contributes to cost efficiency and service reliability in logistics networks (Kah-Shien Tan et al., 2009; Bank & Murphy, 2017). Accurate and timely warehouse information about inventory levels, turnover, and space utilization supports better decision-making in transport planning and supply chain coordination, thereby linking warehouse performance closely to overall logistics competitiveness (Grant, 2017; Nagendra & Gyaneshwar, 2017).

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Sustainable Warehouse

A sustainable warehouse can be understood as a set of organizational and technological solutions designed to deliver warehouse processes efficiently while maintaining high social standards and minimizing environmental impacts (Kah-Shien Tan et al., 2009; Malinowska et al., 2018). In this perspective, warehouse design and operation must integrate the three pillars of sustainability—economic, environmental, and social—so that financial efficiency, labor welfare, and ecological performance are achieved simultaneously rather than in isolation (He et al., 2017; Delmonico & Bezerra, 2020). Recent studies have operationalized sustainable warehouse through performance indicators and measurement systems that capture energy efficiency, waste and emission reduction, occupational health and safety, and community responsibility in warehouse operations (Bank & Murphy, 2017; Torabizadeh et al., 2019). Torabizadeh et al. (2019) identify 33 key performance indicators grouped into economic, environmental, and social dimensions, showing that improvements across these indicator groups contribute significantly to overall sustainable warehouse management system performance. Building on this work, the present study treats sustainable warehouse as a second-order latent construct formed by its economic, social, and environmental dimensions to examine its impact on sustainable logistics performance in the toll-road corridor context (Prabodhika et al., 2021; Lewandowska & Dawson, 2021).

Economic Dimension

The economic dimension of a sustainable warehouse comprises both operational and financial aspects of warehousing that directly or indirectly create economic value for firms and stakeholders (He et al., 2017; Torabizadeh et al., 2019). Typical indicators include efficiency in receiving, storage, picking, and shipping processes, utilization of storage capacity, lead time performance, and cost savings achieved through better layout and inventory policies (Chen et al., 2017; Cagliano et al., 2011). In this sense, warehouse economic performance becomes a critical driver of logistics competitiveness because it shapes logistics costs, service reliability, and the ability to support market growth, especially for small and medium-sized enterprises that face resource constraints (Karolina & Paulina, 2021; Paul, 2021). Beyond operational efficiency, the economic dimension also encompasses risk management, incentive structures, wage standards, and the involvement of local suppliers, which influence both cost structures and the distribution of economic benefits in the logistics ecosystem (Karolina & Paulina, 2021; Larson, 2021). Studies on regional logistics networks show that strong logistics infrastructure and efficient warehousing can generate agglomeration effects, lower unit transport costs, and reinforce regional economic development, particularly in urban clusters connected by multimodal transport systems (Lakshmanan, 2011; Ji et al., 2023). In this study, the economic dimension captures how warehouse operations around toll-road rest areas contribute to sustainable logistics performance through better cost efficiency, service quality, and economic resilience in the Trans-Java corridor (Viswanadham & Gaonkar, 2003; Newman, 2015).

Social Dimension

The social dimension of a sustainable warehouse reflects the quality of human resource management, industrial relations, and social responsibility toward workers, customers, and surrounding communities (Torabizadeh et al., 2019; Delmonico & Bezerra, 2020). Key indicators include recruitment and selection practices, provision of employee benefits, training and skills development, performance evaluation systems, and turnover levels, all of which influence workforce stability and motivation in logistics operations (Kah-Shien Tan et al., 2009; F. D. Wahyuni et al., 2022). Social sustainability also requires attention to workplace discrimination, labor disputes, customer complaints, and occupational health and safety performance, since these factors have direct implications for employee well-being and service reliability (Grant, 2017; Larson, 2021). In logistics and warehousing, safe and fair working conditions are increasingly recognized as prerequisites for long-term operational continuity and reputation, particularly as customers and regulators place greater emphasis on social accountability in supply chains (He et al., 2017; Kumar et al., 2018). Empirical studies on sustainable logistics performance show that improvements in worker safety, community engagement, and customer satisfaction reinforce economic and environmental outcomes, leading to more stable and resilient logistics systems over time (Zagloel et al., 2024; Zulkiffli et al., 2022). Accordingly, the present study models the social dimension of sustainable warehouse through indicators such as occupational safety, grievance handling, community programs, and social responsibility for products and services, and examines how these practices contribute to sustainable logistics performance in the toll-road rest-area context (Prabodhika et al., 2021; Mensah et al., 2020).

Environmental Dimension

The environmental dimension of a sustainable warehouse covers all aspects of resource use and ecological impact arising from warehousing and related logistics activities (He et al., 2017; Torabizadeh et al., 2019). Indicators commonly used in the literature include the use of recycled or recyclable materials, reduction in energy consumption, water reuse, environmentally friendly packaging, emission and waste reduction, and investments in environmental protection projects within the facility (Bank & Murphy, 2017; Malinowska et al., 2018). These practices aim to reduce the environmental footprint of logistics operations while maintaining or even improving service levels and cost performance, in line with broader low-carbon logistics and green supply chain objectives (He et al., 2017; Jinru et al., 2022). Research on sustainable logistics systems shows that logistics activities, particularly road

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transport and warehousing, are significant contributors to energy use and greenhouse gas emissions, making environmental improvements in these nodes essential for achieving national sustainability targets (Larson, 2021; Ji et al., 2023). Studies of sustainable logistics performance further highlight that simultaneous progress in economic, environmental, and social dimensions yields more stable and robust improvements than focusing on environmental initiatives alone, underscoring the need for integrated environmental strategies in logistics planning (Teh et al., 2022; Lenort et al., 2022). In this study, the environmental dimension of the sustainable warehouse construct captures concrete practices such as energy-saving lighting, renewable energy use, waste and emission management, and compliance with environmental regulations in warehouses located around Trans-Java toll-road rest areas, and evaluates their contribution to sustainable logistics performance (Wit & Pylak, 2020; Pieroni et al., 2018).

Logistics 4.0

Logistics 4.0 refers to the transformation of logistics systems through the integration of advanced digital technologies such as cyber-physical systems, Internet of Things, big data analytics, cloud computing, and autonomous equipment (Orestis & Stavros, 2021; Sun et al., 2022). These technologies enable real-time tracking and tracing, automated planning, and data-driven decision-making, which together enhance efficiency, visibility, and responsiveness in logistics networks (Strandhagen et al., 2017; Helo & Thai, 2024). From a business model perspective, Logistics 4.0 is closely linked to emerging sustainable business models because digitalization supports resource efficiency, green logistics, and sharing-based service concepts that can improve all three dimensions of the triple bottom line (Strandhagen et al., 2017; Wit & Pylak, 2020). Systematic reviews indicate that Industry 4.0 and Logistics 4.0 technologies have been increasingly deployed to support sustainable logistics initiatives, although their implementation depth and integration with sustainability strategies vary widely across firms and sectors (Delmonico & Bezerra, 2020; Sun et al., 2022). In this study, Logistics 4.0 is modeled as a moderating construct that may strengthen the relationship between sustainable warehouse and sustainable logistics performance by enhancing monitoring, coordination, and control of sustainability-oriented warehouse practices (Nantee & Sureeyatanapas, 2021; Oubrahim et al., 2022).

Sustainable Logistics Performance

Sustainable logistics performance describes the extent to which logistics systems achieve economic, environmental, and social objectives in an integrated manner over time (He et al., 2017; Delmonico & Bezerra, 2020). Metrics used to evaluate this performance typically include cost and service efficiency, energy and emission intensity, waste generation, labor safety and welfare, and customer satisfaction, often combined into composite indices for cross-firm or cross-country comparison (Prabodhika et al., 2021; Lenort et al., 2022). Cross-country analyses show that higher logistics performance is associated not only with stronger economic conditions but also with healthier social systems and better governance, while at the same time contributing to environmental pressures through increased transport activity (Larson, 2021; Ji et al., 2023). To address this dual role, recent studies advocate simultaneous improvement of economic, environmental, social, and customer-related dimensions of logistics performance, supported by sustainable logistics management maturity and green innovation capabilities (Lewandowska & Dawson, 2021; Zulkiffli et al., 2022). In line with these insights, the present study conceptualizes sustainable logistics performance as a multi-dimensional outcome reflecting the combined effects of sustainable warehouse practices, Logistics 4.0 adoption, and broader sustainability efforts in the toll-road logistics ecosystem (Mensah et al., 2020; Zagloel et al., 2024).

CONCEPTUAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

As illustrated in Figure 1, the conceptual framework of this research is represented by a structural model that maps the relationships between the observed constructs.

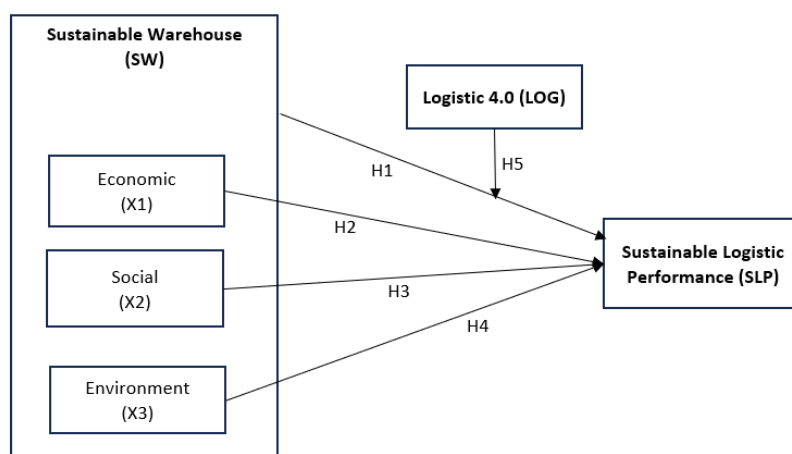


Figure 1. Conceptual Framework of the Study

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The Effect of Sustainable Warehouse on Sustainable Logistics Performance

A sustainable warehouse is positioned in this study as an integrated construct that combines economic, social, and environmental practices in warehousing operations (Kah-Shien Tan et al., 2009; Malinowska et al., 2018). When such practices are implemented consistently, warehouses are expected to contribute not only to operational efficiency and cost reduction but also to safer working conditions and lower environmental impacts, which together form the basis of sustainable logistics performance (He et al., 2017; Torabizadeh et al., 2019). In the context of toll-road rest areas, sustainable warehouses may enhance logistics performance by providing more reliable storage and handling services, supporting smoother freight flows, and enabling better service quality for logistics users along the corridor (Viswanadham & Gaonkar, 2003; Larson, 2021). Based on this reasoning, the following hypothesis is proposed:

H1: Sustainable warehouse (SW) positively influences sustainable logistics performance (SLP).

The Effect of the Economic Dimension on Sustainable Logistics Performance

The economic dimension of sustainable warehouse reflects the effectiveness and efficiency of warehouse operations and the broader financial contribution of warehousing activities to firms and stakeholders (Chen et al., 2017; Cagliano et al., 2011). Indicators such as receiving and shipping efficiency, storage capacity utilization, picking time, unloading performance, and economic incentives are expected to strengthen logistics performance through reduced costs, improved service reliability, and better use of toll-road infrastructure (Karolina & Paulina, 2021; Lakshmanan, 2011). Prior research shows that firms and regions with stronger logistics and warehouse performance tend to achieve higher logistics competitiveness and more sustainable economic growth, particularly when logistics solutions are designed to support efficiency and resilience simultaneously (Paul, 2021; Ji et al., 2023). Therefore, the following hypothesis is proposed:

H2: The economic dimension of sustainable warehouse positively influences sustainable logistics performance (SLP).

The Effect of the Social Dimension on Sustainable Logistics Performance

The social dimension of sustainable warehouse encompasses human resource practices, occupational health and safety, industrial relations, and social responsibility toward customers and communities (Torabizadeh et al., 2019; Delmonico & Bezerra, 2020). Warehouses that provide fair employment conditions, adequate training, safety programs, and responsive handling of complaints are more likely to maintain a stable and motivated workforce, which in turn supports reliable logistics operations and service quality (F. D. Wahyuni et al., 2022; Grant, 2017). Empirical studies on sustainable logistics performance highlight that social improvements, such as better working conditions and community engagement, reinforce economic and environmental outcomes, creating more resilient logistics systems over time (Larson, 2021; Zagloel et al., 2024). Accordingly, the following hypothesis is proposed:

H3: The social dimension of sustainable warehouse positively influences sustainable logistics performance (SLP).

The Effect of the Environmental Dimension on Sustainable Logistics Performance

The environmental dimension of sustainable warehouse relates to how warehousing activities manage energy, materials, emissions, and waste in order to minimize ecological impacts while supporting operational needs (Bank & Murphy, 2017; Malinowska et al., 2018). Practices such as energy-efficient lighting, the use of renewable energy, water recycling, environmentally friendly packaging, and systematic waste and emission reduction can lower the environmental footprint of logistics activities along toll-road corridors (He et al., 2017; Jinru et al., 2022). Studies on green and low-carbon logistics demonstrate that firms which invest in environmental improvements often experience benefits in cost efficiency, regulatory compliance, and reputational value, which contribute to more sustainable logistics performance overall (Teh et al., 2022; Lenort et al., 2022). Based on these arguments, the following hypothesis is proposed:

H4: The environmental dimension of sustainable warehouse positively influences sustainable logistics performance (SLP).

The Moderating Role of Logistics 4.0 in the Relationship between Sustainable Warehouse and Sustainable Logistics Performance

Logistics 4.0 represents the application of advanced digital technologies—such as cyber-physical systems, Internet of Things, big data analytics, and autonomous equipment—to integrate and automate logistics processes in real time (Strandhagen et al., 2017; Orestis & Stavros, 2021). In the warehouse context, these technologies can enhance visibility, monitoring, and control over sustainability-related practices, for example by enabling real-time tracking of inventory, energy usage, emissions, and safety incidents (Helo & Thai, 2024; Nantee & Sureeyatanapas, 2021). When sustainable warehouse practices are supported by a high level of Logistics 4.0 capability, their impact on sustainable logistics performance is expected to be stronger because digital systems allow more precise planning, faster response to disruptions, and better reporting of sustainability outcomes (Delmonico & Bezerra, 2020; Oubrahim et al., 2022). Therefore, the following moderating hypothesis is proposed:

H5: Logistics 4.0 (LOG) positively moderates the effect of sustainable warehouse (SW) on sustainable logistics performance (SLP), such that the relationship becomes stronger at higher levels of Logistics 4.0 implementation.

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METHODOLOGY

This study employs a quantitative approach using a survey design and a cross-sectional research strategy. The design was selected because the study aims to test causal relationships among latent variables representing sustainable warehouse, Logistics 4.0, and sustainable logistics performance in a real business context. The unit of analysis is the business manager or decision-maker directly involved in warehousing and logistics operations. Purposive sampling was used in order to target respondents whose roles were relevant to the operational and strategic issues examined in the study. From the planned sample, 191 valid responses were collected and analyzed, yielding a response rate of 69.5 percent.

The questionnaire captured respondent profile data as well as responses to indicators measuring the economic, social, and environmental dimensions of sustainable warehouse, the Logistics 4.0 construct, and sustainable logistics performance. All items were assessed using a Likert-style response format, allowing the variables to be modeled as latent constructs in the PLS-SEM framework. Data analysis was conducted using Partial Least Squares Structural Equation Modeling. This approach was chosen because it is suitable for analyzing complex structural relationships involving latent constructs, higher-order dimensions, moderation effects, and predictive orientation in applied management research.

The analysis followed two main stages. First, the outer model was tested to assess convergent validity, composite reliability, outer loading, reliability, discriminant validity, and multicollinearity through VIF indicators. Second, the inner model was examined to evaluate model fit, explanatory power, and the significance of structural paths through bootstrapping with 5000 samples at a 5 percent significance level. This methodological structure is appropriate for the study because the research does not only test direct effects but also examines sustainable warehouse as a higher-order construct and Logistics 4.0 as a moderator. Such a design allows a more refined analysis of how sustainability dimensions operate individually and collectively in shaping sustainable logistics performance.

VARIABLES AND MEASUREMENT

The independent construct in the study is sustainable warehouse (SW), represented by three main dimensions: economic, social, and environmental. The economic dimension includes warehouse operational performance and warehouse economic performance indicators, the social dimension includes labor practices and responsibility toward product, service, and society, while the environmental dimension includes resource use and environmental commitment. The economic (X1) indicators cover operational elements such as efficient receiving, timely shipping, accurate order fulfillment, effective storage capacity use, short picking time, and efficient unloading, along with broader value-related indicators such as economic contribution, climate risk awareness, financial incentives, wage standards, and local supplier use. These indicators reflect the practical and strategic sides of economic sustainability in warehousing. The social (X2) indicators capture issues such as employee recruitment, employee benefits, training, performance assessment, turnover, discrimination, disputes, customer complaints, occupational safety, community programs, and corruption or malpractice concerns. This dimension is intended to reflect both internal workforce management and the warehouse organization's broader social accountability. The environmental (X3) indicators include recycled material use, efforts to reduce energy consumption, water reuse, lower product or service energy needs, protection of biodiversity and habitats, emission reduction programs, waste reduction, reduced environmental impact of products and packaging, environmental law compliance, and investment in environmental protection. These items collectively operationalize the environmental side of sustainable warehousing. Logistics 4.0 (LOG) is modeled as the moderating variable and represents the use of digital technologies to improve logistics responsiveness, integration, automation, and service customization. Although the source summary highlights that several digital capability indicators such as service adjustment and data-based automatic planning perform relatively better than deeper technology adoption indicators, the construct overall reflects the level of digital logistics maturity among respondents. The dependent variable is sustainable logistics performance (SLP), which captures logistics outcomes consistent with sustainability objectives. This includes outcomes linked to economic efficiency, operational effectiveness, environmental responsibility, and social performance in logistics execution. By structuring the variables in this way, the model enables analysis at two levels. First, it evaluates whether sustainable warehouse as an integrated construct affects sustainable logistics performance. Second, it reveals whether the underlying economic, social, and environmental dimensions explain sustainable logistics performance more clearly than the higher-order construct itself.

RESULTS AND DISCUSSION

The results of this study are based on data analysis conducted using the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach with SmartPLS 3.0 software. The analysis was performed to evaluate the proposed hypotheses and examine the relationships among sustainable warehouse, its dimensions, Logistics 4.0, and sustainable logistics performance.

Based on the hypothesis testing results, the findings are summarized as follows:

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Hypothesis Testing Results

Hypothesis	Koef.	P-Values	Result
Direct Effect			
Sustainable warehouse (SW) positively influences sustainable logistics performance (SLP).	0.0570	0.479	Not supported
H1:			
The economic dimension positively influences sustainable logistics performance (SLP).	0.2959	0.020	Supported
H2:			
The social dimension positively influences sustainable logistics performance (SLP).	0.4709	0.000	Supported
H3:			
The environmental dimension positively influences sustainable logistics performance (SLP).	0.2048	0.017	Supported
H4:			
Moderating Effect			
Logistics 4.0 (LOG) positively moderates the effect of sustainable warehouse (SW) on sustainable logistics performance (SLP).	-0.0357	0.657	Not supported
H5:			

Source: Processed data using SmartPLS (2026)

The Effect of Sustainable Warehouse on Sustainable Logistics Performance

The hypothesis testing results indicate that sustainable warehouse does not have a significant direct effect on sustainable logistics performance. This finding suggests that, in the current stage of development, sustainable warehousing practices in the Trans-Java toll-road rest-area context are still implemented in a fragmented manner, so they have not yet formed a fully integrated system capable of driving logistics sustainability outcomes on their own (Torabizadeh et al., 2019; Delmonico & Bezerra, 2020). From a triple bottom line perspective, it appears that firms tend to emphasize selected economic, social, or environmental initiatives rather than a balanced, holistic configuration, which weakens the overall effect of the higher-order sustainable warehouse construct on sustainable logistics performance (He et al., 2017; Wit & Pylak, 2020). In the context of toll-road logistics ecosystems, logistics performance is also strongly influenced by wider infrastructure, policy, and network conditions, so the contribution of warehouse-level sustainability may be overshadowed by macro-level factors such as corridor connectivity and transport service quality (Lakshmanan, 2011; Viswanadham & Gaonkar, 2003). Therefore, although sustainable warehouse remains conceptually important, the non-supported result for H1 indicates that more mature and integrated implementation across economic, social, and environmental dimensions is required before it can generate a strong and significant impact on sustainable logistics performance.

The Effect of the Economic Dimension on Sustainable Logistics Performance

The results show that the economic dimension of sustainable warehouse has a positive and significant effect on sustainable logistics performance ($\beta = 0.2959$, $p < 0.05$), thus supporting H2. This finding is consistent with prior research which emphasizes that warehouse operational excellence—reflected in efficient receiving, storage, picking, and shipping—remains a core determinant of logistics performance and cost efficiency in competitive supply chains (Chen et al., 2017; Cagliano et al., 2011). In line with studies on sustainable logistics, economic performance such as reduced logistics cost, improved service reliability, and better use of infrastructure is a key driver of sustainable logistics outcomes, particularly in developing regions where logistics costs remain relatively high (Larson, 2021; Syifa & Tohir, 2025). In the Trans-Java toll-road corridor, firms that manage warehouse operations more efficiently are better positioned to exploit the advantages of strategic highway access, shorten lead times, and reduce variability in deliveries (Lakshmanan, 2011; Paula & Isabel, 2017). These improvements not only enhance economic performance but also support sustainability indirectly by lowering waste, avoiding unnecessary trips, and optimizing resource utilization (He et al., 2017; Karia, 2022). Hence, the supported H2 confirms that strengthening the economic dimension of warehousing is an essential and practical lever for improving sustainable logistics performance in this infrastructure setting.

The Effect of the Social Dimension on Sustainable Logistics Performance

The social dimension is found to be the strongest predictor of sustainable logistics performance, with a path coefficient of 0.4709 ($p < 0.01$), thereby supporting H3. This result aligns with literature indicating that social practices—such as fair employment, training, occupational safety, and complaint handling—are crucial for maintaining operational continuity and service quality in logistics systems that depend heavily on human labour (Kah-Shien Tan et al., 2009; Torabizadeh et al., 2019). Studies on sustainable logistics performance also show that social factors like worker well-being, safety, and community relations have a direct and reinforcing influence on logistics service quality and reliability (Zagloel et al., 2024; Mensah et al., 2020). In the context of business actors around rest areas, many operations are small or medium-sized and rely on tight-knit workforces and local networks, so disruptions arising from accidents, disputes, or poor labour conditions can immediately degrade logistics performance (Larson, 2021; Kumar et al., 2018). Conversely, companies that invest in social sustainability—through safety programs, skill development,

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and responsible customer and community engagement—are better able to sustain reliable service levels and adapt to changing demand (Prabodhika et al., 2021; Lenort et al., 2022). The strong and significant effect of the social dimension therefore highlights social sustainability as a practical entry point for improving sustainable logistics performance in emerging logistics ecosystems such as the Trans-Java toll corridor.

The Effect of the Environmental Dimension on Sustainable Logistics Performance

The environmental dimension also exhibits a positive and significant effect on sustainable logistics performance ($\beta = 0.2048$, $p < 0.05$), supporting H4. This finding is in line with studies which demonstrate that environmental practices in warehousing—such as energy-saving building design, renewable energy use, waste reduction, and eco-friendly packaging—contribute to both lower ecological impacts and improved logistics performance when implemented systematically (Bank & Murphy, 2017; Malinowska et al., 2018). Research on low-carbon logistics similarly shows that firms that adopt environmental indicators and performance measurement systems tend to achieve better long-term logistics performance by reducing energy consumption and emissions while maintaining service quality (He et al., 2017; Jinru et al., 2022). In toll-road logistics corridors, where road transport emissions and energy use are particularly salient, environmental measures at the warehouse node can complement improvements in transport operations and help firms respond to increasing regulatory and stakeholder pressure for greener logistics (Larson, 2021; Ji et al., 2023). Although the coefficient for the environmental dimension is smaller than for the social and economic dimensions, its significance suggests that environmental practices are already part of the performance equation and will likely grow in importance as sustainability standards continue to tighten (Teh et al., 2022; Lewandowska & Dawson, 2021).

The Moderating Role of Logistics 4.0

The analysis reveals that Logistics 4.0 does not significantly moderate the relationship between sustainable warehouse and sustainable logistics performance ($\beta = -0.0357$, $p > 0.05$), indicating that H5 is not supported. This result contrasts with conceptual expectations in the Logistics 4.0 literature, which suggests that digital technologies such as IoT, cyber-physical systems, and big data analytics should enhance the effectiveness of sustainability initiatives by improving visibility, coordination, and control (Strandhagen et al., 2017; Orestis & Stavros, 2021). However, prior reviews have also noted that Logistics 4.0 implementation is often partial and fragmented, with many firms adopting isolated technologies rather than fully integrated digital systems (Delmonico & Bezerra, 2020; Oubrahim et al., 2022). The present findings indicate that such a transitional digital stage characterizes the firms in the Trans-Java toll-road corridor, where some tools—such as basic tracking or automated planning—are used, but deeper integration of IoT, analytics, and warehouse management systems remains limited (Nantee & Sureeyatanapas, 2021; Sun et al., 2022). As a result, Logistics 4.0 currently behaves more as an operational support technology than as a strong amplifier of sustainable warehouse practices, so it does not significantly strengthen the SW–SLP linkage in the structural model. This underscores previous arguments that digitalization alone does not guarantee sustainability benefits; instead, technology must be embedded within coherent sustainability strategies and process redesigns to realize its full moderating potential (Wit & Pylak, 2020; Karia, 2022).

Determinant Factors of Sustainable Warehouse (SW)

The PLS-SEM estimation of the Sustainable Warehouse (SW) construct among logistics users along the Trans-Java Toll Road corridor shows that social factors play a particularly prominent role in shaping warehouse sustainability. The weighting analysis, which complements the earlier descriptive statistics, reveals that the construct is primarily driven by indicators capturing time efficiency in inbound operations, the quality of labor relations, and workforce stability, while still reflecting the multidimensional nature of Sustainable Warehouse as proposed by Torabizadeh et al. (2019), who emphasize the integration of economic, environmental, and social dimensions. Within this framework, the indicator efficient receiving process (economic dimension) emerges as the most influential, underscoring that stable and timely material inflows are foundational for sustainable warehousing, in line with recent green-warehousing research that positions process efficiency and optimal space utilization as central performance dimensions.

Social dimension indicators such as the fair and prompt handling of discrimination and labor-dispute complaints and a controlled employee turnover rate also obtain high weights, confirming that sustainability is not only a function of infrastructure and technology but is critically dependent on ethical labor practices, a conducive work environment, and the long-term continuity of human capital. These findings resonate with contemporary discussions on Sustainable Warehouse Management Systems (SWMS), which argue that worker protection, transparent employment relations, and work–life balance are integral to embedding environmental and social responsibility into supply-chain operations. On the economic-operational side, high weights for order-fulfilment accuracy indicator and optimal storage-capacity utilization indicator indicate that lean, accurate, and adaptive processes—reflected in reduced returns, fewer non-value-added activities, and efficient use of space and energy—remain decisive for the economic pillar of warehouse sustainability, echoing recent KPI frameworks in green warehousing.

Environmental indicators related to energy and water management, particularly systematic efforts to reduce energy consumption, energy requirements of products and services, and the reuse or recycling of water, also show notable contributions, aligning with

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studies that highlight energy efficiency, optimized layout, low-carbon equipment, and water-reuse schemes as key levers for reducing warehouses' ecological footprint. At the same time, indicators linked to wage standards, climate-risk identification, local sourcing, and explicit environmental investment receive comparatively lower weights, suggesting that, in this context, these aspects are not yet perceived as core drivers of sustainable warehousing at the facility level. This pattern is consistent with broader evidence that climate-risk integration, biodiversity protection, and long-term environmental investment remain at an early stage of operationalization often constrained by data limitations, complex measurement requirements, and limited regulatory pressure thereby signalling the need for stronger policy incentives, financial mechanisms, and technical capacity building to move from a process efficiency oriented model toward genuinely low carbon and ecologically resilient warehouse systems.

CONCLUSION AND IMPLICATIONS

Conclusion

This study concludes that sustainable warehouse, when modeled as a second-order construct, does not have a significant direct effect on sustainable logistics performance in the context of business actors around TIP/rest areas on the Trans-Java Toll Road. The moderating role of Logistics 4.0 is also not supported, indicating that current digital logistics maturity is not yet sufficient to strengthen the relationship between sustainable warehouse and sustainable logistics performance in a meaningful way. At the same time, the study confirms that the economic, social, and environmental dimensions of sustainable warehouse each positively and significantly influence sustainable logistics performance. Among these, the social dimension is the strongest predictor, followed by the economic dimension and then the environmental dimension, indicating that social and operational practices currently form the most powerful practical basis for logistics sustainability improvement in the observed context.

Implications

The study contributes to sustainable logistics and warehousing literature by showing that the relationship between sustainable warehouse and sustainable logistics performance is more complex than a simple direct-effect assumption. In developing-country logistics ecosystems, sustainability may emerge first through unevenly developed dimensions rather than through a fully mature integrated construct, making dimension-level analysis especially valuable. The findings also contribute to the literature on digitalization by showing that Logistics 4.0 does not automatically strengthen sustainability relationships. Digital adoption must be sufficiently deep, integrated, and strategically aligned before it can act as a meaningful reinforcing mechanism in sustainable logistics systems. For managerial, the findings indicate that improving sustainable logistics performance requires emphasis on concrete practices rather than broad sustainability claims. Priorities should include stronger warehouse operational efficiency, better labor and safety practices, improved customer and community responsibility, and gradual strengthening of environmental programs such as energy efficiency, waste management, and protection investment. The study also supports the development of financing and incentive schemes for sustainable warehouse investment. Fiscal support, low-interest financing, green financing, and collaborative programs involving government, universities, logistics associations, and financial institutions could help firms improve environmental and digital capability in warehouse operations around toll road logistics nodes.

LIMITATIONS AND FUTURE RESEARCH

The study is limited by its cross-sectional design, which captures business conditions at one point in time and cannot fully trace how sustainability and digitalization evolve operationally. The geographic focus on the Trans-Java Toll Road environment also means that the findings may reflect the characteristics of that corridor more strongly than those of other Indonesian logistics regions. Future research can test alternative models, including placing sustainable warehouse as a mediator between organizational capabilities and sustainable logistics performance, or examining moderators such as regulatory pressure, infrastructure readiness, customer pressure, or competition intensity. Further studies can also refine measurement indicators and combine perception-based survey data with objective performance metrics such as logistics cost, lead time, energy consumption, or occupational accident rates in order to deepen understanding of sustainable warehouse effectiveness.

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