

# The effect of Lean manufacturing practices on the environmental performance: a literature review

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**Abstract:** In recent years, the growing interest in the topic of environmental sustainability has prompted the academic community to analyze this topic in increasing depth. In particular, many studies deal with the interaction between environmental sustainability and Lean manufacturing practices. The objective of this study is to review the scientific literature related to Lean Manufacturing and its application to promote sustainability, particularly to reduce energy consumption. Through a systematic literature review, the ultimate goal of this paper is to have a general overview of the scientific research on this topic. Specifically to understand the existing body of knowledge by identifying which Lean practices have been studied for problems related to reducing energy consumption. In addition, this study aims to identify possible gaps and foresee what future research directions might be for this topic.

**Keywords:** Lean manufacturing, Lean practices, environmental sustainability, environmental performance

## I. INTRODUCTION

For several years, awareness for the exploitation of natural resources on earth to support all of humanity's frenetic activities is having negative consequences on our planet. Industrial activities are one of the most significant sources of environmental pollution. Industrial pollution can include emissions of hazardous chemicals into the air, toxic discharge into water, and dangerous waste deposited in landfills. These activities can have a negative impact on human health and on the environment, causing problems such as groundwater contamination, loss of biodiversity, and climate stress (Gaikwad & Sunnapwar, 2020).

The environmental concerns have contributed to organizations taking an active role in designing recyclable products, as well as developing more sustainable services and production processes.) (Benabdellah et al., 2021). Some fundamental prerequisites for achieving this goal are the use of effective strategies and operations, enabled by an energy and resource-saving approach, adequate technology, human capabilities, and an effective organizational context. Lean Production is recognized for its persistent goal of eliminating waste from industrial workshops and service providers.

The Lean organizational model is based on the Toyota Production System of Toyota Motor

Company, which was able to provide an approach that allowed the company to remain competitive and even thrive in the highly competitive automobile market (Womack et al., 1991). Lean thinking has driven the provision of solutions that return more value in more effective ways, i.e. using less human effort, time, inventory, less energy, fewer re-sources and residues. However, current challenges require not only highly productive and responsive production systems, but also eco-efficient systems. (Maxime et al., 2006). Both concepts aim to minimize all types of waste, in all their forms and appearances, including the most difficult to manage, namely the invisible ones (Thanki et al., 2016). This must be achieved without increasing production costs, without hidden external consequences on the environment in the short and long term, so that sustainability is truly pursued and achieved. Despite the interest on this topic there is still room to investigate and expand knowledge. In particular, the link between the Lean approach and sustainability still shows many lines of research to be investigated (Garza-Reyes, 2015). The aim of this study is to research and critically analyse the contributions in the literature. Through a systematic literature review, the paper analyse the effect of Lean manufacturing practices on environmental sustainability, . Section 2 presents the structure of the search done for the selection of studies analysed in the literature

review. A special focus will be on studies investigating eco-efficiency performance related to energy consumption. Section 3 presents the results of the search through a narrative analysis of the literature. Finally, section 4 discusses the results of the analysis and defines possible future lines of research on this topic.

## II. RESEARCH METHOD

This session explores how through the methodology of systematic literature review, the authors were able to gather significant contributions from the literature. The research is carried out to examine the scientific literature related to Lean Manufacturing and its application to promote sustainability, particularly in reducing energy consumption. The ultimate goal is to have a general overview of the scientific research on this topic and understand the existing body of knowledge, identifying possible gaps and predicting what future research directions might be for this subject. In order to guide the papers' investigation, two research questions were formulated, and thanks to this paper they will be answered. The research questions are: (1) What are the emerging topics in today's literature on lean manufacturing practices and their influence on environmental sustainability performance; and in particular on eco-efficiency performance related to energy consumption? (2) What are the main avenues for future research on lean manufacturing and environmental sustainability?

### A. Articles selection

Literature review allows identifying areas where further research is needed, while at the same time identifying those areas where there is already a vast number of studies (Webster & Watson, 2002). As a literature review is a systematic, explicit, and reproducible method, the research question presented in the previous section was addressed based on a systematic review of the existing literature. A systematic literature review (SLR) is a method that adopts a precise, transparent, and explicit approach that includes a series of phases to ensure adequate rigor and transparency in the literature review process (Tranfield et al., 2003).

Denyer & Tranfield, 2009 believe that a systematic literature review consists of the following five consecutive stages: (1) formulating the question, (2) identifying the studies, (3) selecting and evaluating the studies, (4) analyzing and synthesizing, (5) communicating and using the results. To ensure the transparency of the

systematic review process, is needed to explain in detail how individual steps were conducted. In this phase of the systematic literature review, the search strings were defined. The search strings included (lean manufacturing sustainability), (environmental lean manufacturing), (lean manufacturing eco-efficiency), (lean manufacturing energy efficiency), and (lean manufacturing sustainable development). The research process involved defining a specific focus for the research and excluding articles that did not reference the inclusion of both terms or presented a relationship between the two. Additionally, manual checks were performed on all articles that met the search criteria, based on the abstracts of the articles, in order to eliminate those that did not clearly address the topic of lean and green or addressed this topic in contexts other than production. Finally, articles that did not fall within the scope of the research due to the date or type of article were not considered. Articles that also involved social and economic perspectives of sustainability were also excluded.

The research results included only articles that presented a theoretical model or a case study. Additionally, these articles had to be peer-reviewed, published in academic journals, and proceedings of international conferences, these sources are the most useful and reliable for literature reviews. Based on this and the search criteria described in this section, a final sample of 37 articles referring to lean manufacturing and eco-efficiency was identified.

### B. Analysis and synthesis

All documents were collected and analyzed to extract some preliminary insights. In order to do that some quantitative analysis were made. Fig. 1 shows the proportion of publication sources in relation to (a) whether articles were published in journals or conference proceedings, (b) the number of publications per year and (c) the proportion of articles based on their focus.

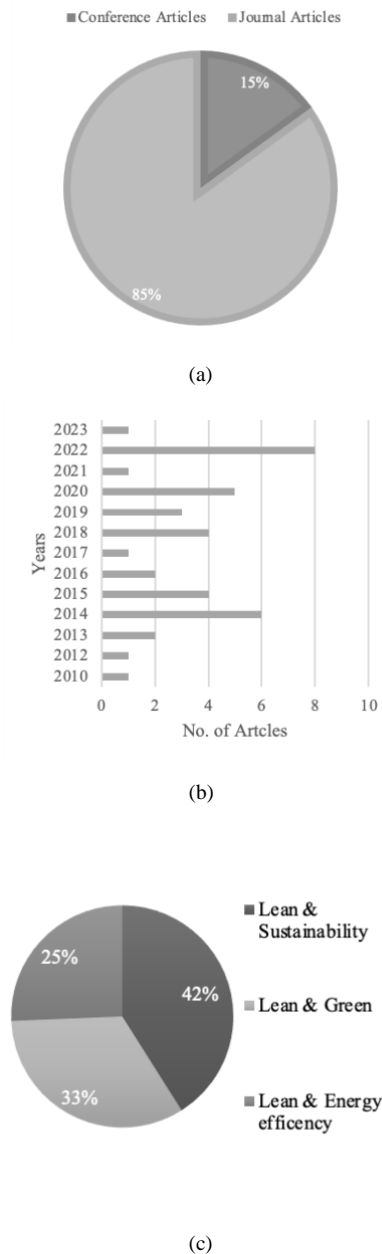


Figure 1. Descriptive data- (a) Proportion of journal conference publication, (b) Year of publication, (c) Number of publications per focus

In general, the results indicate that the lean-sustainability topic continues to have a particular interest and popularity within the research community, as 45% of the publications were published after 2020. This suggests that the lean-sustainability theme is still a new and expanding research field. This can be an interesting fact to understand how much interest in these issues has increased in recent years. Fig. 1 (a) also indicates that, although conferences have been used by researchers to disseminate the results of their lean-

sustainability research, journal publications are still main portion.

This preliminary analysis of the articles showed that there is an association of the concepts of sustainability and eco-efficiency with that of lean. As can be seen in Fig. 1 (c), 33% of the articles recognize the combined Lean-Green approach. Some authors recognize the connection between Lean and sustainability (41%), so in these articles the Lean approach is used to promote sustainability without a combined link with Green practices. Finally, 26% of articles focus on the use of Lean practices to reduce energy consumption within facilities and production processes. The integration and implementation of Lean and Green practices, especially when resources are limited, is a challenge for companies, which some studies suggest requires a supportive framework and cultural transformation. In addition, some authors believe that efficient production along with environmental initiatives provide favorable conditions for maintaining the pursuit of continuous improvement to remain competitive and/or gain a competitive advantage, while providing the operational versatility to respond quickly to market volatility.

### III. FINDINGS

In this session a review of the selected literature will be developed to find answers to the two research questions of this paper. In particular, after conducting a quantitative literature review will now focus on the type of Lean practices used to promote environmental sustainability.

#### A. *The impact of lean manufacturing practices for environmental sustainability*

Based on the various articles present in the literature, the major lean practices used by scholars in this field have been identified. As can be seen from the graph in Fig. 2, the most commonly used lean practice, with a large margin over the others, is Value Stream Mapping, which is present in 25 articles. The second most used lean practice is Kaizen, which is present in 10 articles. The third most used practices are Lean Six Sigma. Regarding the latter, some articles in the literature did not specifically mention the lean practices used, such as (Prasad et al., 2016) or used many lean practices without using a precise theoretical model for their application. For example, (Diaz-Elsayed et al., 2013), in which various lean practices were used such as reducing internal and external setup times, increasing quality rates, improving machine

availability, extending tool life, and reducing batch sizes. Another example is the work of Kurdve et al. (Kurdve et al., 2014), in which lean practices such as standardized work, total quality, pull system, employee involvement, customer focus, stability and robustness, and workplace management were used. For this reason, it was decided to include all of these articles under the category "Others".

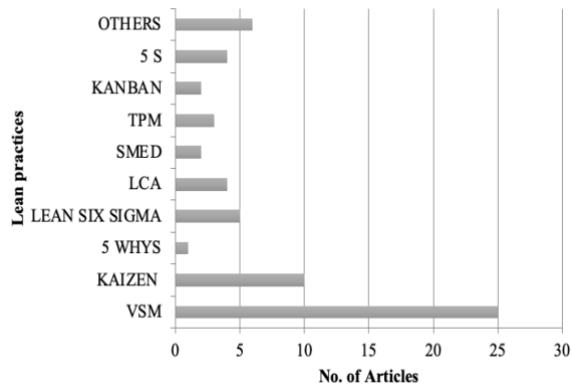


Figure 2. Lean practices mentioned per article

*B. The value stream map for environmental sustainability*

As previously discussed, the Value Stream Map (VSM) is the most widely used lean practice. However, it can be observed from the literature that not all scholars use this lean practice in the same way. In some articles, it is used as the sole practice, while in other cases, it is combined with other lean practices to promote the sustainability or energy efficiency of processes.

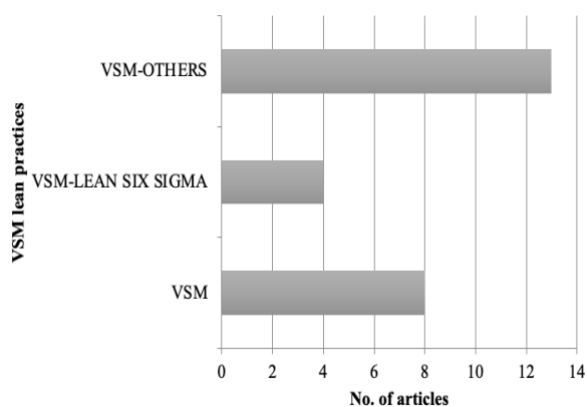


Figure 3. Different types of VSM mentioned per article

As Fig. 3 summarizes, VSM is the practice used in 8 articles. One of the most relevant articles on this topic is certainly that of William Faulkner and Fazleena Badurdeen from 2014 (Faulkner &

Badurdeen, 2014), in which a new VSM, called sustainable VSM (Sus-VSM), is created according to the traditional VSM tool. Through this new tool, the authors were able to visually capture the sustainability performance of the production line. It emerged that the metrics and visual symbols used captured the most important criteria related to environmental sustainability performance (in addition to economic ones) for a subsequent in depth analysis with other more comprehensive techniques. The Sus-VSM helped the company to have an initial evaluation of the production line status and to understand which processes were critical in terms of sustainability by calculating the different cycle times and the number of stocks.

The validity of this new model that associates lean with sustainability is demonstrated in another article by Brown et al. (Brown et al., 2014), which shows how the sus-VSM, created by William Faulkner and Fazleena Badurdeen (Faulkner & Badurdeen, 2014), can be applied to scenarios with different manufacturing system configurations to evaluate their generalizability and clarify their use under challenging conditions. The three case studies conducted reveal that valuable information on the sustainability performance of production systems can be obtained through Sus-VSM, regardless of the nature of the system configuration. Schilling et al. (Schilling et al., 2015) have extended the traditional VSM into the EVSM, which is based on a dual evaluation of time and energy input, through a method called "Dual Energy Signature" that allows for the breakdown of process related energy consumption using "value-added" and "non-value-added" criteria.

Instead, Garza Rejes et al. (Garza-Reyes et al., 2018) aligned the VSM approach with the PDCA cycle, an effective method for enabling the implementation of E-VSM studies in a systematic, repeatable, and continuous improvement cycle. The PDCA approach is a continuous improvement cycle that helps manage processes and constantly improve results through planning, execution, verification of results, and corrective action.

Regarding E-VSM, the strategic objective for its application in the case organization was to effectively identify and measure environmental waste in value stream processes and formulate and undertake appropriate strategies to eliminate/minimize them towards the future state.

Rezeian et al. (Rezaeian et al., 2018) used an energy-oriented VSM to map the entire production process and identify sources of energy waste. They

subsequently analyzed the collected information and identified opportunities for improvement, suggesting solutions to reduce energy consumption and improve the overall efficiency of the production system. The energy-oriented VSM used in this study helped to better understand the flow of energy within the production process and identify critical points for improving energy efficiency. In this way, it was possible to develop a targeted improvement strategy, based on concrete data, which led to an increase in the energy efficiency of the production system. In the work of Muñoz-Villamizar et al. (Muñoz-Villamizar et al., 2019), the VSM was used as an analysis tool to identify opportunities for productivity and environmental performance improvement in a company and to propose specific actions to improve process efficiency and reduce environmental impacts. Three main environmental impacts were identified: waste, energy use, and CO<sub>2</sub> emissions. Based on the results obtained from the VSM, several improvement actions were proposed, including the implementation of a waste management system and the adoption of more energy efficient technologies.

Another widely discussed approach in the literature is the integration of VSM and Lean Six Sigma practice. For example, in Vieira et al. (Viera et al., 2019) article, researchers applied the Lean Six Sigma methodology and Value Stream Mapping (VSM) to improve the efficiency of energy assessments. They used VSM to map the workflow of energy assessments and identify any unnecessary or delay-causing activities. Later, they used the Lean Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) framework to analyze the collected data, identify the root causes of problems, and propose solutions to improve the energy assessment process. The combined approach of VSM and Lean Six Sigma reduced the time required for energy assessments and improved the quality of the analyses.

In conclusion, this series of articles uses VSM and its extensions as the only lean methodology to promote sustainability by first visualizing various wastes and then eliminating them through various actions.

#### IV. DISCUSSION

This section answers the research questions proposed above through a discussion of the literature review conducted.

Addressing the first research question, the literature indicates that scholars and academics are increasingly studying the link between environmental sustainability and lean manufacturing (Benabdellah et al., 2021). The literature review shows that, the influence of lean manufacturing practices with the green manufacturing paradigm and how these two paradigms have been integrated over the years (Taddeo et al., 2019). Particularly in today's literature, the impact of lean manufacturing practices on environmental sustainability is increasingly investigated. In particular, in several studies the direct effect of lean practices is manifested on environmental sustainability through improved eco-efficiency performance. On the other hand, it is interesting to note that not all lean manufacturing practices are equally present within the literature review. In fact, the previous section extensively analyzed the role that the Value Stream Map tool now possesses for improvements related to environmental performance. The literature review revealed how this tool over the years has been not only analyzed, but more importantly modified and adapted from its original function. The studies analyzed show how the value stream map tool has been modified, and integrated with other paradigms, in order to be able to more effectively target issues related to environmental sustainability.

Addressing the second research question, the literature review points to gaps that have not yet been fully investigated. In particular, it can be analyzed that to date link between lean manufacturing practices and environmental sustainability is well established. On the other hand, however, factors that may moderate this relationship are still under-investigated. Unlike more widely studied links such as the impact of lean manufacturing on operational performance, for environmental performance it is still unclear whether in what way certain contextual factors can act as moderating variables.

Another gap that emerges from the literature deals with how lean manufacturing practices can be modified to make them more suitable for improving environmental performance. Indeed, as with the value stream map, other lean practices can be investigated so that they can be modified and adapted to make them more effective for problems related to environmental sustainability. Furthermore, the relationships between various lean manufacturing practices are still poorly investigated in today's literature. In particular, it is

not yet clear whether the combined use of different lean practices can create synergies, capable of influencing environmental performance. It is also not yet clear whether there are cause-and-effect relationships among the various lean practices used to achieve better environmental performance.

A final gap that has emerged in the literature is related to the sequence in which a company decides to implement lean practices to achieve better environmental performance. In the majority of the studies analyzed in this literature review, case studies are taken that implement one or more lean practices. Despite this, there is a lack of studies that define a pathway of implementation of lean practices that companies can follow to achieve high sustainable performance.

## V. CONCLUSION

The study presented in this article offered a systematic review of the literature, answering two research questions. The paper exposed at a theoretical level the emerging themes in today's literature on lean manufacturing practices and their influence on environmental sustainability performance. In addition, this article helped to define future research directions.

Through a systematic review of the literature, it became apparent that the relationship between lean manufacturing and environmental sustainability is a topic of growing interest. Regarding the first research question, the systematic literature review identified how lean manufacturing practices positively influence environmental sustainability and in particular eco-efficiency performance. In particular, today's literature is very focused on the study of one particular lean practice, the Value Stream Map. This practice has been taken into analysis by several authors, to be modified and adapted to needs related to environmental performance. In addition, the systematic review of the literature has revealed several knowledge gaps related to this topic. Consequently, to answer the second research question, several lines of research yet to be explored were identified. The future lines of research are summarized as: (a) Investigating moderating effects of the Lean manufacturing practices-sustainable performance link, (b) How Lean manufacturing practices can change to better meet the needs of environmental performance, (c) Investigating synergies and cause-effect links among Lean manufacturing practices leading to high sustainable performance, (d) Identifying a pathways of implementation of Lean

manufacturing practices leading to better sustainable performance.

This paper has the following limitations. The limitation lies in the fact that we used specific keywords for item identification, so some valuable contributions may have been lost at this stage, or in the later screening stages where the number of items was selected.

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