Expanded Value Stream Mapping with Multidimensional Metrics for Sustainability Assessment

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Abstract

This study identifies and analyzes key indicators (metrics) used to assess sustainability through expanded value stream mapping. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a systematic literature review was conducted, leading to the selection of 44 papers for further analysis. As a result, 40 metrics were identified as the most frequently used in VSM: 15 related to the economic dimension of sustainability, 12 to the environmental dimension, and 13 to the social dimension. The framework proposed based on these metrics enables organizations to effectively address stakeholder needs by balancing economic, environmental, and social considerations.

Keywords: Metrics, Value stream mapping, Sustainability

Introduction

Value Stream Mapping (VSM) is a widely recognized tool in the industry for analyzing and optimizing processes, particularly within lean manufacturing (Rother and Shook, 1999). While economic viability remains essential for business survival, customers have become increasingly aware of sustainability impacts in recent years. This growing awareness has amplified the focus on environmental and social responsibility as critical factors in maintaining a company’s competitiveness (Dieste et al., 2019). In line with this, sustainable VSM has built upon traditional VSM by integrating environmental and social aspects alongside economic considerations, with the aim of minimizing ecological impact, ensuring social responsibility, and meeting stakeholder requirements (Brown et al., 2014). Unlike traditional VSM, which primarily focuses on in identifying and eliminating waste to enhance customer value (Rother and Shook, 1999), sustainable VSM supports sustainable manufacturing by addressing the needs of diverse stakeholders through balancing economic, environmental, and social considerations, collectively known as the Triple Bottom Line (TBL) (Elkington, 1997). Effectively implementing sustainable VSM to achieve sustainability objectives requires integrating relevant multidimensional indicators (metrics) aligned with the TBL dimensions (Helleno et al., 2017).

Previous studies have identified numerous metrics related to sustainable VSM: economic metrics associated primarily with time (Fontoura et al., 2023), quality (Saraswati et al., 2024), cost (Dewi et al., 2023), inventory (Rathore et al., 2023); environmental metrics that focusing on energy (Andreazza de Freitas et al., 2025), water (Larsson and Ratnayake, 2024), materials (Swarnakar et al., 2021), recycled resources (Hartini et al., 2020), and emissions and pollution (Vinodh et al., 2016); social metrics linked to health and safety (Batwara et al., 2024), and employee satisfaction (Marie et al., 2022).

Among the sustainable VSM metrics identified in the reviewed literature, a few have frequently been featured in multiple papers, indicating their sustained relevance across both earlier and recent studies. For example, cycle time has been widely used as a metric by Brown et al. (2014) and more recently by Andreazza de Freitas et al. (2025); energy consumption was adopted by Chiarini (2014) and later by Andreazza de Freitas et al. (2025); and noise level was considered by Brown et al. (2014) and subsequently Batwara et al. (2024). Although previous studies have provided numerous metrics for sustainable VSM, they have overlooked how these metrics address the needs of various stakeholders, such as employees, local communities, labor unions, and regulatory bodies. Further research is needed to identify the most widely used metrics, promoting a more structured and unified approach that focuses not only economic value but also on environmental and social aspects. This enables businesses to effectively address stakeholder requirements, in addition to customer value, through a consolidated tool such as VSM.

Therefore, the objective of this study is to systematically identify and analyze the most frequently used metrics in sustainable VSM. This will provide a comprehensive understanding of key metrics based on TBL, enabling companies to focus on the most relevant ones and make informed decisions to optimize processes while ensuring sustainability. This is operationalized through an extended metrics-based sustainable VSM framework. Ultimately, this comprehensive approach will help organizations align with stakeholder requirements. Additionally, this study can serve as a solid foundation for future research by offering a conceptual framework for the effective implementation of the most widely used metrics in sustainable VSM, addressing not only customer value but also the needs of other stakeholders.

The rest of this work is organized into four sections. Section 2 outlines the methodology used in conducting this study. Section 3 presents the results with a brief explanation. Section 4 discusses the findings, providing a conceptual framework. Finally, Section 5 presents the conclusions, along with directions for future research.

Methodology

To achieve the objectives of this study, a systematic review of the literature on green and sustainable value stream mapping was conducted using the PRISMA guidelines (Moher et al., 2009), as depicted in Figure 1. Two academic databases, Scopus and Web of Science, were selected to identify relevant studies based on three keyword sets closely aligned with the research topic: (*"sustainab*" OR "green" OR "environmental" OR "cleaner production" OR "eco-efficien*" OR "carbon footprint" OR "social" OR "socially* *responsible" OR "corporate social responsibility" OR "stakeholder value"*) AND (*"value stream mapping" OR "value-stream mapping" OR "value stream map" OR "value-stream map"*) AND (*"metric*" OR "indicator*" OR "measure*"*). The search, guided by these keywords, specifically targeted the "Title, Abstract, Keywords" field in Scopus and the "Topic" field in Web of Science.

A total of 276 papers published until 2025 were identified and screened using predefined inclusion and exclusion criteria derived from the study's objective. Based on the inclusion criteria, which focused on research articles and reviews written in English, five papers in other languages were excluded. Additionally, 83 book chapters, conference papers, and other document types were removed. After these exclusions, 188 peer-reviewed articles and reviews were retained for further consideration. Following the removal of 76 duplicates, 112 papers remained for title and abstract screening to assess their alignment with the inclusion criteria. As a result, 15 papers were excluded for being unrelated to VSM, overlooking sustainability aspects in VSM, or not being published in high-quality journals (i.e., those in quartiles 1, 2, or 3 of the SCImago Journal Rank (SJR). Subsequently, 94 accessible papers were deemed eligible for full-text analysis. During this stage, 50 papers that lacked relevant sustainability metrics for VSM, focused solely on traditional VSM metrics with an emphasis on economic performance, or concentrated on comparing lean tools, were excluded. Finally, 44 papers met the inclusion criteria and were selected for further analysis.

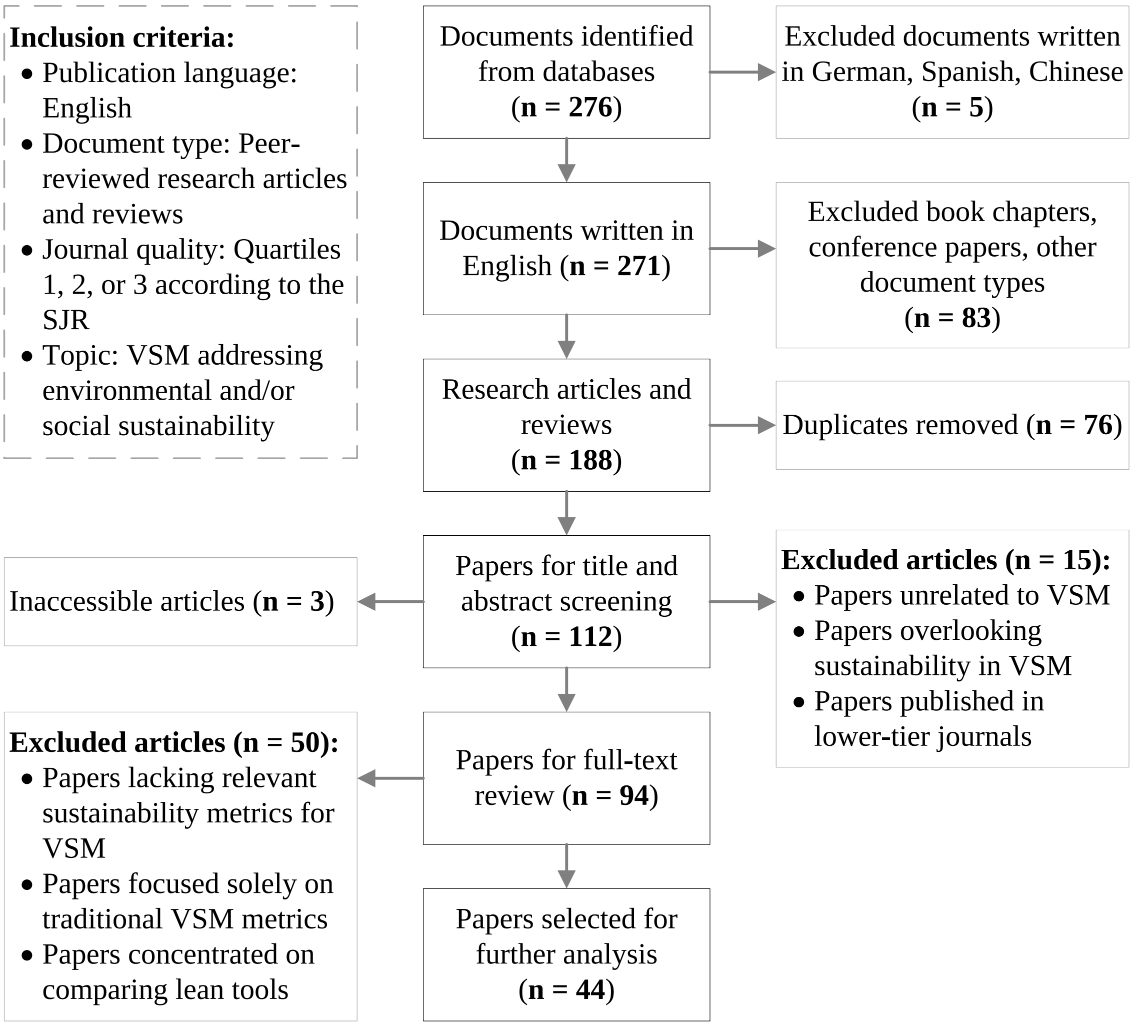

Figure 1 – Systematic review process for screening and selecting relevant papers

Results

This section presents the distribution of the selected papers by publishing journal and the VSM metrics identified in the reviewed literature.

3.1 Distribution of the selected papers by publishing journal

Figure 2 presents the journals that contributed at least two papers, accounting for a total of 17 publications. The remaining 27 papers were obtained from 27 distinct journals, each contributing a single paper. This distribution highlights the wide-ranging scope of the selected topic, covering diverse fields such as sustainability, lean management, business, and engineering. It further underscores that sustainable VSM is a topic of interest across multiple academic disciplines, reflecting its interdisciplinary relevance. Among the publishing journals, the majority centered on sustainability as a key theme, with an emphasis on cleaner production, environmental issues, and social responsibility.

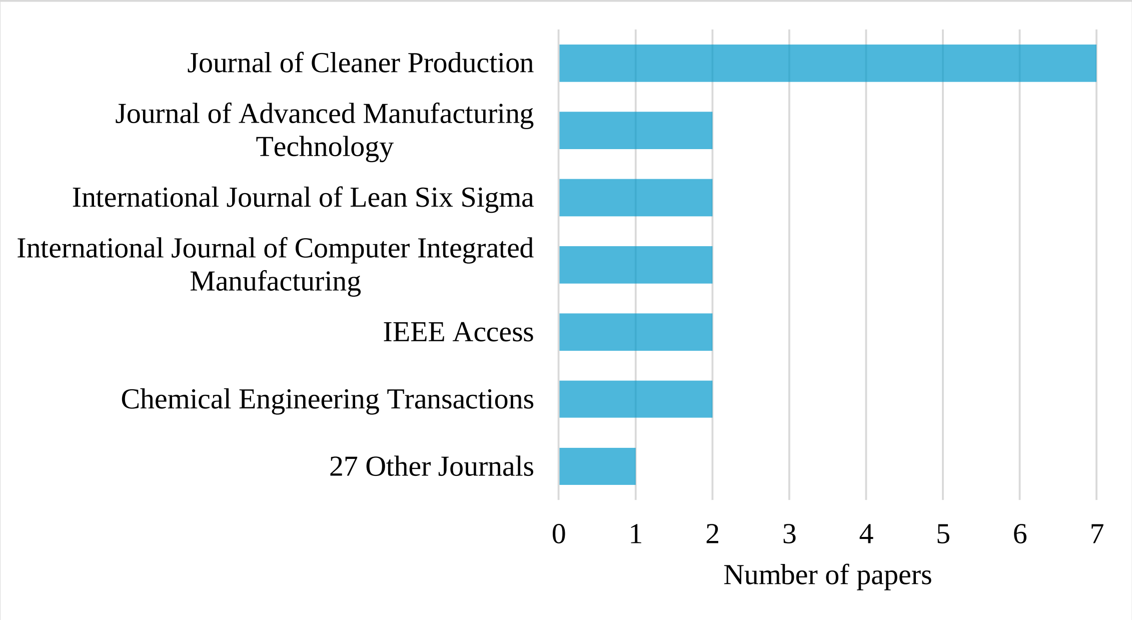

Figure 2 – Distribution of the research papers across publishing journal

3.2 Sustainable VSM metrics identified in the reviewed literature

Consistent with the study's objective, the metrics used in sustainable VSM and their frequency of use in the reviewed literature were determined through content analysis. This process involved systematically recording and coding data, including metrics mentioned in the selected papers. To determine the frequency of use for each indicator (i.e., the number of papers that considered a specific metric), texts (words and phrases) were carefully analyzed (Hsieh and Shannon, 2005). This analysis identified a total of 195 metrics: 74 economic, 71 environmental, and 50 social. Among these, 40 metrics (15 economic, 12 environmental, and 13 social) were found to be the most frequently used, appearing in at least three papers, as shown in Figure 3. Given their sustained relevance in sustainable VSM research, these metrics were considered in the subsequent discussion.

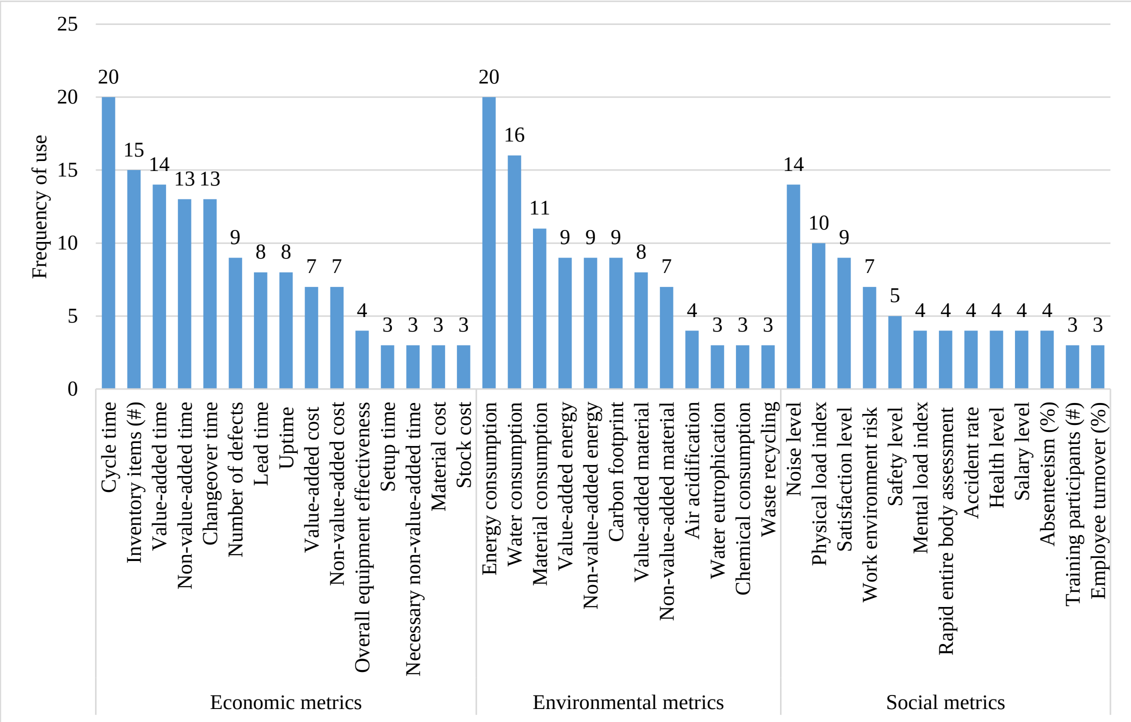

Figure 3 – Frequently used sustainable VSM metrics

The economic metrics emphasize enhancing efficiency, improving quality, reducing costs, and minimizing waste, ensuring economic viability. Among these metrics, cycle time, which appeared 20 times in the reviewed literature, was the most frequently used, underscoring its importance in measuring the duration required to complete a specific process or task. Reducing cycle time is a primary goal in lean practices, as it directly enhances efficiency and productivity. The frequent use of metrics such as number of inventory items (15), value-added time (14), non-value-added time (13), and changeover time (13) highlights the need to minimize excess inventory and reduce the time required to carry out activities, both of which are crucial for waste reduction. Other key metrics, including number of defects (9), lead time (8), and uptime (8), reflect a focus on quality, delivery speed, and equipment availability. Meanwhile, value-added cost (7) and non-value-added cost (7) indicate a growing emphasis on quantifying the financial impact of value-adding and non-value-adding activities, thereby reducing costs. In addition, overall equipment effectiveness (4), necessary non-value-added time (3), setup time (3), material cost (3), and stock cost (3) underline the importance of measuring and improving productivity, reducing time, and lowering costs.

The environmental metrics focus on reducing resource consumption (such as material, energy, and water), waste reduction, and minimizing emissions and pollution. Of these metrics, energy consumption (mentioned 20 times) was the most frequently used in the reviewed literature, underscoring its critical role in environmental sustainability. Reducing energy consumption plays a critical role in lowering operational costs and minimizing environmental impact. Other prominent metrics, such as water consumption (16) and material consumption (11), reflect the importance of optimizing resource utilization and conserving natural resources. Value-added energy (9), non-value-added energy (9), value-added material (8), and non-value-added material (7) have been considered to distinguish between resources used for productive purposes and resource wasted in non-value-adding activities, thereby reducing energy waste. Metrics like carbon footprint (9) and waste recycling (3) underscore the growing attention to climate change and resource recycling, respectively. Air acidification (4) and water eutrophication (3) indicate the need to measure and mitigate environmental pollution caused by industrial processes. Moreover, chemical consumption (3) reflects the need to lower environmental impacts by reducing the quantity of chemicals used.

The social metrics concentrate on well-being, safety, and satisfaction, emphasizing the human-centric aspect of sustainability. Out of these metrics, noise level appeared most frequently (14 times) in the reviewed literature, highlighting the importance of reducing workplace noise to enhance worker health and comfort. Other significant metrics included physical load index (10) and satisfaction level (9), which have been used to assess physical workload and job satisfaction, respectively. Additionally, metrics such as work environment risk (7), safety level (5), and accident rate (4) emphasize the need for safer workplaces and reduced occupational hazards. Further considerations included mental load index (4) and rapid entire body assessment (4), which evaluate mental workload and physical strain related to working posture; health level (4), which reflects the importance of ensuring employees' physical and mental well-being; salary level (4), which highlights the role of fair pay for job satisfaction and employee retention; and absenteeism rate (4) and employee turnover rate (3), which are specifically linked to workplace conditions that affect health and safety. Additionally, number of training participants (3) has been used as a metric to evaluate the effectiveness of employee training.

Discussion

This study provides a more structured and unified approach to the metrics used in expanded (sustainable) VSM by proposing a metrics-based conceptual framework, as presented in Figure 4. The framework demonstrates that the economic metrics, when applied in VSM, can drive outcomes such as reduced time, higher quality, reduced costs, and minimized inventory. Meanwhile, the environmental metrics can be used to achieve outcomes like reduced consumption of resources (energy, water, and materials), increased resource recycling, and lower emissions and pollution. In addition, incorporating the social metrics into VSM can lead to improved health and safety and higher employee satisfaction. The framework emphasizes the importance of starting sustainability assessment and improvement at the operational process level to achieve measurable outcomes that collectively contribute to meeting stakeholder requirements, in addition to customer value.

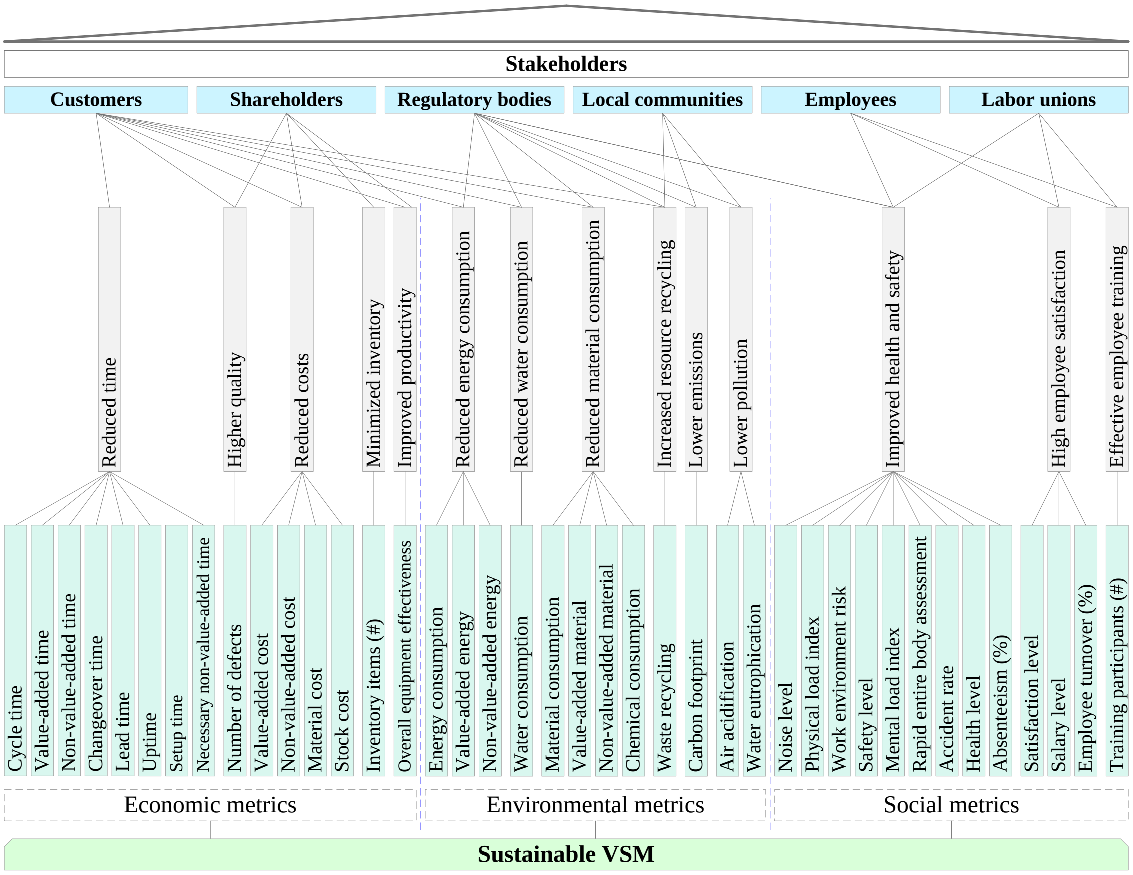

Figure 4 – Metrics-based conceptual framework for sustainable VSM

From the perspective of stakeholder theory, the framework addresses the needs of various stakeholders through measurable outcomes. According to Freeman (1984), stakeholder theory asserts that businesses should consider the interests of all stakeholders, including employees, customers, labor unions, regulatory bodies, and communities, rather than focusing primarily on shareholders. The framework aligns with this core principle of stakeholder theory by identifying key sustainable VSM metrics to assess and improve sustainability, thereby meeting stakeholder requirements. Specifically, it emphasizes the importance of measuring value not just in economic terms but also by integrating environmental and social impacts to promote stakeholder-driven outcomes.

The economic metrics can play a crucial role in addressing the needs of various stakeholders. For customers, these metrics help ensure shorter delivery times, reduced costs, and higher quality, all of which improve satisfaction and increase loyalty. Meanwhile, these metrics help meet the needs of shareholders, who prioritize return on investment and sustainable economic growth. As supporting insights from previous studies, Utama et al. (2022) highlighted the importance considering metrics related to time, costs, and quality in VSM, as they contribute to creating value for customers (Hines et al., 2004). Additionally, Swarnakar et al. (2021) incorporated return on investment and the level of economic sustainability in their conceptual method for assessing sustainability using VSM.

The environmental metrics can be used in VSM to address regulatory requirements, such as conserving natural resources, supporting circular economy principles, and mitigating adverse environmental effects. This is achieved by reducing resource consumption, promoting resource recycling, and minimizing emissions and pollution. Meanwhile, minimizing emissions and pollution can create a safer and healthier environment for local communities. In line with this, Hartini et al. (2020) considered metrics into their VSM approach to reduce resource consumption (e.g., materials and energy) in non-value-added activities and promote waste recycling, while Vinodh et al. (2016) integrated carbon footprint and air acidification into their VSM framework to assess and minimize environmental impacts associated with emissions and pollution. Additionally, stakeholders, including sustainability-conscious customers, play a crucial role in driving the transition towards a sustainable lifestyle by encouraging the reduction of resource consumption and the use of recycled resources (Mengistu and Panizzolo, 2024).

By incorporating social metrics into VSM, organizations can systematically assess and enhance occupational health, safety, and employee satisfaction. This fosters a safer and more supportive workplace, minimizing risks and improving overall well-being. Consequently, businesses can effectively address the concerns of key stakeholders, including employees, labor unions, and regulatory bodies. For instance, Faulkner and Badurdeen (2014) emphasize the use of social metrics for sustainable VSM to address occupational health and safety. In addition, Rosiani et al. (2024) considered the satisfaction level of employees and the number of training participants to assess sustainable manufacturing performance through sustainable VSM.

At its core, the framework underscores that balancing economic, environmental, and social considerations provides a comprehensive approach to fairly addressing the needs of all relevant stakeholders. It specifically highlights that traditional VSM, which historically aimed at enhancing customer value, should be expanded to include the needs of other key stakeholders. In doing so, businesses can create value not just for customers but also for other major stakeholders.

Conclusions

This study presents a set of key multidimensional metrics to effectively assess sustainability through expanded VSM. These metrics provide a balanced approach that goes beyond the traditional focus on operational efficiency and waste reduction, enabling businesses to align their processes with social and environmental sustainability goals. Specifically, the study enhances traditional VSM by (1) integrating environmental and social considerations with economic performance and (2) addressing the needs of diverse stakeholders, rather than focusing primarily on customer value. The proposed framework emphasizes that the identified sustainable VSM metrics can contribute to achieving process sustainability goals while addressing stakeholder requirements. These include reducing time, improving quality, reducing costs, and minimizing inventory within the economic aspect; reducing resource consumption, promoting resource recycling, and minimizing emissions and pollution within the environmental aspect; and enhancing occupational health and safety and improving employee satisfaction within the social aspect.

The implications of the present study extend across both academic and practical realms. From an academic perspective, the study provides a metric-based conceptual framework that future research can build upon to align the concept of sustainable VSM with the needs of diverse stakeholders. It offers valuable insights into sustainable VSM by identifying the most frequently used economic, environmental, and social metrics in the reviewed literature. From a practical perspective, the study emphasizes the need for companies to expand traditional VSM to effectively address stakeholder requirements, thereby enhancing their reputation and gaining a competitive advantage. In addition, addressing environmental and social issues helps businesses comply with the legal requirements set by regulatory bodies. Furthermore, prioritizing workplace well-being improves employee satisfaction, reduces employee turnover, and increases productivity.

As future research directions, it would be valuable to empirically test and validate the framework presented in this study through real-word case studies, including those in the healthcare sector. Developing a stakeholder satisfaction index that provides a quantitative measure to track how well stakeholder needs are met through sustainable VSM would also be a relevant pursuit. Additionally, exploring the integration of technologies such as the Internet of Things, cloud computing, big data analytics, machine learning, and enterprise resource planning to enhance data collection, sharing, and utilization, particularly through real-time visualization and simulation, would expand the capabilities of sustainable VSM and represent a promising area for future research.

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