Integration of Life Cycle Assessment and Value Stream Mapping to Ensure Sustainable Development: A Literature Review

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Abstract. Traditional lean tools such as value stream mapping (VSM) do not account for environmental benefits. Simultaneously, life cycle assessment (LCA) does not account for improving manufacturing performance. Given the advent of the concept of sustainable development as an approach to fulfill the needs of the world's population without destroying the planet, integration of environmental benefits and manufacturing performance presents the next frontier of the industrial improvement. LCA can be integrated with VSM to ensure a sustainable development of the manufacturing industry. This paper presents a review of literature on integration of the tools-LCA and VSM. The reviews show that the main motivation factor is to enhance sustainable development. Further, a key finding is the benefit as a guide for decision making, fostering of a systematically improvement focus and increased engagement expanding the focus to include the sustainable aspect in addition to traditional lean measures. This is enabled through a systematically approach with assessing and visualization of the production process performance from a sustainable viewpoint.

Keywords: Sustainable manufacturing · Lean · Value stream mapping · Life cycle assessment · Literature review

1 Introduction

The concept of Lean has been known as a crucial strategical weapon to remain competitive in a global market for the manufacturing sector. The aim of Lean is to create customer value while eliminating any kind of waste in the organization. Thus, it is important to have efficient, streamlined, and precise production processes and normally use lean measures such as efficiency, quality, and costs to achieve this.

Although the importance of improving production performance, the manufacturing industry can no longer ignore environmental concerns. Despite of its great role in economic growth, its environmental impacts are not satisfactory. SMEs are greatly accountable for carbon emissions, and responsible for 70% of industrial pollution, and are a major source of CO_2 emissions [1]. Thus, there is a need for a fundamental shift from unsustainable growth and development patterns towards sustainable development within the earth's limits.

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Lean and sustainability are two major concepts within the manufacturing industry-each strategy has the potential to maximize the output. Lean to enhance process flow and lead time by minimizing waste from the production process and sustainability to enhance a process and mechanism to attain sustainable development [2].

One of the tools within Lean is the VSM with the purpose of improving production performance by identifying material and waste flows, and specifying the activities' cycle time, downtimes, and delays. From the viewpoint of the customer, it could be understood as everything that comprises value-adding and non-value-adding steps [3]. This approach is based on analysis of a production process by splitting it up into individual value-and non-value-adding steps in the viewpoint of the customer. The next is to improve the process by removing the non-value-adding steps.

The number of tools and methods for environmental assessment on the shop is rather low [4]. One of the most complete tools for environmental assessment is LCA with the purpose to provide in-depth data on environmental life cycle impacts related to all the stages of a product's life [3]. This includes raw material extraction, materials processing, production, transportation, use, maintenance, repair, and disposal or recycling.

In the contemporary scenario, jointly applying LCA and VSA towards environmentally sustainable manufacturing is bringing new perspective into companies. Integrating LCA with VSM offers a path for this restructuring through a model for decision-makers in terms of assessing trade-off between traditional lean measures and environmental aspects in organizations [3]. Based on this, our research aims at answering the following research questions (RQ)s:

- RQ1: What are the motivations for integrating LCA with VSM?
- RQ2: How does LCA integrate with VSM?
- RQ3: What are the benefits of integrating LCA with VSM?

This gives us valuable knowledge about how to successfully integrate LCA into the VSM as a part of a management system, to incorporate environmental aspects along with production performance.

2 Research Method–Systematic Literature Review

To answer our RQs we have chosen a systematic literature review (SLR) as research method. The SLR was conducted based on the approach proposed by Bulto' et al. [5] which highlight SLR as a method reliable to provide collective insight through theoretical synthesis into fields and can be argued as a process that increases the methodological rigor. Our SLR used following criteria:

- The academic databases Web of Science and Scopus for articles were chosen.
- Search string "value stream mapping" AND "life cycle analysis/assessment".
- Publication dates from 2010 to 2022.
- Relevant journal articles and conference paper whose main content focus on the link between LCA and VSM were selected. Papers applying a peer review process and English as language.

After conducting the search 32 papers were found, and the following criteria were used for a final selection:

- Title screening, abstract screening, and paper screening based on inclusion and exclusion criteria.

This resulted in 13 papers that met all criteria.

3 Results and Discussion

3.1 Pattern in Research Literature

Extent literature shows few articles using LCA and VSM simultaneously to reduce environmental impacts and improve production performance. In a period of 12 years the total number of articles assessed was 13 as listed in Table 1. The distribution in journals and conferences showed a broad dissemination, where Procedia CIRP had the largest number but with only 2 articles. Figure 1 illustrates the growth over time in the literature based on publication year, and the pattern on research literature shows that almost 90% were published after 2015. The motivation factors, description of the integration and the benefits are summarized in Table 2. More in-depth descriptions can be found in each of the articles.

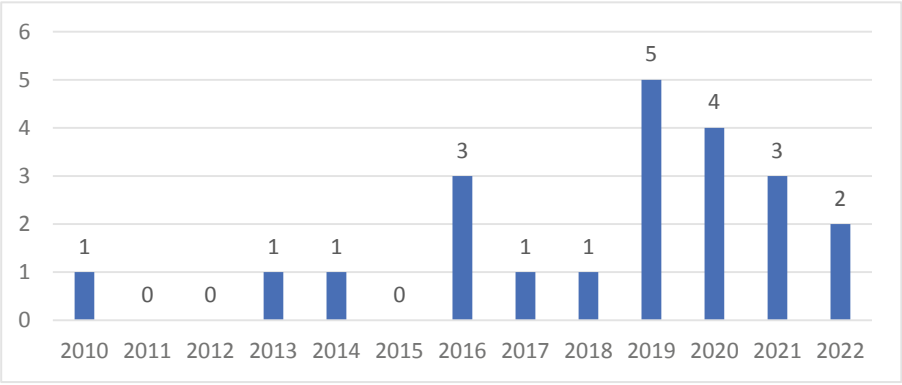

Fig. 1. Distribution of the reviewed literature, 2010–2022.

3.2 Motivations for Integrating LCA with VSM

The first research question was to examine the motivation factors to integrate LCA and VSM for manufacturers. First of all, the LRS shows none were motivated by prioritizing economic growth and traditional lean measures such as efficiency, quality and costs. It was noticed that all of the 13 articles were motivated by sustainability development due to manufacturing industries are greatly accountable for industrial pollution and contribute remarkably to environmental deterioration. In the light of the upcoming crisis of solving UNs sustainable goals and the excessive consumption of natural resources, the LRS shows that lean is more important than ever to reap the benefits from emerging sustainability and integrate with lean for improved sustainability operational performance.

It is seen as important to continuing to improve traditional lean such as productivity, but it is time for a remarkable change. Thus, there is a need for an increased incorporation of environmental consideration into production and management systems.

Table 1. Final selection of articles from the SLR review.

No	Author/year	Title	Journal/conference
1	(Yadav and Gahlot, 2022) [6]	Green Lean Six Sigma sustainability-oriented framework for small and medium enterprises	International Journal of Quality and Reliability Management
2	(de Oliveira Rezende et al. 2022) [7]	A Lean and Green approach for the eco-efficiency assessment on construction sites: description and case study	Clean Technologies and Environmental Policy
3	(Salvador et al. 2021) [3]	Towards a green and fast production system: Integrating LCA assessment and VSM for decision making	Environmental Impact Assessment Review
4	(Mudgal et al. 2021) [8]	LCA of Cast Stone Manufacturing: A Case Study	Procedia CIRP
5	(Heravi et al. 2020) [9]	Energy consumption and carbon emissions assessment of integrated production and erection of buildings' prefabricated steel frames using lean techniques	Journal of Cleaner Production
6	(Samant and Prakash 2020) [10]	Achieving lean and Improving Sustainability through VSM for Complex Manufacturing	IOP Conference: Materials Science and Engineering
7	(Estrada-González et al. 2020) [11]	Decreasing the environmental impact in an egg-producing farm through the application of LCA and lean tools	Applied Sciences (Switzerland)

(*continued*)

Table 1. (*continued*)

No	Author/year	Title	Journal/conference
8	(Shahbazi et al. 2019) [4]	Comparison of four environmental assessment tools in Swedish manufacturing: A case study	Sustainability (Switzerland)
9	(Karunarathna et al. 2016) [12]	Decision support framework for the sustainability of traditional brass industry-a Sri Lankan case study	Proceedings: International Conference on Industrial Engineering and Operations Management
10	(Thiede et al. 2016) [13]	Integrated Analysis of Energy, Material and Time Flows in Manufacturing Systems	Procedia CIRP
11	(Vinodh et al. 2016) [14]	LCA integrated value stream mapping framework to ensure sustainable manufacturing: A case study	Clean Technologies and Environmental Policy
12	(Banawi and Bilec 2014) [15]	A framework to improve construction processes: Integrating lean, green and six sigma	International Journal of Construction Management
13	(Paju et al. 2010) [16]	Framework and indicators for a sustainable manufacturing mapping methodology	Proceedings-Winter Simulation Conference

3.3 Insights from the Description of LCA Integrated with VSM

The second research question was to identify how LCA integrates with VSM. Findings from this showed that the overweight of the articles had done the analysis separately and concluded actions based on the analysis one by one. These articles mostly argue that this gave better overview when prioritizing and deciding actions for improving production performance and reducing the environmental impact. A few of the articles presented a new method, where the principles from VSM and findings from LCA were combined in one model. These articles described a guideline with the steps and a model where the results from VSM and LCA both were illustrated (Table 2).

Table 2. Research work pertains to integration of LCA and VSM.

No	Motivation	Description	Benefits
1	SMEs are greatly accountable for industrial pollution and contribute remarkably to environment deterioration	An eight-facet green lean six sigma framework, which encompasses systematic application of different tools	The incorporated LCA and VSM assist in the analysis of various Green and Lean aspects that provides cause for further improvements
2	A need for a new production mindset–considering the environmental impacts of a building's entire life cycle	A lean and green approach in three steps: 1) VSM, 2) LCA, 3) eco-efficiency assessment	Guide decision-makers on selecting more lean and sustainable construction technologies, materials and/or production strategies
3	Integrating environmental commitment to manufacturing concerns seems unavoidable towards a more sustainable conduct	An approach to a practical integration of LCA and VSM to improve environmental and manufacturing aspects	Decision making improving the environmental performance; environmental preference, economic feasibility, and ease of implementation
4	Reducing the sources of carbon emission due to human activity will help to reduce the Green House Gases	Proposing a method for performing a "cradle-to-gate" CO_2 emissions, by mapping the collected data using LCA and VSM	Greener options, based on quantification of the CO_2 emission of a product from extraction of its raw material to the final product
5	Importance of reducing CO_2 emissions and the energy consumption in construction	To assess the impact of lean techniques (VSM, JIT, continuous flow, TPM), the LCA is used	Reduce environmental impact through waste elimination compared to not using lean techniques
6	VSM suffers from including environmental impact associated with the value stream	Integration of LCA with VSM with a system for score regards to impact of lean and green	Coming up with improvements ideas towards achieving lean orientation and reducing environmental impact
7	The environmental impact of egg production in Mexico is scarcely reported	Design an eco-efficient approach based on LCA and VSM	Helps to facilitate sustainable productivity and leverages benefits that meet lean and environmental needs
8	Few tools and methods exist that specifically target environmental initiatives on the shop floor	Combination of tool to include different types of data collection and analysis	Combining tools lead to better prioritizing, decision-making and increased engagement

(*continued*)

Table 2. (*continued*)

No	Motivation	Description	Benefits
9	Industrialists struggle in decision making process of costing and environmental impact	A decision-making framework for costing and environmental management aspects	Approach for decision making for new designs and products to promote better environmental practices
10	Environmental objectives become increasingly relevant for manufacturing companies in additional to economic objectives	Development of a methodology to analyze energy, material, and time flows of manufacturing systems in an integrated manner	Foster systematic improvement focus on most relevant aspects and also avoids environmental improvements at the expense of economic drawbacks
11	Modern manufacturing systems are expected to be lean and sustainable	A practical framework for VSM integrated with LCA to ensure sustainable performance	Identify specific improvement opportunities for reducing the environmental impacts along with lean
12	The construction industry generates significant waste and produces a host of emissions	A framework integrating lean, green and Six Sigma. VSM and LCA to determine wastes-quantify the environmental impacts	Identify and quantifying wastes and then gives the possibility to embark on improve it afterwards
13	Controlling the environmental impacts is becoming more important for manufactures	A framework with LCA and VSM connecting the production parameters to sustainability indicators	Takes chosen sustainability indicators into consideration

A success criteria when implementing lean as a tool or method is to follow-up actions after the implementation. This study shows that only two of the articles discussed how actions from the analysis should be followed-up. Which is alarming if the intention is creating a sustainable culture for working with the environmental impact.

3.4 Benefits for the Organization

The third research question was to examine the benefit of integrating LCA and VSM in manufacturing companies. This LRS shows that benefits can be categorized within three main areas: assessment of sustainability and production performance, guiding decision making, and fostering continuous improvement extended with sustainability.

First main area regards to assessment of sustainability and production performance aims to provide a structured approach to a practical integration with the aim to apply more sustainable principles in additional to production performance in an organization. By conducting VSM for the current state and future state along with LCA this will give the organization an overview of potential gains. Further, a comparison with the current state and future state for both lean metrics and environmental impacts gives the organization a potential gain from the proposed change.

How to impact environmental reduction without disregarding production performance is something a manufacturer should think carefully on [3]. Therefore, the second main area-guiding decision making based on assessment of environmental impacts in combination with lean metrics-is of high value supporting cleaner industrial practice along with economic concern. The LCA-VSM model by Salvador et al. [3] has developed a decision-making model based on multi criteria assigning score regards to environmental preference, economic feasibility, and ease of implementation. This gives you a benefit based on prioritizing action measures regards to level of contribution along with implementation potential. By comparing current and future state, this can give the organization a valuable overview hindering action that might have conflict results. Some action might not fully contemplate both dimension–environmental and lean measures. Other action that might improve on and worsen the others, as well as some might improve or worsen both. Thus, the benefit will be to guide decision makers to either approve or withhold action promoting greener and more economical initiatives.

The last main area is about the benefit-fostering an **e**xtended systematic continuous culture to include sustainability in a traditional lean concept. When performing an analysis where the two methods are combined, it results in the development of a culture for continuous improvement where environmental impacts and economic activities are evaluated in a symbiotic collaboration. Thiede et al. [13] highlights that such approach will benefit by fostering a systematic improvement culture. They argue that focusing and progress by systematically working on most relevant aspects and also avoiding environmental improvement at the expense of production performance is a key to making sure that this will contribute to fostering continuous improvement.

4 Conclusion

The aim of this paper was to provide a review of literature on integration of LCA and VSM in manufacturing regarding motivational factors, how to integrate them and the benefits for the manufacturers.

Firstly, the main motivational factor identified is the potential to extend existing lean tools to include tools based on sustainability, as an approach towards ensuring sustainable benefits. All papers show that the main motivational factor for LCA and VSM integration is always the want of environmental improvement, dealing with the climate crisis and the possibility to incorporate this view with Lean. The LRS shows that it is time for a radical change from a business where decisions tend to be made by prioritizing profits, to including reduction of negative environmental impacts of the economic activities. Undoubtedly, integration of LCA with VSM is seen as a valuable solution providing a possible path for sustainable productivity. Combining LCA with VSM can reduce the environmental impacts while caring for economic aspects. Supporting an approach of integrating the two methods should be done to apply more sustainable principles in an organization.

Secondly, there are two main ways in which LCA is integrated with VSM. The first way to do it is conducting separate analyses and thereafter looking at them separately to investigate the improvement potential within production and environmental impact. The second way of doing it shows the making of a model where both methods are integrated,

so that VSM and LCA are used as a combination to select and prioritize areas in the value chain to do environmental impact reductions and improve production performance. Here, a few studies also use this for specific follow-up activities in the companies afterwards.

Lastly, the LRS identified three main benefits of integrating LCA with VSM. (1) Assessment of sustainability and production performance: By integrating the two methods, one achieves a structured, cohesive overview, presenting a thorough assessment of environmental impacts and production performance. (2) Guiding decision making: By combining the two, it can be used as a decision support tool that makes sure a company takes take of its environmental impacts while not sabotaging the economic activity. (3) Fostering continuous improvement extended with sustainability: When performing an analysis where the two methods are combined, it results in the development of a culture for continuous improvement where environmental impacts and economic activities are evaluated in a symbiotic collaboration.

A limitation of this study is the lack of research within this field with only 13 articles in a period of 12 years. Future research opportunities should include more empirical research on manufacturing industry implementing LCA with VSA. This to identify opportunities to embark on and barriers to solve.

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