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Exploring the intersection of lean practices and sustainability: A bibliometric perspective

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Abstract
The integration of lean management principles with sustainable operational practices has gained significant scholarly attention in recent years. This study conducts a comprehensive bibliometric analysis to examine the global research trends in this domain between 2021 and 2025. A total of 392 articles were retrieved from the Web of Science database using a structured query incorporating keywords related to lean manufacturing and sustainability. Analytical tools such as VOSviewer and Biblioshiny were employed to map the intellectual and thematic structure of the field. The results reveal a steady increase in publication output, with China, the USA, Brazil, and India being the most prolific contributors. Thematic and trend analyses indicate a growing convergence of lean practices with emerging digital technologies, particularly Industry 4.0, artificial intelligence, and agile strategies. While foundational themes such as implementation, quality, and performance remain central, the emergence of bridging and niche themes highlights the diversification of research interests. Leading institutions and high-impact journals were identified, with the *International Journal of Lean Six Sigma* and *Sustainability* being the most prominent sources. The study offers valuable insights into the current state and future directions of research on lean and sustainable operations, emphasizing the need for continued exploration of integrative frameworks and sector-specific applications.

Keywords: Lean management, sustainable operations, bibliometric analysis, Industry 4.0, VOS viewer, Biblioshiny

1. Introduction
Lean management, originating from the Toyota Production System, is a strategic philosophy centred on eliminating waste, streamlining processes, and maximizing value delivery to customers. Its foundational principles such as just-in-time production, continuous improvement (Kaizen), and respect for people have been widely adopted across industries to enhance operational efficiency and competitiveness(Womack & Jones, 1997) [9].In recent decades, the growing global imperative for sustainability encompassing environmental stewardship, social responsibility, and economic viability has catalysed scholarly and industrial interest in aligning lean practices with sustainable operations (Pearce *et al*., 2021) [6]. This alignment is not merely conceptual; lean techniques such as reducing overproduction, optimizing process flows, and eliminating defects directly support environmental objectives by lowering resource consumption and minimizing waste generation (Nadeem *et al*., 2025; Simukonda & Emuze, 2024) [5, 7]. The integration of advanced digital technologies has further strengthened this synergy (Buhaya & Metwally, 2024) [3]. Tools associated with Industry 4.0, including the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, enable real-time monitoring, predictive maintenance, and data-driven decision-making capabilities that simultaneously improve operational agility and advance sustainability outcomes (Buer *et al*., 2021; Buhaya & Metwally, 2024; Sunder & Prashar, 2024) [2, 3, 8].This convergence of lean principles, sustainability objectives, and digital transformation represents a pivotal evolution in modern operations management (Frecassetti *et al*., 2024) [4].
Despite the expanding literature, research at this intersection remains fragmented, with diverse methodological approaches and sector-specific applications. Bibliometric analysis offers a systematic means to map this emerging knowledge domain, identify influential contributors, and highlight thematic trajectories (Aria & Cuccurullo, 2017) [1]. Accordingly, this study undertakes a bibliometric investigation of 392 peer-reviewed articles published between 2021 and 2025, aiming to address four key questions:
What are the global trends in research output?

Which countries, institutions, and authors lead the discourse? What thematic structure defines lean–sustainability research?

What are the gaps and future directions for study?

To answer these questions, this study conducts a bibliometric analysis of 392 articles retrieved from the Web of Science database, spanning 2021 to 2025, using advanced analytical tools such as VOSviewer and Biblioshiny. The findings aim to provide a holistic understanding of the intellectual and thematic landscape, guiding researchers, policymakers, and practitioners toward integrative frameworks and innovative applications of lean and sustainable practices.

2. Research Materials and methods

An important element of research process is choosing the methods and resources for data analysis. The data for this study has been obtained from one of the online databases. Among the well - known databases frequently employed in bibliometric researches are Web of Science, Scopus, Google Scholar, etc. For this study, the data was collected from Web of Science. The software used for analysis is VOS Viewer and biblioshiny. Once the database is selected, the next step is to decide the query string. In this study, documents were extracted using the search terms "Lean Managemen*" OR "Lean Practice*" OR "Lean Manufactur*" AND "Sustainable Operation*". Further details of the search strategy are given in Table 1.

Table 1: Parameters of the search strategy

Database	Web of Science
Search Date	11th July 2025
Search Word	Lean Management and Sustainable Operation
category	All fields
Query String	"Lean Managemen*" OR "Lean Practice*" OR "Lean Manufactur*" AND "Sustainable Operation*"
Total docs before filtration	5897
Subject criteria	No Filtration
Document type	Article
Period time	2021-2025
Language	English
Source type	Journal
Publication Stage	Final
Total Docs after filtration	392

3. Results and Discussion

Figure 1 Trending topic analysis highlights the evolving focus areas within lean and sustainable operations research from 2021 to 2025. In recent years, themes such as Industry 4.0, dynamic capabilities, and time have emerged as dominant topics, indicating a shift toward digitalization and agility in operations. Core concepts like lean management, implementation, and performance maintained strong presence around 2023, reinforcing their foundational role in the field. Earlier, between 2021 and 2022, research concentrated on developing models, frameworks, and sector-specific applications like healthcare. Notably, principles, financial performance, and lean implementation were among the earliest explored, suggesting an initial emphasis on theoretical grounding and outcome-based assessments. It shows a shift from theoretical frameworks (2021–2022) to digitalization and agility (2023–2025), with emerging themes like data analysis indicating future directions. The frequency and timing of these terms reflect a maturing field that is gradually aligning traditional lean practices with advanced technologies and strategic capabilities.

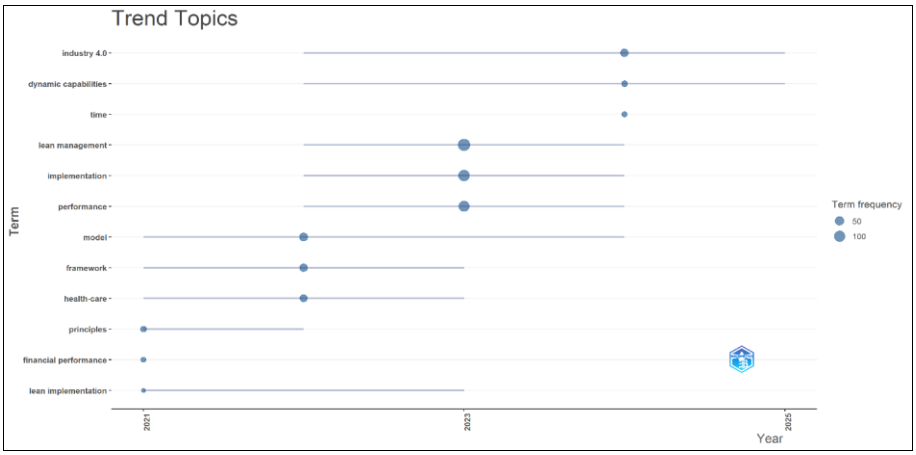

Fig 1: Trending topics

The table 2 depicts the global distribution of research contributions in Lean Management and Sustainable Operations, with China leading significantly with 172 contributions indicating its strong focus on Sustainability. China and USA emerge as significant contributors, demonstrating their dedication to waste reduction and Sustainability. the distribution of publications indicates that both developed and developing nations are actively contributing to the academic discourse on lean and sustainable operations.

Table 2: Annual Scientific Production

Country	Frequency	%Doc
China	172	17.13147
USA	103	10.25896
Brazil	79	7.868526
UK	64	6.374502
Italy	56	5.577689
India	55	5.478088
Australia	34	3.386454
Spain	34	3.386454
Poland	28	2.788845
Switzerland	27	2.689243

Figure 2 presents the most influential authors in lean and sustainable operations research include Rundall TG, Shortell SM, and Tortorella GL, each with 10 publications. Authors like Antony J, Blodgett JC, and Klein LL also stand out with 7 publications each. This indicates a core group of scholars driving the field, alongside emerging contributors like Garza-Reyes JA and Afum E.

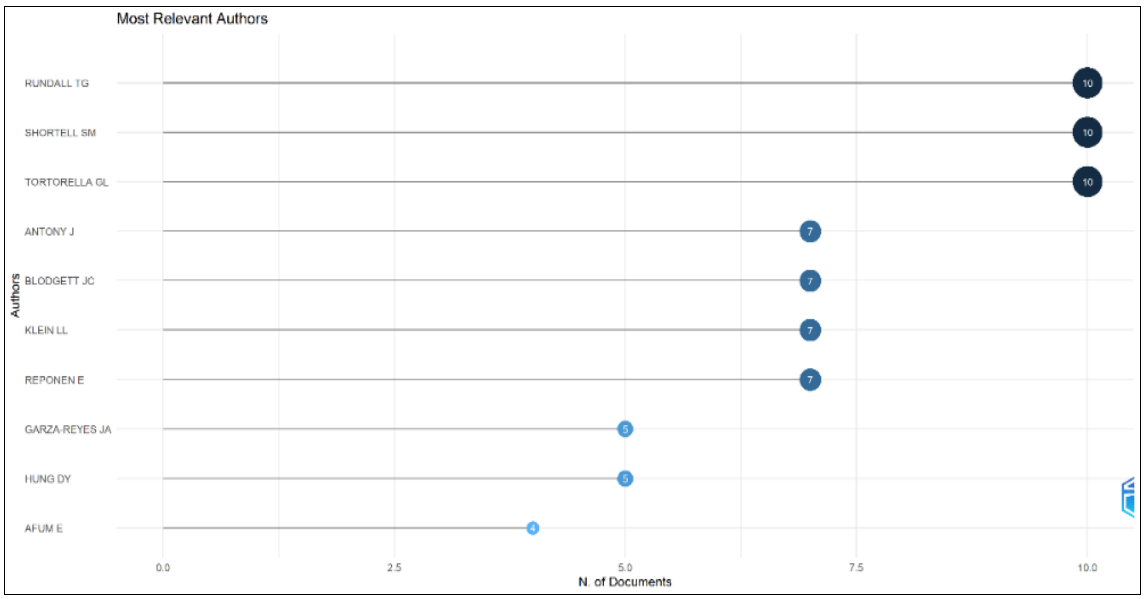

Fig 2: Most relevant authors

Table 3 shows leading institutional contributors to lean and sustainable operations research reflect strong representation from North America, Europe, and South America. The University of California System (14 articles) and UC Berkeley (13 articles) highlight the dominance of the United States in scholarly output. From Europe, the University of Melbourne (Australia), Norwegian University of Science and Technology, and University of Helsinki each contributed significantly, with 10 publications each, emphasizing active research engagement in the Nordic region. Notably, Brazilian institutions such as the Federal University of Santa Catarina (UFSC), Federal University of São Carlos (UFSCar), and Federal University of Santa Maria (UFSM) have also emerged as key players, together contributing over 25 publications. This regional spread underscores the global interest in integrating lean practices with sustainability, with particularly strong research clusters in the USA, Brazil, and Europe.

Table 3: Most relevant Affiliation

Affiliation	Articles	% Doc
University of California System	14	3.571429
University of California Berkeley	13	3.316327
University of Melbourne	12	3.061224
Norwegian University of Science and Technology (NTNU)	10	2.55102
University of Helsinki	10	2.55102
Universidade Federal De Santa Catarina (UFSC)	9	2.295918
Universidade Federal De Sao Carlos	9	2.295918
Universidade Federal De Santa Maria (UFSM)	8	2.040816
University of Padua	8	2.040816
Us Department of Veterans Affairs	8	2.040816
Veterans Health Administration (VHA)	8	2.040816

Table 4: Most relevant Sources

Sources	Articles	% Doc
International journal of lean six sigma	35	8.92857
Sustainability	34	8.67346
Production planning & control	23	5.86734
Journal of manufacturing technology management	12	3.06122
Applied sciences-basel	10	2.55102
Total quality management & business excellence	10	2.55102
International journal of operations & production management	9	2.29591
Journal of cleaner production	9	2.29591
Buildings	7	1.78571
International journal of production economics	7	1.78571
Operations management research	7	1.78571
Quality management in health care	7	1.78571

The International Journal of Lean Six Sigma (35 articles) and Sustainability (34 articles) are the two leading publication outlets in lean and sustainable operations, together accounting for over 17% of the total research output. These are followed by Production Planning & Control (23 articles), reflecting a strong focus on manufacturing and operational efficiency. Other significant sources include the Journal of Manufacturing Technology Management and several interdisciplinary journals, indicating a blend of both technical and sustainability-oriented publishing platforms. This distribution highlights the field's dual focus on lean methodologies and sustainable practices across diverse industrial and academic contexts.

Figure 3 thematic map analysis of lean and sustainable operations research reveals four key theme categories. Motor themes such as *strategy*, *agile*, *knowledge*, *Industry 4.0*, and *design* are highly developed and central to the field, indicating a strong focus on digital transformation and strategic integration. Niche themes like *artificial intelligence*, *5S*, are specialized and mature but less connected to the core structure. Emerging or declining themes such as *lean methodology*, *patient loss management*, and *data analysis* are underdeveloped and may represent fading interest or potential future directions. Basic themes—including *lean management*, *implementation*, *performance*, *quality*, and *barriers*—are foundational yet lack depth, signalling opportunities for further exploration. Bridging themes like *sustainable performance*, *total quality management*, and *big data analytics* lie near the centre, highlighting their integrative role in advancing the field. Overall, the map underscores a growing alignment between lean practices and digital, sustainable innovation while identifying gaps for future research.

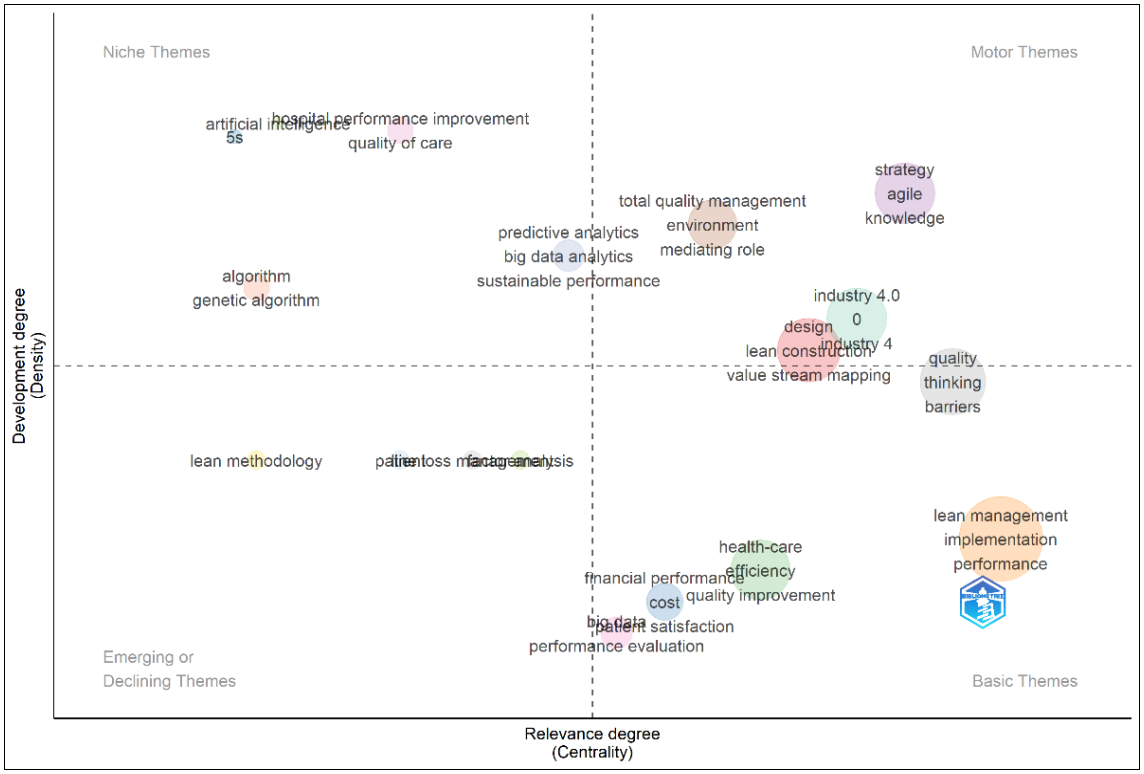

Fig 3: Thematic map

The table 5. Findings of co-occurrence analysis shows strong interconnections among keywords, with "lean management" (137 occurrences, 414 link strength) and "implementation" (110 occurrences, 576 link strength) as central nodes, frequently co-occurring with "performance," "Industry 4.0," and "sustainability." Cluster 1 highlights lean's impact on performance and green practices, aligning with sustainability goals (Pearce *et al*., 2021) [6]. Cluster 2 reflects the integration of lean with digital technologies like AI and IoT, emphasizing optimization models (Sunder & Prashar, 2024) [8]. Cluster 3 focuses on quality-driven methodologies in healthcare, with "Six Sigma" and "leadership" as key connectors (Januszek *et al*., 2023). Cluster 4 underscores sustainability frameworks and barriers, particularly in construction (Simukonda & Emuze, 2024) [7]. Cluster 5, with low link strength, suggests underexplored foundational principles. Trend analysis shows a shift from theoretical frameworks (2021–2022) to digitalization and agility (2023–2025), with emerging themes like data analysis indicating future directions.

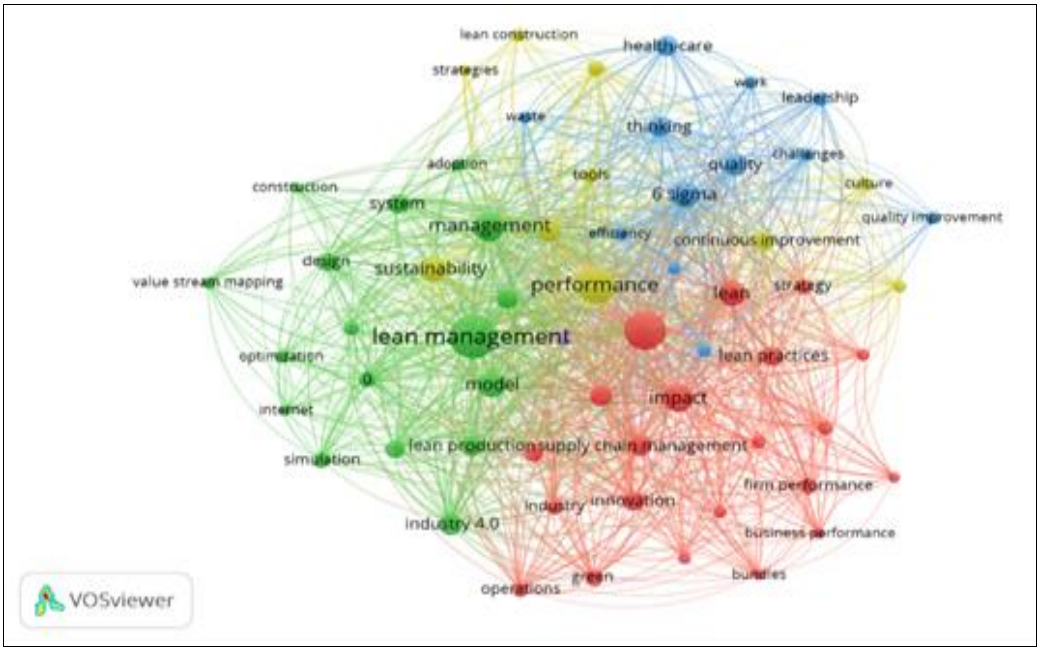

Fig 4: Co-occurrence analysis

Table 5: Findings of co-occurrence analysis

Items of Key word- 61 Cluster- 5 Total ling strength- 3855

Clusters	Keyword	Occurrences	Total Ling strength
Cluster 1	Bundles	10	57
	Business performance	10	57
	Dynamic capabilities	12	49
	Firm performance	18	92
	Green	20	99
	Impact	57	278
	Implementation	110	576
	Industry	16	53
	Innovation	27	132
	Just-in-time	10	54
	Lean	47	31
	Lean manufacturing	31	15
	Lean Practices	18	9
	Operation performance	16	91
	Operations	15	85
	PLS-SEM	14	64
	Process improvement	12	65
	Strategy	10	36
	Supply chain	12	72
	Supply chain management	13	10
	System	28	141
Cluster 2	0	18	115
	Adoption	11	43
	Construction	10	39
	Design	25	125
	Improvement	27	149
	Industry 4	16	108
	Industry 4.0	35	182
	Integration	24	137
	Internet	10	54
	Lean management	137	414
	Lean production	26	141
	Management	63	320
	Model	45	211
	Optimization	13	61
	Simulation	18	94
	Systems	21	82
	Value stream mapping	11	17
Cluster 3	6 Sigma	45	256
	Challenges	14	90
	Context	14	79
	Efficiency	14	53
	Health- care	30	98
	Leadership	15	97
	Quality	34	165
	Quality improvement	14	49
	SMEs	11	61
	Thinking	30	167
	Waste	12	65
	work	14	53
Cluster 4	Barriers	18	100
	Continuous improvement	23	117
	Critical success factors	11	63
	Culture	12	66
	Framework	35	182
	Lean construction	14	43
	Performance	92	456
	Strategies	10	36
	Sustainability	48	223
	Tools	16	95
Cluster 5	Principles	13	59

4. Conclusion

This bibliometric analysis provides a comprehensive overview of global research on lean management and sustainable operations from 2021 to 2025. The results reveal that both developed and emerging economies actively contribute to this field, with China, the U.S.A., Brazil, and India being the most prolific. Thematic analysis indicates that while foundational topics such as implementation,

performance, and quality remain central, there is a marked shift toward the integration of lean practices with advanced digital technologies such as Industry 4.0, artificial intelligence, and big data analytics. Leading institutions and journals play a pivotal role in shaping this discourse, fostering interdisciplinary approaches that bridge efficiency with sustainability. From the analysis, several research gaps and promising future directions have been identified. Basic themes such as lean management, implementation, performance, quality, and barriers are foundational but underdeveloped, requiring deeper theoretical and empirical exploration. Emerging or declining themes, including lean methodology, patient loss management, and data analysis, remain underexplored and may represent potential research frontiers. Niche themes such as AI and 5S are mature yet insufficiently integrated with the core lean–sustainability discourse. Cluster 5 in the co-occurrence analysis shows low link strength, indicating unexplored principles and concepts worthy of further investigation. The research also exhibits a sectoral bias toward manufacturing, with limited application in fields such as agriculture, logistics, and education.

Overall, the findings highlight a dynamic and maturing research landscape with significant opportunities for theoretical advancement and practical application.

5. Limitations and Future Scope

While this study provides valuable insights, it has certain limitations. The analysis was restricted to the Web of Science database, which may have excluded relevant studies indexed in other databases such as Scopus or Google Scholar. Only English-language articles were considered, potentially overlooking important contributions in other languages. The study period was limited to 2021–2025, meaning long-term trends beyond this timeframe were not examined. Moreover, bibliometric analysis inherently focuses on quantitative patterns and does not capture the qualitative depth of individual studies.

Future research should focus on stronger integration of digital technologies—such as AI, IoT, and big data analytics—into sustainable lean frameworks, expanding sector-specific applications beyond manufacturing, and developing holistic frameworks that balance efficiency with environmental, social, and economic goals. Addressing organizational and cultural barriers, as well as conducting cross-regional comparative studies, could yield valuable insights into the geographical variations in lean–sustainability adoption. Collectively, these directions will guide the creation of more resilient, inclusive, and sustainable operational models across industries.

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