Available online at: http://publikasi.mercubuana.ac.id/index.php/ijiem

IJIEM (Indonesian Journal of Industrial Engineering & Management)

ISSN (Print) : 2614-7327 ISSN (Online) : 2745-9063

Key Performance Metrics for Green Warehousing in Manufacturing Supply Chains: A Review

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ARTICLE INFORMATION

Article history:

Received: 13 September 2024
Revised: 20 November 2024
Accepted: 14 December 2024

Category: review paper

Keywords:
Green warehousing
KPI
Sustainable suply chain
A review

DOI: 10.22441/ijiem.v6i1.29955

A B S T R A C T

This research highlights the significance of adopting eco-friendly methods in storage, which is a vital part of the manufacturing supply chain. Although green warehousing is still in its early stages, and there is less literature and empirical data on the subject, its potential for sustainable growth is enormous and requires additional exploration. The study's objective is to identify areas in research that have not been adequately addressed and to establish key performance indicators (KPIs) relevant to green warehousing. This will be achieved by a thorough investigation of existing literature. The research methodology employs well-regarded databases such as Publish or Perish, Proquest, and Google Scholar. It utilizes keywords such as "key performance indicators" and "green warehousing". A study of bibliographic data is performed using VOS Viewer to find patterns and concentration of research in this field. The results provide a range of KPIs for environmentally friendly warehousing, such as energy usage, waste management, efficiency in utilizing warehouse space, and monitoring of carbon emissions. The discussion emphasizes the importance of using eco-friendly warehousing practices to decrease greenhouse gas emissions and improve the efficiency of supply chains. The study suggests that researchers create practical case studies based on observation and participate in interdisciplinary research. For professionals in the industry, it recommends adopting quantifiable KPIs and allocating resources to develop environmentally friendly infrastructure.

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1. INTRODUCTION

The business sector increasingly prioritizes environmentally sustainable practices, driven by growing public concern for the environment. Business activities intersect with environmental, economic, and social dimensions, necessitating the integration of sustainable principles at every stage of the supply chain. While eco-friendly warehousing holds considerable promise for advancing sustainable development, research in this area remains limited. Adopting environmentally

friendly practices in warehousing is a relatively recent trend, and there is a paucity of literature, case studies, and empirical evidence to validate its effectiveness. Nevertheless, implementing green strategies in warehousing is viewed as a promising approach to achieving both environmental sustainability and efficient supply chain management (Castillo, 2022).

Warehouses play a crucial role as a central point in any industrial supply chain. The growth of the trade industry and the rising need for mass customization have resulted in a higher requirement for warehouse space and buildings. Warehousing operations account for approximately 11% of the global logistics industry's greenhouse gas (GHG) emissions. Aligned with worldwide patterns, the emphasis on ecologically conscious and sustainable warehousing methods has stimulated fresh investigations into management principles, technology, and machinery aimed at reducing warehouses' carbon emissions. The carbon footprint of a warehouse refers to the cumulative greenhouse gas (GHG) emissions, measured in carbon equivalent units, that are directly generated from the activities carried out within the warehouse (Bartolini et al., 2019).

Warehouses are involved in many logistics operations, such as shipping, storage, assembling, loading, labeling, repackaging, and distribution. Warehouses are crucial for manufacturing organizations. Hence every company strives to gain competitive advantages by having their own warehouses. By implementing strategic measures, specifically through monitoring the company's performance accomplishments, the aim is to enhance competitiveness against other industry players (Muttaqin et al., 2022). This paper aims to identify a research gap by analyzing literature reviews related to Key Performance Indicators for Green Warehousing in the Manufacturing Supply Chain. The goal is to identify the most important KPIs for green warehousing in the manufacturing supply chain and support further research.

2. RESEARCH METHOD

2.1 Database, Keywords, and Inclusion Criteria

The methodology used to identify studies relevant to this review is based on the work of Luu (2016), Bartolini et al. (2019), and Margareta et al. (2020). Three reputable databases, specifically Publish or Perish, Proquest, and Google Scholar, are employed to search for pertinent material to achieve comprehensive study coverage. The search query includes "Key Performance Indicators" and "Green Warehousing." Data analysis is performed using the VOS viewer software on the database.

2.2 Vos Viewer

This study uses Vos viewer, a bibliographic map visualization tool developed in 2010 by Nees Jan van Eck and Ludo Waltman (https://www.vosviewer.com). The analysis was focused on the title and abstract of the publication, processed with Vos viewer software and analyzed using the binary counting method to identify co-occurrences. The results of the analysis are shown in Figure 1.

Figure 1. Occurance analysis using Vos viewer

In Figure 1. The results of the occurrence analysis showed that in the previous study, the measurement of key performance of these controllers in green warehousing had small nodes. Indicating that research with this theme is still not much. From the results of the analysis shown by Vos Viewer, green warehousing research is still new research.

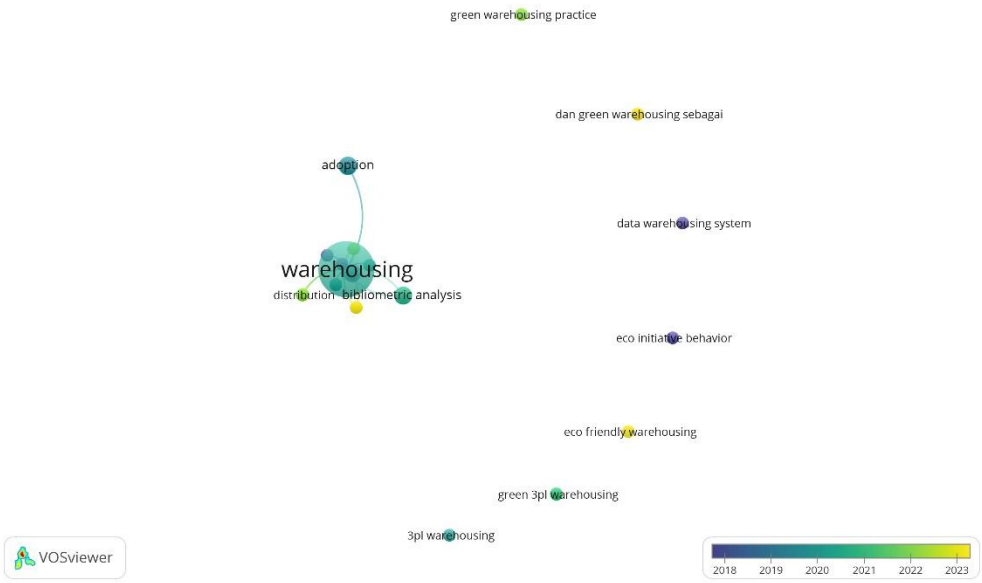

Figure 2. Trend topic analysis using Vos viewer

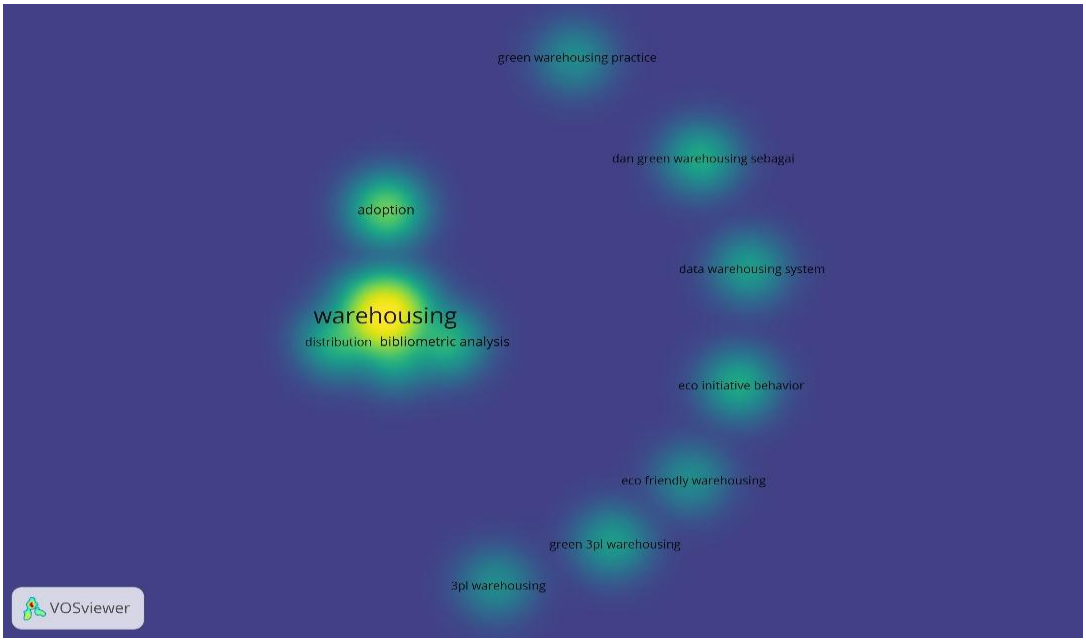

Figure 3. Density visualization analysis using Vos viewer

Density visualization analysis in Figure 3 shows that research on *green warehousing* is still not dense, so it is very possible to conduct research in this field.

3. RESULT AND DISCUSSION

Table 1 presents various Key Performance Indicators (KPIs) used to measure the effectiveness of green warehousing activities. These KPIs are divided into several dimensions, each with specific indicators that are measure

Table 1. Key performance indicators of green SCOR

Dimension	Key Performance Indicators	Reference
Green SCOR	Energy Consumption Waste Management Efficiency of Warehouse Space Use Monitoring and Measuring Carbon Emissions Measuring Water Use Transportation Efficiency	(Luu, 2016)
	Labor productivity Efficiency of warehouse space use Efficiency of using warehouse equipment Waste management Energy use Reduction of greenhouse gas emissions Use of environmentally friendly materials Use of green technology Reduction in the use of plastic packaging	(Margareta et al., 2020)
	Energy Efficiency Waste Management Use of Eco-friendly Materials Environmental impact of warehouse activities	(Bartolini et al., 2019)
	Emission Reduction Total Cost Reduction Improved service	(Bhavani et al., 2022)
	Water use Energy use Use of hazardous materials Production efficiency Delivery reliability Percentage of liquid and solid waste Production cost Product inventory	(Patradhiani et al., 2023)
	Raw material efficiency Energy use Water use Reduction of hazardous materials Environmental sanitation Packaging reuse Product handling	(Effendi et al., 2019)
	Recycled defective products Solid waste recycling Recycling of liquid waste	(Fitriana et al., 2022)
	Reduce level inventory Investment update (sales) of excess material supplies Sale of waste materials Sale of excess capital equipment Reduce energy use	(pramesti et al., 2020)
	Water use Percentage of hazardous materials Hazardous waste	(Maini Heryanto, 2022)
	Energy use rate Waste Reduction Efficiency of picking goods Work accident rate The use of eco-friendly materials in warehouse operations	(Minashkina & Happonen, 2023)
	Energy consumption Total cost	(Modica et al., 2021)
	Waste reduction Carbon emission reduction Energy efficiency Cost savings Environmental compliance	(Sukjit & Vanichchinchai, 2020)

Dimension	Key Performance Indicators	Reference
Green SCOR	Energy efficiency Efficiency measurement and logistics optimization Measurement of social and ethical values Cost measurement	(Agyabeng-Mensah et al., 2020)
	Energy efficiency Waste management Use of eco-friendly materials	(Rasheed, 2022)
	Sustainable Strategies in Material Handling: Measurement of the effectiveness of sustainable strategies implemented in material handling in warehouses. Greening Activities: Measurement of activities that contribute to greening efforts in the warehouse, such as waste management, energy efficiency, use of environmentally friendly materials, and so on.	(Boenzi et al., 2016)

In an effort to optimize sustainability and efficiency in supply chain management, various dimensions and key performance indicators (KPIs) have been identified from several sources. Luu (2016) emphasizing energy consumption, waste management, warehouse space use efficiency, carbon emission monitoring, water use, and transportation efficiency. Margareta et al. (2020) recommends labor productivity, the use of warehouse space and equipment, the reduction of greenhouse gas emissions, environmentally friendly materials, green technology, and the reduction of plastic packaging. Bartolini et al. (2019) highlighting energy efficiency, waste management, eco-friendly materials, and the environmental impact of warehouse activities. Bhavani et al. (2022) focusing on reducing emissions and total costs, and improving services. Effendi et al. (2019) discusses raw material efficiency, energy and water use, hazardous material reduction, environmental sanitation, packaging reuse, and product handling. Fitriana et al. (2022) emphasizes the recycling of defective products and solid and liquid waste. Pramesti et al. (2020) identify reduction in inventory levels, sales of excess capital materials and equipment, and reduction in energy use. Heryanto (2022) focuses on water use, percentage of hazardous materials, and hazardous waste.

Discussion

This discussion discussed the results of the analysis of environmentally friendly warehousing practices in the context of the manufacturing supply chain and the identification of Key Performance Indicators (KPIs) relevant to green warehousing. Here are the main points that can be highlighted from the results of this study:

The Importance of Green Warehousing

a. Significance of Warehousing in Supply Chain: Warehouses play a crucial role in various logistics activities such as shipping, storage, assembly, and distribution. The development of the trade sector and the increasing demand for mass customization add to the need for space and warehouse buildings. Warehousing accounts for about 11% of the total GHG (Greenhouse Gas) emissions generated by the global logistics sector, demonstrating the need to adopt green practices in the sector.
b. Global Trends and Research Needs: Although green warehousing is a relatively new concept lacking literature and empirical data, global trends show an increasing interest in sustainable warehousing practices. This research shows that green warehousing can be a potential solution to achieve environmental sustainability and supply chain efficiency.

Limitation this study.

While interdis-ciplinary research is recommended, the study does not integrate findings from engineering, logistics, or policy domains, which could enrich its conclusions.

4. CONCLUSION

4.1 Implications and Conclusions

a. Research Potential: The study results show that green warehousing has great potential to be further developed in the context of sustainability. The lack of previous research creates opportunities for more in-depth study and the development of richer

literature.

b. Practical Applications: Comprehensive KPI identification can assist companies in designing and implementing eco-friendly warehousing strategies. These KPIs can monitor and improve warehouse environmental performance, reduce GHG emissions, and improve operational efficiency and sustainability.
c. The way forward: Given the importance of sustainability in business operations, further research and empirical data collection on green warehousing is urgently needed. This will help companies adopt eco-friendly practices more effectively and encourage their contribution to global environmental conservation.

Overall, this study provides a solid foundation for understanding and developing KPIs for green warehousing in the manufacturing supply chain while identifying areas requiring further research.

4.2 Suggestion

Based on the results of the analysis and discussion on green warehousing in the manufacturing supply chain, here are some suggestions that can be taken to encourage green warehousing practices:

1. Advice for Researchers

a. Development of Empirical Case Studies: Conduct empirical case studies in various industries to collect concrete data on the application of green warehousing. This can include direct measurement of KPIs that have been identified.
b. Cross-Disciplinary Research: This involves combining perspectives from various disciplines, such as industrial engineering, environmental management, and economics, to enrich research on green warehousing.
c. Model and Framework Development: Creating a more comprehensive model and framework for green warehousing that can be adapted by different industries. This includes implementation guidance, measurement tools, and performance metrics.
d. Focus on Green Technology: Research and develop green technologies, such as energy management systems, green automation, and waste management technology, that can be applied in warehouses.

2. Advice for Industrial Practitioners

a. Implementation of measurable KPIs: Incorporate and execute KPIs identified through research to gauge and enhance the environmental performance of the warehouse. These activities encompass the monitoring of carbon emissions, the optimization of energy efficiency, and the management of trash.
b. Training and Education: Offer comprehensive training and education programs to warehouse personnel, focusing on the significance of environmentally sustainable practices and providing them with the necessary knowledge and skills to effectively execute them. The effectiveness of green warehousing programs relies heavily on the employee's awareness and understanding.
c. Green infrastructure investment: Investing in environmentally sustainable infrastructure, such as buildings certified by the Leadership in Energy and Environmental Design (LEED) program, the adoption of renewable energy sources, and the implementation of efficient waste management systems.
d. Engaging in cooperative efforts with suppliers and partners: Collaborating closely with suppliers and logistical partners to guarantee that the supply chain upholds eco-friendly practices. This can encompass the utilization of eco-friendly raw materials and enhanced transportation efficiency.

3. Advice for Policymakers

a. Regulations and incentives should be established to promote the adoption of environmentally-friendly practices in warehousing. Companies that successfully apply these practices should be rewarded with incentives. These incentives might be tax cuts, financial support, or recognition for enterprises demonstrating strong environmental performance.
b. Global and domestic norms: Promote implementing national and international standards for environmentally-friendly warehousing to unify and standardize the industry's most effective methods and practices.
c. Allocation of resources and assistance for

research: Allocate financial resources and offer assistance to further the study of eco-friendly warehousing, encompassing the creation of novel technologies and approaches to enhance productivity and environmental friendliness.

4. Advice for the General Public
   a. Consumer Awareness: Promoting customer consciousness on the significance of environmentally sustainable practices in logistics and motivating them to select items from companies that adopt eco-friendly warehousing.
   b. Community Support: Establishing a community or support group with a specific focus on sustainability in logistics and warehousing to facilitate the exchange of information, experiences, and best practices.

Recommendation for future research

1. Expand the scope to include cross-industry comparisons and regional analyses.
2. Explore technological enablers (e.g., IoT, AI) in achieving green warehousing goals.

Acknowledgment

The authors gratefully acknowledge the financial support from the Directorate of Research, Technology, and Community Service, Ministry of Education, Culture, Research, and Technology of the Rep. Indonesia, through the Master's Thesis Research Grant Scheme in 2024, under contract No.058/E5/PG.02.00/PLBATCH2/ 2024.

REFERENCES

Agyabeng-Mensah, Y., Ahenkorah, E., Afum, E., Dacosta, E., & Tian, Z. (2020). Green warehousing, logistics optimization, social values and ethics and economic performance: the role of supply chain sustainability. *The International Journal of Logistics Management*, 31(3), 549–574. https://doi.org/10.1108/IJLM-10-2019-0275

Bartolini, M., Bottani, E., & Grosse, E. H. (2019). Green warehousing: Systematic literature review and bibliometric analysis. *Journal of Cleaner Production*, 226, 242-258. https://doi.org/10.1016/j.jclepro.2019.04.055

Bhavani, G. D., Meidute-Kavaliauskiene, I., Mahapatra, G. S., & Činčikaitė, R. (2022). Pythagorean Fuzzy Storage Capacity with Controllable Carbon Emission Incorporating Green Technology Investment on a Two-Depository System. *Energies*, 15(23). https://doi.org/10.3390/en15239087

Boenzi, F., Digiesi, S., Facchini, F., Mossa, G., & Mummolo, G. (2016). Greening Activities in Warehouses: A Model for Identifying Sustainable Strategies in Material Handling (pp. 0980–0988). https://doi.org/10.2507/26th.daaam.proceedings.138

Castillo, R. (2022). Green Warehousing Practices in the Philippines. *The Indonesian Green Technology Journal*, 11(01). https://doi.org/10.21776/ub.igtj.2022.011.01.01

Effendi, U., Dewi, C. F., & Mustaniroh, S. A. (2019). Evaluation of supply chain performance with green supply chain management approach (GSCM) using SCOR and DEMATEL method (case study of PG Krebet Baru Malang). *IOP Conference Series: Earth and Environmental Science*, 230(1). https://doi.org/10.1088/1755-1315/230/1/012065

Fitriana, R. N., Ifada, A. B., Lestari, T. O. P. D., & Hidayah, S. R. (2022). Performance Evaluation and Measurement of SMEs King of Honey Using the Green SCOR Metho. *Journal of Soft Computing Exploration*, 3(1), 12-18. https://doi.org/10.52465/joscex.v3i1.63

Luu, M. (2016). Developing the implementation of green warehousing at IKEA Finland.

Maini Heryanto, R. (2022). Green Supply Chain Performance Measurement using Green SCOR Model in Agriculture Industry: A Case Study. *Jurnal Teknik Industri*, 24(1). https://doi.org/10.9744/jti.24.1.53−60

Margareta, W., Ridwan, A. Y., & Muttaqin, P. S. (2020). Green Warehouse Performance Measurement Model for 3PL

Warehousing. *ACM International Conference Proceeding Series*, 180-186. https://doi.org/10.1145/3400934.3400968

Minashkina, D., & Happonen, A. (2023). Warehouse Management Systems for Social and Environmental Sustainability: A Systematic Literature Review and Bibliometric Analysis. *Logistics*, 7(3). https://doi.org/10.3390/logistics7030040

Modica, T., Perotti, S., & Melacini, M. (2021). Green warehousing: Exploration of organisational variables fostering the adoption of energy-efficient material handling equipment. S*ustainability (Switzerland)*, 13(23). https://doi.org/10.3390/su132313237

Muttaqin, P. S., Margareta, W., & Zahira, A. D. (2022). Green warehouse performance monitoring system design using analytical hierarchy process and supply chain operation reference. *Applied Engineering and Technology*, 1(3), 146–153. https://doi.org/10.3176/aet.v1i1.687

Patradhiani, R., Anugrah, B., Wisudawati, N., & Studi Teknik Industri, P. (2023). Model Penilaian Kinerja Green Supply Chain Management dengan Pendekatan Green Supply Chain Operation Reference Untuk Mengurangi Pencemaran Lingkungan. *Integrasi Jurnal Ilmiah Teknik Industri*, 8(1), 23-31.

pramesti, R., Baihaqi, imam, & bramanti, woro geodita. (2020). Membangun Green Supply Chain Management (GSCM) Scorecard. *Jurnal Teknik ITS*, 9(2), 164.

Rasheed, T. (2022). Supply Chain Sustainability Through Green Practices in Manufacturing: A Case Study from Pakistan. *South Asian Journal of Operations and Logistics*, 57-71. https://doi.org/10.57044/sajol.2022.1.1.2205

Sukjit, S., & Vanichchinchai, A. (2020). An Assessment of Motivations on Green Warehousing in Thailand. 2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA), 539–542. https://doi.org/10.1109/ICIEA49774.2020.9102035