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BARRIERS TO THE IMPLEMENTATION OF SUSTAINABLE WAREHOUSING: A SYSTEMATIC LITERATURE REVIEW

M. Rizki Gusri[1], Erna Mulyati[2], Maniah[3]

[1,2] Master of Logistics and Supply Chain Management, International Logistics & Business University, Jl. Sariasih No. 54, Sukasari, Bandung, West Java 40151, Indonesia

A B S T R A C T

The implementation of sustainable warehousing is an important element in efforts to decarbonize the supply chain and achieve Environmental, Social, and Governance (ESG) goals. Although the environmental, social, and economic benefits of sustainable warehousing practices have been widely reported, the level of implementation is still relatively limited due to various multidimensional obstacles. This study aims to identify and analyze the main factors that hinder the implementation of sustainable warehousing through a Systematic Literature Review (SLR) approach. The review process was conducted using a four-stage protocol with searches on five major scientific databases, namely Scopus, Taylor & Francis, IEEE Xplore, ScienceDirect, and Google Scholar. From a total of 79,116 initial publications, 50 selected articles (from 2020–2025) were analyzed thematically and quantitatively. The results of the study revealed six dominant barriers, namely high initial investment costs (30%), technological and infrastructure limitations (22%), lack of skills and human resource resistance (16%), high energy consumption and dependence on fossil fuels (14%), weak regulations and policy support (10%), and challenges in integrating digital systems such as WMS, IoT, and AI (8%). These findings confirm that the barriers to sustainable warehousing are systemic and interrelated, with economic and technological factors dominating and being significantly influenced by social, energy, and institutional aspects. This research contributes to the enrichment of the logistics sustainability literature by providing a comprehensive mapping of barriers and offering a conceptual basis for the development of holistic, adaptive, and long-term implementation strategies.

Keywords: Sustainable warehousing, Implementation barriers, Systematic literature review, Sustainable logistics, Industry 4.0 technology, Warehouse management system

1. INTRODUCTION

Introduction Sustainable warehousing is a warehousing management approach that aims to optimize operational efficiency and effectiveness through the use of organizational and technological solutions, so that the company's financial targets can be achieved while minimizing environmental and social impacts (Malinowska, 2019). The main objective is to create environmentally friendly, resource-efficient, low-emission warehousing operations with long- term economic value (Majeed et al.., 2025, Nicoletti & Appolloni, 2024).

In order to measure and implement these sustainability principles, various studies have grouped sustainability indicators in warehousing into several main categories: environmental, economic, social, and technological/operational (AlHerimi et al., 2025), Ishizaka et al., 2022). From an environmental perspective, indicators include energy efficiency through the use of energy saving technologies, the use of renewable energy such as solar panels, waste reduction through the 3R principle, carbon footprint control, and efficient water management (Majeed et al.., 2025, Perotti et al., 2023, Nicoletti & Appolloni, 2024). In terms of economics, the indicators focus on operational efficiency, energy cost savings, waste and material cost reduction, and return on investment from the application of green technology (Abu Tabanjeh et al., 2025 ; Perotti et al., 2025). Social indicators assess occupational health and safety, employee training and awareness of environmentally friendly practices, as well as inclusive working conditions that support worker welfare (Malinowska, 2022 ; Krause, 2025). Technology and operational indicators include the use of 4.0 technologies such as IoT, WMS, and robotics, the level of automation in warehouse processes, the use of sensor-based monitoring systems, and the optimization of location

*Corresponding author
E-mail addresses: ikigusri@gmail.com (M. Rizki Gusri)

and layout to reduce internal travel and energy consumption (Perotti et al.., 2025 ; Ishizaka et al., 2022 ; Uysal & Tosun, 2014).

The implementation of sustainability in logistics and manufacturing warehouses still faces significant challenges, particularly related to high energy consumption due to inefficient old infrastructure and minimal initial investment in environmentally friendly technologies such as digital energy management systems, IoT sensors, and solar panels (Majeed et al., 2025; Perotti et al., 2023).

A Systematic Literature Review (SLR) is a method used to map research developments, dominant themes, and research gaps in a systematic and transparent manner through the analysis of reputable scientific literature. The SLR study conducted by (Maniah et al., 2022) shows that this approach is effective in identifying knowledge structures and research gaps through a measurable process of article selection and synthesis. However, the application of SLR that specifically examines the factors, indicators, and challenges of sustainable warehousing implementation is still limited, thus opening up opportunities for further research in this field.

Previous studies have identified various major obstacles in the implementation of sustainability management, ranging from economic and operational aspects to social and policy aspects. Recent studies show that high implementation costs, capital constraints, and the high cost of renewable energy integration are the dominant challenges limiting the application of green technology in warehousing facilities (Abu Tabanjeh et al., 2025; Ibrahim et al., 2024). On the operational side, limitations in digital infrastructure, the complexity of implementing Industry 4.0 and Logistics 5.0, and difficulties in managing energy and carbon emissions are also significant obstacles (Cannava et al., 2024; Tudisco et al., 2024). Other studies also emphasize the low awareness and competence of industry players regarding low-carbon practices and poverty as important barriers to the implementation of sustainable preservation strategies (Ibrahim et al., 2024). In addition, several studies reveal that regulatory disruptions, lack of government support, and weak ESG policy frameworks further slow down implementation (Kudrenko & Hall, 2024). Additional challenges related to warehouse location, adequacy of renewable energy supply, and pressure from stakeholders have also been found to influence the achievement of warehouse sustainability goals (Abu Tabanjeh et al. 2025, Uysal & Tosun, 2014). Based on the complexity of the barriers to sustainable warehousing identified in the literature, this study aims to analyze the main factors that hinder the implementation of sustainable practices, including financial, regulatory, technological, infrastructure, and social and environmental constraints (Abu Tabanjeh et al., 2025; Cannava et al., 2024; Ibrahim et al., 2024), identify the relationship between knowledge gaps and technical competencies with the effectiveness of green warehousing (Ibrahim et al., 2024; Uysal & Tosun, 2014), evaluating the role of regulations and policy support in encouraging the adoption of sustainable practices (Kudrenko & Hall, 2024), assessing the impact of technological and infrastructure limitations on company readiness (Cannava et al., 2024; Tudisco et al., 2024), analyzing the influence of stakeholder dynamics and customer resistance on adoption decisions (Wan Ahmad et al., 2016), and formulating comprehensive strategic recommendations to improve implementation effectiveness through technological innovation, human resource capacity building, and stakeholder collaboration (Baglio et al., 2025; Chen, 2025). This research is expected to provide empirical and theoretical contributions in understanding obstacles and developing solutions to improve the operational sustainability of warehousing.

2. METHOD

This study uses a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize empirical and conceptual findings related to practices, barriers, driving factors, and technological innovations in sustainable warehousing. The SLR approach was chosen for its ability to provide a comprehensive, transparent, replicable, and objective understanding of the development of concepts, best practices, and implementation challenges of sustainable warehousing, as well as enabling systematic analysis of cross-disciplinary thematic patterns (Abu Tabanjeh et al., 2025; AlHerimi et al., 2025).

This study followed four main stages, from Stage 1 to Stage 4, as adapted from (Sridhar et al., 2024).

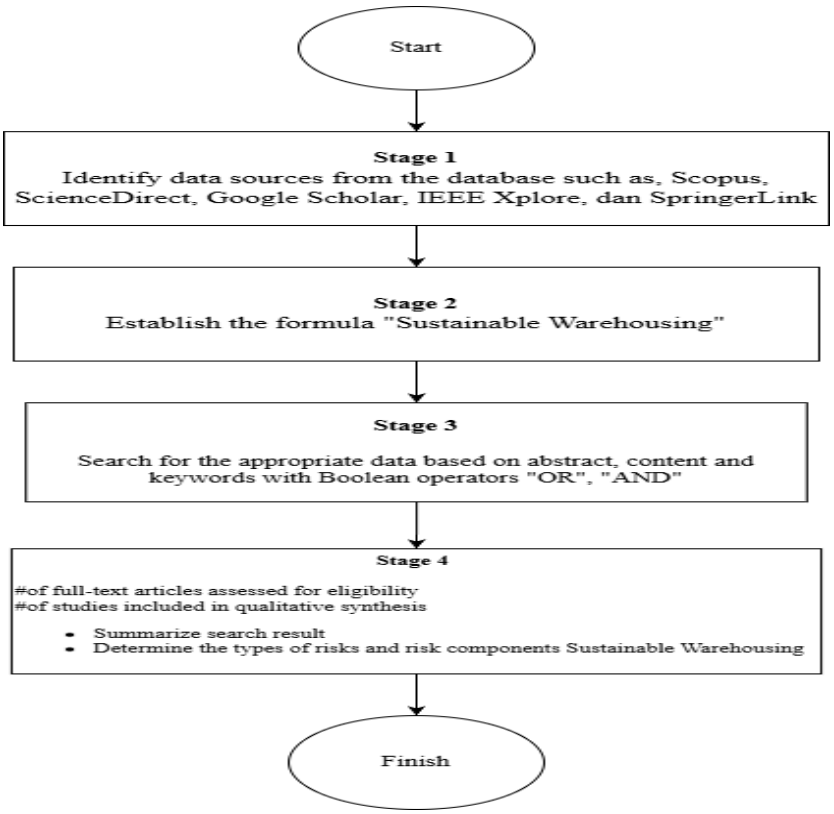

Figure 1. Steps in SLR Methodology Research

Literature identification was conducted through a comprehensive search of leading scientific databases, including Scopus, Taylor & Francis, Google Scholar, IEEE Xplore, and ScienceDirect, to ensure broad and inclusive coverage of interdisciplinary studies (Cannava et al., 2024; Ibrahim et al., 2024). The search strategy used a combination of Boolean operators: "AND" and "OR" with the following keywords: ("sustainable warehousing") AND ('barriers' OR "inhibiting factors" OR "challenges") OR ("warehouse sustainability") formulated based on terminology trends in the main literature on logistics sustainability (Abu Tabanjeh et al., 2025); (Tudisco et al., 2024).

The selected articles are then examined to extract a brief summary of their main content.

a. Stage 1: Identifying database sources based on predetermined search criteria. At this stage, a total of (79,116) articles were identified.
b. Stage 2: Selecting relevant articles from the initial collection based on titles that match the research topic, resulting in (620) articles.
c. Stage 3: Articles were filtered based on the relevance of abstracts and keywords, resulting in (286) articles.
d. Stage 4: In the final stage, articles that did not meet the inclusion criteria were excluded, resulting in a total of (50) eligible studies. The annual distribution of these publications (from 2020 to 2025) is summarized in Table 2.

Tabel 1. Number of Publications Based on Database Source

Database Source	Stage 1 (Article)	Stage 2 (Title)	Stage 3 (Abstract & Keywords)	Stage 4 (Final Selection)
Scopus	315	43	36	8
Taylor dan Francis	41.915	181	84	7
Google Scholar	1.390	42	35	15
IEEE Xplore	441	110	106	11
ScienceDirect	35.055	244	25	9

Total	79116	620	286	50

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Based on Table 1, the systematic literature review process yielded 50 articles, which were then further examined by the researchers. These articles were taken from various databases: IEEE Xplore (11), Scopus (8), Taylor & Francis (7), ScienceDirect (9), and Google Scholar (15). In the final selection stage, the researchers summarized the relevant findings and proposed solutions from each study.

3. RESULT AND DISCUSSION

This section presents findings from the article selection process through a systematic literature review. From this search, 50 articles related to barriers to the implementation of sustainable warehousing were found, which were then grouped based on the main determinant categories that currently apply. After grouping, an analysis of the distribution of publications per year was carried out, followed by a discussion of various factors that hinder sustainable warehousing.

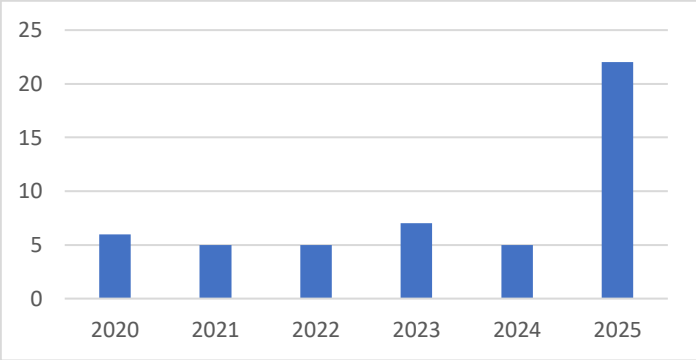

Figure 2. Number of Studies by Year

Analysis of Current Factors Hindering Sustainable Warehousing

Table 1 (Part 2) shows that there are 50 relevant articles on factors hindering sustainable warehousing. The results of the analysis reflect the latest developments in these articles.

Tabel 2. Analysis Results for Each Article

Article Topic	Author	Conclusion
Transformation of logistics facilities in Italy towards net-zero emission warehouses through analysis of environmentally friendly practices and their effects on the environment over a four-year period.	Perotti, S., Coslovich, M., & Granata, E. (2023).	The research results indicate that the application of energy-saving technology tends to provide sustainable benefits and consistent reductions in energy consumption in the long term
Focusing on tensions in sustainable warehousing, particularly regarding automation and ergonomic workplace design	Gruchmann, T., et al. (2021)	Implementing these practices requires additional transformational actions to address internal and external social sustainability tensions.
Aiming to achieve environmentally sustainable warehousing practices, with a primary focus on consumer electronics products.	Chiang, T.-A., Che, Z.-H., & Hung, C-W (2023)	Designing an efficient method for combining and setting a selection list of goods for sustainable warehouse management, using K-means clustering techniques and Prim's Minimum Spanning Tree algorithm.
Reviewing and conceptualizing the role of 4.0 technology for sustainable warehousing	Perotti, S., et al. (2024)	Using a comprehensive process-based method to address challenges such as customer demand, availability of skilled labor, and rising energy costs.
Considering traditional and sustainable factors for warehouse selection	Mittal, R., & Obaid, A. (2023).	Simultaneously considering the economic, environmental, and social dimensions of sustainability (triple bottom line) for warehouse location selection
Sustainable Warehousing, focusing on its features and estimated implementation costs.	Payel, F.T. (2020)	Sustainable warehousing is crucial for green logistics and can reduce carbon emissions by up to 32% with minimal changes to traditional warehouses
Enhancing sustainability in warehouses through decision support tools for green storage allocation issues	Maria A.M. Trinity & Asma Rakiz (2025)	The SLAP strategy can reduce travel distance (GI) and fuel consumption (EI) by up to 33%, and labor requirements (SI) by up to 3.00 FTE positions per month

Using experimental design and simulation methods to examine factors that influence key performance indicators such as Shelf Utilization, Labor Utilization, and Total Pick Time	Thairach, A., et al. (2025)	Important factors affecting manual order picking in small and medium-sized warehouses, then determining the optimal value for each factor to improve warehouse sustainability based on several performance measures

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Article Topic	Author	Conclusion
Cost Effectiveness of Implementing Sustainable Practices and Technologies in Warehouse Operations	Tan, A., Wahab, SN, & Gerth, F. (2025)	Integrating sustainable practices and technologies in warehousing results in substantial cost savings and operational efficiency
Sustainable Warehousing: The Interaction Between Human Well-being and Energy Consumption	Cais, M., et al. (2025)	Gaps in the literature regarding the joint consideration of human-centered and energy perspectives in sequence selection supported by MHE
Advances in IoT for Sustainable Transportation and Warehousing	Singh, B. (2025).	IoT acts as a powerful transformative framework for developing sustainable transportation systems, minimizing emissions, and improving operational efficiency
Industry 4.0 Technology and Sustainable Warehousing: A Systematic Literature Review	Phan, M.H., & Ali, I. (2021)	The importance of Industry 4.0 technology in achieving sustainable warehousing across economic, social, and environmental perspectives
Sustainable Warehousing: Selecting the Best Warehouse for Solar Transformation	Boztepe, R., & Çetin, O. (2020)	aimed at reducing electricity consumption by producing their own electricity in solar warehouses
identifying the appropriate criteria for the transition from conventional warehousing to sustainable warehousing	Vasileva, A., et al. (2022)	Identifying the most appropriate criteria for the transition from conventional warehousing to sustainable warehousing
Utilizing digital technology to improve sustainable warehouse management	Drissi Elbouzidi, A., et al. (2025)	Operational focus areas may differ from strategic CCA outcomes, highlighting travel emissions as actionable in real-time
Integrating Industry 4.0 with warehouse management to achieve Sustainable Development Goals.	K. Aravindaraj, P. Rajan Chinna (2022)	Key benefits include improved operational efficiency, product monitoring and tracking, and safety aspects
Heat Recovery Strategies in Logistics Warehouses and Data Centers for Sustainable Residential Heating	Sakji, I., Ndhaief, N., & Rezg, N. (2025	Optimizing heat transfer and space utilization enhances energy efficiency, reduces waste, and lowers the need for additional heating systems.
Long-term assessment of the Participatory Order Assignment (POA) system in a warehouse environment	De Lombaert, T., et al. (2025)	The positive short-term effects of implementing Participatory Order Assignment (POA) persist over time in real-world warehouse settings
Sustainability impacts of automated warehouses in Industry 4.0 scenarios	Cosma, A.M.I, et al. (2025)	Warehouse sustainability is enhanced by technological changes driven by Industry 4.0, particularly through the integration of IoT to optimize traceability and reduce costs.

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Article Topics	Author	Conclusion
A simulation-based approach to evaluating green warehousing measures	Cannava, L., et al. (2025)	Simulation results indicate significant potential for renewable energy sources to reduce environmental impact and for Battery Energy Storage Systems (BESS) to increase self-consumption
Concept of a decision support system for sustainable warehousing	Malinowska, M. (2022).	proposes a system using the COMET method to build a sustainable warehousing assessment model and suggests improvements
Ranking model for measuring energy efficiency for warehouse operation sustainability	Dimitrov, L., & Saraceni, A. (2023)	Key performance indicators (energy consumption and package output), indexing systems, and ranking models were selected to assess productivity
From warehouses to Net-Zero logistics facilities: A simulation-based roadmap for achieving carbon reduction and energy efficiency	Cannava, L., & Perotti, S. (2025).	Full implementation of the roadmap resulted in a clear reduction in annual energy consumption and CO2e emissions, with EUI falling to 16.9 kWh/m² per year and CO2e emission intensity to 15.4 tons from the baseline case value

Improving warehouse picking efficiency through integrated allocation and routing policies, with a focus on case studies for sustainable and smart warehousing.	Bashatah, J.A., & Elnaggar, G.R. (2025)	Storage allocation significantly impacts picking efficiency more than routing decisions
A systematic review of Key Performance Indicators (KPIs) for sustainability in warehousing	Alherimi, N., Ahmed, V., & Bahroun, Z. (2025)	This establishes an overview of sustainability KPIs across environmental, social, and economic dimensions, and classifies the literature into four main thematic applications: supply chain activities, modeling approaches, performance management tools, and warehouse automation.
Green warehousing practices and their impact on strategies to increase PV self-consumption in logistics warehouses	Cannava, L., et al. (2024)	Green warehousing (GW) practices and sustainable warehousing concepts are crucial for reducing the environmental impact of logistics operations, as warehouses contribute significantly to supply chain emissions
A simulation-based approach was used to evaluate green warehousing measures	Cannava, L., et al. (2025)	The strategic evaluation process for selecting green warehousing (GW) demonstrates the benefits of integrating renewable energy sources and related strategies

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Article Topic	Author	Conclusion
Focusing on recent social and environmental sustainability practices for warehouse management systems (WMS)	Minashkina, D. (2024).	Warehouses are crucial for supply chain sustainability, requiring social and environmental practices to remain efficient and profitable
A GenAI Technology Approach to Sustainable Warehouse Management Operations	Moica, S., et al. (2025)	Significant cost savings were observed at the daily, monthly, and annual operational levels, highlighting economic viability and sustainability
Energy consumption at transfer points (TP) in passive and plus-energy warehouses	Zajac, P. (2025)	Transfer points (TP) significantly affect the energy intensity of short-distance transport and entire pallet warehouses, with ignoring them leading to an underestimation of total energy consumption by up to 30%.
Its economic, environmental, and social dimensions. This highlights strategies such as energy efficiency, waste reduction, and ethical practices to improve operational efficiency and reduce environmental impact.	Sharkasi, A.M., & Akkartal, E. (2025)	Balancing economic growth with environmental and social responsibility can enable warehouses to meet operational goals and global warehouse sustainability objectives
Identifying the main motivations, characteristics, adopted technologies, and strategies for smart warehouses	van Geest, M., et al. (2022)	SLR identifies domains where smart warehouses are implemented, motivations for adoption, characteristics, technologies, and challenges
Transition to Net-Zero Warehouses: Empirical Insights and Best Practices in Italy	Perotti, S., et al. (2023)	reveals significant emission reductions (3% to 56%) depending on the facilities and green warehousing solutions implemented
Green warehousing practices and their impact on strategies for increasing self-consumption of PV in logistics warehouses	Cannava, L., Javan, F.D., F.D., Najafi, B., & Perotti, S. (2024)	Green warehousing (GW) practices and sustainable warehousing concepts are crucial for reducing the environmental impact of logistics operations, as warehouses contribute significantly to supply chain emissions
Optimization of Storage Location Setting for Non-Traditional Warehouse Layouts Based on the Spark Plug Algorithm	Zhang, X., Mo, T., & Zhang, Y. (2023).	A multi-objective optimization model is proposed, considering storage location assignment, order picking efficiency, and rack stability as optimization objectives for warehouse sustainability.
A smart control approach for warehouse performance optimization in Industry 4.0 using machine learning	France, A., & Bányai, T. (2025)	Machine learning-based regression models, specifically LightGBM, can effectively uncover hidden performance patterns in warehouse operations

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Article Topic	Author	Conclusion

Costs of Designing and Constructing Sustainable Warehouses Based on Applicable Fire Regulations	Pawluk, K., et al. (2024)	Fire protection and evacuation conditions significantly affect investment time and costs.
Focusing on sustainable logistics practices, particularly in warehousing, and identifying drivers, barriers, and best practices for their implementation	Abu Tabanjeh, S.T., et al. (2025).	Sustainable warehousing is a continuous journey that requires continuous innovation, advanced technology, and collaborative efforts across industries to address emerging challenges and opportunities
The role of growth in the transportation and warehousing sectors, Gross Domestic Product (GDP), and renewable energy consumption in controlling carbon emissions in Indonesia	Wahyudi, H., et al. (2025)	Rapid growth in the transportation and warehousing sector, driven by urbanization and increased logistics, significantly increases carbon emissions due to dependence on fossil fuels.
Warehouse Management System (WMS) for Social and Environmental Sustainability	Minashkina, D., & Happonen, A. (2023)	WMS is integrated with other warehouse subsystems to improve social and environmental sustainability in warehousing
Sustainable City GDP, Transportation, and Warehousing	Setiawan, M. I., et al. (2020)	Factors affecting GDP in Transportation and Warehousing include aircraft arrivals, aircraft departures, passenger departures, departing passengers, baggage loading and unloading, cargo loading and unloading, and cargo loading, all of which affect
the effectiveness of Corporate Social Responsibility (CSR) in implementing social sustainability practices in the warehousing industry of developing countries, particularly using a hybrid approach	Ali, S.S., & Kaur, R. (2021).	The impact of social sustainability practices in warehouses in developing countries on the effectiveness of CSR
Decarbonization of warehousing activities through digitization and automation with WMS integration for sustainability support operations	MInashkina, D., & Happonen, A. (2020)	Digitalization, automation, and robotization in warehousing, combined with WMS, can lead to CO2 reduction for 3PLs and their customers

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Article Topic	Author	Conclusion
Mapping sustainable warehouse processes in the Banten agro-hub using Business Process Modeling Notation	Wahyuni, F. D., et al. (2022)	Sustainable warehouses in the Agro-hub are built by designing purchasing, data recording, packaging, inventory, and logistics processes
Optimizing the efficiency and costs of company logistics warehouses from a green supply chain management perspective	Chen, Y., (2025)	GSCM significantly impacts logistics warehouse costs by reducing energy consumption, labor costs, waste disposal, environmental remediation, and inventory storage costs
GenAI Technology Approach for Sustainable Warehouse Management Operations	Moica, S., et al. (2025)	The integration of GenAI in warehousing and receiving processes significantly improves efficiency, accuracy, and operational performance in the automotive logistics sector
Sustainable inventory models with controllable carbon emissions in green warehouse farming	Mashud, A.H.M., et al. (2021)	Proposing a sustainable inventory model for retailers with a two-warehouse system that sell non-perishable goods, providing insights for efficient transportation and minimum carbon emissions to maximize profits
A new sustainable warehouse management approach for workforce and activity scheduling	Popovic, V., et al. (2021)	Optimal scheduling reduces costs, improves efficiency, and creates space to process larger quantities of goods with the same or fewer resources
Legislative measures and certification for sustainable warehouse construction and design	Mikhova, L. (2020).	Sustainable development is increasingly impacting warehousing and storage activities, influencing the construction of new facilities and the renovation of existing ones.
Development of environmental and social performance indicators in warehousing, including indicator selection using the Fuzzy	Bajec, P., et al. (2020)	Identifying potential environmental and social indicators for warehousing, including equations and units of measurement

Delphi Method, priority determination using the Best-Worst Method, and analysis of the dominance of environmental indicators in emissions measurement.	

(SOURCE: AUTHOR'S ANALYSIS, 2025)

Table 2 presents an overview of the article themes, author identities, and main findings summarized from various reviewed literature. The analysis shows consistency in the results of various studies, which is a fundamental component in studies using the SLR approach.

Influencing factors	Author	Article	Percentage
Cost	Payel, FT (2020). Pawluk, K., et al. (2024). Tan, A., Wahab, SN, & Gerth, F. (2025). Mikhova, L. (2020)	15	30
Infrastructure limitations	Phan, MH, & Ali, I. (2021). van Geest, M., et al. (2022). Cosma, AMI, et al. (2025). Minashkina, D., & Happonen, A. (2023)	11	22%
Lack of skills	Gruchmann, T., et al. (2021). Cais, M., et al. (2025). Minashkina, D. (2024). Ali, SS, & Kaur, R. (2021)	8	16
Energy consumption	Wahyudi, H., et al. (2025). Zajac, P. (2025). Cannava, L., et al. (2024). Perotti, S., et al. (2023)	7	14
Lack of regulation	Mikhova, L. (2020). Abu Tabanjeh, ST, et al. (2025). Vasileva, A., et al. (2022)	5	10
Digital integration systems (WMS, IoT, AI)	Minashkina, D., & Happonen, A. (2020). Drissi Elbouzidi, A., et al. (2025). Moica, S., et al. (2025)	4	8
Total		50	100%

(SOURCE: AUTHOR'S ANALYSIS, 2025)

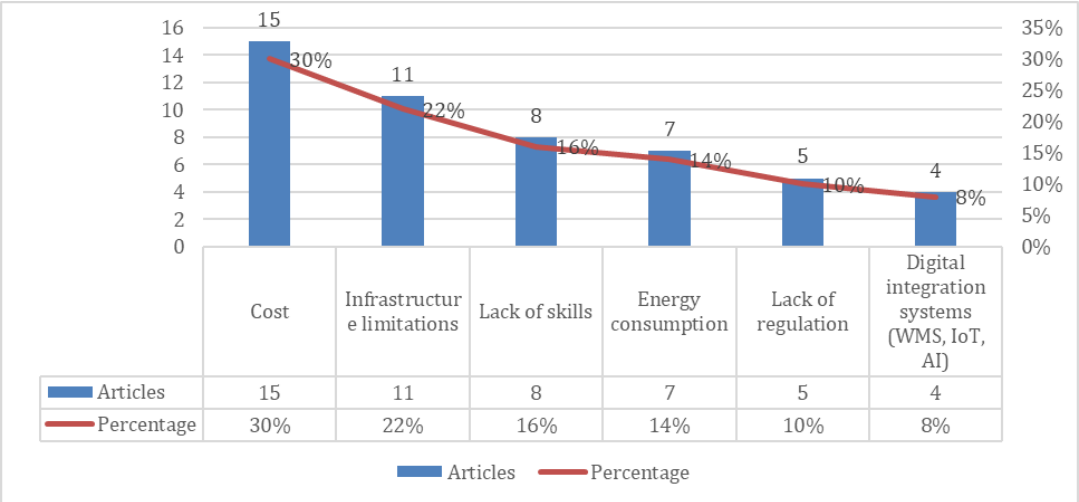

Figure 3. Trends in factors hindering sustainable warehousing

Based on a systematic literature review of 50 articles from various international databases, Table 3 identifies six factors that hinder sustainable warehousing: high initial investment costs (30%), limitations in technological and digital infrastructure (22%), lack of skilled labor and human resource resistance (16%), high energy consumption and fossil fuel dependence (14%), lack of supportive regulations, incentives, and standards (10%), and lack of digital integration systems (WMS, IoT, AI)

(8%). The variation in the contribution of each factor reflects differences in strategic significance, measurable impact, and frequency of discussion in scientific literature.

The visualization results show that high initial investment costs are the most dominant inhibiting factor, appearing in 15 articles or around 30% of the total research. This finding is consistent with the literature stating that initial investments in green technology, sustainable building design, automation, and energy management systems remain a significant financial burden, especially for small and medium-sized enterprises (Payel, 2020); (Pawluk & et al., 2024); (Tan et al., 2025). Although the long-term benefits of energy efficiency and emission reduction are widely recognized, the perceived short-term return on investment (ROI) often hinders adoption decisions.

The second prominent inhibiting factor is technological and infrastructure limitations, which appear in around 22% of articles. This obstacle reflects the uneven readiness of digital and physical warehouse infrastructure to support the implementation of Industry 4.0 technologies, such as the Internet of Things (IoT), automation systems, and WMS integration. Several studies emphasize that the lack of interoperability between systems and the high complexity of technology are major obstacles to achieving optimal performance (Phan & Ali, 2021); van Geest & et al., 2022; (Cosma & et al., 2025).

In addition, the decline in skilled labor and human resource resistance was noted in approximately 16% of articles. These obstacles indicate that the transition to sustainable warehousing is not only technical but also socio-organizational in nature. (Gruchmann et al., 2021) emphasize that the implementation of automation and ergonomic technologies requires worker acceptance and continuous competency improvement. Furthermore, recent literature describes a tension between energy efficiency and human well-being, which, if not managed properly, can slow down the transformation of the warehouse ecosystem (Cais et al., 2025; Minashkina, 2024).

High energy consumption and dependence on fossil fuels are factors that appear in about 14% of articles. Although various approaches such as the use of renewable energy, net-zero warehouses, and energy storage systems have been proposed, their implementation still faces technical, economic, and contextual obstacles, especially in developing countries (Cannava et al., 2024; Perotti et al., 2023). (Wahyudi et al., 2025, p. 025) states that the rapid growth of the transportation and warehousing sectors has contributed significantly to increased carbon emissions due to the dominance of fossil fuels. In addition, (Zając, 2025) shows that inaccuracies in energy consumption measurements can cause overall damage to the warehouse environment.

The next obstacle is the lack of regulations, incentives, and supporting standards, which was identified in about 10% of the articles. This factor reflects the importance of public policy in encouraging the implementation of sustainable practices. Several studies state that immature regulations, limited incentives, and a lack of technical guidance on the transition from conventional warehouses to sustainable warehouses create a horizon for industry decision makers (Mikhova, 2020); (Vasileva & et al., 2022); Abu Tabanjeh & et al., 2025).

Finally, difficulties in integrating digital systems, including WMS, IoT, and artificial intelligence-based technologies, emerged as the smallest challenge (around 8%), but remained strategically relevant. The literature shows that without comprehensive integration systems, the potential of digitalization to support energy efficiency, emissions reduction, and data-driven decision-making cannot be optimally utilized (Minashkina & Happonen, 2020; Drissi Elbouzidi & et al., 2025; Moica & et al., 2025).

Overall, the results in the figure confirm that the barriers to implementing sustainable warehousing are multidimensional and interrelated, with economic and technological factors dominating, but still significantly influenced by social, energy, and institutional aspects. Therefore, the strategy for transforming to sustainable warehousing requires a holistic approach that integrates public policy, technological readiness, human resource development, and long-term poverty-based investment planning.

4. CONCLUSION

This systematic literature review synthesizes findings from 50 peer-reviewed articles published between 2020 and 2025, using a rigorous four-stage selection protocol from five major academic databases. The analysis reveals that the implementation of sustainable warehousing is constrained by six key barriers that exhibit multidimensional characteristics and complex interdependencies. High initial investment costs emerge as the most dominant barrier (30%), reflecting the substantial capital

requirements for green technologies, sustainable infrastructure, and automation systems that challenge traditional return on investment frameworks, particularly for resource-constrained companies. Technological and infrastructure limitations (22%) underscore the heterogeneity of digital readiness levels and inadequate interoperability between legacy systems and Industry 4.0 systems, while human resource competency deficits and organizational resistance (16%) emphasize the criticality of the social-organizational dimension in the sustainability transition. Furthermore, persistent energy consumption patterns and dependence on fossil fuels (14%), regulatory ambiguity and inadequate policy support (10%), and digital system integration challenges (8%) collectively form formidable barriers that go beyond purely technical considerations.

This research finding establishes that barriers to sustainable warehousing are inherently systemic rather than isolated, with economic and technological factors dominating but still substantially influenced by social, energetic, and institutional dimensions. This research contributes to the theoretical understanding of logistics sustainability by illuminating the complex transformation dynamics in warehousing operations and the need for a paradigm shift from fragmentary interventions to holistic strategies. The study demonstrates that effective implementation requires the synergistic integration of supportive policy frameworks, enhanced infrastructure readiness, sustainable human capital development, long-term sustainability-oriented investment planning, cross-industry collaboration, and human-centered innovation approaches. These insights provide an operationalizable framework for practitioners and policymakers to advance sustainable warehousing practices while contributing to the broader discourse on supply chain decarbonization and Environmental, Social, and Governance compliance. Future research needs to empirically examine the effectiveness of integrated interventions, explore contextual variations across geographic and sectoral settings, and develop a robust maturity assessment framework for sustainable warehousing implementation in advancing global sustainability goals.

5. ACKNOWLEDGE

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