Sustainable Warehouse Features: A Systematic Literature Review

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Abstract

This paper investigates and analyses the features of sustainable warehousing by conducting a systematic literature review (SLR) to create a significant insight of the expanding and growing trends of sustainable warehousing, to fit perfectly within the net-zero supply chain strategies and adapting to the new value adding practices of Industry 5.0. Using a set of 65 publications, including journal papers, conference papers, and reviews, for the last 10 years, between 2013 and 2023, the SLR highlights and considers several green logistics areas that are essential to help redesign the features of sustainable warehouses. The paper also emphasizes the need for further research to develop new models for warehouses that can be implemented in the Industry 5.0 supply chain to achieve net-zero goals. In other words, the paper is trying to understand the current state of sustainable warehousing and identify areas where improvements can be made to make warehouses more sustainable and environmentally friendly, and to help the industry move towards a net-zero supply chain. Additionally, the paper is suggesting that there is a need for more research to be done to create new models for warehouses that can be applied in the Industry 5.0 supply chain, in order to reach net-zero goals.

Keywords
Warehouses; Green Logistics; Sustainability; Sustainable Warehousing.

1. Introduction
Warehouses are major contributors to the rise of carbon emissions in supply chains. Thus, it is not shocking that the consideration of scholarly research to sustainable warehousing has been growing in recent years.

The contribution of warehouses to the creation of carbon and other greenhouse gases (GHG) and their impact climate change can no longer be unseen. Warehousing activities contribute almost 11% of the total GHG emissions caused by the activities and operations of the logistics industries across the whole world (Doherty and Hoyle, 2009). Therefore, organizations are taking considerations to environmental and social issues of warehouses other than the economic objective. As these two aspects of sustainability have been neglected as important measures by many organizations (Elkington, 1998).

The remainder of this paper addresses the following topics: the research methodology is explained in Section 2 followed by an overview of published literature and outcomes leading to the main features of a sustainable warehouse in Section 3; Section 4 discusses the possibilities of the implementation of the model in the era of industry 5.0; and finally, Section 5 delivers the conclusions.

2. Research Methodology
Systematic literature review (SLR) is a structured methodological technique to reach a profound understanding and insights about specific topics (Briner and Denyer, 2012). SLR has become one of the main methodologies applied for evidence-based practice (Hohenstein et al., 2015). This study examines published literature by applying an SLR approach adapted from the five-step guideline by Garza-Reyes (2015). Figure 1 offers an overview of the SLR.
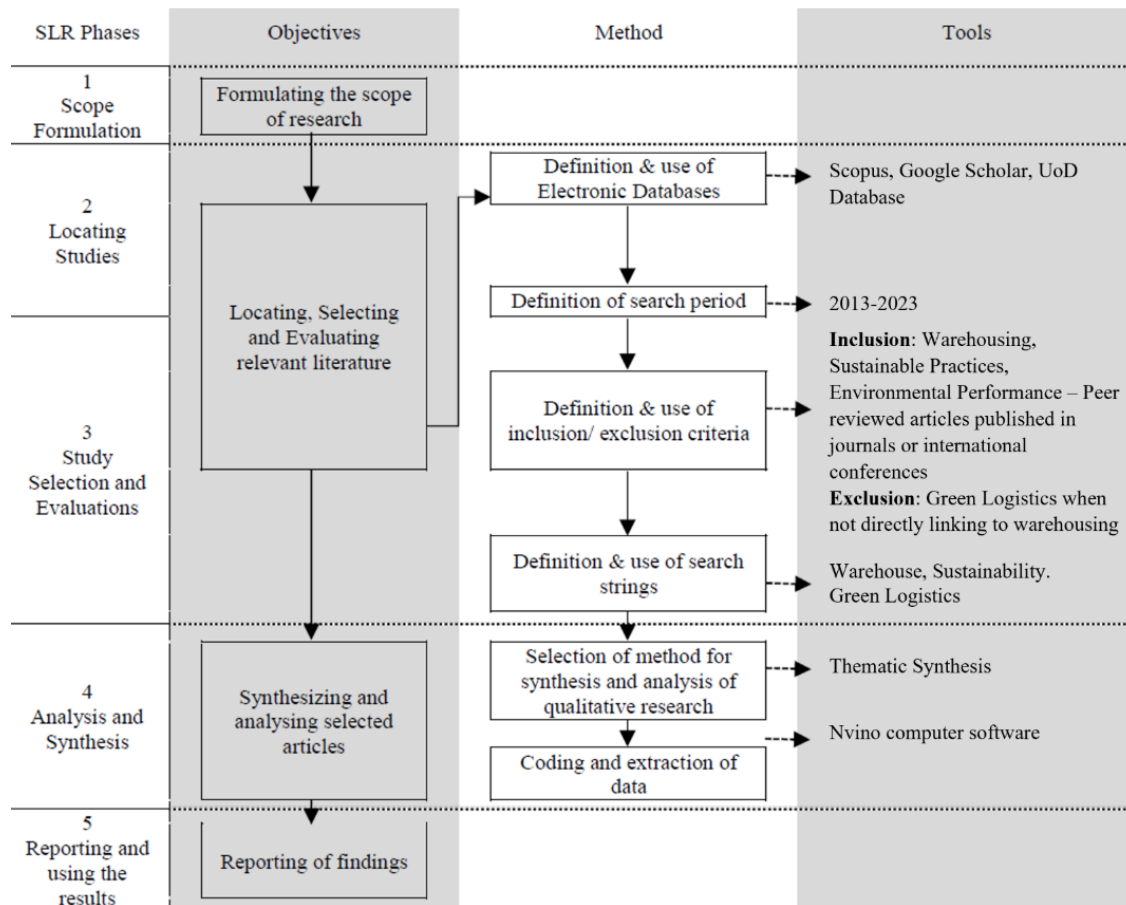
SLR Phases	Objectives	Method	Tools
1 Scope Formulation	Formulating the scope of research		
2 Locating Studies	Locating, Selecting and Evaluating relevant literature	Definition & use of Electronic Databases	Scopus, Google Scholar, UoD Database
		Definition of search period	2013-2023
3 Study Selection and Evaluations		Definition & use of inclusion/ exclusion criteria	**Inclusion**: Warehousing, Sustainable Practices, Environmental Performance – Peer reviewed articles published in journals or international conferences **Exclusion**: Green Logistics when not directly linking to warehousing
		Definition & use of search strings	Warehouse, Sustainability. Green Logistics
4 Analysis and Synthesis	Synthesizing and analysing selected articles	Selection of method for synthesis and analysis of qualitative research	Thematic Synthesis
		Coding and extraction of data	Nvino computer software
5 Reporting and using the results	Reporting of findings		

Figure 1: Systematic literature review steps

Scopus, Google Scholar, and University of Derby database were the three different databases to be used in searching for related literature, to guarantee that all related research papers are included (Crossan and Apaydin, 2010).
The most important and essential issue to carry out queries in databases is the identification of keywords that allow classifying all papers that are related to the research goals (Hartmann-Boyce et al., 2014).

The keywords were split into two groups as follows:

Group 1: keywords include general terms linked to warehousing, logistics activities and supply chain processes, i.e.: Warehouses, Logistics, Distribution Centres, Supply Chain, Warehousing, Logistics Decisions, Supply Chain Managements (SCM), Supply Chain Network, Warehouse Management, Industry 4.0, Industry 5.0.

Group 2: keywords include more specific words related to sustainability, i.e.: Sustainable Development, Sustainability, Environmental Impact, Carbon Emissions, Green Supply Chain, Green Warehousing, Environmental Management, Green Logistics, Climate Change, Environmental Sustainability, Green Technology, Environmental Warehouse. Sustainable Warehouse.

After running the queries using group 1 keywords total of 5540 publications were found. Then when combined with group 2 keywords, we recovered 317 papers in total from all databases, after checking for duplication and selecting only papers written in English. The significance of the papers found was assessed by checking the titles and abstracts of the papers, to disregard those papers that did not meet the inclusion criterion. A total of 70 papers was

obtained. Only papers in peer-reviewed academic journals and international conferences were retained reducing the total number of papers to 65. Figures below present infographics of the descriptive data.
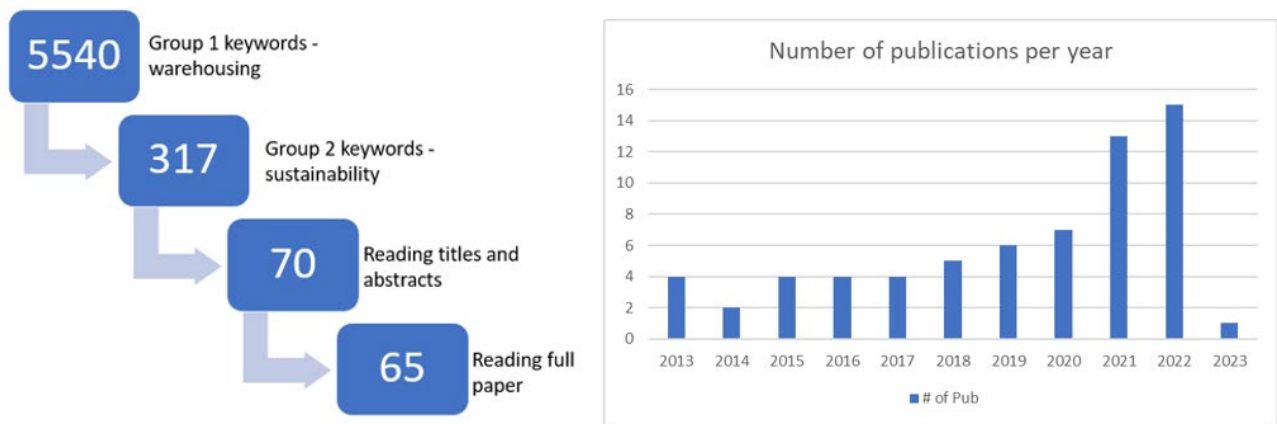
Figure 2: Descriptive data

3. Sustainable Warehousing

The SRL shows, that there are many publications relating to different aspects of sustainable warehouse, The most cited papers are summarized in the table below.

The literature highlights the importance of the sustainable warehouse, characterizing the factors affecting the level of sustainable development and specifying the level of a sustainable warehouse, which helps in building an initial model to include the feature of sustainable warehouse.

Table 1: Most cited papers

Authors	Title	Year	Cited by
Soleimani, H., Govindan, K., Saghafi, H., Jafari, H.	Fuzzy multi-objective sustainable and green closed-loop supply chain network design	2017	185
Bartolini, M., Bottani, E., Grosse, E.H.	Green warehousing: Systematic literature review and bibliometric analysis	2019	77
Fichtinger, J., Ries, J.M., Grosse, E.H., Baker, P.	Assessing the environmental impact of integrated inventory and warehouse management	2015	69
Shaw, K., Irfan, M., Shankar, R., Yadav, S.S.	Low carbon chance constrained supply chain network design problem: a Benders decomposition-based approach	2016	64
Facchini, F., Mummolo, G., Mossa, G., Digiesi, S., Boenzi, F., Verriello, R.	Minimizing the carbon footprint of material handling equipment: Comparison of electric and LPG forklifts	2016	41
Noh, J., Kim, J.S.	Cooperative green supply chain management with greenhouse gas emissions and fuzzy demand	2019	39
Soysal, M., Çimen, M.	A Simulation Based Restricted Dynamic Programming approach for the Green Time Dependent Vehicle Routing Problem	2017	36

Yu, Z., Khan, S.A.R.	Green Supply Chain Network Optimization Under Random and Fuzzy Environment	2022	34
Porsani, G.B., de Lersundi, K.D.V., Gutiérrez, A.S.-O., Bandera, C.F.	Interoperability between building information modelling (Bim) and building energy model (bem)	2021	27
Boenzi, F., Digiesi, S., Facchini, F., Mossa, G., Mummolo, G.	Greening activities in warehouses: Amodel for identifying sustainable strategies in material handling	2015	27
Md Mashud, A.H., Pervin, M., Mishra, U., Daryanto, Y., Tseng, M.-L., Lim, M.K.	A sustainable inventory model with controllable carbon emissions in green-warehouse farms	2021	22
Wahab, S.N., Sayuti, N.M., Ab Talib, M.S.	Antecedents of green warehousing: A theoretical framework and future direction	2018	16
Ali, S.S., Kaur, R., Khan, S.	Evaluating sustainability initiatives in warehouse for measuring sustainability performance: an emerging economy perspective	2022	15
Burek, J., Nutter, D.	Life cycle assessment of grocery, perishable, and general merchandise multi-facility distribution center networks	2018	15
Micic, N., Neagu, D., Campean, F., Zadeh, E.H.	Towards a Data Quality Framework for Heterogeneous Data	2018	15

Warehousing includes receiving, put away, storage, sorting, material handling, picking, packing and different equipment and automotive tools for the storage of materials, and the necessary building facilities to protect goods (Saderova et al., 2020). Warehousing is regarded as a value-added activity of organisational operations. This is because it connects the nodes between production lines and end customers, and it plays an important role in delivery performance and customer satisfaction (Dubey et al., 2017; Jie et al., 2015).

Warehouses' roles have evolved to include manufacturing, assembly, reverse logistics, and other value-added services. As a result, warehouse operations are critical to improving overall organisational performance and strengthening supply chain and logistics sustainability (Bartolini et al., 2019; Hamdy et al., 2022) Although warehouse operations face numerous sustainability challenges, warehousing sustainability improvement has received little attention. As a result, organisations must make several significant and strategic decisions to address these issues (Ali and Phan, 2022).

Most warehouse decisions are primarily motivated by economic sustainability. Because reducing inventory levels and carrying costs, enhancing order fulfilment, or raising customer service levels are the primary priorities in warehousing management (Shi et al., 2019).

The sustainability of warehouse operations in general and environmental sustainability in particular have so been the subject of few studies (Ahmadi et al., 2017). The issues posed by sustainability requirements for warehousing decisions will be addressed by research on this subject, which will also aid in enhancing warehouse sustainable performance measures. When improving warehouse operations, organisations must consider not only the economic but also the environmental and social aspects of sustainability, otherwise the long-term supply chain and logistics performance will suffer (Staudt et al., 2015). Organizations must accelerate the transition to sustainable innovations and practises by implementing environmentally and socially responsible warehouse operations (Zuchowski, 2015). This is critical because the negative impact of warehouse operations has grown exponentially (Hu et al., 2022), and these activities have severe environmental, social, and economic consequences (Ishizaka et al., 2022).

Sustainable warehousing is a strategic solution for mitigating negative sustainability impacts (Hsu et al., 2013), because sustainable warehousing decisions consider not only traditional economic issues, but also environmental and social issues when aiming to improve sustainable performance.

In the literature, there are few examples of sustainable warehouse models and frameworks (Malinowska et al., 2018). Marchant (2010) proposed a three-stage sustainable warehouse model that addresses the business: economic, environmental, and social dimensions of warehousing. This model attempted to highlight a broader range of criteria to assist organisations in achieving the lowest negative sustainability impact. Nonetheless, (Zuchowski, 2015) discussed how strategic implementation of sustainable warehouse management solutions reduces CO2 and greenhouse gas emissions, resulting in sustainable warehousing.

Despite this, research on sustainable warehouses is still in its early stages. Almost all studies stated that sustainable innovative technologies help to reduce energy consumption as well as CO2 and greenhouse gas emissions from warehouse operations, and that sustainable innovative technologies provide solutions to reduce the environmental and social impacts of warehouse operations.

More research is needed to support and investigate the link between environmentally sustainable warehouse operations and sustainable innovative technologies. Furthermore, sustainable innovative technologies can reduce unexpected environmental risks in warehouses and provide a variety of potential solutions to warehousing sustainability (Trab et al., 2017, Adeseun et al., 2018).

Mostafa et al., (2019) discussed the potential benefits of using automatic sensors and the Internet of Things (IoT) to monitor the HVAC system. Where the systems will capture instantaneous real-time data about the surroundings and share it with warehouse management systems (WMS) for processing and converting into useful information to improve tactical decisions and day-to-day operations plans. As well Trab et al., (2017) study proposed an IoT conceptual model of sharing warehouse objects to effectively monitor and mitigate environmental disasters in warehouse operations.

According to Ding and Kaminsky (2020), the use of sensing technologies in monitoring and managing various environmental issues improves warehousing security and transparency significantly. Based on a review of the literature, information technologies and resilience (Al-Talib et. al., 2020), lean (Manikas et al., 2021), agility and continuous improvement practises (Al- Refaie et. al., 2020), sustainable measures (Bennett et. al., 2017), and employee competence and skill levels (Rahimić et. al., 2012).

A list published by Malinowska et al, (2018) consist of 22 warehouse activities that can improve the level of the sustainability performance in warehouse, all these activities can be grouped into the 4 main features mentioned in the model.

Sustainable Warehouse
1. **Level of Automation**
2. **Green Lean Practices**
3. **Employee Training**
4. **Resources and Energy Consumption**

Figure 3: Sustainable Warehouse Features

Sustainable Warehouse Features

- **Level of Automation**

The information system architecture of the warehouse is the base and first step towards sustainability, as innovation and sustainability can be considered as two faces of the same coin. Improving the level of automation will improve managing and monitoring inbound and outbound activities within the warehouse and replace inventory with information. Nevertheless, by using automation, organizations will become more customer focused, improving their customer-service levels, and becoming more sustainable (Davenport and Ronanki, 2018).

- **Green Lean Practices**

Green lean practices will not only improve the operational performance of a warehouse but also its social and environmental performances too as it is based on a sustainability-oriented continuous improvement approach (Garza-Reyes et al., 2014). Green lean practices are based on using natural renewable sources, and incorporates circular economy best practices such as 9Rs, therefore it is environmentally friendly and supports net-zero strategy by reducing carbon footprint and GHG emission rates (Owusu and Asumadu-Sarkodie, 2016).

- **Employee Training**

Human involvement in warehouse activities is as important as technology, digitalization, and automation. Highlighting this point is the main difference -or improvement- between industry 5.0 and industry 4.0, therefore upskilling, educating, and training employees is essential to create a sustainable ecosystem inside the warehouse and through the whole supply chain. Employees training will improve skills, abilities, and level of and knowledge (Elnaga and Imran, 2013), leading to improving work quality, and reduced faults, waste, and customer complaints making the organization more sustainable (Karatepe, 2013).

- **Resources and Energy Consumption**

An organization is considered sustainable when they focus on activities that provide present benefit without compromising the needs of future generations (Tlusty and Thorsen, 2017). For that selecting the right resources and replacing non-renewable resources by renewable, natural, and non-virgin ones especially for energy is a key factor for any organization to become more sustainable (Ulucak and Ozcan, 2020). Therefore, using the right source of energy more efficiently and measuring its performance will improve the triple bottom line KPIs for a warehouse as this will not only cut costs and save money, but it will also directly impact social and environmental performance of the warehouse by reducing GHG emissions, and improve employee's safety and wellbeing too (Owusu and Asumadu-Sarkodie, 2016).

4. Sustainable Warehousing and Industry 5.0

While many businesses worldwide are still adjusting to I4.0, Industry 5.0 (I5.0) was first announced in 2018, and the debate over I5.0 has already begun. In research they published in 2018, Ozdemir and Hakim described how the Fifth Industrial Revolution got started. After A. Haleem and M. Javaid (2019) released a research letter on the applications of I5.0 in orthopaedics, the subject of I5.0 got more notoriety. Many business innovators and technology executives anticipate I5.0 autonomous production with human intelligence even if I4.0 is still in its early stages (Nahavandi, 2019).

The concept of I5.0 should be understood as reintroducing the lost dimension of a "human centric in I4.0," according to the participants in a workshop held by the European Commission in 2020. They also agreed that I5.0 is neither a replacement nor an alternative to the current I4.0 paradigm, but rather an evolution and logical continuation of it. As a result, the idea of I5.0 is focused on principles like as resilience, sustainability, and human centricity (See Figure below) rather than technologies (Müller, 2020) . Any firm wanting to reach net-zero supply chain in the near future must take sustainability into account in both the strategy and operational strategies, as sustainability is one of the pillars of Industry 5.0.

Figure 4: Industry 5.0 component

5. Conclusions

Sustainable and green logistics has vast potential especially in warehousing and is a promising solution to many problems and challenges our world and organizations are facing, particularly the issues of climate change and global warming.

At current time, the amount and depth of research for sustainable warehousing practises and features is minimal but is a good ground-breaking effort to further initiate research and discovery of possible developments.
This paper has presented a model including four main features for a sustainable warehouse which are: level of automation, green lean practices, employees training and resources and energy consumption, which is based on up-to date published literature and mirroring the main pillars of Industry 5.0. Authors extremely believe that more research is needed to field the warehousing in general and sustainable warehousing, especially in the scoop of Industry 5.0.

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Biography

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Moayad Al-Talib is a researcher in the field of the supply chain, with a passion for exploring and understanding the complexities of the industry. He has presented and published numerous papers at international conferences. He obtained his PhD from the Centre for Supply Chain Improvement at the University of Derby. During his time at the university, he engaged in various research projects and collaborated with other researchers in the field. Moayad's research focus and expertise are in Supply Chain Resilience, Supply Chain Management, Sustainability, IoT and Information Technologies roles in the field of Supply Chain.

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