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INTEGRATED LEAN GREEN AND SIX SIGMA FOR SUSTAINABILITY: A BIBLIOMETRIC ANALYSIS

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Abstract

Sustainability is the need for today. Manufacturing industries are struggling to ensure sustainable operations in their business processes. Strategies like lean manufacturing, green manufacturing and six sigma can help to overcome these challenges. In view of this. This study attempts to review the existing research on the Integration of Lean Green and Six Sigma (LG&SS) strategies used to achieve sustainability. An exhaustive literature study and bibliometric analysis were conducted to understand the contribution of these strategies in the domain of sustainability. 126 papers were selected for the current research from peer reviewed referred journals and conference proceedings of international repute. It helped to identify four important clusters (1) need for integration of lean, green, and six sigma (2) various sectors implemented LG&SS (3) frameworks for the integration of LG&SS (4) sustainability attained with LG&SS's assistance. The study highlights the current status of research in the domain and also provide future directions to fill existing gaps and also assists industrial practitioners to generate more efficient deployment strategies.

Keywords: *Lean, Green, Six Sigma, Sustainability, Bibliometric analysis*

1. INTRODUCTION

Indian manufacturing sector is in an acclivitous stage as "Make in India" initiative to promote India as a worldwide manufacturing centre has encouraged global giants to move their manufacturing facilities in India. The nation is making a steady progress towards Industry 4.0 owing to government programs and policies like National Manufacturing Policy, which intends to increase manufacturing's contribution to GDP to 25% by 2025 (IBEF, 2023). However, this rapid growth leads to high consumption of natural resources including energy and produces a lot of greenhouse gas emissions, which causes effects including worldwide warming, changing the climate, and environmental destruction. (Kim et al., 2014; Mittal & Sangwan, 2014). Therefore, it is essential to the manufacturing industries to adopt practices for reducing pollutants and waste, encouraging growth in the economy, and conserving natural resources (Dilip Maruthi & Rashmi, 2015). Finding ways to succeed that are suitable for and encouraging of social and environmental sustainability is one of the most challenging issues that organizations currently have to cope with (Sarkis, 2005). A potential remedy might be the inclusion of Six Sigma with strategies like Lean and Green (Garza-Reyes, 2015a).

In the past ten years, research has increasingly focused on integrating LG&SS approach for holistic performance improvement of the business. (Gaikwad & Sunnapwar, 2020a). These frameworks addressing operational issues, environmental issues and social challenges become easier to execute for the organization and the practitioner (Raval & Kant, 2017). The popularity of bibliometric analysis has significantly increased due to the appearance of numerous software in recent years and capable of exposing linkages among interdisciplinary

approaches (Ellili, 2022). Researchers can find trends in many study fields as well as journal performance using this quantitative approach.

The current study uses a bibliometric analysis approach to identify deficiencies in the current body of knowledge, acknowledge the integration of LG&SS in the existing research, and suggest potential future areas for improvement.

Following are the investigation's research issues attempts to answer in the domain of integrated LG&SS:

1. What has been an overall pattern over time in LG&SS research and publications?
2. Which authors, groups, and nations have significantly contributed in the domain?
3. Which publications have received the highest citations and which sources have been cited the most frequently?
4. Which keywords and subjects appear most frequently?

2. RESEARCH METHODOLOGY

This study employed quantitative and qualitative methods to conduct trend, bibliometric, and content assessments using VOS viewer software. Various analyses carried out in this research are (1) Trend assessment; (2) analysis of bibliometric author citations; (3) Co-citation study of bibliometric publications; (4) Co-citation analysis in bibliometric references; (5) Analysis of co-citations in bibliometric journals; (6) Key term research and progression; and (7) analysis of qualitative content.

2.1 Data Collection

The Scopus database has been selected and reviewed because it is

one of the most relevant and reliable citation database sources of acceptable-quality academic research documents. An extensive, meticulously updated abstract and reference data, and brings together all associated academic articles from numerous fields in a single way. It quickly finds trustworthy research, identifies experts, and provides users with access to reliable data, analysis, and tools for analysis. (Elsevier, 2023). In this study, the terms and keywords including "Lean, Green, and Six Sigma" and

"Waste reduction, Environmental, and Six Sigma" are used to search most appropriate research publications from the Scopus citation database. This brought about a total of 171 research papers. After reviewing the abstracts and careful consideration, finally 126 articles are selected for bibliometric analysis. Figure 1 illustrates various levels of data filtering. To conduct the bibliometric study, data was filtered and then converted into CSV file before being transmitted to VOSViewer.

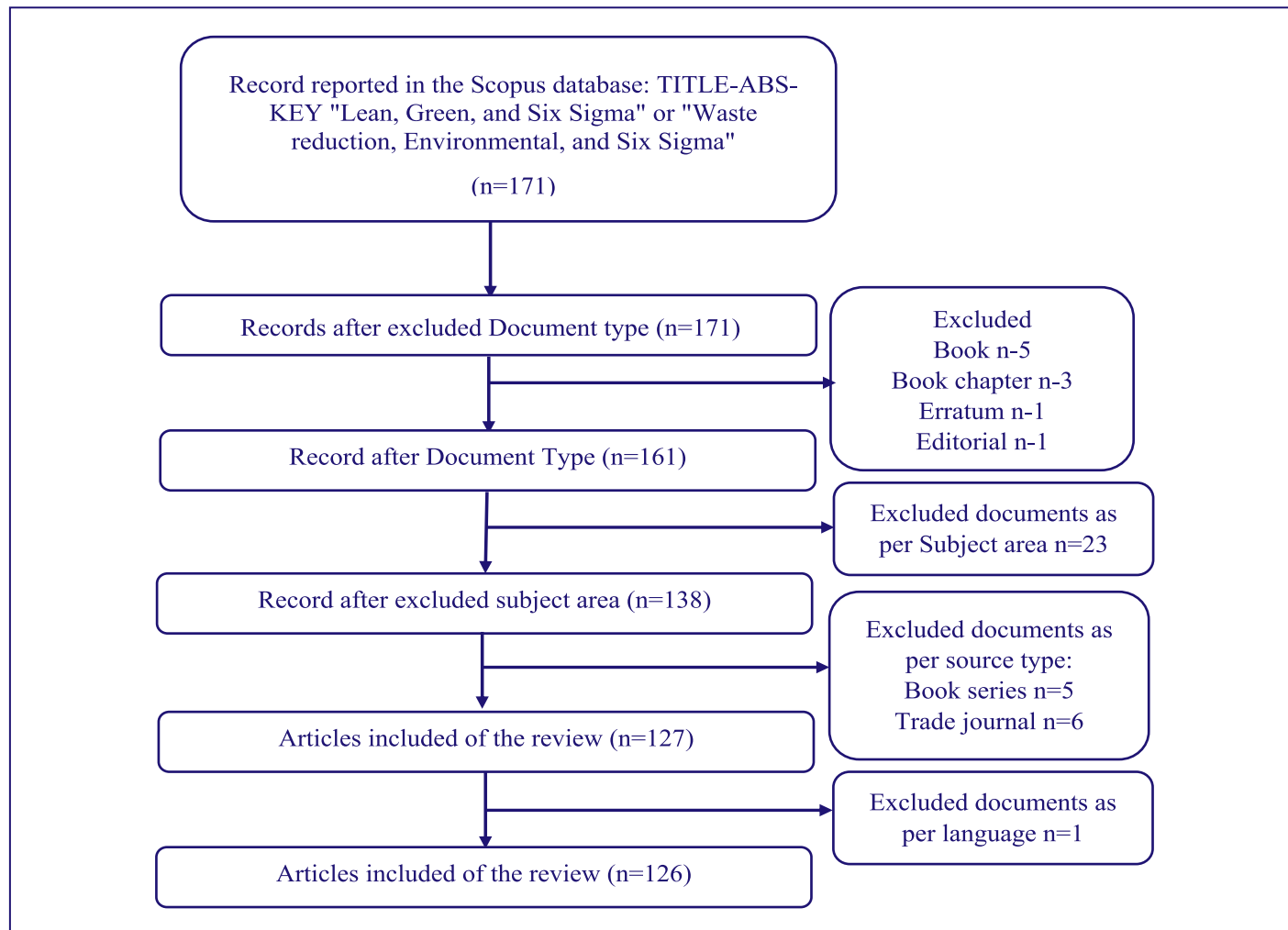


Fig. 1. PRISM diagram indicating the total number of Papers via each level of filtration.

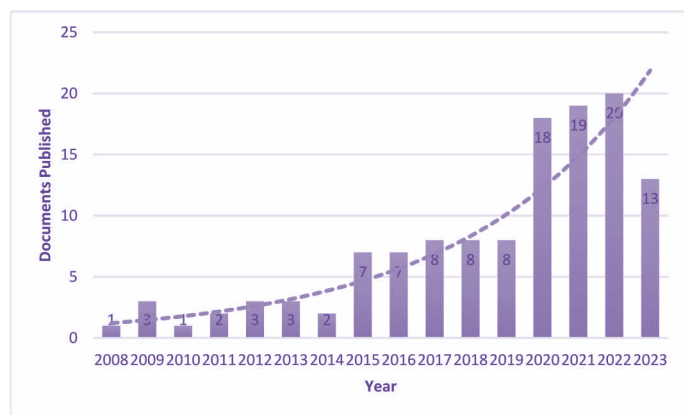


Fig. 2. Trend in LG&SS articles publication

3. ANALYSES OF TRENDS, BIBLIOMETRIC, EVOLUTION, AND CONTENT

The following section current overview of the selected 126 research publications that were utilizing trend, bibliometric, development, as well as content studies.

3.1 The trend in lean, green, and Six Sigma articles

The total number of articles published in the LG&SS research field is represented in the figure 2. In 2008, the initial study on LG&SS was published. Only 8 papers at most were published annually during the 2008–2019 evolution of this field. The

number of LG&SS publications climbed in 2022, peaking at 22 papers, the number of papers decreased the next year, reaching a total of 13 papers. Since there are more publications being published in the Scopus database, it appears that academic scholars are becoming more interested in integrated LG&SS. According to this trend assessment, the growing recognition of the significance of the subject matter of LG&SS along with the growing incorporation of LG&SS into business strategy and organizational reporting processes are both responsible for the rise in publications in this area.

3.2 The most important authors, Institutions and Countries

Top five reported authors are mentioned in the table 1 below, along with the affiliations and countries to which they belong. According to the data, the authors from New Zealand and Morocco (Farrukh et al., 2020). have earned the most citations, while three of the top five authors are from India (S. Kumar et al., 2016; Kaswan & Rathi, 2019; Gaikwad & Sunnapwar, 2020a). The table 1 shows that a significant amount of research on integrated LG&SS was conducted in India.

Table 1. Most cited researchers, institutions, and nations.

Sr.No	Author	Documents	citations	Average citation per Documents	Organization	Country	References
1	Farrukh A.; Mathrani S.; Sajjad A.	5	38	7.6	School of Food and Advanced Technology, Massey University	New Zealand	(Farrukh et al., 2020, 2021,2022,2023a, 2023b)
2	Kaswan M.S.; Rathi R.	4	260	65	Lovely Professional University, Phagwara, Punjab,	India	(Kaswan & Rathi, 2019, 2020a, 2020b, 2021)
3	Gaikwad I.; Sunnapwar V.	2	49	24.5	Sardar Patel College of Engineering, Mumbai,	India	(Gaikwad & Sunnapwar, 2020a, 2020b)
4	Cherrafi A.; Elfezazi S.; Govindan K.; Garza-reyes J.A.; Benhida K.; Mokhlis A.	1	214	214	Cadi Ayyad University, Marrakech,	Morocco	(Cherrafi et al., 2017)
5	Kumar S.; Luthra S.; Govindan K.; Kumar N.; Haleem A.	1	184	184	International Institute of Technology and Management, Murthal, Haryana,	India	(S. Kumar et al., 2016)

Table 2. Top 10 cited documents on integrated LG & SS area.

Sr.No.	Author	Citations	Title
1	(Cherrafi et al., 2017)	214	A framework for the integration of Green and Lean Six Sigma for superior sustainability performance
2	(S. Kumar et al., 2016)	184	Barriers in green lean six sigma product development process: An ISM approach
3	(Garza-Reyes, 2015b)	182	Green lean and the need for Six Sigma
4	(A. Banawi & Bilec, 2014a)	149	A framework to improve construction processes: Integrating lean, green and six sigma
5	(Chugani et al., 2017)	137	Investigating the green impact of Lean, Six Sigma and Lean Six Sigma: A systematic literature review
6	(Belhadi et al., 2020)	125	The integrated effect of Big Data Analytics, Lean Six Sigma and Green Manufacturing on the environmental performance of manufacturing companies: The case of North Africa
7	(Kaswan & Rathi, 2019)	113	Analysis and modelling the enablers of Green Lean Six Sigma implementation using Interpretive Structural Modelling
8	(de Freitas et al., 2017)	99	Impacts of Lean Six Sigma over organizational sustainability: A survey study
9	(Hussain et al., 2019)	97	Green, lean, Six Sigma barriers at a glance: A case from the construction sector of Pakistan
10	(Sagnak & Kazancoglu, 2016)	83	Integration of green lean approach with six sigma: an application for flue gas emissions

3.3 The papers with the highest citation counts

In this section, the top ten articles on LG&SS that were published in the Scopus database between 2008 and 2023 are analysed. The most popular publications, as seen in the table 2, focused primarily on how LG&SS addressed the operational, processes and environmental issues. Other studies have examined integrated LG&SS as a practice in various sectors helps to archive sustainability.

3.4 Most cited references journals

Using a bibliographic coupling analysis, the top ten reference sources have been identified in this section. The top journals that published articles on LG&SS are included in the table 3. Most publications on integrated LG&SS are published in Emerald (International Journal of Lean Six Sigma), followed by Elsevier (Cleaner Production). Additionally, documents produced in a Cleaner Production have the most citations.

Table 3. Reference sources with the highest citation counts

Sr.No.	Source	Documents	Citations	Citations per documents	Publisher
1	International Journal of Lean Six sigma	14	559	39.93	Emerald
2	Journal of Cleaner Production	8	592	74.00	Elsevier
3	Proceedings of the international conference on industrial engineering and operations management	8	9	1.13	IEOM Society
4	TQM journal	7	184	26.29	Emerald
5	Benchmarking	6	29	4.83	Emerald
6	International Journal of Quality and Reliability Management	4	134	33.50	Emerald
7	International Journal of Six sigma and Competitive advantage	4	52	13.00	Inderscience
8	Business strategy and the Environment	3	62	20.67	John Wiley and Sons Ltd
9	Production Planning and Control	3	215	71.67	Taylor and Francis
10	Quality Engineering	3	25	8.33	Taylor and Francis

3.5 Significant and popular articles and topics

Utilize VOS viewer to find articles that are significant and popular. Two factors, includes the number of citations

overall and citations per year, are used to discover popular and most significant publications. Upcoming authors who are investigating different study approaches can be helped

Table 4. Summary of significant and popular article based average citations per year

Sr.No	Authors	Journal Name	Cited by	Average citation per year
1	(Belhadi et al., 2020)	Journal of Cleaner Production	126	42.00
2	(Cherrafi et al., 2017)	International Journal of Production Research	214	35.67
3	(Singh et al., 2021)	Journal of Cleaner Production	64	32.00
4	(Kaswan & Rathi, 2019)	Journal of Cleaner Production	114	28.50
5	(Kaswan & Rathi, 2020a).	Environmental Impact Assessment Review	80	26.67
6	(S. Kumar et al., 2016)	Production Planning and Control	185	26.43
7	(Hussain et al., 2019)	Building and Environment	97	24.25
8	(Chugani et al., 2017)	International Journal of Lean Six Sigma	138	23.00
9	(R Rathi et al.,2022)	Journal of Cleaner Production	23	23.00
10	(Garza-Reyes, 2015b)	International Journal of Lean Six Sigma	183	22.88

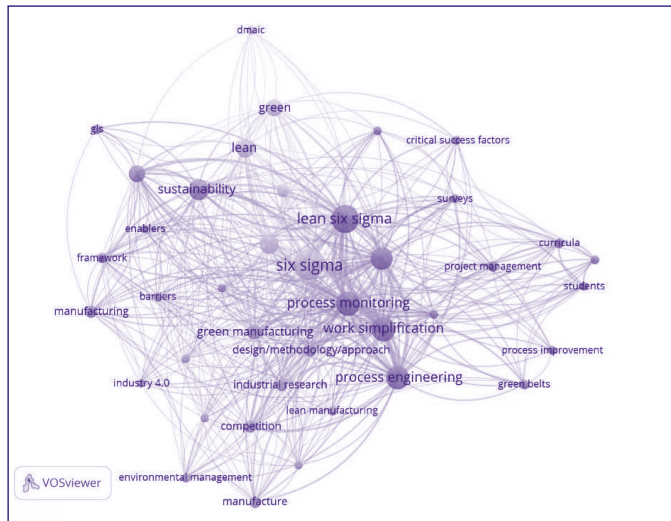


Fig. 3. Co-occurrence analysis of Keywords

3.6 The most common keywords

The growth and advancement of integrated LG&SS research were conceptualized using co-occurrence analysis of all terms. For a given keyword, a minimum limit of five was taken and filtered in order to create a valid analysis. For 727, this gives the yield of 43 keywords. The figure 3 depicts the findings, which reveal that the terms Six Sigma, lean Six Sigma, work simplification, process monitoring, process engineering, lean production, sustainability, and sustainable development are the most frequently utilized.

These terms appear frequently in research, which indicates that more analysis has been done regarding the effects of integrated LG&SS, Lean Six Sigma, and sustainable development, as well as the effects of LG&SS on work simplification, Process monitoring, and Project management. Sustainability (blue), Lean six sigma (red), Six Sigma (yellow) and Green manufacturing (green), are the four main clusters, as indicated in the figure 3. In the Lean Sigma Cluster, describe how the integrated LG&SS improved project management (A.-A. Banawi & Bilec, 2014) and monitoring. Lean six sigma ultimately proposes a way to minimize waste (Antony et al., 2005; Drohomerski et al., 2014; Dilip Maruthi & Rashmi, 2015; Yadav & Desai, 2016; Raval & Kant, 2017).

In the sustainability cluster, describe the various frameworks utilized to develop integrated LG&SS within the manufacturing sector (Ben Ruben et al., 2018; Cherrafi et al., 2017; Farrukh et al., 2020; Gaikwad & Sunnapwar, 2020a; Saxena et al., 2020; Zhu et al., 2018). In the Green Manufacturing cluster, describe how to use green techniques to be successful in the market, as well as how to use green tools for operational excellence and continuous development (Chian et al., 2017; Dilip Maruthi & Rashmi, 2015; Govindan et al., 2015; Jabbour et al., 2016; S. Kumar, Kumar, Kuldip, et al., 2015; Oliveira et al., 2016; Yuan & Xiang, 2018). Details how to implement the DMAIC methodology for combining

the six sigma and lean methodologies in order to accomplish sustainable development are provided in the six sigma cluster. (M. Kumar et al., 2006; Garza-Reyes et al., 2014; Hess et al., 2015; Garza-Reyes, 2015a; Ben Ruben et al., 2017; Powell et al., 2017; Erdil et al., 2018; Gholami et al., 2021; Kaswan & Rathi, 2020a).

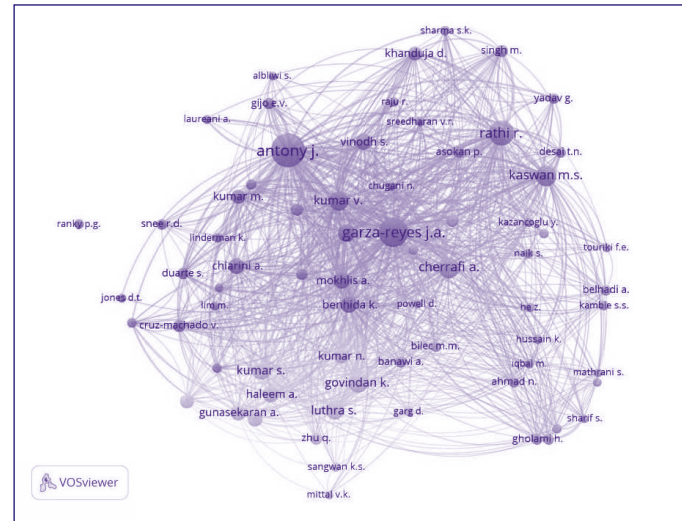


Fig. 4. Co-citation analysis of authors

4. THE INTEGRATED LG & SS LITERATURE'S CITATION MAPPING AND VISUALIZATION

4.1 Mapping and visualization of co-citations

Utilizing VOSviewer, We carry out citation analysis. VOS viewer accepts bibliometric data as input and outputs it with different coloured output indicators. We decide to carry out a co-citation analysis taking into account a minimum of 25 citations. Also seen in Fig.4. The result is displayed in four colours: red (Lean Six Sigma, a need for lean, green, and six sigma) (Garza-Reyes et al., 2014; Garza-Reyes, 2015a), methodology for the integration of Lean and Green); blue (implementation of LG&SS in the various sectors) (AlZawati et al., 2020; Gani et al., 2022; Hussain et al., 2019; Jayathirtha & Raghunath A, 2013; S. Kumar et al., 2016; Sreedharan V et al., 2018; Zhu et al., 2018); green (framework for the integration of LG&SS) (A.-A. Banawi & Bilec, 2014; A. Banawi & Bilec, 2014b; Cherrafi et al., 2017; Gaikwad & Sunnapwar, 2020b; Gandhi et al., 2021; Kaswan & Rathi, 2020a; Sony & Naik, 2019); yellow (conceptualization of LG&SS and sustainability) (Caiado et al., 2018; Garza-Reyes, 2015c; Garza-Reyes et al., 2014; Ruben et al., 2018; Yadav & Desai, 2016); The second step involves a thorough content analysis of 21 articles that have been shown to be strongly interconnected shown in table 5. We do this to understand, explain, and verify their connections. As a result, four main research streams in the literature are identified. (1) a need for lean, green, and six sigma (2) various sectors implemented LG&SS. (3) framework for the integration of LG&SS (4) sustainability attained with LG&SS's assistance.

4.2 Co-authorship visualization

Using VOS viewer once more, we also investigate the network of co-authors among academics working in the integrated LG&SS

domain. Such co-authorship analysis is useful since it identifies scholars working on integrated LG&SS subjects. Fig. 5 illustrates the way co-authorship is visualized.

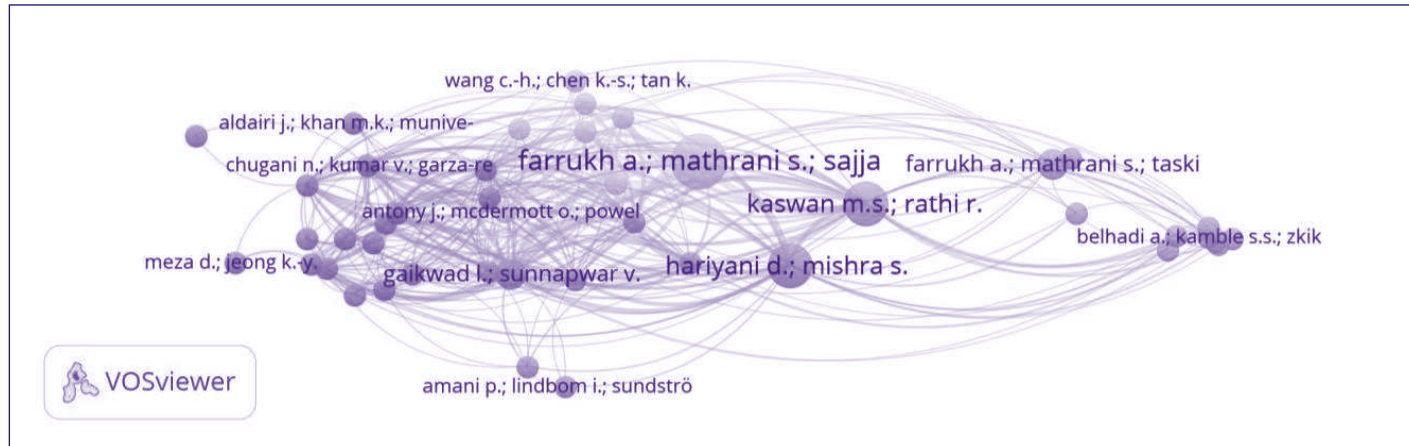


Fig. 5. Co-authorship analysis of authors

Table 5. Summary of key paper in each stream

Authors (Year)	Type of Paper	Methods/ Technique/ Data collection	Key findings
First steam: a need for lean, green, and six sigma			
(Garza-Reyes, 2015b)	Review	Systematic literature review	The study enables researchers to gain a deeper and broader understanding of the concurrent implementation of operational improvement and ecological initiatives and aids professionals in developing more practical deployment techniques.
(S. Kumar, Kumar, & Haleem, 2015)	Empirical	Brainstorming meetings, questionnaire-based surveys, statistical evaluation,	The 'Sustainable Green Lean Six Sigma'-related key success factors (CSFs) have been rated.
(Gholami et al., 2021)	Empirical	value stream mapping	The results showed that a DMAIC-based strategy worked well for ecological value stream mapping should be standardized and made more efficient in order to accomplish sustainability for the environment.
Second steam: Various sectors implemented LG&SS			
(Belhadi et al., 2020)	Empirical (Manufacturing)	Hybrid Factorial Analysis Structural Equation Modeling	Verify that Big Data Analytics (BDA) has a direct adversely affects ecological performance (EP), and also include green and lean six sigma are crucial bridging factors that function as an accelerator for the indirect impacts of BDA on EP
(Hussain et al., 2019)	Empirical (Construction)	Brainstorming meetings, questionnaire-based surveys, ISM, MICMAC	Using ISM methods, an 11-level hierarchal model was created. The findings demonstrate that GLS is less effective in unpredictable political environments, the absence of government legislation, a lack in consumer engagement and understanding of LG&SS, a lack of resources as well as the support of the upper levels.
(Sagnak & Kazancoglu, 2016)	Empirical (flue gas emissions)	Measurement System Analysis and Gage Control	Limitation of lean and green can be overcome by the six sigma. negative ecological effects of firms' products or services by improving environmental effectiveness by combining lean, green, and six sigma.
(Singh et al., 2021)	Empirical (MSMEs)	Exploratory Factor Analysis, Best Worst Method	According to the study's findings, environmental enablers are in a close second to strategic enablers in terms of importance.
(Raja Sreedharan et al., 2018)	Empirical (Public Sector)	Questionnaire-based surveys	Black belts and supply chain professionals have identified the positive effects of merging ecological supply chain leadership with lean six sigma. As a result, the challenges the public sector faces are eliminated, resulting in to efficiency improvement.
(Fatemi & Franchetti, 2016)	Empirical (Manufacturing)	Questionnaire-based surveys	According to a study, using the Sustainable Lean Green Six sigma methodology will reduce costs and impact on the environment.
Third steam: Framework for the integration of LG&SS			
(Cherrafi et al., 2017)	Empirical	VSM-Value Stream Mapping ' LCA- Life Cycle Assessment	The outcomes showed that LG&SS integration enabled organizations to reduce the cost of both mass and energy streams by 7–12%, and to cut their use of resources by 20–40% on aggregate.

(A. Banawi & Bilec, 2014a)	Empirical	LCA, VSM	A methodology has been established to assess the environmental effects of construction efficiency and to assist contractors in evaluating possibilities to lessen the negative effects of their current practices and increase overall effectiveness.
(R. Rathi et al., 2022)	Empirical	LCA and Social lifecycle assessment	Sustainability focused LG&SS helps to reduce improves environmental ability and process efficiency.
(Gaikwad & Sunnapwar, 2020b)	Empirical	Questionnaire-based surveys, Structural equation model	In terms of operating, economic, social, and impact on the environment, the anticipated result shows that integrated practices are beneficial to businesses. Additionally, it provides a thorough and systematic strategy for problem-solving via continuous, gradual enhancement in the manufacturing sector..
(Gandhi et al., 2021)	Empirical	ISM MICMAC analysis	The model's highest level is indicated by the "Lack of collaboration and mutual confidence among management and workers". "Weak legislation" is a significant obstacle to the adoption of LG&SS across Indian industries of manufacturing.
(R. Rathi et al., 2022)	Empirical	Questionnaire-based surveys	Integrate Industry 4.0 and Green Lean Six Sigma (GLSS) have aspects in common with regard to enablers and barriers, and the combined use of methods as well as instruments from each methodology strengthens their shared emphasis on improving sustainability.
Fourth steam: Sustainability attained with LG&SS's assistance			
(de Freitas et al., 2017)	Empirical	Questionnaire-based surveys	This study found a link between Lean Six Sigma and organizational sustainable development, mostly due to repercussions on the triple bottom line's Economic pillar. Additionally, the importance of the cost dimension for organizational sustainability was highlighted, along with the 5 impacts that have the most influence over companies.
(Erdil et al., 2018)	Empirical	Value Stream Map	By incorporating sustainability objectives into all Lean, Six Sigma improvement projects, the results of the research will broaden their relevance and speak to sustainability's economic, social, and ecological facets.
(Caiado et al., 2018)	Review	Systematic Literature review	The suggested framework outlines fresh perspectives and methods for achieving a harmony among the concerns of services regarding technology, society, economy, and the environment.
(Kaswan & Rathi, 2020a)	Empirical	principal Component Analysis, Best Worst Method	The findings show that Management related ,organizational and environmental barriers are the top three obstacles.
(Kaswan M.S. et al., (2023)	Empirical	Grey relation analysis (GRA) Best Worst Method Sensitivity Analysis	The productivity-related factor has been discovered to be the most important of the other criteria. In order to identify the project with the greatest potential for sustainable improvement, Six sustainability-related criteria were used to evaluate potential GLS initiatives in the manufacturing industry using GRA.
(Yadav V. & Gahlot P. 2022)	Empirical	DMAIC approach	The most significant obstacles to the implementation of GLSS have been determined to be a financial constraint, a lack of interaction with consumers, and a lack of awareness of Kaizen. LCA , 5S and Environmental value stream mapping have also been discovered to be the most frequently used GLSS tools.

5. PATHS FOR FUTURE RESEARCH

This study's main goals were to review the literature on LG&SS that had been published between 2008 and 2023 and to identify conceptual contributions to the creation of an integrated model. In order to promote LG&SS research. We identify current gaps in literature and use them as a foundation for fresh research investigations.

1. LG&SS approach adoption and awareness in emerging nations, particularly in the industrial sector, need to be investigated.
2. To ensure effective execution of LG&SS, a model for the LG&SS preparedness index must be developed.
3. It is required to explore enablers and barriers of LG&SS approach to help organizations for the sustainability initiatives.
4. A theoretical framework that combines LG&SS into one approach must be created, tested, and validated through empirical application in a real-world industrial environment.
5. An integrated monitoring and measuring system is needed to

assess the performance of LG&SS for the Sustainable development.

6. Little evidence is available for comprehensive inclusion of social aspect in the LG&SS paradigms so social aspect can be considered as a one prime factor for further research.
7. Need to explore practical implications and challenges of sequential or simultaneous deploying LG&SS.
8. It is still essential for investigating the adverse consequences of integrating LG&SS.
9. There is need to put more emphasis on the SMEs in order to support them in implementing LG&SS, approach.
10. Need to explore how to execution the LG&SS to emerging and developing countries

6. CONCLUSION

In this review paper, we conducted systematic assessing the literature on LG&SS integration to understand current issues as well as future directions for the focus area. We identified 126 research papers published in journals and conference

proceedings between 2008 and 2023 relevant to our focus area. The review enabled us to divide papers in to four stream i.e., (1) a need for lean, green, and six sigma (2) various sectors implemented LG&SS. (3) framework for the integration of LG&SS (4) sustainability attained with LG&SS's assistance. This review paper enabled to identify the ten major gaps that must be investigate for further research in this direction: need to explore the existing awareness and implementation status of LG&SS Strategies in developing countries specifically manufacturing sector ; To ensure the implementation of LG&SS is effective, a model for the LG&SS readiness index must be developed; Require to explore enablers and barriers of LG&SS approach to help organizations for the sustainability initiatives; must provide a theoretical framework that combines LG&SS into a single methodology, complied by its test and validation through its empirical application in industries ; A comprehensive monitoring and system of measurement must be created to measure LG&SS Sustainability performance; Little evidence is available for comprehensive inclusion of social aspect in integrated LG&SS paradigms so social aspect can be considered as a one prime factor for further research; Need to explore practical implications and challenges of sequential or simultaneous deploying LG&SS in the organization; Need to investigating the adverse consequences of integrating LG&SS approach.

The review paper enables scholars to learn more about the integrated LG&SS strategy and to identify future initiatives. It can be also useful to Industrial practitioners, to support them in developing more sensible objectives and approaches for their adoption.

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