Review

Lean Six Sigma Impact Analysis on Sustainability Using Partial Least Squares Structural Equation Modeling (PLS-SEM): A Literature Review

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Abstract: The Lean Six Sigma (LSS) philosophy and sustainability have become topics of interest since the 1990s; they have generally been analyzed together since 2012. Numerous professionals, managers, and researchers have sought methodologies by which to assess their impact and know their effectiveness within companies. During the past decade, the application of partial least squares structural equation modeling (PLS-SEM) has been widely accepted in various modeling, prediction, or multivariate analyses as a way to measure the impact of LSS on sustainability. This study conducts a literature review to identify the use of PLS-SEM in measuring the impact of LSS on sustainability. A systematic review methodology has been employed, applying five search criteria to three scientific database platforms. This approach has been helpful to identify PLS-SEM as a valuable methodology for measuring the impact of LSS on sustainability. One of the research findings is that LSS practices positively impact 83% of economic indicators, 78% of environmental indicators, and 70% of social indicators. This article creates a theoretical foundation for future research on these issues, outlining research opportunities to generate future studies. It also allows researchers and managers who are interested in improving sustainability indicators to access valuable knowledge regarding what types of LSS tools could be used.

Keywords: lean; Six Sigma; Lean Six Sigma; impact; sustainability; economic; social; environmental; PLS-SEM

1. Introduction

Many world-class manufacturing companies use the concept of lean (L) as an improvement method. Its objectives are eliminating waste and non-value activities in production processes, cost reduction, and achieving faster service with less human effort, time, and equipment by applying tools and techniques that fulfill these objectives [1,2]. Six Sigma (SS) is used in manufacturing industries to reduce and eliminate defects and variability [3] in production, delivery and cycle times, forecasting, quality, customer service, and logistics, among others [4]. It uses various methods, such as "define, measure, analyze, improve and control" (DMAIC) for existing processes, and "define, measure, analyze, design, and verify" (DMADV) for new products or processes [5]. Both L and SS are complementary approaches to achieving good performance [6]. Their integration is known as Lean Six Sigma (LSS). LSS identifies customer needs and eliminates waste while reducing process variability [7]. As Nunes (2015), Costa (2021), and Snee (2010) have mentioned [6–8], this is the preferred approach to driving continuous improvement in production.

The application of L, SS, and LSS philosophy has spread in various sectors, ranging from manufacturing to public and private sectors, such as software industries, financial services, healthcare, education, sales [9], construction, human resources [3], the food industry [10], and the chemicals, petrochemicals, and pharmaceutical industries [11], among

others. Malesios et al., Antony et al., Elkhairi et al., Gandhi et al., and Singh et al. [12–16] indicate that one of the main factors in adopting L practices corresponds to the company's size. Their application is more challenging in small and medium enterprises, due to technical barriers such as the lack of planning, experience, strategic perspective, management commitment, support, cooperation, and trust. Elkhairi et al. [14] consider limited resources to be economic barriers and resistance to change to be social barriers. In comparison, Vlachos and Siachou [17] mention knowledge acquisition, company organizational culture, and training as critical success factors in LSS implementation.

Despite the barriers presented in different industries, proper L, SS, and LSS applications improve the efficiency, flexibility, and quality of the processes and improve the sustainability of each of the projects [18,19]. Sustainable development integrates three pillars: economic, social, and environmental [20], and it has become one of the primary objectives of any organization [21]. According to Kader et al. and Khodeir et al. [22,23], there is a close relationship between the success of LSS implementation and operational performance by reducing resources and costs; in social performance, by ensuring health and safety of workers, generating a better company work climate; in environmental performance, by eliminating waste, reducing pollution and improving resource conservation.

Review articles by Caldera et al., Ruben et al., and Francis et al. [24–26] evaluate the impact of L on the environmental pillar. Ciccullo et al. [27] analyze the impact on the social and environmental pillars without considering the economic pillar. Few studies consider the three pillars simultaneously [28–30]. However, only Henao et al. [28] refer to the methods used to evaluate the impact of L in terms of the economic, social, and environmental pillars.

Researchers' efforts to evaluate the impact of LSS on industries' sustainability use different methods, such as the analytic network process (ANP) [31], data envelopment analysis (DEA) [32], interpretive structural modeling (ISM) [33], multi-criteria decision-making (MCDM) [34], multilevel regression [35], multiple linear regression (MLR) [36], covariance-based structural equation modeling (CB-SEM) [37], and partial least squares structural equation modeling (PLS-SEM), among others.

Using PLS-SEM as a statistical method guarantees an adequate level of confidence and robustness by which to determine the relationships between the constructs [38]. PLS-SEM represents a significant advance compared to traditional analysis methods, making it the most widely welcomed emerging approach to determining the relationship between LSS and sustainability [12]. Furthermore, a study by Cataldo et al. [39] proposes the PLS-SEM method as being suitable for determining sustainability indicators. The nature of the model allows researchers to identify the critical variables that provide accurate and reliable information on the relationships between a series of constructs.

The preference for this method for the analysis of sustainable industries is based on the advantage of simultaneously analyzing a large number of dependency relationships [39,40]. PLS-SEM is suitable for models that seek prediction and theory development; it is also more flexible regarding research sample size, with a good model fit [41]. Additionally, PLS-SEM models do not require data normality [42] and can handle predictive and reflective models [43].

The data required for modeling can be obtained from secondary data such as files and primary data through surveys. The most common technique is the use of surveys. PLS-SEM will collect such data and use statistical techniques, such as Harman's single factor and the full collinearity assessment test, to determine whether there are common method biases that reveal an inadequate application of the external and internal measurement model. PLS-SEM requires the reliability and validity of the variables or constructs before establishing their relationship. Therefore, it will first measure the factor loadings, internal consistency (using Cronbach's alpha and composite reliability), convergent validity (using the average variance factor extracted), and discriminant validity (using the Fornell–Larcker criterion and the heterotrait–monotrait ratio of correlations). Finally, it will evaluate the

effects between variables and the predictive quality that allows the acceptance or rejection of the hypotheses [44].

Researchers using PLS-SEM will have reliable constructs and indicators for analyzing the relationship between LSS and sustainability. Therefore, the importance of this study lies in providing the variables that address the impact of LSS on sustainability to avoid conceptual errors in future models or studies.

This review analyzes the use of the PLS-SEM method to measure LSS impact on the three pillars of sustainability, identifying the lean constructs and indicators for the determination of the prediction model, including the resulting interaction between the constructs.

Knowledge of these findings will allow researchers to deepen their understanding of the LSS constructs, identify the most widely used and validated indicators, determine their interaction with sustainability, and ensure the reliability and fit of the model's results. Furthermore, they will provide information for constructing models for future research that is intended to measure this impact on industries. This will also allow industries to identify the best practices that improve sustainable pillars and help them to achieve their business objectives.

This study is structured as follows. The subsequent section describes the research objectives, followed by the methodology adopted for the literature review. The result and discussion are presented in four main sections. Finally, the conclusions, implications, and future research are outlined.

2. Research Objectives

This paper investigates PLS-SEM utilization in measuring the impact of LSS on the three pillars of sustainability. Therefore, its aims are: (1) to learn the L, SS, or LSS constructs used in scientific research, employing the PLS-SEM methodology; (2) to identify which indicators in each sustainability pillar are impacted by LSS; (3) to identify L, SS or LSS constructs that have a positive impact on the sustainability pillars.

3. Methodology

Understanding the relationship of LSS terminology with sustainability has become essential for industries because it improves productivity and performance, generates cleaner production, and a healthy environment [45] that persists over time [46]. This impact has been measured over time using various statistical tools. One of these is PLS-SEM [12]. Therefore, a systematic literature review (SLR) has been used to determine if PLS-SEM is widely used to evaluate the impact of LSS on sustainability.

The SLR consists of five phases: (1) establishing the research scope, (2) article identification, (3) review and selection of articles, (4) analysis of the results, and (5) reporting the results (adapted from [47,48]); the structure of the review is shown in Figure 1. It is essential to follow these steps to avoid including unnecessary papers that are unrelated to the topic and may introduce information biases [49].

3.1. Establish Research Scope

Specific research questions have been formulated for this literature review, establishing the scope of the research [50]:

1. How many articles have been published on the impact of L, SS, and LSS tools on sustainability using PLS-SEM? From what year? Which type of industries?
2. What are the main L, SS, or LSS constructs used in scientific research to measure the impact on sustainability through the application of PLS-SEM?
3. Which sustainability pillars and indicators are commonly used in the articles?
4. Which L, SS, or LSS constructs positively affect sustainability indicators?
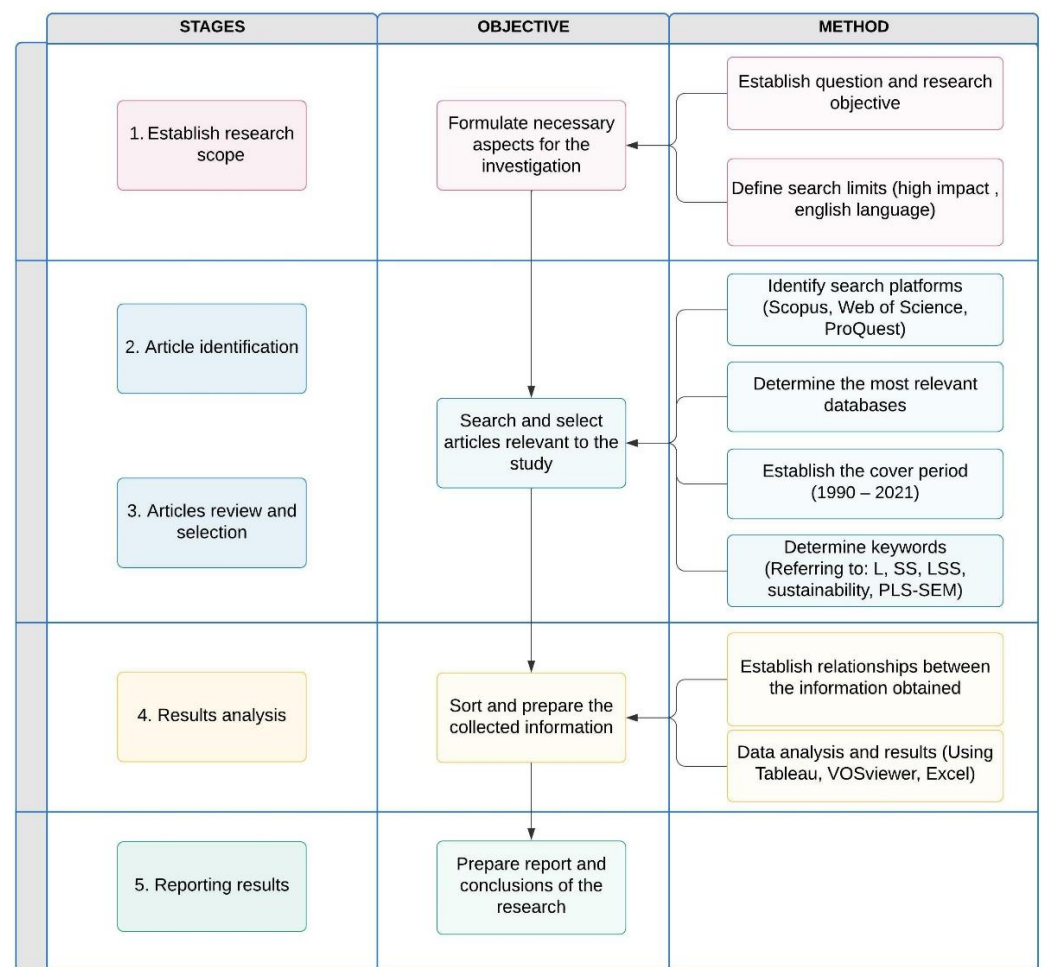
Figure 1. Literature review structure adapted from [47,48].

3.2. Article Identification

In this study, three search platforms, Scopus, Web of Science, and Pro-Quest, comprising a large amount of material covering the topics of L, SS, LSS, manufacturing, and sustainability, were employed [28].

The research period was determined. It would include papers published from 1990, the year in which the multivariate analysis technique was introduced, until the present day [51].

It is essential to determine the keywords necessary to identify the variables related to the topic of study. Words or phrases can be searched by applying categories such as the title, keywords, or abstract [52]. As shown in Table 1, using these terms will identify the search string for the research.

Table 1. Research keywords.

	Characteristics	Keywords
1.	LSS	TITLE ("lean" OR "Six Sigma" OR "Lean Six Sigma" OR "lean manufacturing" OR "lean tools" OR "lean practices" OR "management continuous")
2.	Sustainability	TITLE ("environmental" OR "social" OR "economic" OR "sustainability" OR "sustainability impact" OR "impact" OR "sustainable" OR "sustainable performance" OR "green")
3.	PLS-SEM	ALL ("PLS" OR "partial least squares" OR "PLS-SEM")

3.3. Articles Review and Selection

This paper used the following review criteria, and the results can be seen in Table 2.

Table 2. Search results summary, sorted by database platform.

	Scopus	Web of Sciences	Pro-Quest
First criterion	9312	46,663	17,944
Second criterion	1207	17,035	16,943
Third criterion	101	81	244
Fourth criterion	40	26	3
Fifth criterion (Result)	40	7	3

First Criterion: Articles that contained the search terms, were written in English, published between 1990 and 2021, and from high-impact journals are considered. The search obtained 9312 articles in Scopus, 46,663 in Web of Science, and 17,944 in Pro-Quest, finding 73,919 articles in total.

Second Criterion: Terms related to sustainability were then added to the search, i.e., those related to LSS and sustainability were obtained. Those papers that include the economic, social, and environmental pillars were considered, regardless of whether they were evaluated separately or simultaneously. The new search obtained 1207 articles in Scopus, 17,035 in Web of Science, and 16,943 in Pro-Quest, finding 35,185 articles in total.

Third Criterion: Terms related to PLS-SEM were then added to the search. In this search, "ALL" was used because authors could then place PLS-SEM as being in the title or elsewhere. From this search, 101 articles were found in Scopus, 81 in Web of Science, and 244 in Pro-Quest, a total of 426 articles.

Fourth Criterion: A detailed article review was then carried out through a manual verification of the title, keywords, and abstract to identify if the article related to the impact of LSS on industries' sustainability, as evaluated with the PLS-SEM method. Thus, 40 articles were found in Scopus, 26 in Web of Science, and 3 in Pro-Quest, with 69 articles found in total.

Fifth Criterion (Result): By using three platforms that contained different databases, it was inevitable that there would be duplicated articles, so at this point, the duplicate article's elimination was considered. Scopus was the first database platform to be reviewed; all the information collected was unique and different, however, when reviewing the Web of Science database, only 7 articles were different from those previously found. When searching Pro-Quest, the 3 articles that were found differed from the previous ones, resulting in 50 articles to be analyzed later.

The search results, arranged by criteria, are shown in Figure 2.
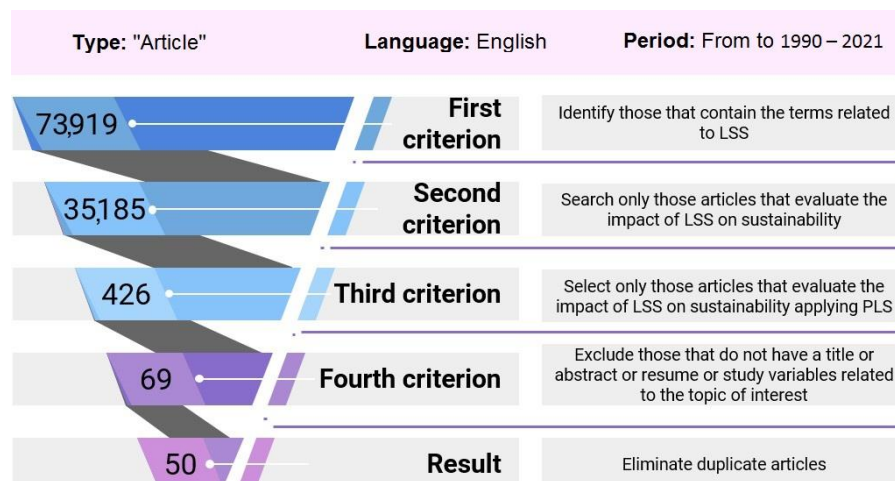
Figure 2. Summary of search methodology and results.

4. Results and Discussion

4.1. Study General Overview

Many business research studies have used PLS-SEM for analysis since the 1990s [51], from predictive modeling [53] to discussion and consistency analysis [54]; however, it was only from 2012 that it was employed to measure the impact of the L, SS and LSS philosophies on sustainability. The first publication, by Vinodh et al. [55], analyzed the impact of lean in a general way in Indian industries. It was considered as part of lean philosophy, affecting customer response, changes in business, just in time (JIT) flow, supplier development, and cellular manufacturing. Operational performance was measured according to the number of defects and the production cost, finding a strong positive relationship in the model as presented and analyzed with Visual PLS.

This result is supported by Tăucean et al. [56], who indicate that since 2012, the study of L and sustainability concepts has intensified simultaneously, now being among the most popular research topics [57]. As shown in Figure 3, from 2012–2015, only one paper/year has been found regarding the impact of L on sustainability and applying PLS-SEM. After 2018, the publication rate went up to more than nine papers/year, and the highest value was in 2020, with fifteen papers.
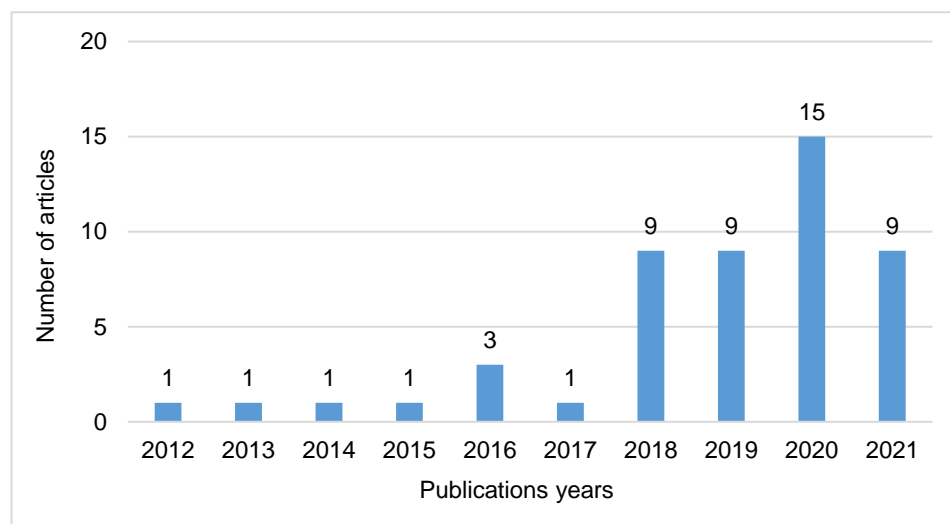
Figure 3. The number of articles published per year.

The reviewed papers reveal the country of their study, except in the case of the research carried out by Kovács et al. [58]. The authors do not mention the specific countries studied but indicate that their research was carried out based on a sample taken from industries in America, Asia, Africa, and Europe. Other authors have analyzed how L practices impact sustainability in several countries that belong to the same continent, such as the study by De Giovanni et al. [59], who surveyed industries in Italy, France, the United Kingdom, Spain, Germany, Portugal, the Netherlands, and Belgium. It is clear from Figure 4, through a chromatic map, that Malaysia and Indonesia are the countries where more articles related to this topic have been published, followed by Brazil with five papers, and India with four.

Table 3 shows a breakdown of authors who have used PLS-SEM to measure the impact of L, SS, and LSS on sustainability, sectioned by countries and by years. On the one hand, it can be seen that the most significant number of studies are in Asia, with 28 papers. According to Ndubisi et al. [60], Asia is considered one of the fastest economic growth areas worldwide, leading organizations to seek more sustainable production to comply with international regulations and support the bottom line [61].
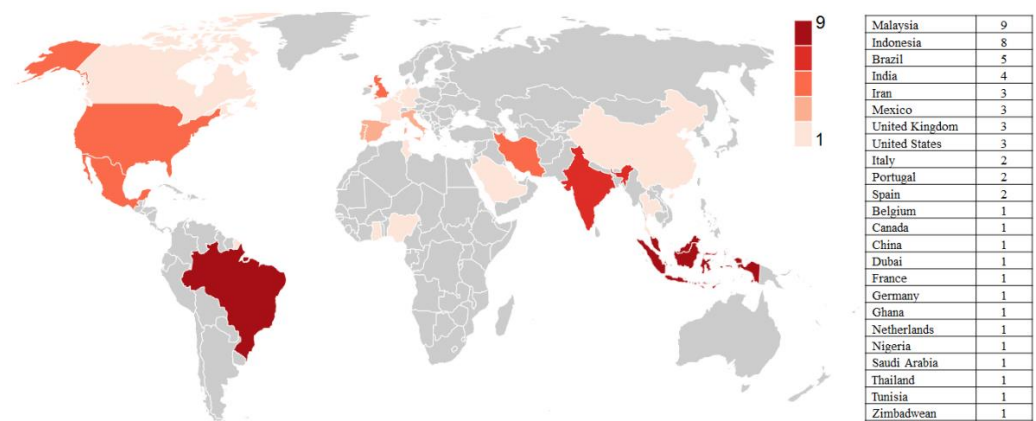
Figure 4. Chromatic map of countries, analyzed according to the number of reviewed articles.

On the other hand, fewer studies are in Africa, with five papers. According to Allu and Emuze [62], considering the lack of knowledge and scarcity of resources for sustainable innovations, few industries implement these practices, so it is not a topic that attracts further development and research in such countries [63].

Table 3. Geographic area and publication years, arranged by their reviewed articles.

Continent	Country	Publication Years					
		2012–2013	2014–2015	2016–2017	2018–2019	2020–2021	Total
America	Brazil Canada Mexico United States	[64]		[65]	[66–70]	[10,58,71–74]	13
Africa	Ghana Nigeria Tunisia Zimbabwe				[75,76]	[58,77,78]	5
Asia	China Dubai India Indonesia Iran Malaysia Saudi Arabia Thailand	[55]	[79]	[80,81]	[82–90]	[2,21,58,91–102]	28
Europe	Belgium France Germany Italy Netherlands Portugal Spain United Kingdom		[103]	[104]	[105,106]	[58,59,107]	7
TOTAL		2	2	4	18	27	53

The author who has published the most papers is Godinho Filho, who has written four papers studying the impact of LSS on companies' sustainability in Brazil. The first study was conducted in 2016, considering the application of three lean tools, statistical process control (SPC), employee involvement, and total productive maintenance (TPM) in 16 industries, to measure operational performance through stock levels and operational costs, obtaining a positive relationship between the constructs [65]. Subsequently, in 2020, he authored two publications [71,108]. One of them added seven lean tools to his research and evaluated the operational performance. Environmental performance was measured as a single construct, obtaining a positive result for the proposed model. His other re-

search, developed in the same year, focused only on the food industry and evaluating lean practices, and also considered the SS methodology in terms of its operational performance. It also emphasized the barriers that can be found in the food industry to becoming sustainable enterprises.

Figure 5 shows an analysis of the authors' co-occurrence, with the collaborations they maintain to create and publish the articles of interest for this study.
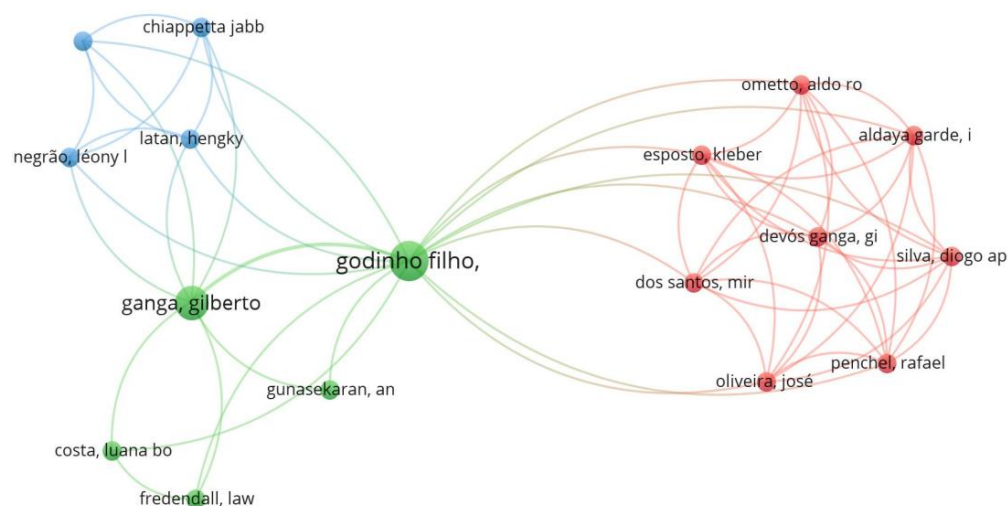
Figure 5. Author relationships in the reviewed articles.

The research focus is reflected in Figure 6, shown by a graph of keyword co-occurrence, in which "lean practice", "lean manufacturing", "management", "impact", "benefit", "operational performance", and "environment performance" stand out, showing a relationship between L and the pillars of sustainability. However, the co-occurrence with "social performance" is not reflected, affirming the point mentioned by Henao et al. [28], which highlights this pillar as being the least studied and the one of less interest to authors; therefore, it represents a source of future research.
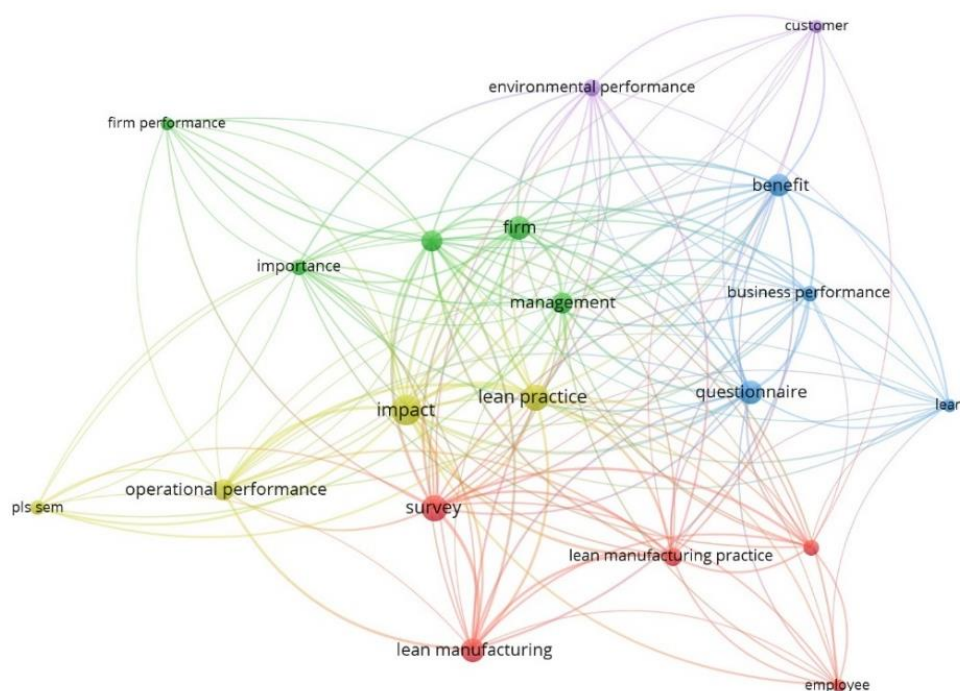
Figure 6. Keywords relationship for reviewed articles.

Additionally, the words "survey" and "questionnaire" also stand out, given the nature of the methodology investigated, since the data most commonly used for the PLS-SEM model comes from surveys previously conducted on the constructs measured [109].

Fifty-three industrial sectors were analyzed in the papers, as shown in Figure 7. The electrical and electronics industries were the most widely studied at 40% (20 articles), followed by the metals industry with 38% (19 articles), food and beverage (30%), plastics (30%), the automotive industry (26%), chemicals (24%), textiles and textile products (24%), and transportation equipment (20%); these represent the industries that have been studied in at least 10 of the reviewed articles.
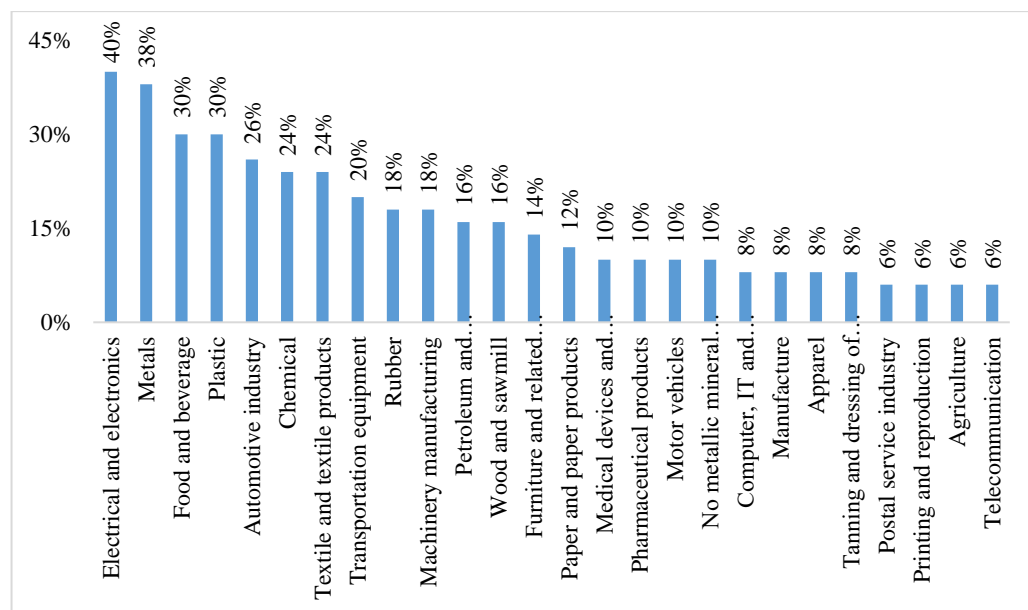
Figure 7. The major industries, analyzed according to the number of reviewed articles.

According to Menon and Ravi [110], the electrical and electronics industry seeks to generate strategies to become competitive and sustainable, making them sources of research to identify the key enablers that drive sustainability. Fox et al. [93] evaluate the performance of the electrical and electronics industry in Malaysia, using Smart PLS software, obtaining an increase in the productivity, speed, and flexibility of all its processes.

In other literature review papers, the electronics and metal industries are among the top five topics in those who study L practices in terms of sustainability indicators [1,26].

Additionally, the industries that have been studied in only one article out of fifty and that might represent interesting subjects for future research are: cement [94], detergents [78], agrochemical, battery [76], stone and glass [72], the police [101], export companies for government agencies [89], capital goods [65], ceramics [103], and the service industry [75].

The application of the PLS-SEM model to assess the impact of LSS on indicators is measured by developing constructs or latent variables to establish the relationships between them. Figure 8 shows the summary of the findings found in the research articles. The items or variables (in rectangles) of the LSS construct represent 57 practices or tools for the model. Likewise, 34 economic indicators, 11 social indicators, and 15 environmental indicators can be found in the sustainability indicators, detailed in Sections 4.2 and 4.3. Using these indicators in PLS-SEM application studies to assess companies' compliance in the field of sustainability guarantees a robust, reliable, and valid model.
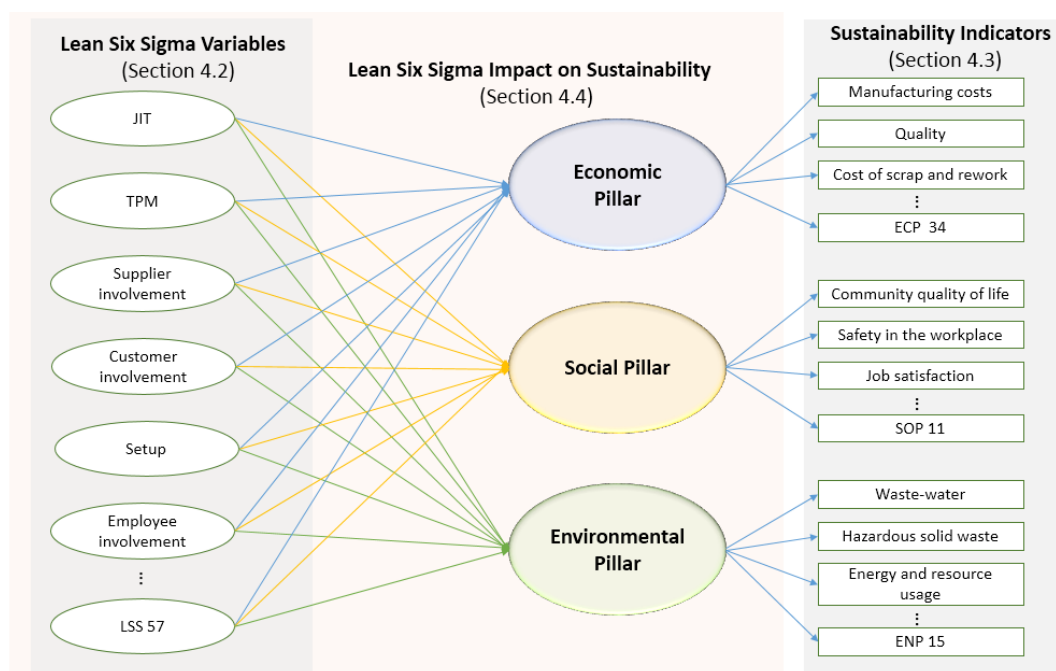
Figure 8. Representative PLS-SEM model indicators and constructs for measuring the impact of LSS on sustainability.

The interaction between the LSS latent variables and the sustainability pillars, detailed in Section 4.4, reflects the predictions of the models analyzed in this study.

4.2. Lean Six Sigma Constructs

L, SS, and LSS have been used in this SLR since, individually, they have been the most frequently named methodologies for improving processes [108]. L improves process speed, SS increases product quality, and LSS offers a combination of both [111].

Forty-five papers, representing 90% of the total number of articles reviewed, analyze the impact of L on sustainability, as shown in Figure 9. Three articles (6%) analyze the impact of SS, and only two articles (4%) analyze the impact of LSS.
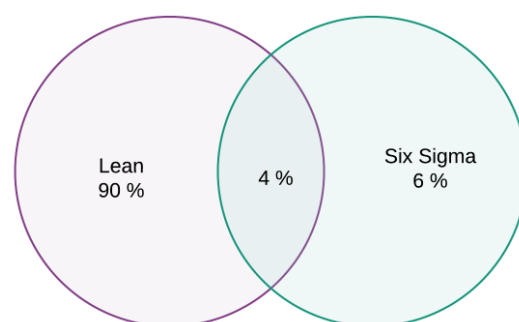
Figure 9. The application of lean (L), Six Sigma (SS), and Lean Six Sigma (LSS) tools in the reviewed articles.

The adoption and selection of L, SS, or LSS tools depend solely on the needs of each of the companies [112]. The literature review found fifty-seven constructs of L, SS, and LSS that the various authors used to conduct their research, including technical tools related to process quality management and social tools related to human resource management. Figure 10 shows the main L, SS, and LSS constructs used in the articles. JIT constructs were used in 44% of the papers, TPM in 42% of the papers, and supplier development in 40% of the papers. In addition, it can be seen that among the top ten LSS practices,

social tools stand out, which confirms the findings of Alhuraish et al. [19], who state that companies achieve successful L implementation, mainly based on employee involvement and cultural change.
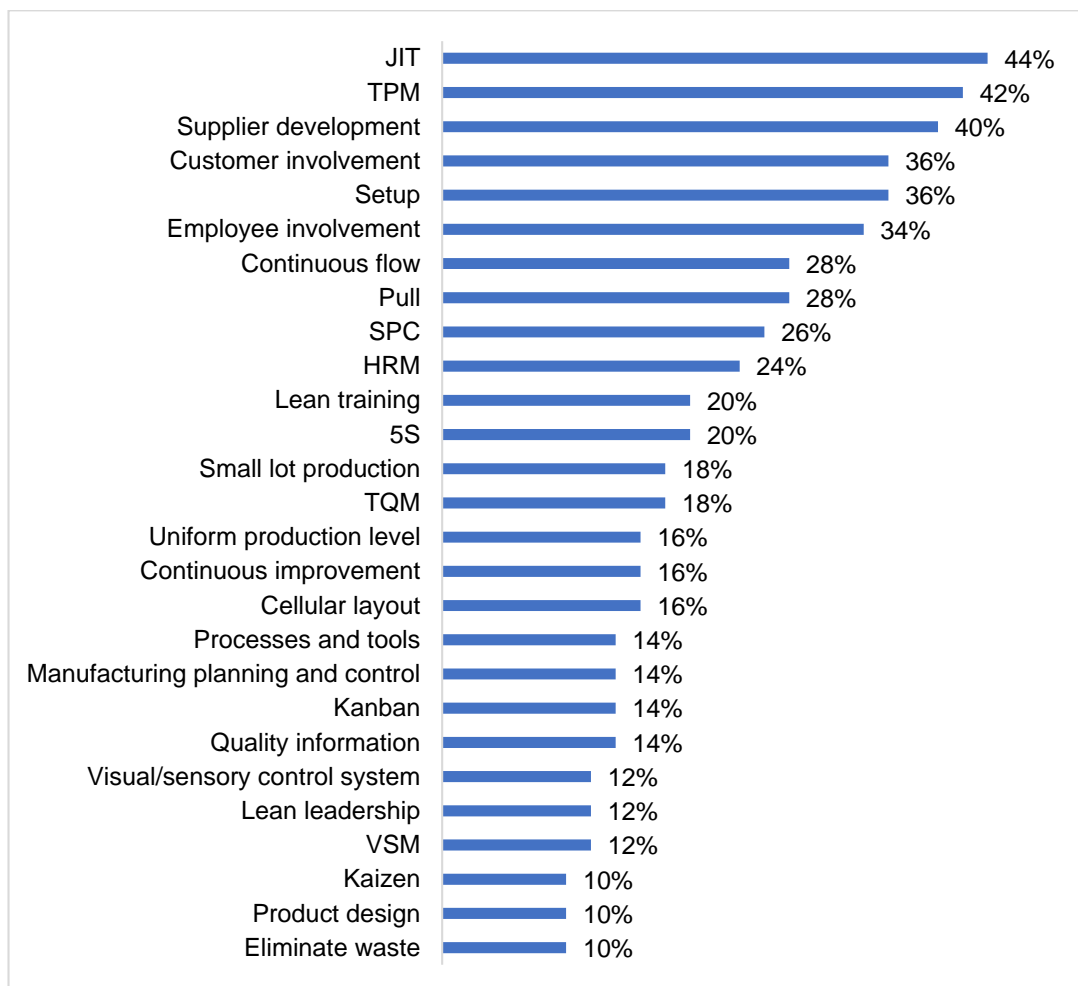
Figure 10. The main L, SS, and LSS constructs that are analyzed in the review articles.

Of the 57 practices found, 53% were used in fewer than five articles, so they require further research exploration, representing the least implemented practices within organizations. Table 4 shows the practices found in the articles reviewed and the authors who have used these practices in their research.

Table 4. Authors grouped according to the principles and the tools analyzed.

L, SS, LSS Principles and Tools	Authors
Just in time (JIT)	[2,55,58,64,70,71,74,76,79,80,84,86,88,90,93,95,96,102,104–107]
Total productive maintenance (TPM)	[2,58,65,67,71,74,79,84–86,88,93,95–97,100,102,104,105,107,108]
Supplier development	[55,59,67,71,74,76,78,82–86,88,93,95,97,100,105,107,108]
Customer involvement	[55,59,66,67,70,71,74,77,79,81–83,86,93,95,105,107,108]
Setup	[2,64,67,70,71,73,74,85,87,90,93,95,97,100,104–106,108]
Employee involvement	[21,65,67,74,75,77,78,83,84,93–95,98,103–105,108]
Continuous flow	[2,55,67,71–74,87,91,93,95,98,105,108]

Table 4. *Cont.*

L, SS, LSS Principles and Tools	Authors
Pull	[67,69,71,72,74,85,92,95,97,100,104–106,108]
Statistical process control (SPC)	[65,67,70,71,74,75,84,88,92,93,95,105,108]
Human resource management (HRM)	[58,68,69,71,79,81–84,86,104,107]
Lean training	[68,69,75,78,83,84,88,96,103,104]
5S	[58,69,73,87,91,93,96,102,104,106]
Small lot production	[59,85,87,92,93,97,100,104,106]
Total quality management (TQM)	[58,64,70,79,81,84,86,96,107]
Uniform production level	[55,72,84,85,88,93,97,100]
Continuous improvement	[66,72,77,80,83,88,93,102]
Cellular layout	[55,85,87,88,91,93,97,100]
Processes and tools	[2,66,72,75,76,84,94]
Manufacturing planning and control	[66,76,81–84,93]
Kanban	[69,70,87,90,92,93,102]
Quality information	[75,80,81,93,98,103,104]
Visual/sensory control system	[76,90,92,93,104,106]
Lean leadership	[68,69,81,83,96,104]
Value stream mapping (VSM)	[72,88,91,93,104,106]
Kaizen	[87,90,102,104,106]
Product design	[70,75,82,83,93]
Eliminate waste	[21,72,78,80,93]
Standardization	[72,76,87,88]
Quality improvement	[72,75,84,88]
Improving facility layout	[91,92,104,106]
Flexible resources	[85,93,97,100]
Incentives	[68,83,103,104]
Workload balancing	[69,91,104,106]
Reduction of inventory	[76,78,102]
Six Sigma focus on metrics	[75,101,108]
Six Sigma structural improvement	[75,101,108]
Six Sigma role structure	[75,101,108]
Jidoka	[76,104,106]
Zero defects	[2,80,93]
New process technology	[78,104,106]
Quality at source	[66,100]
Lead time reduction	[59,64]
Lean culture	[80,96]
Policy deployment	[104,106]
Quality function deployment (QFD)	[104,106]
Coordination between departments	[68,75]
Lean progress target	[68,83]

Table 4. *Cont.*

L, SS, LSS Principles and Tools	Authors
Reduce cycle time	[78,91]
Mindset and attitude	[94,96]
5 Why	[93]
Root cause	[104]
Six Sigma methodology	[101]
Safety health environment	[88]
Problem solving	[66]
Performance oriented	[83]
External integration	[94]
Critical to quality (CTQ)	[75]

The application of LSS in industries has been considered as a means for achieving sustainable development goals [21,33]; despite several studies supporting it [21,94,100,113], some authors mention that L practices do not relate to all the pillars of the triple bottom line [83,107,114]. A debate has arisen about whether LSS benefits all sustainability pillars. Some studies indicate that while seeking an improvement in environmental and social performance, economic performance can be affected [11], or vice versa [25].

4.3. Sustainability Indicators

Previous studies show that the economic pillar is the one that is most frequently measured and is the most important one for companies. Therefore, it is the most relevant to verifying improvement when applying L methodologies [28]. Figure 11 shows the percentage of articles that analyze the impact on economic, environmental, and social performance. On the one hand, 44 papers (88%) evaluate the economic pillar; on the other hand, only five papers (10%) evaluate economic, social, and environmental pillars [21,83,94,100,107]. Therefore, they create a study gap for future research considering the three pillars of sustainability.
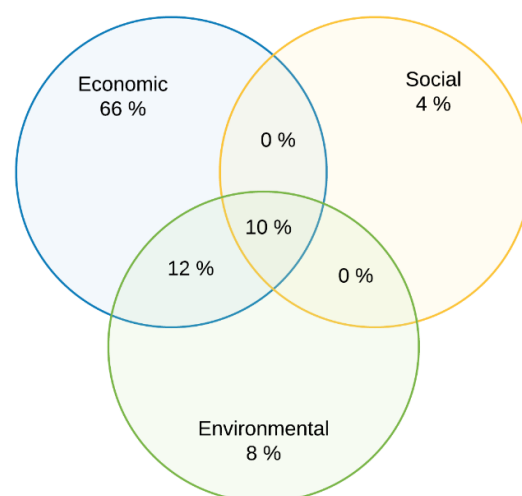

Figure 11. Sustainability pillars addressed by the reviewed articles.

Indicators used to measure the company's sustainable performance have been identified throughout the various research papers. However, it is essential to mention that the indicators used in each study depend specifically on the context, industries, and sustainable

awareness that each study wishes to reflect [115]. Table 5 shows the indicators that are present in the articles reviewed.

Table 5. Sustainability indicators, according to the pillars used in the reviewed articles.

Economic		Social	Environmental
Productivity	Process variability	Community quality of life	Air emission
Improvement in employee performance	Scrap and rework cost	Safety in the workplace	Wastewater
Employees understanding the process	Return on investment	Job satisfaction	Hazardous solid waste
Improvement in housekeeping	Delivery	Customer retention and loyalty	Environmental accidents
Reduction in inventory	Flexibility	Green image	Consumption of dangerous substances
Reduction in cycle time	Overtime	Relationship with the community	Consumption for hazardous/harmful/toxic materials
Reduction in human errors	Launch of new products	Health and safety of the society	Enterprise's environmental situation
Market share	Lead time	Society wellbeing in all operation	Energy and resource usage
Growth in sales	Capacity utilization	Sense of accomplishment	Raw material consumption
Growth in net profit margin	Competitive advantages	Team spirit	Environmental regulations and standards
Return on assets	Return on sales	Organizational learning	Life cycle
Return on equity	Reliability		Internal and external audits
Defects	Dependability		Environmental impact monitoring
Manufacturing costs	Company's image		Pollution prevention
Net income	OEE		Reduce, reuse and recycle
Loyalty level, satisfaction	Process efficiency		
Products and service quality	Available equipment		

Table 6 shows the indicators used by the authors in their published articles, which information contributes to researchers' knowledge as a starting point for new studies.

Table 6. List of authors, sorted by the sustainability indicator used.

Pillar	Indicator	Authors
Economic	Manufacturing costs	[21,55,59,65,66,68,73,75,83,87,90,92,95,100,102–107]
	Quality of products and service	[21,58,59,66,67,75,87,90,95,98,100,104,106,108]
	Cost of scrap and rework	[21,58,67–69,71,72,75,86,92,104,108]
	Market share	[59,71,75,78–80,83,84,87,100,105]
	Growth in sales	[59,68,71,73,75,78,83,84,86,87,105]
	Reduction in inventory	[65,67,71,72,86,91,92,95,105,108]
	Growth in net profit margin	[59,71,72,75,78,80,83,95,100,104]
	Reduction in cycle time	[67,75,79,80,90,91,104–106]
	Flexibility	[66,69,72,76,87,93,100,102,106]
	Lead time	[59,66,71,72,86,97,103,104,108]
	Productivity	[83,85,87,93,102,104,108]
	Return on investment	[68,72,79,80,84,86,87]
	Return on assets	[75,78,79,84,86,105]
	Delivery	[66,67,72,87,100,102]
	Loyalty level, satisfaction	[75,83,95,98,104]

Table 6. *Cont.*

Pillar	Indicator	Authors
	Improvement in employee performance	[91,98,103]
	Launch of new products	[66,102,106]
	Competitive advantages	[68,69,106]
	Employees understanding the process	[91,104]
	Net income	[75,105]
	Process variability	[75,108]
	Capacity utilization	[67,108]
	Return on sales	[79,87]
	Process efficiency	[104,108]
	Available equipment	[106,108]
	Reduction in human errors	[91,104]
	Improvement in housekeeping	[91]
	Return on equity	[78]
	Defects	[105]
	Overtime	[66]
	Reliability	[87]
	Dependability	[76]
	Company's image	[100]
	Overall equipment effectiveness (OEE)	[58]
Social	Community quality of life	[83,94,100]
	Safety in the workplace	[21,94,100]
	Job satisfaction	[82]
	Customer retention and loyalty	[83]
	Green image	[83]
	Relationship with the community	[100]
	Health and safety of the society	[83]
	Society wellbeing in all operation	[83]
	Sense of an accomplishment	[107]
	Team spirit	[107]
	Organizational learning	[81]
Environmental	Wastewater	[59,64,67,70,74,94,100,107]
	Hazardous solid waste	[59,64,67,70,74,78,94,100]
	Energy and resource usage	[58,59,64,71,78,83,84,100]
	Air emission	[59,64,67,70,74,94,107]
	Environmental accidents	[59,67,70,74,78,84,94]
	Consumption for hazardous/harmful/toxic materials	[64,67,70,71,74,83]
	Enterprise's environmental situation	[67,70,74,78,83,84]
	Raw material consumption	[2,21,28,84,100]
	Consumption of dangerous substances	[83,94,100]
	Environmental regulations and standards	[94,100]

Table 6. *Cont.*

Pillar	Indicator	Authors
	Life cycle	[21,84]
	Internal and external audits	[21,84]
	Environmental impact monitoring	[21]
	Pollution prevention	[2]
	Reduce, reuse and recycle	[2]

L implementation has positively impacted financial and operational performance [28]. However, financial indicators have received more attention in studies than operational performance indicators [115]. Operational performance is about looking to improve production capacity, being more flexible, and minimizing resource use. Financial performance is based on cost reduction [116]. Srinivasan et al. [72] indicate that improving operational performance improves financial performance; this finding is affirmed by Baroma et al. [1], who mention that "eliminating waste" undoubtedly leads to cost reduction. Valente et al. and Ghobakhloo et al. [86,105] measure ten and six L constructs, respectively, in organizational performance, considering a single construct analyzing economic and operational indicators, ensuring a significant improvement in their indicators when applying L. However, other studies show that an improvement in both performances is not always achieved. In his study, De Giovanni et al. [59] show that the application of L can improve operational performance as measured by lead time, time to market, quality standards, and level of service. At the same time, the application of L does not benefit financial performance as measured by sales growth, profit targets, and market share; when this situation occurs in this study, it indicates a partial benefit in the performance indicators.

In this literature review, both financial and operational performance indicators were considered to be economic performance indicators. Of the articles reviewed, 34 economic indicators were used in the 44 articles. Figure 12 reflects only the leading indicators, where 45% of the papers used manufacturing cost as a sustainability economic indicator to evaluate the benefit of LSS constructs.

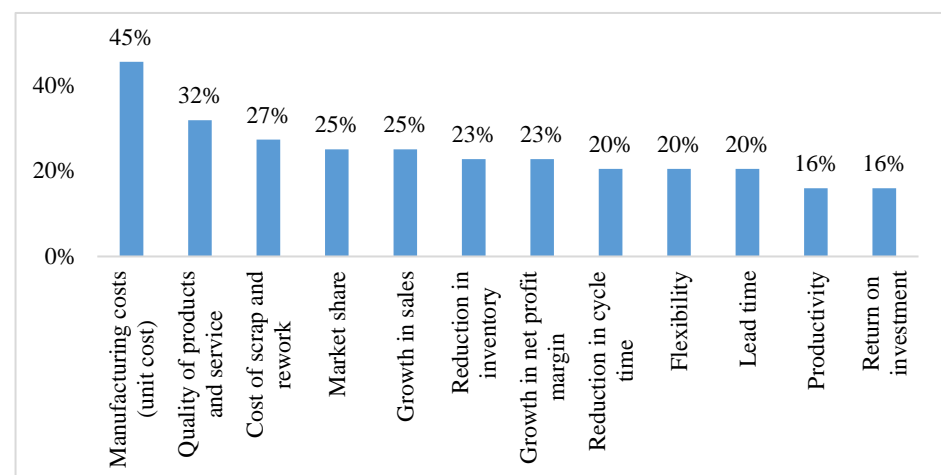**Figure 12.** The leading economic indicators used in the reviewed articles.

The social indicators recognize human importance in terms of working conditions, improved relationships and communication, and minor community disturbance [30]. As shown in Figure 13, eleven social indicators were found in the reviewed papers, where the community quality of life and safety in the workplace indicators were used in three articles (43%).
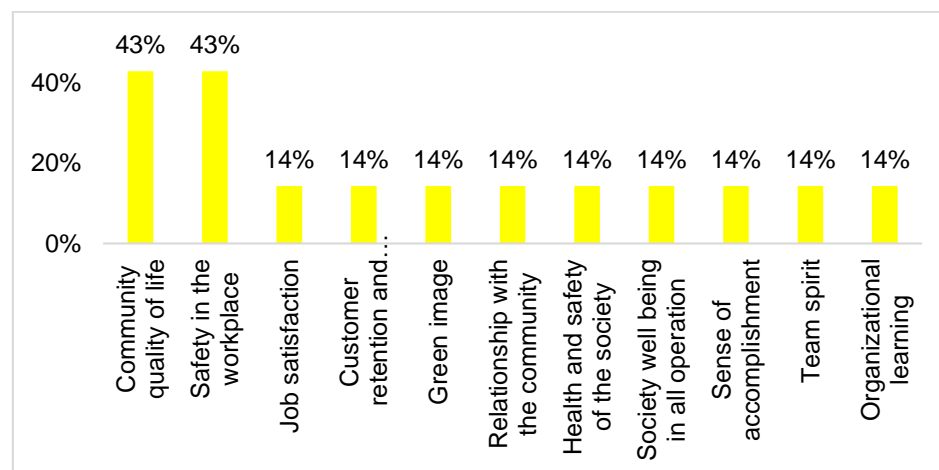
Figure 13. Social indicators used in the reviewed articles.

As mentioned above, the social pillar is the most infrequently evaluated performance in the research. The practices that will guarantee an improvement in the performance of this pillar correspond to human resource management (HRM) and other lean social tools. According to Mohaghegh et al. and Yazdani et al. [81,107], HRM can improve the sense of accomplishment, team spirit, and organizational learning, which includes the ability of employees to solve problems, the ability to learn from past experiences, and the ability to share their knowledge with others. Likewise, Minh et al. [82] state that employees' satisfaction with their workplace, physical wellbeing, and skills will benefit from customer relations, human resources, and product design participation.

According to Farias et al. [31], applying L practices can improve environmental performance due to reducing all types of waste and resources consumption, such as energy, water, and others [64]. In their study of Chinese industries, Chen et al. [4] found that the application of JIT, setup, TPM, production flow, and controlled processes can positively influence pollution prevention, resource reduction, reuse, and recycling.

On the other hand, Dieste et al. [47] indicate that greater productivity and efficiency with more frequent deliveries generate more transportation and movements, which generates more waste; moreover, a new product design or technological innovation could cause damage to the environment. It is a controversial issue. Despite this, in our study, no articles have been found that support this negative effect of environmental performance; however, some studies show that applying L will not obtain any benefit in terms of environmental indicators [64]. In their structural equation model, Green et al. [71] conclude that practices related to JIT, such as kanban, lot size reduction, and JIT scheduling, are not related to environmental performance. On the other hand, Green stresses that practices related to TQM, such as customer focus, product design, and SPC are positively and significantly related to environmental performance, considering air emissions, effluent waste, solid wastes, the consumption of toxic materials, and environmental accidents.

In the literature review, fifteen environmental indicators were found that will support further investigation of the behavior of this performance concerning the LSS tools. Figure 14 shows the leading indicators. Wastewater, hazardous solid waste, and energy and resource usage stand out, with eight articles (53%) out of the fifteen articles that analyze environmental impacts in their research.

4.4. Lean Six Sigma Methodology Impact on Sustainability

Souza and Dekkers [117] indicate that not all constructs are related to the three pillars of sustainability; therefore, it is necessary to analyze the impact on sustainability individually. Table 7 summarizes the L, SS, and LSS constructs studied in the articles reviewed. For each construct, the number of reviewed articles where the structural equation modeling results indicated positive, partial, negative, or no impact on the economic, social, and

environmental pillars is shown. A value of zero in the table indicates that there have been no articles linking that LSS practice to one of the sustainability pillars. Furthermore, a positive impact indicates that the LSS practice has positively influenced performance improvement; a partial relationship indicates that not all LSS practices studied will perform well in all indicators measured in the model. However, if a negative impact is found, it indicates that the implementation of that LSS practice generated a detrimental effect on the sustainability pillar measured. Finally, when a null impact is obtained, it indicates that there is not enough statistical evidence to demonstrate the relationship between the LSS construct and the performance studied.
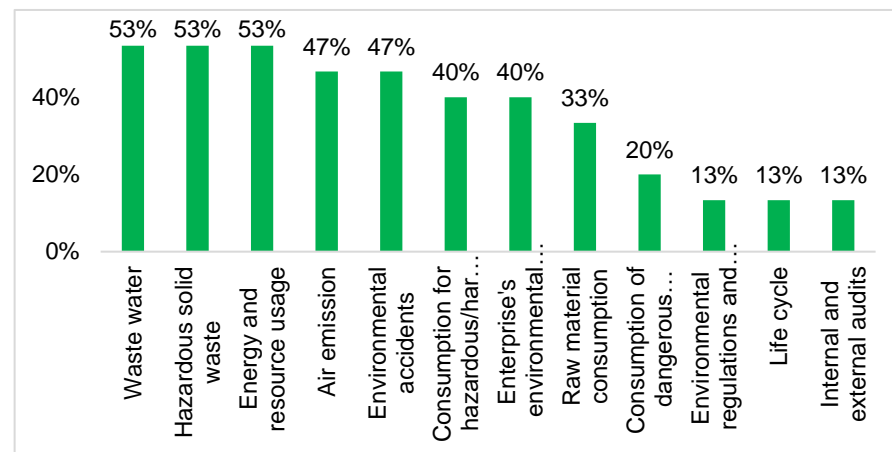

Figure 14. The leading environment indicators used in the reviewed articles.

Table 7. The impact of L, SS and LSS principles and tools on the sustainability pillars.

Practice	Economic/Operational				Social				Environmental			
	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative
JIT	16	2	0	0	0	0	1	0	4	0	4	0
TPM	18	1	0	0	1	0	1	0	6	0	2	0
Supplier development	15	0	3	0	2	0	2	0	8	0	1	0
Setup	12	1	1	0	1	0	0	0	4	0	3	0
Customer involvement	11	0	2	0	2	0	2	0	6	0	1	0
Employee involvement	16	0	0	0	3	0	0	0	6	0	1	0
Continuous flow	11	1	0	0	0	0	0	0	3	0	1	0
Pull	9	1	1	1	1	0	0	0	4	0	1	0
SPC	11	0	0	0	0	0	0	0	4	0	1	0
HRM	6	1	3	0	3	0	1	0	3	0	2	0
5S	8	1	0	0	0	0	0	0	1	0	0	0
Lean training	9	0	1	0	1	0	0	0	3	0	0	0
Small lot production	6	1	1	0	1	0	0	0	1	0	1	0
Continuous improvement	8	0	0	0	1	0	0	0	1	0	0	0
Cellular layout	7	0	1	0	1	0	0	0	1	0	0	0
Uniform production level	5	1	2	0	1	0	0	0	2	0	0	0
TQM	5	1	0	0	0	0	2	0	3	0	2	0
Quality information	5	0	0	1	0	0	1	0	0	0	0	0
Kanban	3	0	3	0	0	0	0	0	0	0	1	0
Manufacturing planning and control	3	0	2	0	0	0	3	0	1	0	1	0
Processes and tools	5	0	0	0	3	0	0	0	4	0	0	0
VSM	3	2	1	0	0	0	0	0	0	0	0	0
Lean leadership	2	0	1	0	1	0	1	0	1	0	0	0

Table 7. *Cont.*

Practice	Economic/Operational				Social				Environmental			
	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative
Visual/sensory control system	4	1	0	1	0	0	0	0	0	0	0	0
Eliminate waste	4	1	0	0	1	0	0	0	2	0	0	0
Product design	3	0	0	0	2	0	0	0	2	0	0	0
Kaizen	3	1	1	0	0	0	0	0	0	0	0	0
Workload balancing	2	1	1	0	0	0	0	0	0	0	0	0
Incentives	4	0	0	0	1	0	0	0	1	0	0	0
Flexible resources	4	0	0	0	1	0	0	0	1	0	0	0
Improving facility layout	2	1	0	1	0	0	0	0	0	0	0	0
Quality improvement	3	1	0	0	0	0	0	0	1	0	0	0
Standardization	3	1	0	0	0	0	0	0	0	0	0	0
New process technology	2	1	0	0	0	0	0	0	1	0	0	0
Zero defects	3	0	0	0	1	0	0	0	1	0	0	0
Jidoka	2	1	0	0	0	0	0	0	0	0	0	0
Six Sigma role structure	3	0	0	0	0	0	0	0	0	0	0	0
Six Sigma structural improvement	3	0	0	0	0	0	0	0	0	0	0	0
Six Sigma focus on metrics	3	0	0	0	0	0	0	0	0	0	0	0
Reduction of inventory	3	0	0	0	0	0	0	0	1	0	0	0
Mindset and attitude	2	0	0	0	1	0	0	0	1	0	0	0
Reduce cycle time	2	0	0	0	0	0	0	0	1	0	0	0
Lean progress target	2	0	0	0	1	0	0	0	1	0	0	0
Coordination between departments	2	0	0	0	0	0	0	0	0	0	0	0
QFD	0	1	1	0	0	0	0	0	0	0	0	0
Policy deployment	0	1	1	0	0	0	0	0	0	0	0	0
Lean culture	2	0	0	0	0	0	0	0	0	0	0	0
Lead time reduction	0	0	1	0	0	0	0	0	1	0	1	0
Quality at source	2	0	0	0	1	0	0	0	1	0	0	0
Performance oriented	1	0	0	0	1	0	0	0	1	0	0	0
CTQ	1	0	0	0	0	0	0	0	0	0	0	0
External integration	1	0	0	0	1	0	0	0	1	0	0	0
Problem solving	1	0	0	0	0	0	0	0	0	0	0	0
Safety health environment	1	0	0	0	0	0	0	0	0	0	0	0
Six Sigma methodology	1	0	0	0	0	0	0	0	0	0	0	0
Root cause	0	1	0	0	0	0	0	0	0	0	0	0
5 Why	1	0	0	0	0	0	0	0	0	0	0	0
Total	264	25	27	4	33	0	14	0	83	0	23	0
(%)	83%	8%	8%	1%	70%	0%	30%	0%	78%	0%	22%	0%

L, SS, LSS constructs positively impact 83% of economic indicators and 78% of environmental indicators in the reviewed articles. In the environmental pillar, 22% indicate that they have not found any relationship between the constructs. On the other hand, in the social pillar, 70% indicate that they have found a positive effect, and 30% indicate that L constructs are not related to the social pillar.

4.4.1. L, SS, LSS and Economic Pillar

TPM is the most widely evaluated practice regarding economic performance (19 articles), of which 95% result in a positive impact on performance; only one of the articles mentions partial performance, which means that it can influence some economic indicators. TPM impact economic performance by eliminating waste via performing planned

maintenance, which ensures increased productivity [96] by having greater availability of equipment and avoiding equipment failure during production [107].

JIT is evaluated in 18 articles, of which 89% demonstrate positive results. It allows costs reduction in terms of storage or inventory levels [118], also influencing the speed, reliability, on-time deliveries, and flexibility of production [28]; however, 11% (2 articles) indicate that the application of JIT has only a partial relationship with economic performance.

Ghobakhloo et al. [79] indicate that JIT is positively related to the financial indicators and negatively related to the operational indicators, which contradicts the findings of Hadid et al. [104].

Employee involvement is considered relevant to economic performance; sixteen articles have used these practices to measure performance impact; 100% indicate that the relationship between the two constructs is positive. This result confirms the findings mentioned by Abreu-Ledón et al. [119], who focus on the workforce as one of the practices that substantially impact economic performance. Marín-Garcia et al. [103] state that employee involvement does not directly influence economic performance but is rather a means to obtaining a sustainable advantage when applying L, SS, or LSS.

4.4.2. L, SS, LSS and Social Pillar

Through the application of lean manufacturing focusing on the social aspect, it is intended that organizations should focus on meeting the needs of both employees and society [120]; among the practices where the result in terms of social impact has been of interest to the research can be found as follows:

Despite having been evaluated in only 3 articles, the processes and tools indicate that there is a positive relationship with the social pillar in 100% of these papers. This is happening because it mainly aids in using tools, methods, production techniques, equipment, and materials properly, ensuring that organizational processes are carried out without interruptions, and obtaining better workplace safety [94].

Employee involvement has been analyzed in 3 articles, all showing positive results in terms of its impact. It is because these practices are mainly responsible for keeping employees trained and empowered, giving them the ability to be participants in problem-solving meetings. Hence, it improves the morale and motivation of employees [121].

4.4.3. L, SS, LSS and Environmental Pillar

TPM evaluates the environmental impact of the tools in 8 articles. They contribute to the performance positively and significantly in 75% of the articles; this can happen, as TPM helps reduce waste produced by machines in terrible conditions [19], such as dust, chemical vapors, and oil leakage [122].

JIT, like TPM, evaluates environmental performance in 8 articles, of which 50% indicate that positive and significant performance is obtained, while the other 50% indicate that no impact is generated. There is a debate that is ongoing concerning the benefit of JIT implementation. Studies claim that JIT, by ensuring that products are delivered more frequently, also produces significantly more traffic congestion, causing an increase in the amounts of CO_2 emitted; therefore, it does not result in an improvement in the environmental performance of operations [122]. On the other hand, they emphasize the positive benefit of JIT by reducing the deterioration of materials by excess inventory, leading to the reduction of energy and emissions [25].

Additionally, customer involvement is among the most studied factor when measuring the impact on the environmental pillar, there is a positive effect in 86% (6 articles) of the seven articles found. This result is confirmed by Huo et al. [123], who mention that customer involvement allows processes to be adjusted according to accurate information regarding their demand, avoiding overproduction, ensuring the proper handling of raw materials, preventing them from becoming obsolete, reducing the use of resources, and avoiding pollution.

5. Conclusions

This article highlights the use of PLS-SEM to measure the impact of L, SS, and LSS on sustainable performance. It points out the most utilized L, SS, and LSS constructs, and the benefits obtained in each indicator found in the economic, social, and environmental pillars. Through a deep analysis of the L tools, it is necessary to indicate that the application of this philosophy is broad and can be carried out in different industrial contexts, its impact being more frequently studied in the electrical and electronics, metals, and food and beverage industries.

The L practices that are used most frequently are JIT, TPM, supplier development, customer involvement, setup, employee involvement, continuous flow, pull, SPC, and HRM. The most frequently used indicators in the economic pillar are manufacturing cost, products and service quality, scrap, and rework cost. The relevant indicators in the social pillar are community quality of life and safety in the workplace. The relevant indicators in the environmental pillar are wastewater, hazardous solid waste, and energy and resource usage.

It was found that 66% of L, SS, and LSS evaluations on sustainability utilized only the economic pillar, 12% used the economic and environmental pillars, and only 10% utilized all three pillars of sustainability. The social pillar is the least studied, leaving a gap for further research.

The relationship and impact of L, SS, and LSS constructs on the sustainability pillars were analyzed as being positive, negative, partial, or having no impact. It was found that the application of L, SS, and LSS practices have a positive impact on 83% of the economic indicators, on 78% of the environmental indicators, and on 70% of the social indicators. However, the results also show a null relationship between L, SS and LSS constructs and 30% of the social indicators.

6. Implications

This study provides information to researchers and practitioners about a statistical methodology (PLS-SEM) that is currently being used to analyze the impact of LSS on sustainability indicators. The motivation arises from two parameters, the first given by a few articles that simultaneously analyze the three sustainability pillars. The second is intended to demonstrate that the PLS-SEM methodology is the statistical tool most commonly used to measure the interrelation between LSS and sustainability. Its use cannot only be in the social sciences for which it was initially developed; its application has expanded in terms of quality and sustainability, as demonstrated in this study.

The results of the PLS-SEM prediction models evaluated in the 50 articles reviewed indicate the relationships found for each of the LSS practices on sustainability, whether they are positive, negative, partial, or if there is no statistical evidence to guarantee the relationship between the constructs.

Furthermore, the study identifies the selection of appropriate variables, validated by PLS-SEM, to construct new prediction models. The study's findings show a set of 57 practices corresponding to the LSS construct, 34 economic indicators, 11 social indicators, and 15 environmental indicators that researchers can use in their future studies when assessing the impact of LSS on sustainability.

Finally, the findings allow industries to make decisions based on the information revealed. Industries' continuous improvement teams can use this type of research to determine the most common lean practices that are applied to improve sustainability.

7. Limitations and Directions for Future Research

On the one hand, there are limitations in this study; firstly, the searching process includes three leading database platforms, omitting information that can be found elsewhere. Other database platforms can be employed to expand the number of publications. Secondly, the searching process considers the terms L, SS, LSS, lean tools, lean practices

and continuous improvement as the basis for the search string, excluding terms such as JIT, TPM, SPC, setup, among other constructs.

On the other hand, limitations provide opportunities for future research. For example, this study considers articles using the PLS-SEM methodology to measure the LSS impact on sustainability in a general way. Future research can include specific analyses in continents or countries, according to companies' size, types of companies, and organizational culture.

Finally, practitioners and researchers can broaden this study using other methodologies, such as ANP, DEA, ISM, MCDM, multilevel regression, and MLR, and establish whether or not the results obtained with those methodologies differ from those indicated in the present study.

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