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Research Article

DRIVING SUSTAINABILITY IN WAREHOUSE OPERATIONS THROUGH THE GREEN STREAM MAP FRAMEWORK

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Abstract

This research focuses on the applicability of Lean in sustainability reporting of warehouses with the purpose of evaluating its efficiency through the Green Stream Map Framework. The integration of Lean methodologies aims for the improvement of the accuracy and relevance of sustainability reporting to bring about more effectiveness and positive changes in operations and the environment. Thus, the study, based on Lean principles, demonstrates the possibility to improve the effectiveness of warehousing, minimize waste, and optimize the usage of resources in the sector to support sustainable management. The findings of this study offer a solid reference for applying Lean-driven sustainability reporting in practice by demonstrating its potential for promoting sustainable development and enhancing the efficiency of warehouse operations. This research is beneficial in providing insights on how lean can be implemented in attaining sustainability objectives hence improving the efficiency of the warehouse system.

Keywords: Lean practices, VSM methodology, Green Stream Map (GSM) framework,Warehouse, Workforce Sustainability Index, Net Material Footprint.

INTRODUCTION

Sustainability has become a business goal across most corporations; from being viewed as a social responsibility of an organization, it has rapidly become part of their mission statement (Choudhary *et al.,* 2019). The widespread global acceptance of sustainability has been strongly reinforced by governments recognizing the United Nations Sustainable Development Goals (SDG) as an actionable agenda rather than theoretical propaganda (Bartolini *et al.,* 2019). They are driving urgent actions to address alarming issues through various climate summits. Following suit, corporates are focussing and adopting sustainable business practices (Edirisuriya *et al.,* 2018).

Sustainability emphasizes optimal resource utilization with minimal environmental impact, particularly in energy consumption and waste management (Farrukh *et al.,* 2022). Traditional warehouse operations consume significant energy and generate significant waste. Efficient practices minimize waste, encourage recycling, instil reuse, and implement sustainable packaging solutions (Vienažindienė *et al.,* 2021). Additionally, optimizing transportation and logistics within and outside the warehouse substantially reduces the carbon footprint. This includes route optimization and the use of electric or hybrid vehicles (Moul, 2021). While several corporations have begun reporting Environmental, Social, and Governance (ESG) data pertaining to their supply chains, they do not yet satisfy standards such as GRI (Global Reporting Initiative) and SASB (Sustainability Accounting Standards Board) (Mohsen *et al.,* 2023). In addition to gaps in completeness, the reports often report estimates instead of data. Compliance continues to be a challenge for many enterprises (Pizzi *et al.,* 2023). Challenges in compliance are indicative of discrepancies in the understanding and acceptance of sustainability throughout the organization (Wiraputra *et al.,* 2024). While sustainable goals are earnestly accepted by the top management, they are accepted and implemented on the floor only as mechanical practices. Data gathering for ESG reporting has to be initiated from the supervisory levels of management. Limited comprehension and participation in the goals at the grassroots level leads to inept reporting (García Torea, 2022). This study aims to provide warehouse managers with actionable tools and methodologies to better measure and report on these sustainability initiatives. This will support compliance with sustainability standards as well as develop an organizational culture that encourages accepting environmental responsibility. Lean principles have supported managers to steer through and effectively incorporate upgrades in warehousing. Converging sustainability practices with Lean principles will develop an enhanced system with wide acceptance and efficacious functioning (Jum'a *et al.,* 2022). This objective is central to the research as it explores the potential of Lean principles to enhance the efficacy of sustainable practices in the operational aspects of warehousing, aligning with global sustainability goals and contributing to a more efficient and responsible supply chain ecosystem. Effective sustainability initiatives require the active involvement of ground-level managers through a bottom-up approach (Lakshmanan *et al.,* 2023). Providing these managers with tools similar to those used in operations measurement and reporting will promote the effectiveness of sustainability efforts (Tasdemir & Gazo, 2018). The core objective of this study is to assess the effectiveness of the integration of Lean principles into sustainability reporting within the domain of warehouse operations. The dataset employed in this research primarily illustrates the application of the proposed framework. The original data sourced from organizational sustainability reports is complemented by estimated values to demonstrate the framework's functionality and potential insights it can offer when applied in a real-world context.

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LITERATURE REVIEW

Sustainability and operational efficiency

The synergy between Lean and green initiatives is highly beneficial. Companies that adopt this dual approach tend to outperform the sustainability and operational efficiency of those that focus on just one of the strategies (Hartini & Ciptomulyono, 2015).Lean practices accord benefits that surpass mere environmental improvements, encompassing strategic and operational enhancements across a broad spectrum of sustainability issues (Caiado *et al.,* 2019). An integrated approach to the implementation of Lean and sustainable operations is imperative to fully capitalize on the potential gains in performance across diverse dimensions of sustainability (Piercy & Rich, 2015).

Lean practices in improving supply chain performance

Lean management focuses on minimizing waste in manufacturing and the supply chain, thereby inherently resulting in a decrease in environmental waste. By focusing on waste reduction, resource optimization, and continuous improvement methods of Lean, the warehouse not only enhances its operational efficiency but also contributes positively to environmental sustainability (Voronova, 2022). Process innovation enhances the effectiveness of sustainability and Lean practices in improving supply chain performance. Innovative processes boost operational efficiency and support sustainability goals (Rasheed *et al.,* 2023). Integrating Lean methods with Industry 4.0 in warehouse management streamlines operations while enhancing environmental performance, making it a key aspect of the smart Lean-green approach (Tripathi *et al.,* 2021). The delineation of elementary Lean methods and housekeeping procedures serves as a foundational framework for warehouse managers, offering a systematic approach to identifying opportunities for mitigating energy usage, reducing costs, and curbing emissions within sustainable warehousing paradigms (Khuntia *et al.,* 2018). Furthermore, the integration of such methodologies holds promise for bolstering worker safety, well-being, and overall job satisfaction (Akkucuk, 2018).

Warehouse safety and operational efficiency

Effective visualization is a valuable tool for enhancing warehouse safety and operational efficiency, supporting sustainability goals, and providing a foundation for continuous improvement in logistics operations (Cantini *et al.,* 2020).Together, Lean and Industry 4.0 demonstrate a robust positive correlation with sustainability. VSM 4.0, an integration of VSM with Auto-ID and Big Data, provides benefits in real-time data collection and waste monitoring (Kabzhassarova *et al.,* 2021). When Lean tools such as VSM are integrated with warehouse order fulfilment processes, they facilitate a more efficient flow of goods from the warehouse to retail shelves and subsequently to the customer, whether via in-store or online channels. This integration ensures better product availability and accelerates response times, optimizing both the supply chain and customer service dimension along with supporting the sustainability goal of waste reduction (Marques *et al.,* 2022). To harness the inherent synergies and compatibilities between Lean initiatives and environmental considerations, the literature has endeavoured to align and integrate the Lean and Green paradigms through a variety of approaches. This integration aims to ensure that Lean initiatives incorporate environmental aspects, and reciprocally, that environmental strategies consider principles of Lean operations (Diaz-Elsayed *et al.,* 2013; Elemure *et al.,* 2023; Indah *et al.,* 2020; Zekhnini *et al.,* 2022).

Green Stream Map-GSM Framework:

While the primary objective of VSM is to identify non-value-added activities within processes, the proposed Green Stream Map (GSM) aims to pinpoint the significant sources of energy consumption, material usage, and waste generation at the process level (Chihana *et al.,* 2018). Additionally, GSM seeks to assess aspects of employee well-being within operational activities, highlighting its multifaceted approach to enhancing sustainability in supply chain management (Furrer *et al.,* 2018).The Green Stream Map (GSM) framework aims to ensure broad applicability across industries. By focusing on foundational warehouse processes common to most sectors, the GSM framework is designed for mass adoption and scalability (A. Moul, 2021).

The Lean management principles integrated with comprehensive sustainability metrics make the framework adaptable to specific industry requirements while maintaining a consistent core structure (Ogarkov, 2019). Each process within a warehouse is driven by distinct sustainability factors and must be assessed individually; these evaluations can then be aggregated for comprehensive reporting (Serral *et al.,* 2024). Table 1 details a variety of equipment used throughout the processes of warehouse operations. These pieces of equipment are some of the major partners in the overall sustainability of warehouse operations together with the employees.

The GSM model is grounded on the postulate that a lean process is not only time and resources-saving, but also aware of its carbon footprint, resource usage, and employees' health (Senthilkannan & Parameshwaran, 2019). GSM suggests moving from the Lean model to the Sustainable business model which would mean integrating sustainability into the organization's key processes (WarehouseBlueprint, 2024). The results of this research show that traditional Lean symbols are modified to point at processes that impact the environment, and new symbols are developed to indicate ESG policy interfaces and checkpoints (Akter *et al.,* 2022). Therefore, the GSM tracks the streams of environmental impacts and social contributions, which leads to the development of a map of the ESG streams in the warehouse operations.

Table 1. Warehouse Equipment

Operation Category	Equipment	Warehouse Function
Material Handling Equipment (MHE)	Forklifts (Standard, Reach, Counterbalance)	Lifting and moving pallets and heavy loads
	Pallet Jacks (Manual, Powered)	Moving pallets within the warehouse
	Conveyor Belts	Transporting items across short distances
	Order Pickers	Picking orders from high storage shelves
Storage Systems	Racking Systems (Selective, Drive-in, Pallet Flow, Cantilever)	Organizing and storing inventory in an accessible manner
	Shelving Units	Storing smaller items not requiring palletization
	Bins and Containers	Organizing small parts or bulk items
Packaging Equipment	Wrapping Machines	Securing pallets and goods for storage or transport
	Strapping and Banding Machines	Securing packages with straps
	Labelling Machines	Applying labels for identification and shipping
Loading Dock Equipment	Dock Plates and Levellers	Bridging the gap between the dock and transport vehicles
	Dock Doors	Sealing the warehouse when not in use
	Dock Shelters and Seals	Protecting the loading area from external elements
Safety and Security Equipment	Safety Barriers	Protecting pedestrians from traffic within the warehouse
	CCTV Systems	Monitoring activities within the warehouse
	Fire Safety Equipment	Ensuring fire safety with extinguishers, sprinklers, and alarms
Cleaning and Maintenance Equipment	Sweepers and Scrubbers	Cleaning warehouse floors
	Pressure Washers	Cleaning docks and warehouse exteriors
	Tool Kits	Performing equipment maintenance
Office and Administration	Computers and Tablets	Managing inventory and processing orders
	Printers and Scanners	Printing shipping labels and scanning barcodes
	Two-Way Radios	Facilitating communication among staff
Technology and Automation	Warehouse Management Systems (WMS)	Tracking inventory and optimizing workflow
	Automated Guided Vehicles (AGVs)	Automated transportation of goods within the warehouse
	Robotic Arms	Automating the picking and placing of items
Utility Equipment	Generators and Power Backup	Providing continuous operations during power outages
	Lighting (Energy-efficient LED fixtures)	Illuminating the warehouse efficiently
	HVAC Systems	Maintaining climate control within the warehouse environment

METHODOLOGY

Study Approach

To demonstrate the GSM framework, a dataset was created from available sustainability reports of a specific organization (Table 2). For this study, missing data points were estimated using a combination of company-specific sustainability reports and industrywide averages derived from comprehensive case studies and literature. Actual data from sustainability reports of select companies provided valuable insights into specific data points. The incomplete or unavailable data for certain variables, however, was supplemented with industrywide averages obtained from rigorous case studies and research papers. Alignment with broader industry trends and benchmarks brought a level of granularity in assessments. While acknowledging potential biases and limitations of extrapolation, transparency was built into the estimation process. Sensitivity analyses ensured the robustness of the estimated values and correlated their implications on the overall analysis. This constructed dataset provides a comprehensive baseline for the GSM framework. This approach aims to explore and encourage the potential application of the framework in a real-world context, not to draw final conclusions.

Workforce Sustainability Index (WSI)

For comparability, each of the applied sustainability indicators was normalized before aggregation and was scaled to a range from 0 to 100 by means of the Min-Max normalization procedure, where

$$Normalized\ Value = \left(\frac{Value - Min\ Value}{Max\ Value - Min\ Value}\right) \times 100$$

The indicators are outlined in the given table no. 3. SSA's unit of measurement is the index score. It was established that each of the selected indicators had an influence on the sustainability of the workforce and weights were assigned to each of them in a relative sense. These weights are determined through a synthesis of the articles available in the literature by several authors.
Table 2 Weighted Indicators

Employee Engagement Survey Score	20%
Training Completion Rates	15%
Stress Levels and Mental Health	15%
Turnover and Retention Rates	15%
Health-Related Absences	10%
Incident and Accident Rate	10%
Lost Time Injury Frequency Rate	10%
Ergonomic Risk Assessments (REBA)	5%

Table 3. List of data bases used for data collection

Sr. No	Organisation Name	Report Name	Webpage
1	Maersk	ALL THE WAY-2022 Sustainability report (Maersk, 2022)	https://www.maersk.com/~/media_sc9/maersk/corporate/sustainability/files/resources/2022/maersk-sustainability-yearly-report_2022.pdf
2	Ceva Logistics	2022 CSR report (C. Logistics, 2022)	https://www.cevalogistics.com/documents/2023-05/CMA%20CGM_Rapport%20RSE%202022_EN_V16.pdf
3	DHL	2023 Annual Report (DHL, 2023)	https://group.dhl.com/en/sustainability/sustainability-roadmap/sustainability-reports.html
4	Kuehne+Nagel	2022 Edition Sustainability Report (Kuehne+Nagel, 2022)	https://home.kuehne-nagel.com/en/-/company/sustainability-report-2022
5	Expeditors	Sustainability Report 2023 (Expeditors, 2023)	https://www.expeditors.com/about-us/sustainability
6	Amazon	Building a Better Future Together 2022 Amazon Sustainability Report (Amazon, 2022)	https://sustainability.aboutamazon.com/reporting
7	Prologis	2021-22 ESG Report (Prologis, 2022)	http://www.publicstorage.com/
8	Public Storage	2022 Sustainability Report (Storage, 2022)	http://www.publicstorage.com/
9	Lineage Logistics	Built for This 2022 Sustainability Report (L. Logistics, 2022)	www.LINEAGELOGISTICS.COM
10	DSV Global	Sustainability Report 2023 Towards sustainable supply chains (Global, 2023)	https://www.dsv.com/en/sustainability-esg/our-reporting/sustainability-reports
11	Warehouse REIT	Sustainability Report 2023 (Warehousereit, 2023)	www.warehousereit.co.uk
12	U.S Energy Information Administration	2018 CBECS: Principal Building Activities Warehouse and Storage (Administration, 2018)	https://www.eia.gov/consumption/commercial/pba/warehouse-and-storage.php
13	Sphere WMS	Picking & Packing in Warehouse Operations (WMS)	https://spherewms.com/blog/picking-packing-warehouse-operations-what-how-to-do-it-right
14	Mecalux	The importance of packing in the warehouse (MecaLux)	https://www.mecalux.com/blog/packing-in-warehouse
15	Noatum Logistics	Warehouse Order Picking: Everything You Need to Know Step-by-Step (Logistics)	https://www.noatumlogistics.com/uk/warehouse-order-picking-everything-you-need-to-know-step-by-step/
16	Logiwa	Warehouse Optimization – Algorithms For Picking Path Optimization (Logiwa)	https://www.logiwa.com/blog/picking-path-optimization-algorithm
17	Mental Health America	Workplace Mental Health Toolkit (America)	https://www.mhanational.org/workplace/toolkit
18	Adrian's Safety Solution	Improving Mental Health for Warehouse Workers (Solution)	https://adrianssafetysolutions.com/blog/improving-mental-health-for-warehouse-workers/
19	The New Statesman	Amazon's worker surveillance "leads to extreme stress and anxiety" (Statesman, 2023)	https://www.newstatesman.com/spotlight/tech-regulation/cybersecurity/2023/02/amazon-workers-staff-surveillance-extreme-stress-anxiety
20	Challenge-TRG Recruitment	Looking after your Mental Health & Wellbeing - Top 10 Tips (Warehouse Staff) (Recruitment)	https://www.challengetrg.co.uk/top-10-tips-on-how-to-look-after-your-mental-health-whilst-working-in-a-warehouse/
21	Carbon Trust	Energy efficiency opportunities for warehousing and logistics companies (Trust)	https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/public/Warehousing-and-logistics-guide.pdf
22	Procter & Gamble	Citizenship Report 2022 (Gamble, 2022)	https://us.pg.com/citizenship-report-2022/environmental-sustainability/

WSI was computed based on the weighted sum of indicator scores where every indicator was given a weight based on its importance. The formula used is:

$$WSI = \sum_{i=0}^{n} (w_i \times s_i)$$

where w_i is the weight and *is* the score normalized to each of the indicators.

Construct validity of the index was confirmed through correlation analysis with the other similar existing indices. The reliability test used in the study was Cronbach's Alpha Coefficient which was used to check for internal consistency of the indicators.

Net Material Footprint (NMF)

NMF quantifies the environmental impact of material consumption within an organization by calculating the total material used, both non-renewable and renewable, and subtracting the mass of recyclable waste.

Net Material Footprint = Total Material Used (Non-renewable and Renewable) minus Total Recyclable Waste. The unit of measurement of NMF is tonnes.

This metric incorporates the Waste Reduction Ratio that indicates the proportion of total waste that is successfully recycled, thus evaluating the effectiveness of waste recycling initiatives. Concurrently, the Material Efficiency Ratio assesses how efficiently materials are used per unit of production output. The NMF offers nuanced insights into material usage and the efficacy of recycling and waste management practices, making it an essential tool for environmental sustainability assessments. The fundamental architecture of VSM, as displayed in Figure 2, has been adapted to create the GSM framework. We have redefined traditional VSM to incorporate sustainability. This adaptation ensures that Corporate Social Responsibility and ESG goals are integrated into the operational framework and effectively communicated to customers and suppliers. While maintaining the integrity of VSM, the Warehouse Manager is primarily responsible for implementing these sustainability objectives at the ground level.

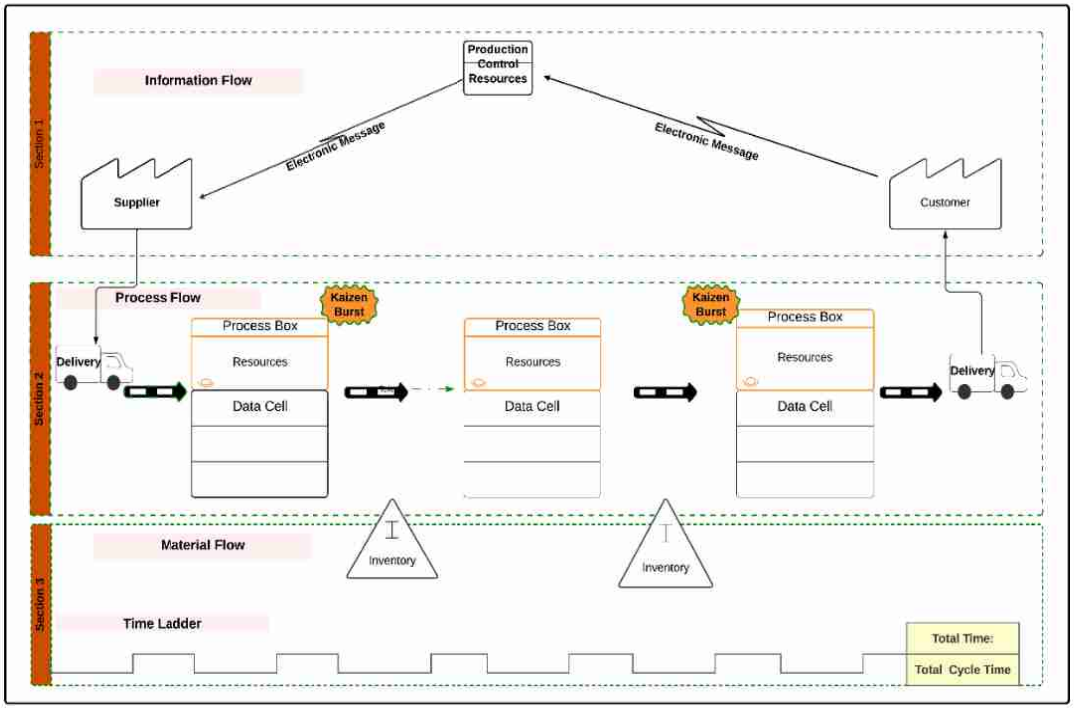

Figure 1 VSM Basic Architecture

The GSM incorporates MHE in the processes of the VSM to better align the framework with warehouse operations. MUDA signs or icons are strategically included around the process boxes to highlight potential inefficiencies of each process from a sustainability perspective. The inventory component of the VSM has been replaced with a Net Zero Balance approach. An Average Grid Emission Factor of 0.5 is being used to calculate net zero. The time ladder section of VSM has been replaced with Net Zero Balance, Net Material Footprint, and Workforce Sustainability Index along with Total Emission, Material Used and Workforce Index. While preserving the essential architecture of VSM, modifications incorporated into the GSM emphasize the sustainability perspective. This division facilitates a clearer understanding of its intricacies and operational dynamics.

Section 1: The upper part of the GSM, as displayed in Figure 3, replaces the traditional VSM's production control function. It primarily deals with the management of ESG goals and policies which determine the design of warehouse operations. The warehouse does not practise sustainability in isolation. These goals are communicated to suppliers and customers for effective outcomes. Customer orders, occasionally referencing sustainable packaging materials and lead times, serve as vital directives to the organization. Consequently, warehouse managers align processes based on ESG directives, ensuring seamless supply chain management that meets customer sustainability needs while minimizing environmental impact.

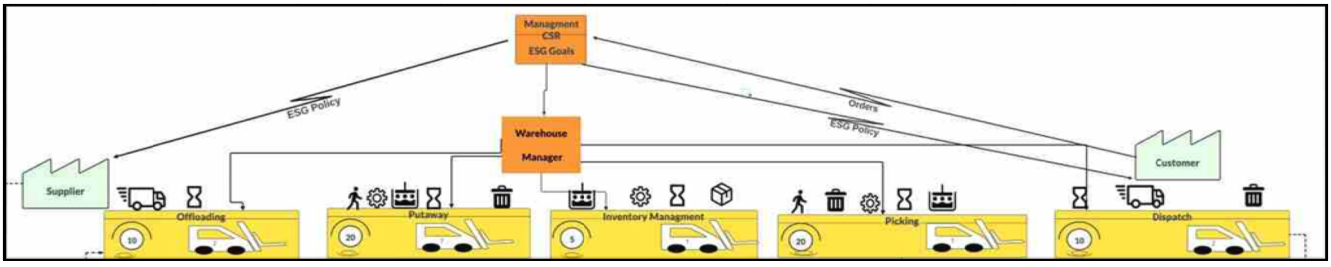

Figure 2. GSM Section 1

Section 2: Figure 4 delineates the mid-section process flow and data cells, analysing the sequence of operations from an ESG perspective. It emphasizes the application of the Lean KAIZEN principles of continuous improvement to achieve the ESG goals. It highlights the role of the warehouse manager in eco-friendly decision-making, facilitating a sustainable approach to process management.

Figure 3. GSM Section 2

Various sustainability indicators are built into the structure of data cells in GSM; they are categorized into distinct sustainability areas such as Energy, Water, Green greenhouse gases (GHG), Waste, Material, Employee, and Supplier.

Section 3: In the lower part of the GSM displayed in Figure 5, each triangle represents a point in the warehouse where the net zero balance is tracked and accumulated. The numbers inside each triangle indicate the net zero balance accumulated for that specific process flow, incorporating the balance of the current process and adding the balance of the previous process.

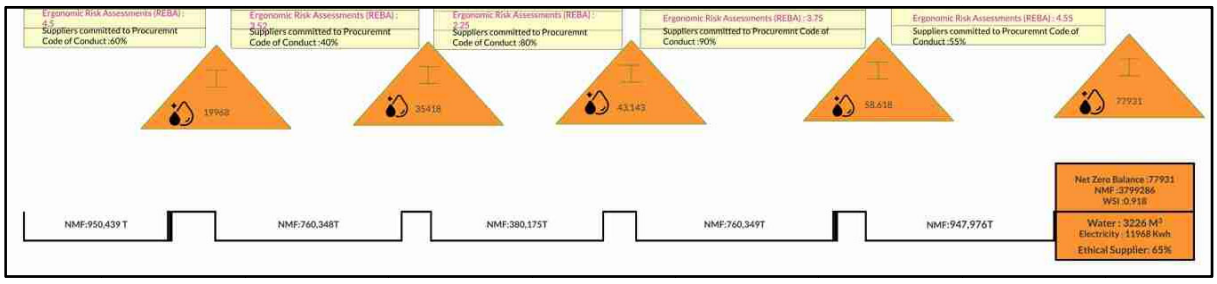

Figure 5 GSM Section 3

The NMF values in GSM reflect each warehouse process and provide a material aspect of the ESG of the process, parallel to VSM, the ladder at the end provides an ESG summary of the warehouse processes and includes NMF, WSI, electricity and water consumption, and the percentage of suppliers adhering to the code of conduct. Table 5in appendix conceptualizes and systematically integrates sustainability indicators with ESG considerations across various warehouse operational stages. It specifically maps the implementation of the sustainability indicators within the warehouse operations.

Illustration of the results

Publicly available data on sustainability at the process level is wanting; existing reports often only provide estimates. To explore and establish the practicable effectiveness of the proposed GSM, constructed datasets were used to demonstrate the framework's functionality (Zhao *et al.,* 2022). These datasets and illustrative representations aim to mirror the ground reality, emphasizing substantial efforts required at the grassroots level to drive sustainability initiatives effectively. Figure 6 presents the GSM framework incorporating the values from the constructed dataset. (A High-Resolution version of the Figure can be found at *https://lucid.app/documents/view/c9dc5a31-0925-4e60-ae06-941bcda51081)*

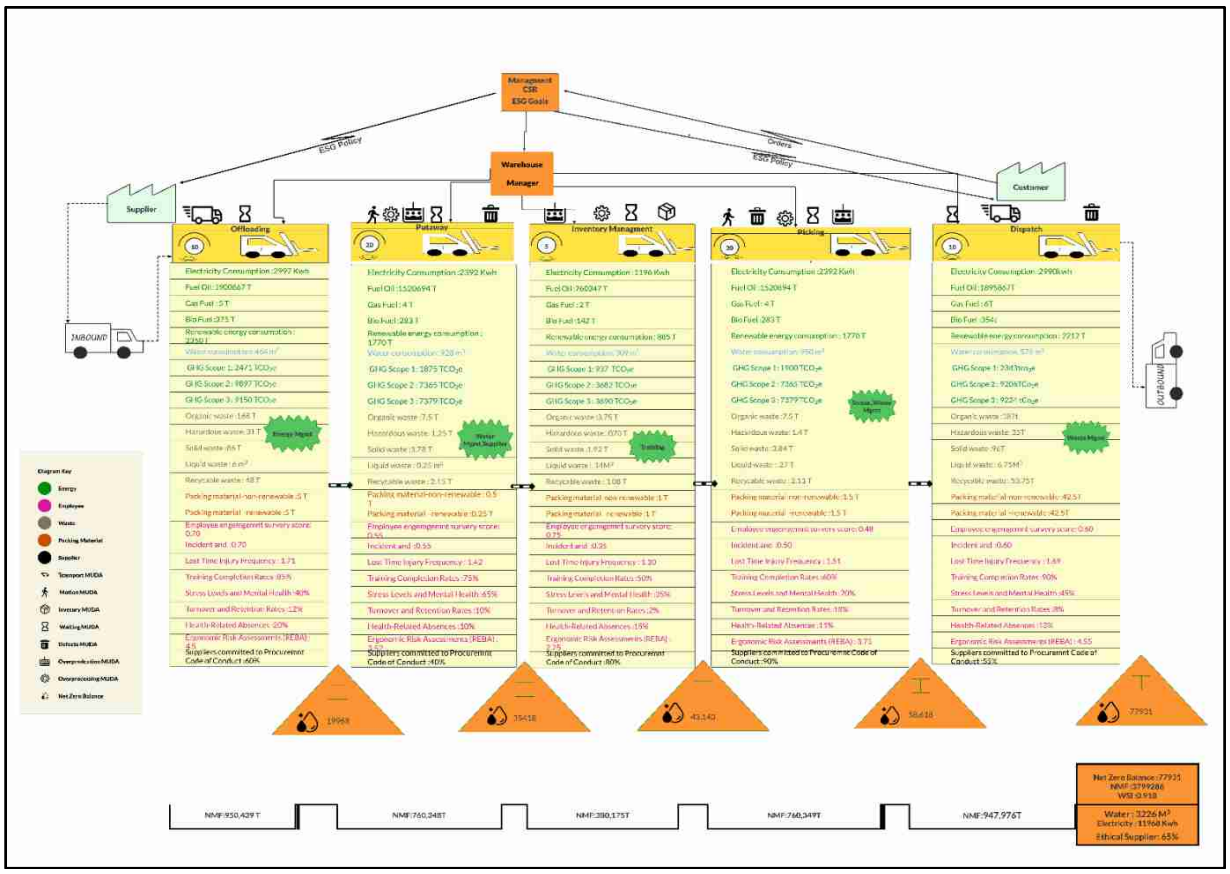

Figure 6. GSM Illustration

RESULTS

GSM Framework Analysis

The GSM illustration based on the constructed dataset provides a comprehensive overview of the TIMWOOD waste of Table1 through different processes of the warehouse.

Environment: Offloading is the process with the highest emissions overall. Scope 2 emissions are consistently the highest across all processes, indicating that electricity and external power consumption during warehouse operations are significant contributors. Direct emissions, although relatively lower than the other Scope 2, still highlight that internal warehouse activities, such as the use of fuel-powered equipment, have a direct impact. Scope 3 emissions are substantial, underlining the significant influence of the broader supply chain on total emissions. Offloading and Dispatch, which connect the warehouse to the outside world, particularly emerge as major contributors. It also reflects the Transport and Motion Muda of Table 1 in the Offloading process.

Social: The data cell reveals that Inventory Management boasts high employee engagement and training rates but also has the highest injury frequency, indicating safety issues. Picking is overwhelmed by the highest stress, health absences, and turnover rates, calling for improved support and work conditions. Offloading shows favourable metrics with low stress, absences, and turnover. Preventive measures are an essential aspect, which is well represented when ergonomic risks are evaluated for all the processes. It also links to the Overproduction Muda of Table 1 in the Picking process and motions Muda in Inventory Management.

WSI: The index scores of each of the warehouse processes are somewhat average making it difficult to pinpoint that workforce sustainability threats are evenly spread throughout the warehouse process. This observation suggests that there is no stage in the workflow where one can relax and it requires the same amount of effort as in the previous stages. More importantly, the index score of inventory management is the highest at 0. 239, which might suggest more serious problems or the need to pay more attention to the sustainability of the workforce since this area is complex and highly relevant to an organization's success. On the other hand, Dispatch yields the smallest index score of 0. 162 which may imply more efficient processes or less concerns about the workforce. However, this score may also conceal other weaknesses or reveal that the problem is not reported at all or underreported as regards the challenges in the workforce area. On the other hand, the current Offloading, Putaway, and Picking efficiency scores are relatively close; thus, a similar strategic approach to improving workforce sustainability can be introduced to all of these processes. It also reveals the flow of Inventory Muda of Table 1 in the Dispatch process.

NMF: Offloading is the process that has the highest material volume with a figure of 950,438. 88 tonnes; the lowest figure is allocated to Inventory Management at 380,174. 55 tonnes. This brings the need to enhance the transportation and packaging in high throughput activities such as Offloading while at the same time putting much effort intothe appropriate handling of stocks in order to reduce resource usage across the warehouse work. Likewise, Putaway and Picking stands at 760,347. 60 tonnes and 760,348. A further 60 tonnes respectively, as mentioned above, provides prospects for the more efficient release of inventory to gain waste reduction. Offloading and dispatch are again an instance of the Overproduction Muda as shown in Table 1.

Waste: It reveals clear patterns of waste management: organic and solid waste have particularly high volumes with 168.75 tonnes Offloaded and 187.50 tonnes Dispatched, indicating significant inflows and outflows at these points, particularly with the dispatch process consistently handling the largest quantity. This pattern suggests that the warehouse effectively manages and processes these types of waste, ensuring a steady flow through the system. It also reflects the Defect Muda of Table 1 in Offloading; lower organic waste in Inventory Management reflects the Waiting Muda of Table 1.Each waste type displays consistent quantities across Inventory Management, Picking, and Putaway, reflecting steady progress through these intermediate stages. Recyclable waste stands out as a significant category, emphasizing the importance of waste sorting and recycling efforts that seem well-integrated into the overall waste management process. Liquid waste, although measured in smaller units (m^3), shows a consistent presence throughout the various stages, reflecting systematic handling practices. Overall, the GSM highlights a structured approach to waste management, where steady inflows and outflows ensure effective processing and movement of waste through the warehouse. Organic waste, which peaks at 187.50 tonnes in Dispatch, highlights the need for waste reduction strategies (KAIZEN). The high recyclable waste volume of 53.75 tonnes highlights a commitment to sustainability through waste diversion. Renewable and non-renewable packing materials have similar values, except in the Putaway process. From a sustainability perspective, the Putaway process is more favourable for renewable materials as it requires only half the effort compared to non-renewable materials, making it more efficient and resource-friendly.

Water: The Picking and Putaway processes are the most resource-intensive, consuming 950 m^3 and 928 m^3 of water respectively. This can be attributed to their extensive activities involving product handling. Dispatch and Offloading processes have moderate water usage. Inventory Management, primarily involving data handling rather than physical movement has the lowest water consumption (309 m^3) among the processes. It also reflects the Over processing Muda of Table 1 in the Picking and Putaway process.

Supplier: Picking demonstrates strong supplier adherence to the code of conduct at 90%, closely followed by Inventory Management at 80%. However, Offloading and Putaway processes exhibit lower compliance rates of 60% and 40% respectively, indicating potential supply chain realignment. By recognising and reducing wastes, GSM also identifies and promotes KAIZEN opportunities to enhance sustainability indifferent the warehouse process. The KAIZEN burst in GSM underscores this potential.

DISCUSSION

Corporations today often publicly disclose their ESG goals and sustainability training in ESG reports. They also provide customers with options for various delivery speeds and eco-friendly packaging, enabling consumers to directly impact the environmental footprint of their orders (Darnall *et al.,* 2022). This transparency and customer engagement reflects a commitment to ethical and sustainable practices, aligning with modern consumer expectations. The logistics and packaging sectors are increasingly influenced by consumer preferences (Arvidsson & Dumay, 2022). GSM incorporates sustainability as a strategic resource and core competency within warehousing and supply chain management, evident in MHE and the Net Zero Balance inventory approach, building a competitive edge (Zickfeld *et al.,* 2023). It reiterates the important role of the warehouse manager in nurturing sustainability practices and competencies (Le *et al.,* 2024). The GSM also emphasizes ongoing organizational learning and adaptation to continuously develop sustainability measures. In alignment with Resource-Based Theory, this approach underscores how GSM utilizes sustainability as a key resource to maintain and improve competitive advantage (Ristyawan *et al.,* 2023). Warehouses are an integral element of a supply chain, they support business operations by storing, consolidating, and distributing products (Vaka, 2024). Functioning as storage and order fulfilment centres, warehouses receive goods, store them, and subsequently dispatch products according to order requirements. As these operations are interdependent and have several other departments depending on them, they function with a high level of coordination (Mishra *et al.,* 2024). While each business has unique warehouse processes and requirements, warehouse operations can generally be categorized into three primary segments: inbound, inventory management, and outbound (Živičnjak *et al.,* 2022). Figure 1 details the functions of each process.

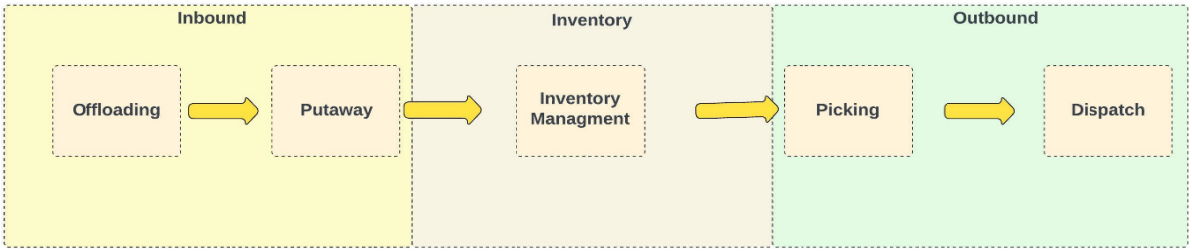

Figure 4 Warehouse Process

Originating from 'The Machine That Changed the World,' the Lean methodology was founded on three fundamental principles—maximizing value creation while minimizing resource utilization, fostering collaborative teamwork, and enabling a rapid learning cycle that facilitates swift adoption (Womak *et al.,* 1990). There is documentation proving that lean principles such as the Seven Wastes, 5S systematic organization, 5 Whys, Poka-Yoke, Kanban, VSM, and JIT inventory management have been internationally adopted in the last decades. They include: cost control, quality enhancement, integrated delivery, dynamic adaptability, culture simplification and adaptability to virtually all industries. (Hardcopf *et al.,* 2021). Freeman's Stakeholder Theory identifies the interests of various stakeholders in operational decisions and how they influence the firm's strategic objectives (Gilbert & Rasche, 2008). The stakeholder theory can effectively drive sustainability by increasing stakeholder knowledge and awareness of sustainability issues, introducing policies that cultivate sustainable practices and collaboration among stakeholders, and developing business strategies that generate value based on sustainability, ensuring mutual benefits for all involved parties (Hörisch *et al.,* 2014). Stakeholder Theory is highly pertinent to supply chain operations, given their vast scope and complexity across extensive networks and numerous stakeholders (Vanichchinchai, 2019).

The fundamental waste identification principles of Lean can be effectively linked to ESG considerations. Table 4 provides a comprehensive ESG overview of the TIMWOOD Model. Any reduction in resource consumption has the potential to enhance operational sustainability (Verma & Jha, 2024).

Table 4.TIMWOOD Model: Lean Definitions, Environmental, and Workforce Impacts

Lean MUDA (Waste) Category	Definition within Lean Paradigm	Environmental Implications	Societal Impacts
Transport	Unnecessary movement of materials, products, or information from one location to another	Carbon footprint of unnecessary transportation; increases fuel consumption	Increases risk of accidents and fatigue
Inventory	Excess materials, products, or information that are stored or waiting to be processed	Increased resource and energy usage in storage; increases the risk of material spoilage and water used for maintenance	This leads to inefficiencies and job dissatisfaction
Motion	Unnecessary movement of people or equipment within a process	The carbon footprint of excessive movement; higher energy consumption	Causes physical strain and potential injuries
Waiting	Delays in operations due to pre-task scheduling inefficiencies or in-process idle time	Energy used and carbon footprint incurred during idle process time; energy wastage	Results in wasted time and potential demotivation
Overproduction	Producing more than is needed	The carbon footprint of avoidable storage and waste of excess stock; leads to excess garbage and material wastage	Increases workload and stress
Over processing	Unnecessary steps in processing (packaging, handling, QA)	Increases resource used and carbon footprint of added processing; extra packaging materials and water usage	Adds complexity and reduces job satisfaction
Defects	Production errors leading to rework or scrap	Carbon footprint from re-processing or disposing of defective products; contributes to higher garbage and material use	Demoralizes employees and increases workload

The Illustration's analysis confirms that GSM has the potential to effectively engage ground-level managers in reinforcing sustainability initiatives through comprehensive metrics and KAIZEN bursts. By integrating Lean management principles into sustainability reporting, the framework empowers managers to optimize operations (Lewczuk *et al.,* 2021). Self - assessed concerns of WSI and NMF include finding safety problems in Offloading, high material consumption, and high quantity of organic and solid waste. The concepts listed in the GSM framework aid in determining critical improvement opportunities such as reducing Scope 2 emissions, optimizing packaging and transportation methods (Elemure *et al.,* 2023). Yet, there is social sustainability which need to be paid attention to concerning stress, sickness absence, and staff turnover (Abobakr *et al.,* 2023).

Further research should be made about Lean and its contribution towards social and environmental sustainability, consumers' leadership to sustainable behaviour and analysis towards big data and machine learning in warehouses. (Ganbold *et al.,* 2020). Software tools as well as GRI standards are evolving and creating a good basis for further progression of new software tools for sustainable warehouse management. However, the chosen GSM framework is quite flexible, yet focused on particular ESG goals and company activities. It promotes sustainable warehousing and storage in areas of emissions, employment practices, waste, water, and supplier policies (Smith, 2023). The framework also includes the notion that sustainability management is the responsibility of the warehouse managers. It stores resource and ESG data that will display KAIZEN bursts and Lean method for improvement chances (Xu *et al.,* 2023).

Conclusion

The GSM framework makes sustainability implementation easy depending on the bottom-up approach that ensures that the operations teams are directly linked to the ESG objectives. Thus, the outlined approach strengthens the correlation of the warehouse's activities with global sustainability objectives. However GSM is an excellent resource; it should be customized for each organization depending on its ESG goals. Further studies can focus on the consequences of consumer-driven sustainability in logistics and the results of TBL and ESG implementation in management decisions in warehouses and the overall applicability of the framework for different types of warehouses can be further developed.

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APPENDIX

Table 5. GSD Data Cell ESG Integration

Sustainability Indicators	Environment Aspect	Social Aspect	Governance Aspect	Warehouse Operational Integration and Impact	Stakeholders and Assets Driving Sustainability
Electricity Consumption	Reduces energy use and carbon footprint	Workforce training on energy conservation	Energy management policies	Powers lighting, HVAC, and equipment throughout the warehouse, affecting all processes	Equipment, Building
Fuel oil	Reduces dependence on non-renewable resources	Training on efficient fuel use and alternatives	Policies on reducing fossil fuel usage in operations	Utilized for heating and powering some machinery, affecting mainly maintenance and emergency operations	Equipment
Gas fuel	Decreases greenhouse gas emissions	Promotes a culture of environmental awareness among staff	Implementation of guidelines for sustainable fuel use	Fuels forklifts and machinery, impacting loading, unloading, and transportation within the warehouse	Equipment
Bio Fuels	Contributes to reduced carbon emissions and pollution	Enhances community health by reducing local air pollution	Adoption of clean energy policies and incentives	Used in bio-fuel-compatible equipment, could impact offloading, putaway, and dispatch operations where such equipment is in use	Equipment
Renewable Energy Consumption	Reduces carbon footprint and fossil fuel use	Encourages workforce involvement in green practices	Regulations for clean energy use in operations	Powers sustainable operations can be integrated into any process to reduce carbon footprint	Equipment, Building
Water Consumption	Enhances water efficiency and conservation	Fosters employee engagement in water-saving practices	Regulations compliance for water usage reduction	Essential for sanitation and cooling; impacts cleaning and maintenance operations	Building
Scope 1	Direct reduction in operational carbon emissions	Involvement in company-led climate action initiatives	Adherence to environmental regulations and internal carbon reduction targets	Direct emissions from onsite fuel combustion; apply to maintenance and any on-site generation processes	Equipment

Scope 2	Lowers indirect emissions from purchased electricity	Engagement programs to promote energy-saving practices	Regulatory compliance with energy consumption and reporting	Indirect emissions from purchased electricity; impact overall warehouse energy efficiency measures	Equipment
Scope 3	Minimizes indirect greenhouse gas emissions	Encourages stakeholder engagement in reducing carbon footprint	Oversees compliance with environmental reporting standards	Emissions from logistics and transport; related to offloading, dispatch, and transportation management.	Logistics coordination, supply chain management, third-party partners
Organic Waste	Supports waste reduction and composting efforts	Engagement in community composting programs	Regulations compliance for waste disposal and recycling	Managed during inventory, particularly in food-related storage and disposal processes	Employees, waste management system, community partnerships
Hazardous Waste	Mitigates environmental contamination and health risks	Involvement in community education on hazardous waste management	Strict adherence to hazardous waste disposal regulations	Handled during receiving and dispatch, requiring specific attention to storage and disposal	Environmental safety officers, waste disposal systems, training programs
Solid Waste	Minimizes landfill use and environmental pollution	Fosters community participation in waste reduction initiatives	Adherence to waste management and reduction regulations	Affects packaging and disposal operations, with an emphasis on waste segregation and management	Waste management systems, employee training, compliance teams
Liquid Waste	Supports pollution prevention and water conservation	Encourages responsible waste management practices among employees	Compliance with wastewater management regulations and policies	Generated from cleaning processes, affecting water treatment and floor maintenance	Waste management systems, employee training programs
Recyclable Waste	Supports waste hierarchy and resource efficiency	Encourages employee participation in recycling initiatives	Adherence to waste management and recycling regulations	Integral to disposal and sorting processes aligns with warehouse recycling initiatives	Employees, waste segregation systems, environmental management policies
Packing Material - Non-Renewable	Increases generation of non-biodegradable waste	Education on the importance of reducing waste and recycling	Standards for minimizing non-renewable packaging use	Used in packaging, affects how goods are prepared for shipping and storage	Procurement team, waste management, suppliers
Packing Material - Renewable	Reduces waste and supports circular economy initiatives	Encourages responsible consumption and production practices	Adoption of procurement policies favouring renewable resources	Part of the packing process, emphasizes the use of sustainable materials	Procurement team, suppliers
Employee Engagement Survey Score	May reflect employee satisfaction with environmental initiatives	Enhances employee morale and promotes inclusivity	Informs management of workforce perspectives	Influences overall operational practices, including training and workplace environment	HR department, management, all employees
Incident & Accident	Minimizes environmental hazards from accidents	Enhances employee well-being and safety awareness	Adherence to health and safety regulations and standards	Relevant to safety procedures during handling and machinery operation	All Employee
Lost Time Injury Frequency	N/A	Enhances focus on employee health and safety in the workplace	Adherence to occupational health and safety regulations	Pertains to safety management in all operational areas, like loading docks and storage areas	Health and safety officers, training programs, PPE, ergonomic equipment
Training Completion Rate	N/A	Enhances employee competency and promotes sustainable practices	Enforces the company's commitment to continuous learning and adherence to sustainability protocols	Reflects on workforce competency, applicable in all areas requiring specialized skills	HR department, training materials, educational tools
Stress Levels and Mental Health	N/A	Enhances worker well-being and job satisfaction	Adoption of workplace mental health programs and policies	Affects employee well-being, relevant to workplace environment and HR policies	HR department, team leaders, mental health professionals
Employee Turnover & Retention Rates	Enhances sustainability through experienced workforce continuity	Fosters job satisfaction and community building in the workplace	Oversight of fair labour practices and retention strategies	Impacts staffing levels, training, and overall workforce stability in all processes	HR department, team leaders, training programs
Health-Related Absences	Reduces environmental impact of healthcare waste	Fosters a healthy workplace, enhancing employee well-being	Adherence to occupational health and safety regulations	Influences staffing and operations management, applies to health and wellness programs	HR, health and safety officers, ergonomic equipment
Ergonomic Risk Assessments (REBA)	Enhances sustainable workforce practices	Improves employee well-being and productivity	Adherence to occupational health and safety regulations	Applicable to workstation design and operation layouts in all areas	HR department, health & safety officers, all employees
Suppliers Committed to Procurement Code of Conduct	Encourages environmental stewardship along the supply chain	Enhances ethical labour practices and social responsibility	Establishes accountability and transparency in supplier relations	Affects supply chain management, particularly in procurement and vendor selection processes	Procurement team, compliance officers

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