Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

# Lean and Green Manufacturing Synergy in the Automotive Industry A Systematic Review from 2010 to 2026

**Jinglin Ding**
University of Malaya
**Suhaiza Hanim Mohamad Zailani**
shmz@um.edu.my
University of Malaya
**Wentong Chong**
University of Malaya

**Systematic Review**

**Keywords:** Lean Manufacturing, Environmental Management Practices, Automotive Industry, Environmental Performance, Systematic Literature Review

**Posted Date:** May 18th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-9321257/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

**Additional Declarations:** No competing interests reported.

**Version of Record:** A version of this preprint was published at Discover Sustainability on September 1st, 2026. See the published version at https://doi.org/10.1007/s43621-026-04522-w.

# Abstract

Under the pressure of global climate change, the automotive manufacturing industry faces the dual challenge of improving operational efficiency and environmental performance. However, existing research on lean manufacturing and environmental management integration suffers from theoretical fragmentation and contradictory empirical results. Following the Systematic Search Flow framework and PRISMA guidelines, this study systematically reviews 46 articles from Web of Science and Scopus (2010–March 2026), combining bibliometric analysis using Bibliometrix and VOSviewer. The findings reveal three developmental stages: relationship validation, mechanism exploration, and digitally driven transformation. Drawing on Triple Bottom Line Theory, Resource-Based View, and Institutional Theory, this study constructs a multi-theoretical framework across micro, meso, and macro levels, identifying three mechanisms through which integration affects environmental performance: process optimisation, capability enhancement, and technology enablement. Integration outcomes are moderated by resource endowments, organisational capabilities, and technological maturity, demonstrating conditional rather than universal applicability. These findings explain contradictory empirical conclusions, offer differentiated strategic guidance for automotive manufacturers, and support the industry's transition toward low-carbon and intelligent manufacturing. Future research should adopt longitudinal designs and extend to circular economy and carbon neutrality frameworks.


# 1. Introduction

Global climate change is pushing manufacturing to shift toward sustainable development [18]. The Paris Agreement has set rules for reducing emissions in industries that use a lot of energy and create high pollution [47]. Manufacturing is a major source of global carbon emissions, so it faces strong pressure from environmental regulations [2]. The automotive industry is a resource-intensive industry. Its environmental impact affects the entire value chain. This industry not only uses large amounts of energy and raw materials directly but also creates indirect environmental effects through its supply chain network [18, 14]. This challenge has led the automotive industry to seek management methods that can improve both operational efficiency and environmental performance [20]. Lean manufacturing and environmental management practices have become two major strategic choices for the automotive industry. Lean manufacturing improves efficiency by removing waste and improving processes [57, 19]. Environmental management practices reduce environmental impact through systematic methods [48]. The waste reduction idea in lean manufacturing matches well with the resource efficiency goals of environmental management [30]. Although combining lean management and environmental practices has practical value and theoretical fit, academic research is still limited. Through analyzing existing research, this study points out three key gaps: scattered research, single theoretical views, and conflicting research results.

First, integration research is scattered and fragmented, with many studies examining only individual lean or environmental indicators in isolation [44]. Related studies are spread across multiple fields, there is a lack of cross field dialogue and cooperation [1]. In terms of research topics, previous studies focus on

specific lean tools or single environmental performance measures. They lack an overall view, which leads to a scattered knowledge system. In terms of methods, previous reviews use narrative approaches. These are quite subjective and cannot systematically reveal the knowledge structure of the research field and how it develops [18]. Therefore, this study employs a systematic literature review following PRISMA guidelines, combined with Bibliometric analysis to map the knowledge structure, identify research frontiers and builds a comprehensive knowledge framework for the lean-environment integration field.

Second, there is a single theoretical perspective to explain the lean and environment relationship. This leads to fragmented understanding and conceptual ambiguity [43]. There is a lack of unified concept frameworks and theoretical agreement [23]. Most studies use the Resource Based View to emphasize resource efficiency or use Institutional Theory to explain compliance pressure. But a single theory cannot fully explain the integration mechanism. However, lean and environment integration involves multi-level interactions at the operational, organisational, and strategic levels. Multiple theoretical perspectives are needed to capture this complexity [36]. Therefore, this study analyzes the integration mechanism from three dimensions which are resource allocation, capability evolution, and value creation. This provides a more complete theoretical explanation.

Finally, existing research on the relationship between lean and environmental performance shows inconsistent results [13]. Some studies emphasize that the two have synergistic effects. For example, there is a positive correlation between lean implementation and pollution reduction in companies with ISO 14001 certification [30], and confirmed that lean practices can indirectly improve financial performance by strengthening environmental management [60]. However, other studies present opposite or more complex conclusions. Rothenberg et al. [45] pointed out that lean factories, in pursuing zero defects and high stability, lead to extra resource input and environmental burden [36]. In addition, existing literature views lean as an effective way to improve environmental performance, but lacks necessary critical examination [21]. For example, Just-in-time delivery may increase carbon emissions through frequent transportation; quick changeover and small batch production may increase energy consumption; excessive pursuit of zero defects may lead to extra testing and rework; and lean culture emphasizes efficiency, which may weaken companies' attention to long term environmental investment. These phenomena show that previous research has ignored the influence of contextual factors, boundary conditions, and mechanism differences. Therefore, this study re-examines the environmental impact of lean from a dialectical perspective. It compares sample characteristics, measurement methods, and contextual variables of existing studies to identify key factors that lead to differences in empirical results. This provides an explanatory and predictive integration framework for the lean-environment relationship.

Based on the research gaps, this study conducts a systematic review of related literature published between 2010 and March 2026. This period is marked by stronger global climate policies and the maturity of lean-green integration practices in the automotive industry. This study aims to fully reveal how automotive industry can effectively integrate lean manufacturing and environmental management

practices to achieve excellent environmental performance. To systematically address these research gaps, this study builds research questions from three dimensions: (1) To address the fragmentation problem, it uses knowledge structure, evolution trend analysis, and theoretical landscape mapping (RQ1); (2) To address the limitation of single theoretical perspectives, it constructs a multi theory integration frameworks and address their limitations (RQ2); (3) To address contradictory research results and the lack of critical examination, it identifies integration mechanisms and contextual factors to provide explanations and balanced practical guidance (RQ3). Specifically, the research questions of this study are as follows:

RQ1: What are the trends, core themes, and theoretical frameworks in lean - environmental integration research within the automotive industry?

**RQ2**

What are the limitations of existing frameworks and how can a multi-theory framework be constructed?

**RQ3**

What mechanisms drive integration's impact on environmental performance and why do empirical studies show contradictory results?

This study makes three original contributions. First, it constructs a multi-theoretical framework integrating Triple Bottom Line Theory, Resource-Based View, and Institutional Theory across macro, meso, and micro levels to explain why integration outcomes vary across organisational and institutional contexts. Second, it comprehensively depicts the knowledge structure, research hotspots, and evolutionary trends of lean and green integration in the automotive industry from 2010 to March 2026 through a systematic literature review and Bibliometric analysis. Third, it adopts a critical perspective, examining the conditions under which lean and environmental are synergistic or conflicting, identifying the background factors and boundary conditions leading to contradictory empirical results, and providing balanced practical guidance for automakers.

The rest of the paper is organized as follows: Section 2 details the methodological design. Section 3 presents the Bibliometric and thematic results. Section 4 discusses findings. Section 5 explains the theoretical, practical, and policy implications. Section 6 concludes with limitations and directions for future research.

# 2. Methodology

This section details the research design, clarifying the procedures for acquiring, selecting, and processing the literature. This explanation ensures transparency in how the research evidence is constructed and enhances the reliability of subsequent research findings.

# 2.1 Research Design

This study adopts a systematic literature review combined with bibliometric analysis to comprehensively analyze the integration of lean manufacturing and environmental management practices in the automotive manufacturing industry. As a standardized research method, the systematic literature review can effectively identify knowledge gaps and areas of theoretical ambiguity, providing a foundation for subsequent theory development and empirical research [28]. Compared with traditional narrative literature reviews, the systematic literature review has significant advantages in terms of objectivity, transparency, and reproducibility, effectively reducing researchers' subjective bias.

The research design follows the systematic search flow framework proposed by Ferenhof and Fernandes [17] which provides a structured, transparent, and reproducible procedure for conducting literature reviews. This framework has been widely used in research due to its clear guidance and organizes the review process into four steps: research protocol definition, analysis, synthesis, and writing [17, 6]. The first phase of this study, the research protocol definition, includes defining the research question, search strategy, database selection, and inclusion and exclusion criteria. This research protocol minimizes confirmation bias and ensures the objectivity of the subsequent search process. In the second phase, the analysis phase, the literature undergoes a three round systematic screening process. In the third phase, the synthesis phase, a knowledge matrix is constructed to systematically extract and organize key information for inclusion in the research, and Bibliometric analysis is conducted to create a knowledge structure map of the field. In the fourth phase, the writing phase, the synthesized results are presented and interpreted to answer the research questions and propose theoretical contributions. The systematic search flow framework structures the procedural conduct of this review, while PRISMA 2020 guidelines are adopted as the complementary reporting standard to ensure transparency in search documentation, screening decisions, and inclusion criteria.

Bibliometric analysis complements the systematic literature review by providing quantitative visualisation of knowledge structures, research clusters, and evolutionary trends that qualitative synthesis alone cannot fully reveal [54]. Tools such as Bibliometrix and VOSviewer are particularly suited to the lean and green integration field, which spans operations management, environmental science, and strategic management, enabling identification of research hotspots, collaboration networks, and emerging themes across disciplinary boundaries.

During the design stage of the research questions, this study clearly defines four core dimensions, namely intervention, population, outcome, and context, to ensure the focus and rigor of the study. The intervention refers to the integration of lean manufacturing and environmental management practices; the population refers to automotive manufacturing enterprises; the outcome refers to environmental performance; and the context refers to the automotive manufacturing background. By defining these four dimensions, this study establishes clear research boundaries and an analytical framework.

## 2.2 Research Protocol Definition

### 2.2.1 Database Selection

This study selects Web of Science and Scopus as the main databases for literature retrieval. These two databases are internationally recognized authoritative academic sources that include the most influential and high-quality journal publications in this research field. The Scopus database is well known for its comprehensive coverage of academic articles and detailed citation records, while Web of Science is recognized for its rigorous journal selection criteria and high-quality indexing system. The dual database search strategy ensures the comprehensiveness of literature retrieval to the greatest extent possible and aligns with standard practices for systematic literature review [53]. This study did not include Google Scholar due to its broader grey literature coverage and lower quality control standards, which may compromise systematic review rigor. The search strategy of this study is developed around three core conceptual dimensions: lean manufacturing, environmental management practices, and the automotive manufacturing industry. Following the principle of high-sensitivity design, combinations of both general and specific keywords were determined through repeated testing to ensure the completeness and specificity of the search results. The search fields were set to Title–Abstract–Keywords to comprehensively capture relevant literature. Boolean operators AND, OR, and NOT were used to control the scope and precision of the search results. The search was conducted in March 2026. The specific search query is shown in the Table 2.1.

Table 2.1
Search Queries

| Source | Scopus | Web of Science |
|---|---|---|
| Keyword Search Statement | TITLE-ABS-KEY( ("lean manufacturing" OR "lean production" OR "lean management" OR "Toyota production system" OR "lean principles") AND ("environmental management" OR "green manufacturing" OR "environmental performance" OR "sustainability" OR "circular economy" OR "cleaner production" OR "eco-efficiency" OR "carbon neutrality" OR "net zero" OR "decarbonization") AND ("automotive" OR "automobile" OR "car manufacturing" OR "vehicle production" OR "automotive industry") ) | TS=( ("lean manufacturing" OR "lean production" OR "lean management" OR "Toyota production system" OR "lean principles") AND ("environmental management" OR "green manufacturing" OR "environmental performance" OR "sustainability" OR "circular economy" OR "cleaner production" OR "eco-efficiency" OR "carbon neutrality" OR "net zero" OR "decarbonization") AND ("automotive" OR "automobile" OR "car manufacturing" OR "vehicle production" OR "automotive industry") ) |

To capture studies on digital transformation and Industry 4.0 integration an emerging trend identified in the preliminary review, a supplementary search query was applied in Scopus for the period 2021 to 2026: TITLE-ABS-KEY(("lean manufacturing" OR "lean production") AND ("Industry 4.0" OR "digital transformation" OR "smart manufacturing" OR "artificial intelligence") AND ("environmental performance" OR "sustainability" OR "carbon emission") AND ("automotive" OR "automobile" OR "vehicle"))

## 2.2.2 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the retrieved literature, clear inclusion and exclusion criteria were established prior to the database search. To enhance clarity and facilitate practical implementation, these criteria were organized into a comparative table as shown in Table 2.2.

Table 2.2
Inclusion and Exclusion Criteria

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Written in English | Written in Other Languages |
| Published Between 2010 and March 2026 | Not Published Between 2010 and March 2026 |
| Focus on Automobile Manufacturing | Not Involved in the Automotive Industry |
| Empirical Studies/ Literature Review | Grey Literature/Commentary/Meta Analysis |
| Quality Assessment Meet Standards | Quality Assessment Did Not Meet Standards |
| Integrating Lean Manufacturing and Sustainable Practices | Only Lean or Only Sustainable Practices |
| Include Environmental Performance Measurement | No Environmental Performance Measurement Included |
| Full Text Accessible | Full Text Inaccessible |

The time span was set from 2010 to March 2026, which reflects recent research trends while ensuring both timeliness and research value. The language was restricted to English publications, which guarantees academic rigor and allows the extraction of high quality, peer reviewed content in accordance with international research standards. Regarding document type, only Articles and Reviews were included. In terms of subject areas, the search focused on the fields of business, management, and engineering, as these disciplines are directly related to practical integration studies. Additionally, to enhance the comprehensiveness of the literature retrieval, manual searching was employed as a supplementary strategy, since some high quality studies may not yet be indexed in major databases. The initial database search in this study yielded the following results in Table 2.3.

Table 2.3
Summary of Database Search and Filtering Results

| Filtering Step | Scopus Main Search | Scopus Supplementary Search | Web of Science |
|---|---|---|---|
| Initial keyword search | 122 | 14 | 88 |
| After time range filter (2010–2026) | 115 | 9 | 83 |
| After document type filter (Article and Review) | 73 | 4 | 66 |
| After language filter (English) | 72 | 4 | 66 |
| After subject area filter | 71 | 4 | 57 |
| Final records for import | 71 | 4 | 57 |

In the Scopus database, the preliminary search result showed a total of 122 records. After sequentially applying limitations for publication year, document type, language, and subject area, 71 studies met the inclusion criteria. A supplementary search yielded 9 initial records in Scopus, which were reduced to 4 studies after applying the same filtering conditions. In the Web of Science database, the initial search identified 88 records. After applying the same filtering conditions, 57 studies were obtained. All records from all three searches were successfully imported into Zotero with no documents lost, resulting in a combined total of 132 imported records. Zotero identified 38 duplicate items, resulting in a final total of 94 studies after deduplication, representing a duplication rate of 28.8%. This rate indicates a considerable degree of overlap between the databases, confirming both the consistency and validity of the search strategy, and falls within a normal and acceptable range.

## 2.2.3 Literature Screening Process

In the first round, all 94 studies were evaluated based on titles only, without reading the full text. Studies were directly excluded if they met any of the following conditions: the title showed no relevance to the automotive industry; the study addressed only lean manufacturing without any environmental content, or only environmental content without lean integration; or the article was clearly non-research in nature. Studies were retained if the title referenced lean manufacturing alongside environmental, green, or sustainability themes, or if the title indicated a focus on automotive manufacturing combined with sustainable practices. This round resulted in the exclusion of 15 studies, leaving 79 studies for the next round.

In the second round, the abstracts of the remaining 79 studies were evaluated. Studies were excluded if the abstract contained no specific environmental performance measurement; if the research object was not an automotive manufacturing enterprise; if the study was conceptual without substantive empirical content; if the full text was inaccessible; or if the publication was identified as a conference proceeding. This round resulted in the exclusion of 32 studies, leaving 47 studies for quality assessment.

In the third round, the remaining 47 studies underwent formal quality assessment using the Joanna Briggs Institute (JBI) Critical Appraisal Tool. This tool includes 10 key assessment criteria and employs a scoring system in which each satisfied criterion receives a score of 1, while criteria that are not satisfied or unclear receive a score of 0. The total possible score ranges from 0 to 10. Based on the total scores, studies were categorized into three quality levels which are high quality (8–10 points), selected for detailed in-depth analysis; moderate quality (6–7 points), included for general analysis; and low quality (below 6 points), excluded from the final analysis. The complete three round screening process resulted in a final portfolio of 46 studies, as visualised in the following Fig. 2.1 PRISMA 2020 flow diagram.

# 2.3 Data Analysis Method

This study adopted a combined quantitative and visualization analytical approach. Descriptive statistical analysis was conducted using Bibliometrix in RStudio. VOSviewer software was employed to construct

scientific knowledge maps. The technical specifications and validation procedures for network analysis are detailed below.

To visualize collaboration patterns and knowledge structures, VOSviewer software was employed for science mapping [54]. VOSviewer utilizes the VOS layout algorithm, which positions nodes based on their similarity strength, thereby clearly representing relationships within Bibliometric networks. For community detection, the software employs modularity based clustering, which identifies research groups by maximizing the ratio of within-cluster connections relative to between-cluster connections [55]. The clustering resolution parameter was set to 1.0, with a minimum cluster size of 3 nodes. Network quality was assessed using the modularity score, where values above 0.3 indicate significant community structure. In all network visualizations, node size represents frequency or activity level, link thickness indicates connection strength, and colors distinguish different clusters in collaboration networks or time periods in temporal evolution networks. Table 2.4 summarises the complete analytical workflow adopted in this study.

Table 2.4
Analytical Workflow Following the Systematic Search Flow Framework

| Step | Systematic Search Flow Phase | Task | Tool or Method |
|---|---|---|---|
| 1 | Protocol | Research Questions Formulation | Intervention, Population, Outcome, Context Framework |
| 2 | Protocol | Database Search and Keywords Design | Scopus and Web of Science |
| 3 | Analysis | Deduplication and Import | Zotero |
| 4 | Analysis | Three Rounds Screening | Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 |
| 5 | Analysis | Quality Assessment | Joanna Briggs Institute Critical Appraisal Tool |
| 6 | Synthesis | Data Extraction | Microsoft Excel |
| 7 | Synthesis | Bibliometrix Analysis | Bibliometrix and VOSviewer |
| 8 | Synthesis | Content Analysis | Data Extraction Matrix |
| 9 | Writing | Results Interpretation and Framework Construction | Literature Synthesis |

# 2.4 Data Extraction and Analysis

Following the requirements of the Systematic Search Flow framework, a standardised data extraction form was developed in Excel to systematically extract information from the 46 included studies. The extracted content covers two categories: basic bibliographic information and core research content. At

the data analysis level, this study adopts a two-level analytical strategy combining macro-level and micro-level approaches. At the macro level, Bibliometric analysis was conducted using Bibliometrix and VOSviewer to quantitatively visualise the knowledge structure and evolutionary trends of the field. At the micro level, content analysis was performed based on the data extraction matrix through systematic cross-study comparison, completing three core tasks in sequence identifying research evolutionary stages, synthesising theoretical frameworks, and analysing contradictory findings and boundary conditions.

## 2.5 Methodological considerations and limitations

This study acknowledges several methodological limitations inherent in the research design that may affect the comprehensiveness of findings.

- Database coverage: The literature search was restricted to Web of Science and Scopus databases, supplemented by a targeted digital transformation and industry 4.0 related studies [53]. While this strategy enhances coverage compared to single database approaches, relevant studies indexed in regional or discipline specific repositories may still have been excluded.
- Language and document type: Non-English publications and gray literature were excluded, which may limit the geographical and contextual diversity of perspectives.
- Quality assessment: Despite the use of standardized JBI Critical Appraisal Tool, the application of evaluation criteria inevitably involves researcher judgment and interpretation.
- Temporal scope: By focusing on publications from 2010 to March 2026, earlier foundational works that established key theoretical frameworks may have been omitted. Seminal studies such as King and Lenox [30] and Rothenberg et al. [45] are therefore treated as background references in the introduction rather than included in the systematic analysis.
- SSF framework adaptation: Although the SSF method provides clear procedural guidance, its application was adapted to suit the specific context of this review. Such adaptations, while necessary, may introduce minor deviations from the original protocol.

These limitations have been considered throughout the data synthesis and interpretation process. Their transparent disclosure is consistent with established standards for rigorous systematic review methodology, as advocated by Ferenhof and Fernandes [17].

## 2.6 Ethical considerations

This study is based on secondary data from a publicly available academic database. It does not involve human participants, experiments, or confidential information, and therefore, no ethical approval was required. All sources are cited in accordance with academic standards.

# 3. Results

This chapter presents the bibliometric analysis of 46 included studies using Bibliometrix and VOSviewer, covering publication trends, journal distribution, keyword co-occurrence, institutional collaboration, and co-citation patterns.

Figure 3.1 shows the annual publication trend from 2010 to March 2026, showing a three stage development. During 2010 to 2013, the output was relatively scarce. From 2014 to 2019, research grew steadily, shifting from relationship verification to mechanism exploration and framework development. After 2020, publication volume accelerated significantly, reaching a peak in 2024, which is closely related to the increasing emphasis on sustainable manufacturing, carbon neutrality commitments, and the promotion of international climate policies such as the Paris Agreement. The data for 2026 reflects only the first quarter of the year, as the search was conducted in March 2026.

Figure 3.2 presents the keyword co-occurrence network. Node size reflects keyword frequency and edge thickness indicates co-occurrence strength. The colour gradient ranges from dark blue to yellow–green, reflecting the temporal distribution of the retained sample rather than the full search window of 2010 to March 2026. Two dominant clusters emerge: the first is centred on lean and green, forming the conceptual core of the field, the second encompasses supply chain management, implementation, and performance, predominantly in darker tones, indicating these themes were more prominent in earlier studies. More recent keywords including sustainability, circular economy, and re-manufacturing appear in yellow–green, reflecting a shift from operational lean tools toward system level sustainability concepts. The model node bridges both clusters, highlighting ongoing efforts to develop integrative frameworks across this research field.

Figure 3.3 presents the journal distribution of the final sample. The distribution reflects Bradford's Law, with a small core of journals accounting for a disproportionate share of publications. Sustainability and the Journal of Cleaner Production emerge as the dominant outlets, collectively contributing the largest share of the sample, which reflects the growing alignment between lean manufacturing research and sustainability science. The second tier includes International Journal of Production Economics, International Journal of Sustainable Engineering, Management Systems in Production Engineering, and Production Planning and Control, indicating that lean and green integration research has been absorbed across both operations management and environmental engineering disciplines. The remaining publications are dispersed across more than 20 journals, confirming the interdisciplinary nature of this research field spanning manufacturing, sustainability, and strategic management.

Figure 3.4 presents the institutional collaboration network, where node size reflects publication activity and link thickness indicates co-authorship frequency. The network reveals a geographically diverse yet structurally fragmented landscape, with active research clusters concentrated in Central Europe, South Asia, Eastern Europe, and Latin America. A distribution broadly consistent with the global footprint of the automotive manufacturing industry. The direct presence of industry actors such as Volvo Group and Skoda Auto University confirms that practitioner, academic linkages exist within the field, though these remain exceptions. Despite this geographic breadth, strong intra-cluster cohesion and limited inter-

cluster connectivity suggest that cross-regional collaboration remains underdeveloped, which partly explains the contextual variation and inconsistent findings observed across reviewed studies.

Figure 3.5 displays the author collaboration network where node size reflects publication volume and co-authorship frequency, and distinct colours represent research groups identified by VOSviewer's clustering algorithm. The network shows a multi-cluster structure with strong connections within groups but limited links between them. Several research teams stand out as the most active. Mihail emerges as the most prominent node, leading a Romanian cluster. A dense South Asian cluster is centred on Arunagiri and Gnanavelbabu alongside Ruben and Asokan, reflecting the high volume of lean-green research conducted in the Indian automotive context. Jabbour leads a well connected Brazilian cluster whose work remains widely cited. Urbaniak and David represent an active Polish research group. Overall, collaboration in this field remains largely contained within national or regional groups, with few visible connections across clusters. This pattern explains the varied methods and inconsistent findings found across the reviewed studies.

Figure 3.6 presents the co-citation network of the most frequently cited works, where node size reflects citation frequency and distinct colours represent different citation clusters identified by the algorithm. Chiappetta Jabbour [27] stands out as the largest node, confirming its role as the central foundational reference in lean-environment integration research within the automotive sector. Matsuo [38] and Ben Ruben [4] form a secondary tier of highly cited works, followed by Bergenwall [5], Buyukozkan [10], and Lim [35], each representing a distinct research strand covering supply chain resilience, quantitative modelling, circular economy, and lean sustainability measurement respectively. The network also includes a group of more recent publications such as Queiroz [43], Gama [22], and De Carvalho [11] which appear as smaller peripheral nodes, indicating that these works are entering the citation network but have not yet reached the influence of the foundational core. Overall, the co-citation structure reflects a field built on a small number of highly influential studies, while expanding its intellectual base toward digital transformation and circular economy themes in recent years.

Figure 3.7 presents the co-citation density map corresponding to Fig. 3.6, where colour intensity from blue to yellow indicates the concentration of co-citation activity. Rather than repeating the network structure, this map highlights the relative weight of each reference within the field. Chiappetta Jabbour [27] generates the strongest yellow hotspots, confirming their dominant influence. A secondary green band covers Ben Ruben [4] while the outer blue regions represent more recent and peripheral works that are still entering the citation network. The density distribution reinforces the conclusion that the field's knowledge base remains concentrated around a small foundational core, supporting the need for the broader theoretical synthesis proposed in this review.

Table 3.1 presents the top 15 most cited publications. Citation counts are sourced from Scopus and recorded as of March 2026. Citations range from 42 to 399, with Jabbour et al. [27] remaining the most influential study, establishing the foundational link between lean manufacturing, environmental management, and operational performance in the Brazilian automotive sector. The research topics

reflect a clear evolutionary trajectory across three phases. Early studies (2010–2015) focused on relationship validation and barrier identification, establishing the theoretical groundwork for lean-green integration. Middle-period studies (2016–2019) shifted toward mechanism exploration, framework development, and supply chain sustainability. More recent publications (2020–2026) increasingly emphasize technology-driven approaches including Industry 4.0 integration, smart manufacturing, and circular economy adoption, reflecting the growing influence of carbon neutrality commitments and digital transformation in the automotive industry.

Table 3.1
Top 15 Most Cited Publications

| Rank | Author Year | Journal | Total Citations | Key Words | Key Contribution |
|---|---|---|---|---|---|
| 1 | Jabbour et al., (2013) | Journal of Cleaner Production | 399 | Environmental management; Lean manufacturing; Human resource management; Operational performance; Automotive sector; Brazil | Lean manufacturing promotes environmental management practices in automotive industries more effectively than human resource management does, while environmental management practices have a positive but relatively weak effect on operational performance. |
| 2 | Kumar et al., (2016) | Production Planning and Control | 265 | Barriers design for six sigma; Green six sigma; GLS product development; Green product development; Interpretive structural modelling; Lean product development; MICMAC analysis; New product development | The lack of top management commitment is a fundamental barrier leading to the failure of green product and lean product development. |
| 3 | Burawat (2019) | International Journal of Quality and Reliability Management | 182 | Transformational leadership; Lean manufacturing; Manufacturing industry; Sustainability performance; Sustainable leadership | Transformational leadership enhances corporate sustainable performance by driving lean manufacturing practices, with lean manufacturing is a key mediating variable connecting leadership and performance. |

| Rank | Author Year | Journal | Total Citations | Key Words | Key Contribution |
|---|---|---|---|---|---|
| 4 | Matsuo (2015) | International Journal of Production Economics | 176 | Supply chain management; Disruption risk management; Automotive electronics; Toyota Production System | While lean manufacturing is highly efficient, it lacks the ability to directly control key factors in the face of major disasters. |
| 5 | Ben Ruben et al., (2017) | Production Planning and Control | 158 | Lean Six Sigma; Environmental performance; Framework; DMAIC; Environmental impacts | The DMAIC framework, which integrates Lean Six Sigma with environmental impact assessment tools, can reduce production defects and environmental impact, achieving a dual improvement in operational and environmental performance. |
| 6 | Azevedo et al., (2016) | Benchmarking | 109 | Decision support systems; Supply chain management; Agility; Lean production; Industrial performance; Lean; Green; Agile; Index; Automotive industry; Resilient | The LARG index is the first to integrate four dimensions which are lean, agile, resilient, and green into a single benchmark tool, enabling automotive companies to systematically assess their sustainability performance. |
| 7 | Lim et al., (2022) | Sustainable Production and Consumption | 102 | Environmental improvement; Resource efficiency; Circular economy; Production operation; Green-lean | The concepts of lean-green and circular economy were integrated into the continuous improvement process of production |

| Rank | Author Year | Journal | Total Citations | Key Words | Key Contribution |
|---|---|---|---|---|---|
| | | | | | operations, and their practicality was verified in automobile manufacturing companies. |
| 8 | Tripathi et al., (2021) | Journal of Open Innovation Technology Market and Complexity | 81 | Lean manufacturing; Green manufacturing; Industry 4.0; Industrial sustainability; Process optimisation approach; Environmental impacts | An innovative agile model integrating lean, smart, and green approaches is proposed to improve operational performance under Industry 4.0 constraints, validated through case studies in the mining machinery and automotive industries. |
| 9 | Büyüközkan et al., (2015) | Expert Systems with Applications | 76 | Lean Manufacturing, Bayesian Belief Networks, Scenario Analysis, Business Performance | Applies Bayesian Belief Network to assess how lean technique combinations affect financial and environmental performance in automotive industries. |

| Rank | Author Year | Journal | Total Citations | Key Words | Key Contribution |
|---|---|---|---|---|---|
| 10 | Bergenwall et al., (2012) | International Journal of Production Economics | 76 | Toyota Production System; Manufacturing process design; Case study; Automobile industry; Triple bottom line; Sustainability | American automakers still lag Japan in implementing lean manufacturing process design principles, and these differences significantly impact their sustainable performance in economic, social, and environmental aspects. |
| 11 | Tripathi et al., (2022) | Mathematics | 70 | Lean manufacturing; Smart manufacturing; Cyber physical system; Flexible manufacturing system; Artificial intelligence; Industry 4.0 technologies | In the context of Industry 4.0 and under resource constraints, integrating lean manufacturing and smart manufacturing can significantly improve productivity and enhance sustainable shop floor management. |
| 12 | Kumar et al., (2020) | International Journal of Sustainable Engineering | 63 | Sustainable lean manufacturing; Critical success factors; Interpretive structural modelling; Indian automobile industry | Senior management commitment has been identified as a key driver for the implementation of sustainable lean manufacturing in the Indian automotive industry. |
| 13 | Habidin and Yusof (2012) | International Journal of Automotive Technology | 63 | Lean six sigma; Organisational performance; Environmental management systems; | While ISO 14001 environmental certification does not significantly moderate the |

| Rank | Author Year | Journal | Total Citations | Key Words | Key Contribution |
|---|---|---|---|---|---|
| | | | | Structural equation modeling; Automotive | relationship between Lean Six Sigma and organisational performance, companies that have obtained ISO 14001 certification do perform better than those that have not. |
| 14 | Muñoz-Villamizar et al., (2019) | International Journal of Productivity and Performance Management | 56 | Production, Environmental sustainability, Lean management, Environmental performance, Value stream map | Develops OGP-VSM to integrate lean and green practices, improving productivity and environmental performance simultaneously in automotive manufacturing. |
| 15 | Sobral et al., (2013) | Environmental Quality Management | 53 | Lean management; Automobile industry; Environmental indicators; Value stream mapping; Employee training; Data analysis; Interviewing | Lean practices such as employee training and inventory reduction yield real environmental benefits, though managers often underestimate the lean-environment synergy. |

Table 3.2 shows the distribution of theoretical frameworks. Only the primary framework explicitly central to each study was coded. Studies relying solely on methodological tools without invoking theory were excluded. The results reveal a highly fragmented theoretical landscape. Six main frameworks were identified, none achieving dominant adoption: Triple Bottom Line was most frequent, followed by Resource-Based View, Institutional Theory, Systems Theory, and Contingency Theory and Transformational Leadership Theory. Most studies treat theory as an instrumental reference rather than a systematic explanatory lens. TBL's prominence reflects the field's normative orientation toward economic, environmental, and social goals, though its descriptive nature limits mechanistic explanation of lean–environmental integration. This fragmentation partly explains the inconsistent findings in existing empirical work.

Table 3.2
Theoretical Frameworks and Frequency in Lean-Environment Integration Research

| Name of the Theory | Frequency | Representative Literature |
|---|---|---|
| Triple Bottom Line Theory | 16 | [37];[16];[34];[29];[36];[41];[42];[15];[1];[31];[32];[56];[12];[46];[24];[5] |
| Resource Based View | 5 | [58];[50];[27];[49];[59]; |
| Institutional Theory | 4 | [7];[25];[3];[26] |
| System Theory | 3 | [11];[18];[33]; |
| Contingency Theory | 2 | [10];[38]; |
| Transformational Leadership Theory | 2 | [8];[9]; |

Table 3.3 summarises the integration effects and contextual conditions drawn from the top 15 most cited publications. Three effect patterns are identified. Synergistic effects reflect direct positive impacts of integration on environmental performance. Conditional synergistic effects indicate that outcomes depend on enabling preconditions such as top management commitment, government support, and organisational capability. Conflicting effects capture cases where lean practices generate negative environmental consequences, such as increased transport emissions under rigorous just-in-time delivery, or supply chain vulnerability under lean inventory management. Across all three patterns, effect strength and pathways vary considerably, confirming that integration outcomes are context-dependent rather than universal.

Table 3.3
Integration Effects and Contextual Conditions from Top-Cited Studies

| Author (Year) | Integration Path | Integration Effect Type | Impact on Environmental Performance | Scenario Conditions |
|---|---|---|---|---|
| Jabbour et al. (2013) | Lean Manufacturing - Environmental Management - Operational Performance | Synergistic effect | Positive impact but indirect and weak | Brazilian automotive industry |
| Kumar et al. (2016) | Green - Lean-Six Sigma | Conditional synergistic effect requires obstacle identification | Potential for synergy but hampered by relevant organisational factors such as a lack of high-level commitment. | Indian manufacturing |
| Burawat (2019) | leadership - Lean Manufacturing - Environmental Management - Environmental Performance | Conditional synergistic effect | Theoretically potential positive impact, but the lack of environmental performance accountability makes it difficult to implement in practice, and the effects differ significantly between the automotive and non-automotive industries. | Thai manufacturing |
| Matsuo (2015) | Lean Manufacturing - Disaster response capabilities | Conflicting effects | Direct and indirect negative impacts: industry vulnerability, industry supply chain disruptions, and the recommendation of redundant inventory that compromises lean efficiency. | Japan earthquake case |
| Ben Ruben et al., (2017) | Lean Manufacturing - Environmental Performance | Synergistic effect | Direct positive impact | Indian automotive manufacturing industry |

| Author (Year) | Integration Path | Integration Effect Type | Impact on Environmental Performance | Scenario Conditions |
|---|---|---|---|---|
| Azevedo et al., (2016) | Lean+Agile+Resilient+Green | Conditional synergistic effect | There is a synergistic effect, but some aspects require trade-offs. | Portuguese and European automotive manufacturing |
| Lim et al., (2022) | Lean+Sustainable+Circular | Synergistic effect | Comprehensively enhance influence | Supplier's waste plastic recycling |
| Tripathi et al., (2021) | TPS - Lean - Lean+Green - Smart Lean+Green | Synergistic effect | Direct positive impact | Semi-automated, budget-constrained small and medium-sized manufacturing enterprises |
| Büyüközkan et al., (2015) | Lean tools - Value stream mapping + Process improvement - Three performance targets | Conditional synergistic effect | In the worst case, environmental performance is more sensitive to lean implementation failures than financial performance. | Turkish car supplier |
| Bergenwall et al., (2012) | Design Principles - Stability and Standardization - Employee Engagement and Continuous Improvement - Performance Results | Conditional synergistic effect | It has a positive impact, but the factory's environmental benefits reduced due to process instability. | American automotive manufacturing |
| Tripathi et al., (2022) | Identify waste - Eliminate waste and optimize processes - cleaner production - Improve performance | Synergistic effect | Direct positive impact | The wasteful and defective automotive manufacturing industry |
| Kumar et al., (2020) | lean manufacturing + Sustainable Development Goals - performance | Synergistic effect | Direct positive impacts: waste reduction and optimized resource utilization. Indirect positive impacts: increased environmental awareness | Indian automotive manufacturing industry |

| Author (Year) | Integration Path | Integration Effect Type | Impact on Environmental Performance | Scenario Conditions |
|---|---|---|---|---|
| | | | among employees. | |
| Habidin and Yusof (2012) | lean six sigma + environmental management - performance | Conditional synergistic effect | Lean manufacturing improves performance, environmental management practices improve performance, and ISO 14001 is beneficial but it neither enhances nor diminishes performance effects. | Malaysian automotive manufacturing industry |
| Muñoz-Villamizar et al., (2019) | VSM + OGP | Conflict effect | Lean improvements are not necessarily environmentally friendly, the rigorously JIT is applied, the more frequent the deliveries, and the higher the resulting emissions. | Manufacturing companies with defined product family and repeatable flow |
| Sobral et al., (2013) | lean practices-environmental performance | Conditional synergistic effect requires obstacle identification | Managers failed to recognise connection, leaving the environmental potential of numerous tools untapped. | large automotive manufacturer in Brazil |

# 4.Discussion

This chapter builds upon the analytical results presented in Chap. 3 to conduct an in-depth discussion of the research findings and systematically address the three research questions.

RQ1: What are the trends, core themes, and theoretical frameworks in lean - environmental integration research within the automotive industry?

The Bibliometric analysis reveals three distinct developmental stages, each reflecting a fundamental shift in how the research community frames lean-environment integration. During the concept validation stage (2010–2013), studies focused on establishing whether a meaningful relationship existed at all.

Jabbour et al. [27] demonstrated that lean manufacturing promotes environmental management more effectively than human resource management, while Sobral et al. [49] found that managers frequently failed to recognise the connection, leaving the environmental potential of widely deployed tools systematically untapped. From 2014 to 2019, the research question shifted from whether integration existed to how and why it worked. Kumar et al. [33] identified top management commitment as a fundamental barrier, demonstrating that outcomes depended on organisational preconditions rather than tool selection alone. The keyword co-occurrence network reflects this shift, with supply chain management and implementation themes appearing in earlier period. However, knowledge production remained concentrated within sustainability science outlets, limiting systematic exposure to strategic management communities where integration insights are equally relevant. The third stage, marked by a publication peak, reflects a repositioning of lean-environment integration within digital transformation and carbon neutrality agendas. Ferrazzi and Portioli-Staudacher [18] demonstrated that total productive maintenance and just-in-time are consistent causal drivers of environmental outcomes, while Lai and Chang [34] found that combining lean management with digital transformation produces synergistic sustainability effects exceeding either approach independently. Marques et al. [37] further extended the integration paradigm toward circular economy frameworks, connecting this research to carbon neutrality commitments in ways largely absent from earlier stages. Six frameworks were identified, none achieving dominant adoption. Most studies invoke theory instrumentally rather than as a systematic explanatory lens, which partly explains the inconsistent empirical findings documented throughout this review. As Skalli et al. [48] observed the absence of a unified theoretical architecture limits the field's ability to generate cumulative, transferable knowledge. This fragmentation also carries practical consequences: without a coherent theoretical basis, managers lack reliable guidance for selecting integration strategies appropriate to their specific context.

**RQ2**

What are the limitations of existing frameworks and how can a multi-theory framework be constructed?

The theoretical landscape identified in RQ1 reveals not only what frameworks exist but why none of them alone is sufficient to explain lean-environment integration outcomes. Triple Bottom Line Theory dominates the literature, yet its prominence reflects normative orientation rather than genuine explanatory power. Triple Bottom Line specifies what firms should achieve across economic, environmental, and social dimensions, but cannot explain how integration mechanisms operate or why identical practices produce different outcomes under different conditions. The Resource-Based View frames integration as an organisational capability-building process, where lean routines lower the implementation threshold for environmental management through shared waste identification and continuous improvement logic. However, it operates primarily at the meso level and cannot explain how external institutional pressures shape adoption decisions. As Gama and Bonamigo [22] demonstrated, integration outcomes were conditioned by regulatory environments and stakeholder expectations that internal capability configurations alone could not account for. Institutional Theory addresses this macro-level gap by explaining how coercive, normative, and mimetic pressures drive adoption. Yet it provides

limited guidance on how firms translate external pressures into internal capability development, leaving unexplained why adoption produces divergent performance outcomes across otherwise similar institutional environments.

Based on the reviewed literature, this study identifies three integration patterns that differ in both scope and theoretical requirements: tool-based, gradual, and systemic integration. Tool-based integration, exemplified by Muñoz-Villamizar et al.'s [39] Green VSM approach, is adequately explained by RBV alone. Gradual integration, where lean progressively enables environmental management, requires both RBV to explain the internal capability trajectory and Institutional Theory to account for sustaining external pressures. Systemic integration, increasingly evident in Ferrazzi et al. [19] and Lai and Chang [34], extends waste reduction into digitally mediated strategic frameworks, a complexity neither RBV nor Institutional Theory can capture without TBL's normative architecture specifying the multi-dimensional performance goals involved. This complementarity motivates the multi-theoretical framework proposed in this study. Triple Bottom Line operates at the micro-to-meso level, providing normative guidance for firms in balancing economic, environmental, and social objectives across operational and organisational decisions; it specifies what integration should achieve rather than how it is accomplished. RBV operates at the meso level, and Institutional Theory operates at the macro level, explaining how external pressures initiate and sustain integration. Together, these three frameworks address the cross-level explanation problem that has limited existing models, providing the theoretical foundation for understanding why integration outcomes are conditional rather than universal. Figure 4.1 presents the multi-theoretical integration framework proposed in this study.

**RQ3**

What mechanisms drive integration's impact on environmental performance and why do empirical studies show contradictory results?

Building on the multi-theoretical framework constructed in RQ2, this section identifies three mechanisms through which lean-environment integration affects environmental performance and explains why empirical studies continue to produce contradictory findings.

The first mechanism is process optimisation, operating through systematic waste elimination and resource efficiency improvements. Ferrazzi and Portioli-Staudacher [18] confirmed that total productive maintenance and just-in-time consistently drive environmental outcomes across automotive contexts. However, this mechanism is moderated by resource endowment. In large firms, process optimisation achieves genuine win-win outcomes, while in resource-constrained SMEs, lean implementation tends to prioritise short-term cost reduction, marginalising environmental goals.

The second mechanism is capability enhancement, whereby continuous improvement culture and cross-functional routines transform environmental management from an external compliance obligation into an internalised operational process [60]. Jabbour et al. [27] demonstrated that lean manufacturing promotes environmental management capability more effectively than human resource management

alone, and Gama and Bonamigo [22] confirmed that lean-driven capability development produces measurable sustainability improvements when organisational commitment is sustained. Yet where functional silos prevent cross-departmental knowledge transfer, this mechanism is disrupted entirely. Sobral et al. [49] illustrated lean tools were deployed but their environmental potential went unrecognised.

The third mechanism is technology enablement, through which digital tools enhance process transparency and support dynamic carbon accounting. Lai and Chang [34] confirmed that digital transformation amplifies the environmental benefits of lean management, producing synergistic outcomes exceeding either approach independently. However, this mechanism presupposes technological maturity and cross-disciplinary talent that many firms in emerging economies have not yet developed, limiting its generalisability.

The contradictory results across empirical studies reflect not random inconsistency but the conditional structure of all three mechanisms. The same lean practices produce divergent environmental outcomes because effectiveness depends simultaneously on resource availability, organisational capability, and technological readiness. Muñoz-Villamizar et al. [39] captured rigorous just-in-time implementation improved operational efficiency while increasing transport emissions [40]. Wu et al. [58] further showed that firms with short-term sustainability mindsets consistently underinvest in capability-building and technology-enabling mechanisms, explaining why studies focused on immediate metrics frequently report weaker effects. The root of empirical contradictions therefore lies not in whether integration works, but in the conditional nature of the mechanisms through which it operates.

## 5. Implications

Based on the three different research questions raised in this study and the analysis of the literature review, this section will summarize the main contributions as key insights into theory, practice and policy.

# 5.1 Theoretical Implications

This study makes two theoretical contributions. First, it constructs a multi-theoretical framework integrating Triple Bottom Line Theory, Resource-Based View, and Institutional Theory across macro, meso, and micro levels. This cross-level framework provides a more complete explanation of why integration outcomes vary across organisational and institutional contexts than any single theory model can offer. Second, by identifying process optimisation, capability enhancement, and technology enablement as the mechanisms through which integration affects environmental performance, this study provides a conditional rather than deterministic explanation of the lean-environment relationship, directly addressing the contradictory empirical findings that have accumulated in the literature.

# 5.2 Practical Implications

This study offers practical guidance for managers in automotive manufacturing companies. The conditional nature of integration outcomes suggests that firms should select integration strategies based on their specific resource endowment, organisational capability, and technological readiness rather than adopting universal best practices. Resource-constrained firms are better served by tool-based approaches targeting specific operational inefficiencies, while firms with stronger organisational foundations should pursue capability-building strategies that embed environmental management into continuous improvement culture. For firms with advanced digital infrastructure, prioritising investment in real time monitoring and predictive maintenance systems can unlock synergistic sustainability outcomes that neither lean nor digitalisation achieves independently. Cross-functional collaboration structures are essential as functional silos represent a primary barrier to realising the environmental potential of lean implementation.

## 5.3 Policy Implications

This study provides policy directions for governments seeking to accelerate lean-environment integration in the automotive manufacturing industry. First, given that resource constraints represent the primary barrier for SMEs, governments should establish differentiated financial support mechanisms, including equipment subsidies and tax exemptions for early-stage firms and green credit facilities for those pursuing deeper integration. Second, policymakers should promote unified green-lean evaluation standards linked to international benchmarks, providing clear performance targets and reducing assessment inconsistency across firms and regions. Third, governments should invest in interdisciplinary talent development through university and vocational training partnerships, cultivating professionals with both lean and environmental management competencies. Finally, industry-level digital platforms supporting environmental data sharing and collaborative emission reduction would lower the infrastructure barriers that currently prevent many firms from realising the full potential of lean-environment integration.

# 6. Conclusion, Limitations and Future Research Directions

This section, building upon the preceding analysis and discussion, summarizes the core findings, points out the limitations of the research, and offers suggestions for future research.

## 6.1 Conclusion

Through a systematic review and bibliometric analysis of 46 high-quality publications, this study comprehensively reveals the knowledge structure, evolutionary pathways, and mechanisms underlying the integration of lean manufacturing and environmental management practices in the automotive industry. The findings indicate that this research field has evolved through three distinct stages: relationship validation, mechanism exploration, and digitally driven transformation. Lean manufacturing and environmental management exhibit a high degree of conceptual alignment, both centered on waste elimination and continuous improvement. However, integration outcomes are significantly moderated by contextual factors such as resource endowments, organisational capabilities, and technological

maturity, demonstrating conditional rather than universal applicability. This study develops a multi-level theoretical framework and reveals three pathways through which integration affects environmental performance: process optimisation, capability enhancement, and technology enablement. These findings not only provide a theoretical basis for explaining contradictory conclusions in empirical studies but also offer practical guidance for enterprises to select differentiated integration strategies, thereby facilitating the automotive industry's transition toward low carbon, high efficiency, and intelligent manufacturing.

This research contributes to multiple United Nations Sustainable Development Goals. Specifically, by revealing the integration mechanisms between lean manufacturing and environmental practices, this study supports SDG 9 (Industry, Innovation and Infrastructure) through promoting sustainable industrialization. The findings also contribute to SDG 12 (Responsible Consumption and Production) by demonstrating how automotive manufacturers can achieve resource efficiency. Finally, the environmental performance improvements support SDG 13 (Climate Action) by providing pathways for emission reduction in the automotive sector, which is central to achieving the Paris Agreement’s temperature goals.

## 6.2 Limitations

Despite employing a combined approach of systematic literature review and bibliometric analysis, this study has five limitations. First, the literature search was only from Web of Science and Scopus, potentially omitting relevant studies indexed in regional or industry-specific repositories, which may affect the comprehensiveness of literature coverage. Second, the included studies are cross-sectional, lacking longitudinal tracking or experimental designs, which limits in depth analysis of the dynamic evolution of causal mechanisms. Third, heterogeneity exists across studies in terms of conceptual definitions and measurement methods, affecting the comparability and validity of results. Fourth, this study primarily focuses on the automotive manufacturing industry, and the applicability of research findings to other manufacturing sectors requires further validation. While this study emphasizes carbon-related environmental performance because it is crucial in the current policy framework and the automotive industry makes a significant contribution to global emissions, future research should examine other environmental dimensions, such as water consumption or biodiversity impacts. Finally, the exclusion of non-English publications may lead to limited coverage of regional experiences and localized practices, particularly innovative models from emerging economies that may not have been adequately incorporated into the analysis.

## 6.3 Future Research Directions

Based on the above limitations and analysis, this study proposes four main directions for future research. First, developing unified conceptual and measurement models to clarify the core constructs, dimensional classifications, and boundary conditions of lean and environment integration, thereby reducing heterogeneity across studies. Second, employing longitudinal and multi-level research designs to track the dynamic evolution of the integration process, revealing the moderating effects of different contextual factors at various stages and their temporal logic. Third, incorporating variables such as

digital capabilities, leadership styles, and organisational culture to enrich the explanatory power of theoretical models. Fourth, extending the research context to circular economy and carbon neutrality frameworks to explore digitally enabled green lean transformation paradigms, while focusing on the practical pathways of small and medium-sized enterprises and emerging economies to enhance the inclusiveness and applicability of research. These directions will help deepen theoretical understanding, guide practical innovation, and promote the global transformation toward sustainable manufacturing.

## Declarations

# Funding

The authors did not receive support from any organization for the submitted work.

Data availability statement

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests.

# Author Contribution

D.J.L. and S.Z. designed the study and established the research framework. D.J.L. conducted the literature search, performed data collection, carried out bibliometric and content analysis, and wrote the main manuscript text. S.Z. confirmed the research outline, supervised the analytical process, revised the manuscript, and guided the whole process. C.W.T. contributed to manuscript revision. All authors reviewed and approved the final manuscript.

## References

1. Abualfaraa W, Salonitis K, Al-Ashaab A, Ala’raj M. Lean-green manufacturing practices and their link with sustainability: A critical review. Sustainability. 2020;12(3):981. https://doi.org/10.3390/su12030981.

2. Acerbi F, Sassanelli C, Terzi S, Taisch M. (2021). A systematic literature review on data and information required for circular manufacturing strategies adoption. *Sustainability*, *13*(4), 2047. https://doi.org/10.3390/su13042047
3. Azevedo SG, Carvalho H, Cruz-Machado V. LARG index: A benchmarking tool for improving the leanness, agility, resilience and greenness of the automotive supply chain. Benchmarking: Int J. 2016;23(6):1472–99. https://doi.org/10.1108/BIJ-07-2014-0072.
4. Ben Ruben R, Vinodh S, Asokan P. Implementation of lean six sigma framework with environmental considerations in an indian automotive component manufacturing firm: A case study. Prod Plann Control. 2017;28(15):1193–211. https://doi.org/10.1080/09537287.2017.1357215.
5. Bergenwall AL, Chen C, White RE. TPS's process design in american automotive plants and its effects on the triple bottom line and sustainability. Int J Prod Econ. 2012;140(1):374–84. https://doi.org/10.1016/j.ijpe.2012.04.016.
6. Bonamigo A, Barbosa ADS, Rocha EDAS, Werner SM. Facilitators and inhibitors of Lean Service 5.0: an assessment from the knowledge waste management perspective. VINE J Inform Knowl Manage Syst. 2025;55(6):1501–26. https://doi.org/10.1108/VJIKMS-02-2024-0050.
7. Bouazza Y, Lajjam A, Dkhissi B. The impact of lean manufacturing on enviromental performance in moroccan automotive industry. Manage Syst Prod Eng. 2021;29(3):184–92. https://doi.org/10.2478/mspe-2021-0023.
8. Burawat P. (2017). The mediate effect of lean manufacturing on the relationship between transaformational leadership and sustainability performance in thai SMEs. *12*(21).
9. Burawat P. The relationships among transformational leadership, sustainable leadership, lean manufacturing and sustainability performance in thai SMEs manufacturing industry. Int J Qual Reliab Manage. 2019;36(6):1014–36. https://doi.org/10.1108/IJQRM-09-2017-0178.
10. Büyüközkan G, Kayakutlu G, Karakadilar I. Assessment of lean manufacturing effect on business performance using bayesian belief networks. Expert Syst Appl. 2015;42(19):6539–51. https://doi.org/10.1016/j.eswa.2015.04.016.
11. De Carvalho PT, Lopes JD, Raimundo RJ. Innovation impact in the textile industry: From the toyota production system to artificial intelligence. Sustainability. 2025;17(3):1170. https://doi.org/10.3390/su17031170.
12. Dieste M, Panizzolo R, Garza-Reyes JA, Anosike A. The relationship between lean and environmental performance: Practices and measures. J Clean Prod. 2019;224:120–31. https://doi.org/10.1016/j.jclepro.2019.03.243.
13. Duarte S, Cruz-Machado V. Green and lean supply-chain transformation: A roadmap. Prod Plann Control. 2019;30(14):1170–83. https://doi.org/10.1080/09537287.2019.1595207.
14. El Affaki O, Benhadou M, Haddout A. Operational excellence supported by lean management tools, IATF 16949 automotive standard, and industry 4.0 pillars: Evidence from automotive companies in Morocco. Eng Technol Appl Sci Res. 2025;15(3):22718–24. https://doi.org/10.48084/etasr.10600.

15. Elrhanimi S, Abbadi E, L. Assessment model of lean effect (AMLE). Tqm J. 2021;33(5):1021–48. https://doi.org/10.1108/TQM-02-2019-0039. (WOS:000679955100005).
16. Fallahiarezoudar E, Ahmadipourroudposht M, Bagherian Rafi MH, Ngadiman NHA. A systematic approach of maintenance 4.0 towards a sustainable manufacturing policy: A case study on an automobile company. Process Integr Optim Sustain. 2025;9(4):1229–51. https://doi.org/10.1007/s41660-025-00505-y.
17. Ferenhof HA, Fernandes RF. Demystifying the literature review as basis for scientific writing: SSF method. Revista ACB. 2016;21(3):550–63.
18. Ferrazzi M, Portioli-Staudacher A. Driving green through lean: A structured causal analysis of lean practices in automotive sustainability. Eng. 2025;6(11). https://doi.org/10.3390/eng6110296.
19. Ferrazzi M, Tortorella GL, Li W, Costa F, Portioli-Staudacher A. From people to performance: Leveraging soft lean practices for environmental sustainability in large-scale production. Sustainability. 2025;17(9):3955. https://doi.org/10.3390/su17093955.
20. Figueiredo OCD, Oliveira URD, Fernandes A, França V, S. L. B., Lemos WDM. Lean and sustainability in automotive organizations: A comparative analysis with toyota. Gestão Produção. 2025;32:e11424. https://doi.org/10.1590/1806-9649-2025v32e11424.
21. Gaikwad L, Sunnapwar V. Development of an Integrated Framework of LGSS Strategies for Indian Manufacturing Firms to Improve Business Performance: An Empirical Study. TQM J. 2021;33:257–91. https://doi.org/10.1108/TQM-05-2020-0110.
22. Gama MSB, Bonamigo A. Exploring lean manufacturing impact on sustainable performance in automotive companies in Brazil. Int J Lean Six Sigma. 2025;16(2):491–517. https://doi.org/10.1108/IJLSS-01-2024-0009. Scopus.
23. Garza-Reyes JA. Lean and green – a systematic review of the state of the art literature. J Clean Prod. 2015;102:18–29. https://doi.org/10.1016/j.jclepro.2015.04.064.
24. Gopal PRC, Thakkar J. Sustainable supply chain practices: An empirical investigation on indian automobile industry. Prod Plann Control. 2016;27(1):49–64. https://doi.org/10.1080/09537287.2015.1060368.
25. Habidin NF, Hibadullah SN, Fuzi M, Salleh N, M. I., Md Latip NA. Lean manufacturing practices, ISO 14001, and environmental performance in malaysian automotive suppliers. Int J Manage Sci Eng Manage. 2018;13(1):45–53. https://doi.org/10.1080/17509653.2017.1288587.
26. Habidin NF, Yusof SM. Relationship between lean six sigma, environmental management systems, and organizational performance in the malaysian automotive industry. Int J Autom Technol. 2012;13(7):1119–25. https://doi.org/10.1007/s12239-012-0114-4.
27. Jabbour CJC, Jabbour ABLDS, Govindan K, Teixeira AA, Freitas WRDS. Environmental management and operational performance in automotive companies in Brazil: The role of human resource management and lean manufacturing. J Clean Prod. 2013;47:129–40. https://doi.org/10.1016/j.jclepro.2012.07.010.

28. Jesson J, Lacey FM, Matheson L. Doing your literature review. Traditional and systematic techniques; 2011.
29. Kanan M, Dilshad AR, Zahoor S, Hussain A, Habib MS, Mehmood A, Abusaq Z, Hamdan A, Asad J. An empirical study of the implementation of an integrated ergo-green-lean framework: A case study. Sustainability. 2023;15(13):10138. https://doi.org/10.3390/su151310138.
30. King AA, Lenox MJ. Lean and green? An empirical examination of the relationship between lean production and environmental performance. Prod Oper Manage. 2001;10(3):244–56. https://doi.org/10.1111/j.1937-5956.2001.tb00373.x.
31. Kumar N, Mathiyazhagan K. (2020). *Sustainability in lean manufacturing: A systematic literature review*. 0–27. https://doi.org/10.1504/IJBEX.2020.106383
32. Kumar N, Mathiyazhagan K, Mathivathanan D. Modelling the interrelationship between factors for adoption of sustainable lean manufacturing: A business case from the indian automobile industry. Int J Sustain Eng. 2020;13(2):93–107. https://doi.org/10.1080/19397038.2019.1706662.
33. Kumar S, Luthra S, Govindan K, Kumar N, Haleem A. Barriers in green lean six sigma product development process: An ISM approach. Prod Plann Control. 2016;1–17. https://doi.org/10.1080/09537287.2016.1165307.
34. Lai P, Chang A. Research on the relationship between lean management and digital transformation strategy and sustainable development: A case study of the automotive industry in taiwan. Sustainability. 2025;17(21). https://doi.org/10.3390/su17219572.
35. Lim MK, Lai M, Wang C, Lee SY. Circular economy to ensure production operational sustainability: A green-lean approach. Sustainable Prod Consum. 2022;30:130–44. https://doi.org/10.1016/j.spc.2021.12.001.
36. Maldonado-Guzmán G, Garza-Reyes J. Beyond lean manufacturing and sustainable performance: Are the circular economy practices worth pursuing? Manage Environ Qual. 2023;34(5):1332–51. https://doi.org/10.1108/MEQ-11-2022-0324.
37. Marques P, Reis J, Silva W. Integrating circular economy and lean management: A strategic framework for sustainable business transformation. Corp Soc Responsib Environ Manag. 2026. https://doi.org/10.1002/csr.70557.
38. Matsuo H. Implications of the tohoku earthquake for toyota□s coordination mechanism: Supply chain disruption of automotive semiconductors. Int J Prod Econ. 2015;161:217–27. https://doi.org/10.1016/j.ijpe.2014.07.010.
39. Muñoz-Villamizar A, Santos J, Garcia-Sabater JJ, Lleo A, Grau P. Green value stream mapping approach to improving productivity and environmental performance. Int J Productivity Perform Manage. 2019;68(3):608–25. https://doi.org/10.1108/IJPPM-06-2018-0216.
40. Nadeem SP, Garza-Reyes JA, Leung S-C, Cherrafi A, Anosike AI, Lim MK. Lean manufacturing and environmental performance – exploring the impact and relationship. In: Lödding H, Riedel R, Thoben K-D, Von Cieminski G, Kiritsis D, editors. Advances in Production Management Systems. The Path to

Intelligent, Collaborative and Sustainable Manufacturing. Volume 514. Springer International Publishing; 2017. pp. 331–40. https://doi.org/10.1007/978-3-319-66926-7_38.

41. Nguyen DM. Lean experience analysis at a leading automotive manufacturer in Vietnam. Manage Syst Prod Eng. 2023;31(1):9–17. https://doi.org/10.2478/mspe-2023-0002.
42. Pawlik E, Ijomah W, Corney J, Powell D. Exploring the application of lean best practices in remanufacturing: Empirical insights into the benefits and barriers. Sustainability. 2022;14(1). https://doi.org/10.3390/su14010149.
43. Queiroz GA, Filho AGA, Núñez JF, Santa-Eulalia LA, Delai I, Torkomian ALV. Lean and green manufacturing in operations strategy: Cases from the automotive industry. Oper Manage Res. 2024. https://doi.org/10.1007/s12063-024-00477-1.
44. Roth N, Deuse J, Biedermann H. A framework for system excellence assessment of production systems, based on lean thinking, business excellence, and factory physics. Int J Prod Res. 2020;58(4):1074–91. https://doi.org/10.1080/00207543.2019.1612113.
45. Rothenberg S, Pil FK, Maxwell J. Lean, green, and the quest for superior environmental performance. Prod Oper Manage. 2001;10(3):228–43. https://doi.org/10.1111/j.1937-5956.2001.tb00372.x.
46. Ruben RB, Asokan P, Vinodh S. Performance evaluation of lean sustainable systems using adaptive neuro fuzzy inference system: A case study. Int J Sustain Eng. 2017;10(3):158–75. https://doi.org/10.1080/19397038.2017.1286409.
47. Sarkar B, Ullah M, Sarkar M. Environmental and Economic Sustainability through Innovative Green Products by Remanufacturing. J Clean Prod. 2022;332:129813. https://doi.org/10.1016/j.jclepro.2021.129813.
48. Skalli D, Charkaoui A, Cherrafi A, Shokri A, Garza-Reyes JA, Antony J. Analysis of factors influencing circular-lean-six sigma 4.0 implementation considering sustainability implications: An exploratory study. Int J Prod Res. 2024;62(11):3891–917. https://doi.org/10.1080/00207543.2023.2251159.
49. Sobral MC, Jabbour S, A. B. L. D., Chiappetta Jabbour CJ. Green benefits from adopting lean manufacturing: A case study from the automotive sector. Environ Qual Manage. 2013;22(3):65–72. https://doi.org/10.1002/tqem.21336.
50. Thanki SJ, Thakkar J. Interdependence analysis of lean-green implementation challenges: A case of indian SMEs. J Manuf Technol Manage. 2018;29(2):295–328. https://doi.org/10.1108/JMTM-04-2017-0067.
51. Tripathi V, Chattopadhyaya S, Mukhopadhyay AK, Sharma S, Li C, Di Bona G. A sustainable methodology using lean and smart manufacturing for the cleaner production of shop floor management in industry 4.0. Mathematics. 2022;10(3):347. https://doi.org/10.3390/math10030347.
52. Tripathi V, Chattopadhyaya S, Mukhopadhyay AK, Sharma S, Singh J, Pimenov DY, Giasin K. An innovative agile model of smart lean–green approach for sustainability enhancement in industry 4.0. J OPEN Innovation: Technol Market Complex. 2021;7(4):215–35. https://doi.org/10.3390/joitmc7040215.

53. Ullah MS, Sakib MN, Ahsan R, Jakowan. (2025). Do Lean and Green Manufacturing Practices Lead to Sustainability? A Systematic Literature Review and Bibliometric Analysis. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.70504
54. Van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics. 2010;84(2):523–38. https://doi.org/10.1007/s11192-009-0146-3.
55. Waltman L, Van Eck NJ. A smart local moving algorithm for large-scale modularity-based community detection. Eur Phys J B. 2013;86(11):471–85. https://doi.org/10.1140/epjb/e2013-40829-0.
56. Wolff S, Brönner M, Held M, Lienkamp M. Transforming automotive companies into sustainability leaders: A concept for managing current challenges. J Clean Prod. 2020;276:124179. https://doi.org/10.1016/j.jclepro.2020.124179.
57. Womack JP, Jones DT. Lean thinking—banish waste and create wealth in your corporation. J Oper Res Soc. 1997;48(11):1148–1148. https://doi.org/10.1057/palgrave.jors.2600967.
58. Wu L, Subramanian N, Pawar KS, Wang M, Kumar A, Tan KH. A paradoxical perspective on the time dimension of corporate sustainability: Having both finite and infinite mindsets to play the game. J Clean Prod. 2024;480:144082. https://doi.org/10.1016/j.jclepro.2024.144082.
59. Wu P, Feng Y. Using lean practices to improve current carbon labelling schemes for construction materials—A general framework. J Green Building. 2012;7(1):173–91. https://doi.org/10.3992/jgb.7.1.173.
60. Yang MG (Mark), Hong P, Modi SB, editors. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *International Journal of Production Economics*, *129*(2), 251–261. https://doi.org/10.1016/j.ijpe.2010.10.017

# Figures

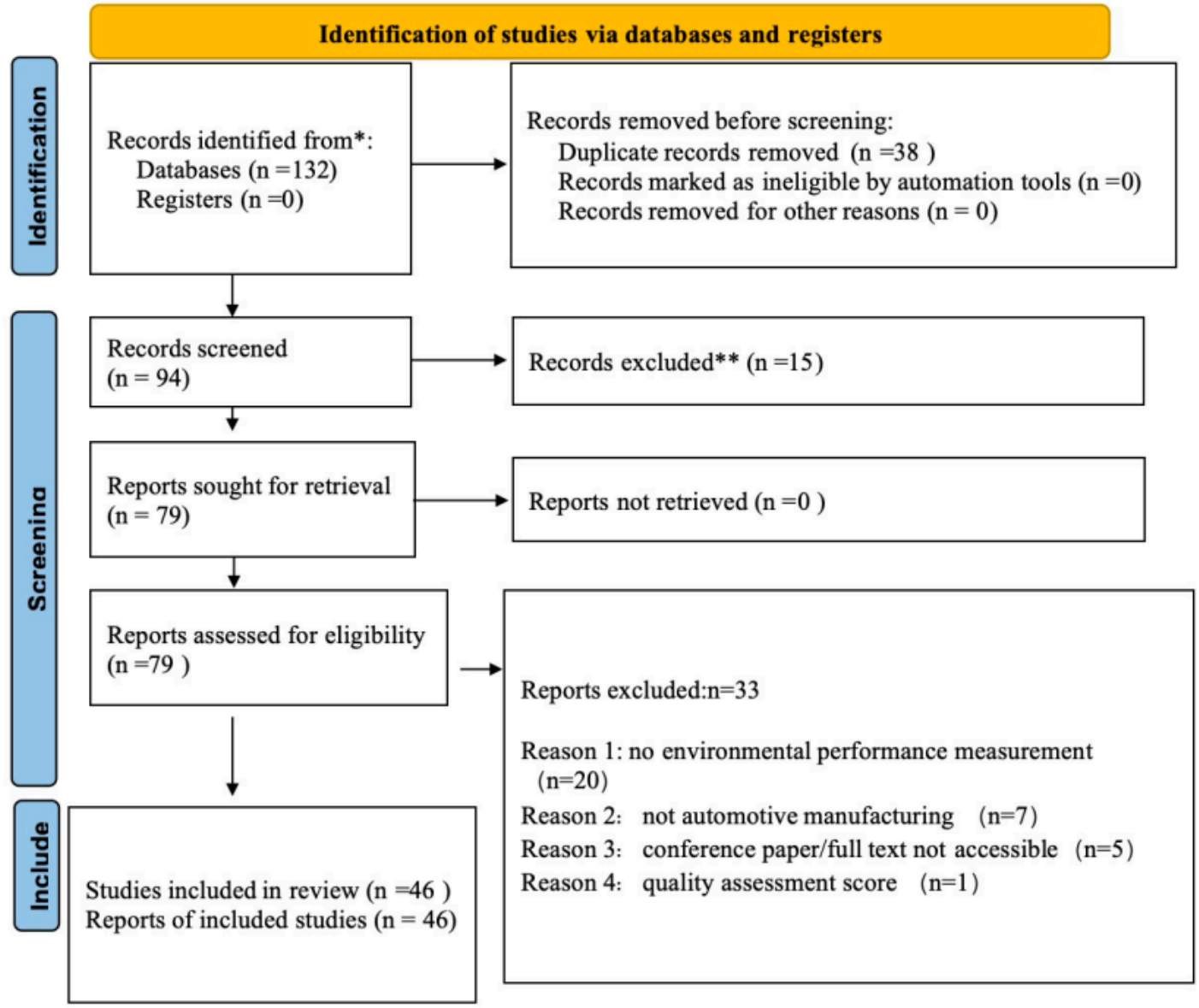



**Figure 1**

Figure 2.1 PRISMA Flow Diagram

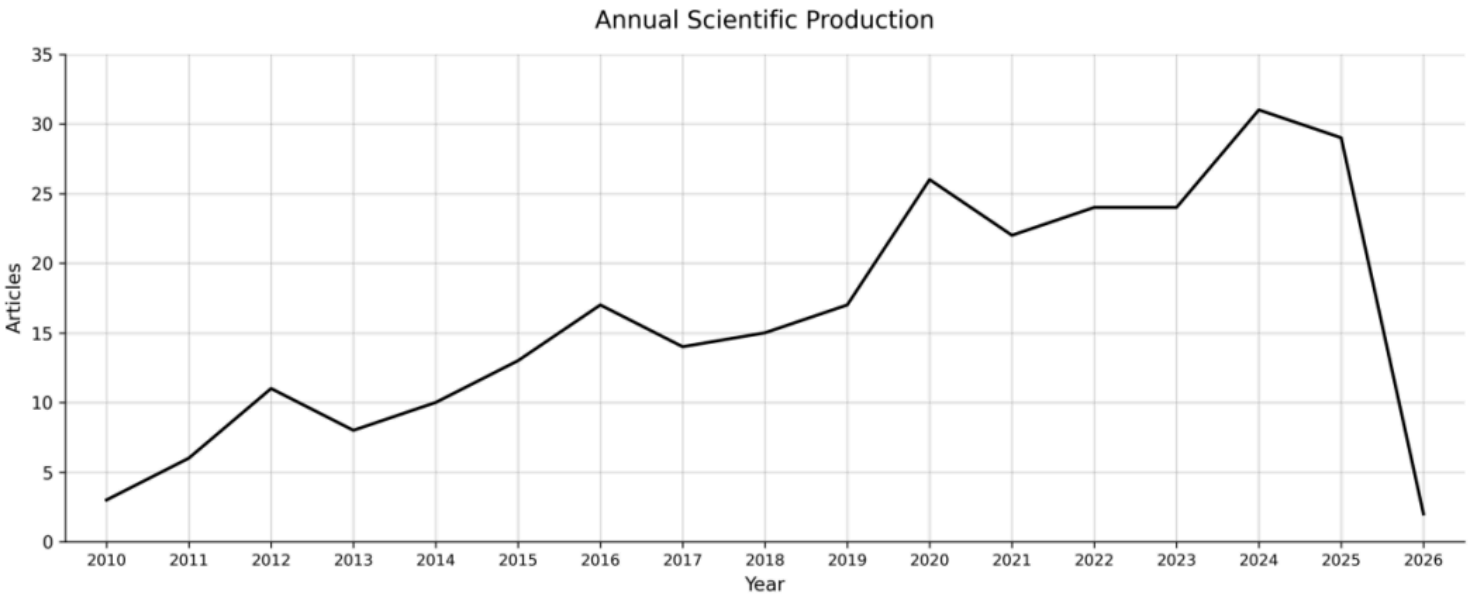



**Figure 2**

Figure 3.1: Annual Publication Trend

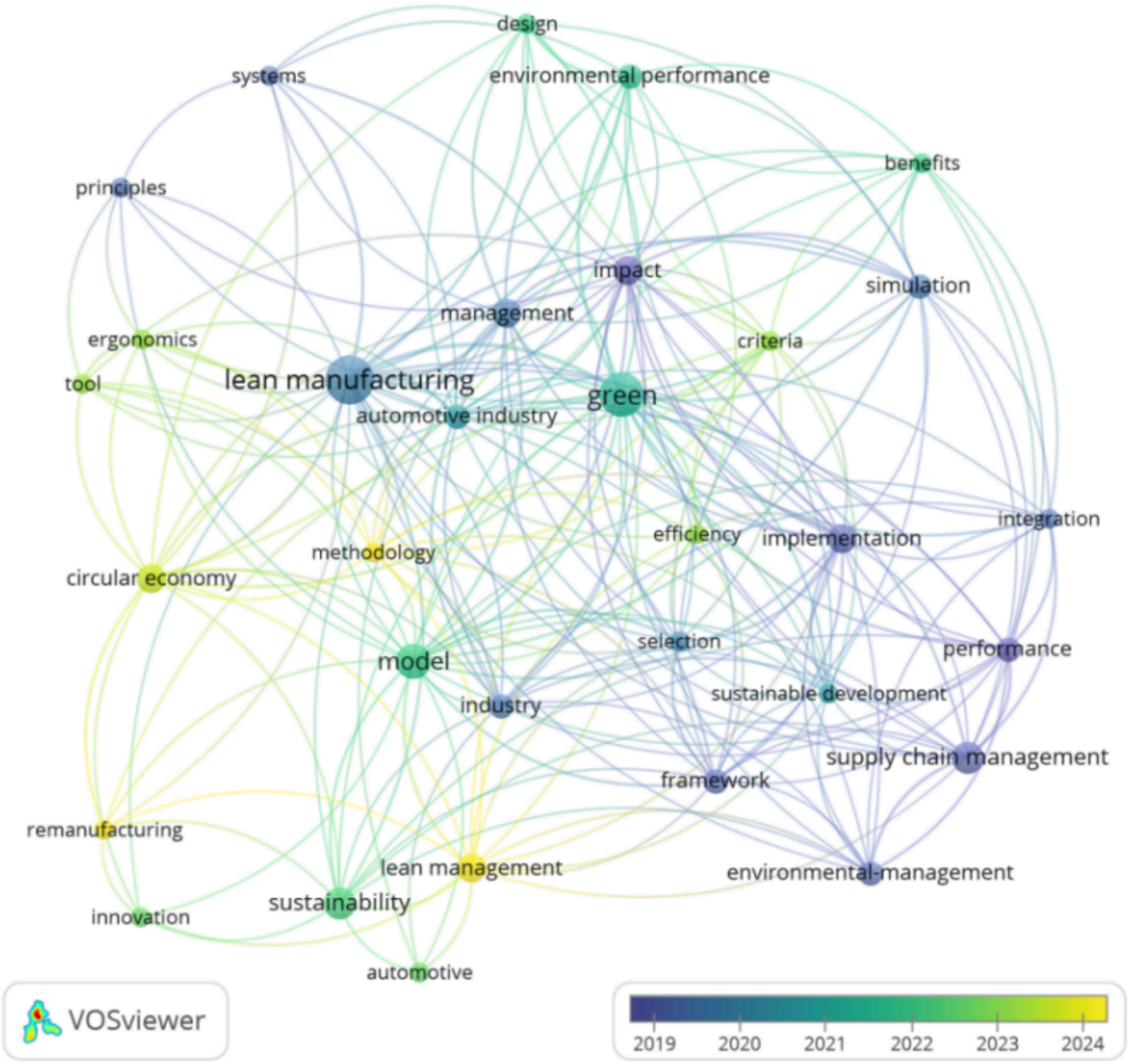



**Figure 3**

Figure 3.2: Keyword Co-occurrence Network

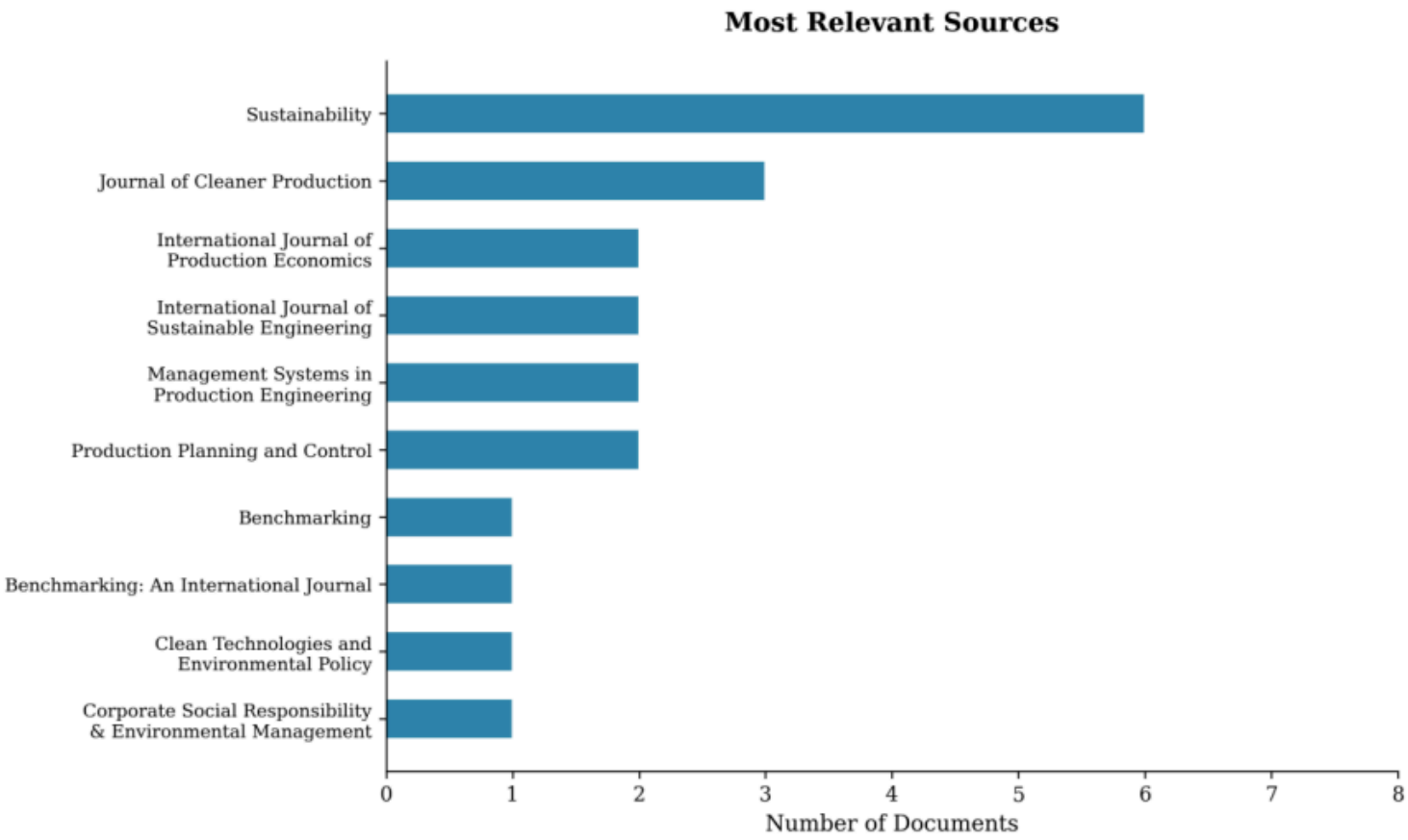



**Figure 4**

Figure 3.3: Journal Distribution

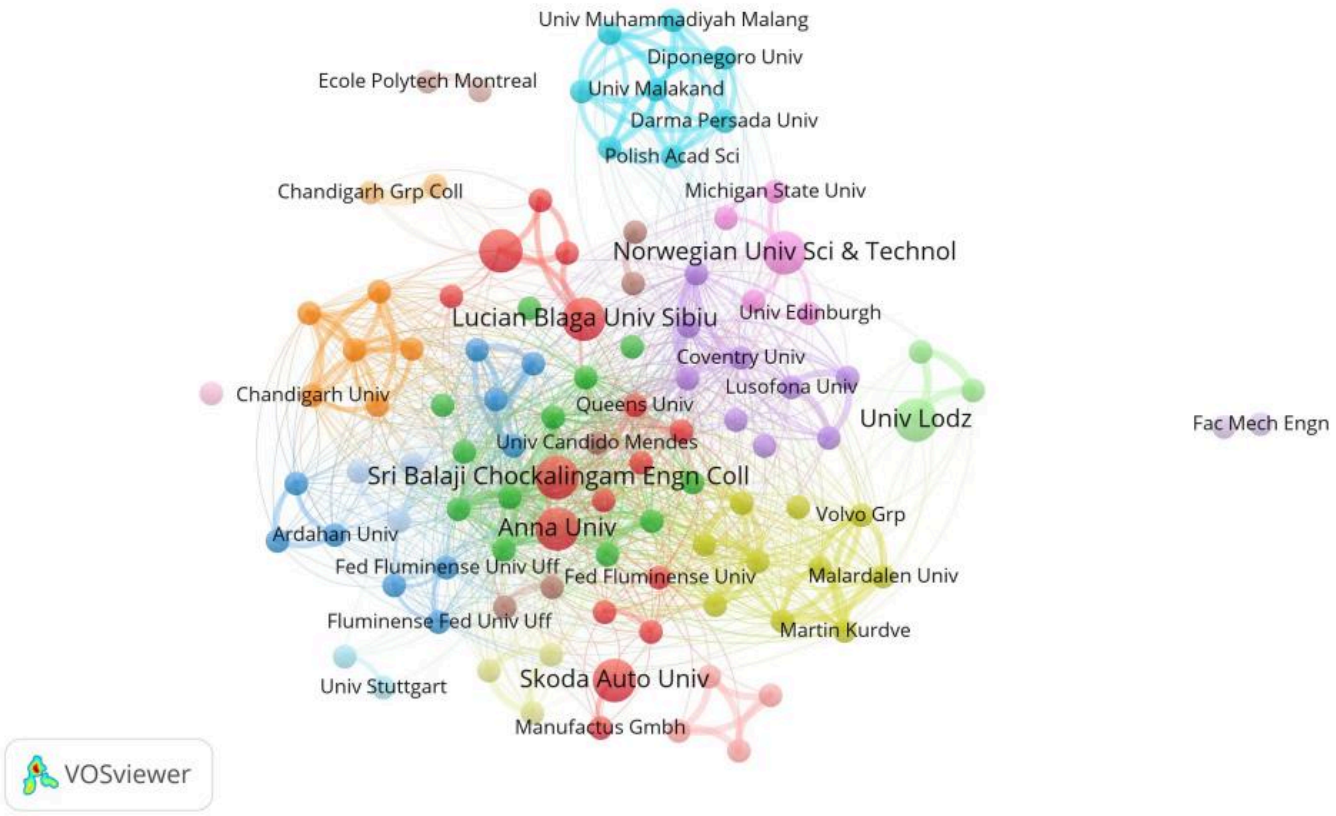



**Figure 5**

Figure 3.4: Institutional Collaboration Network

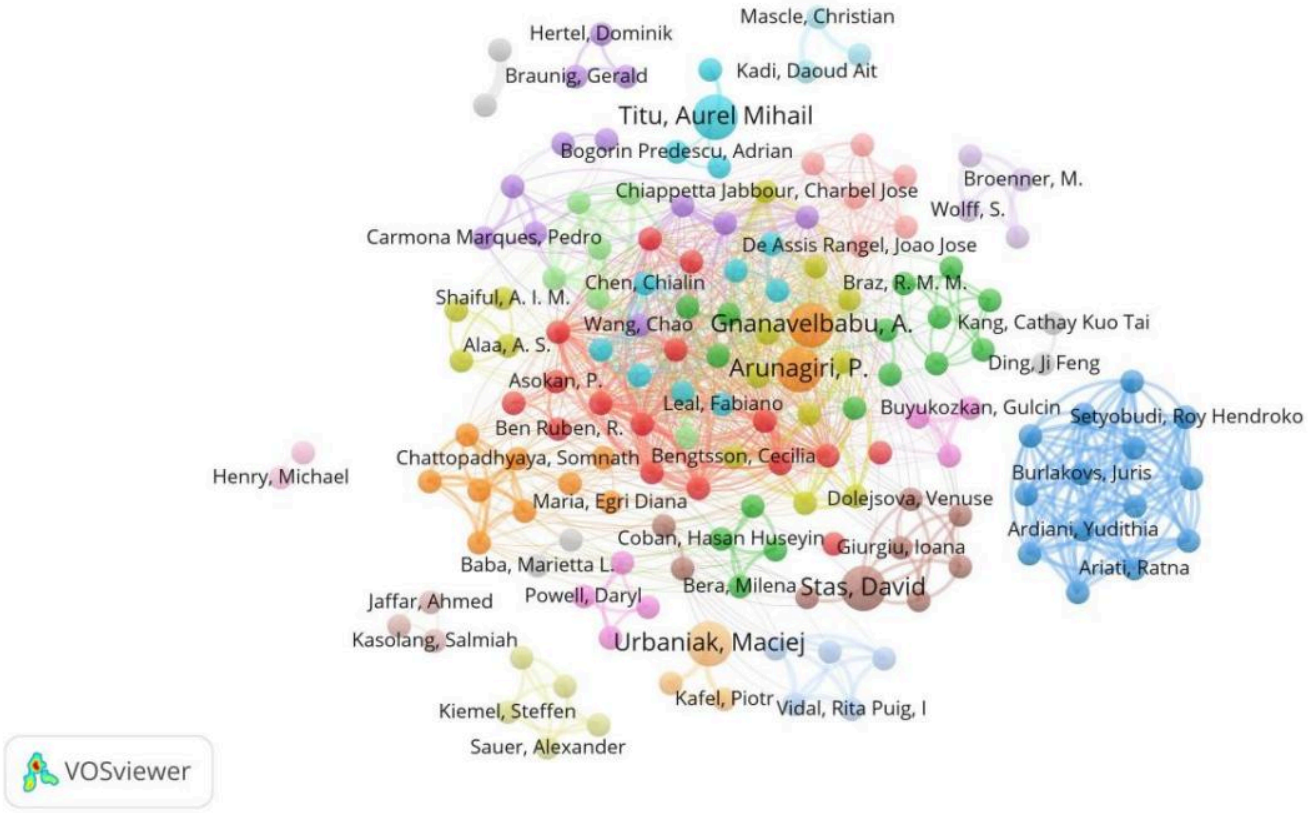



**Figure 6**

Figure 3.5: Author Collaboration Network

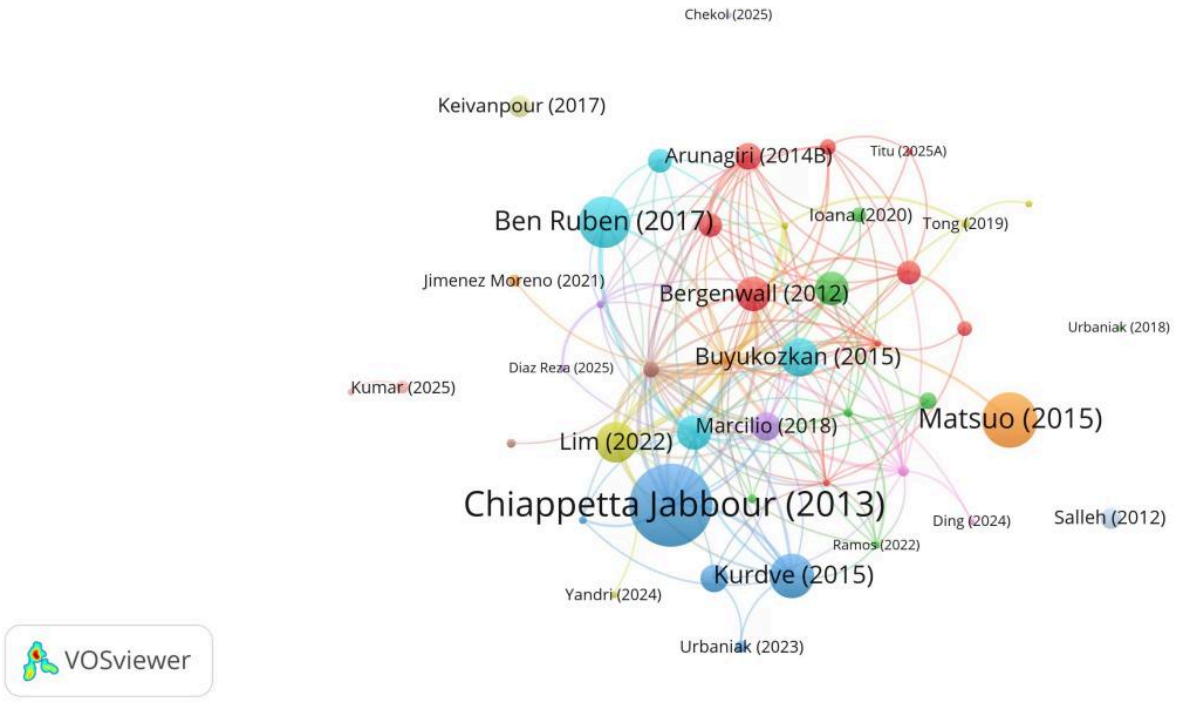



**Figure 7**

Figure 3.6: Co-Citation Network

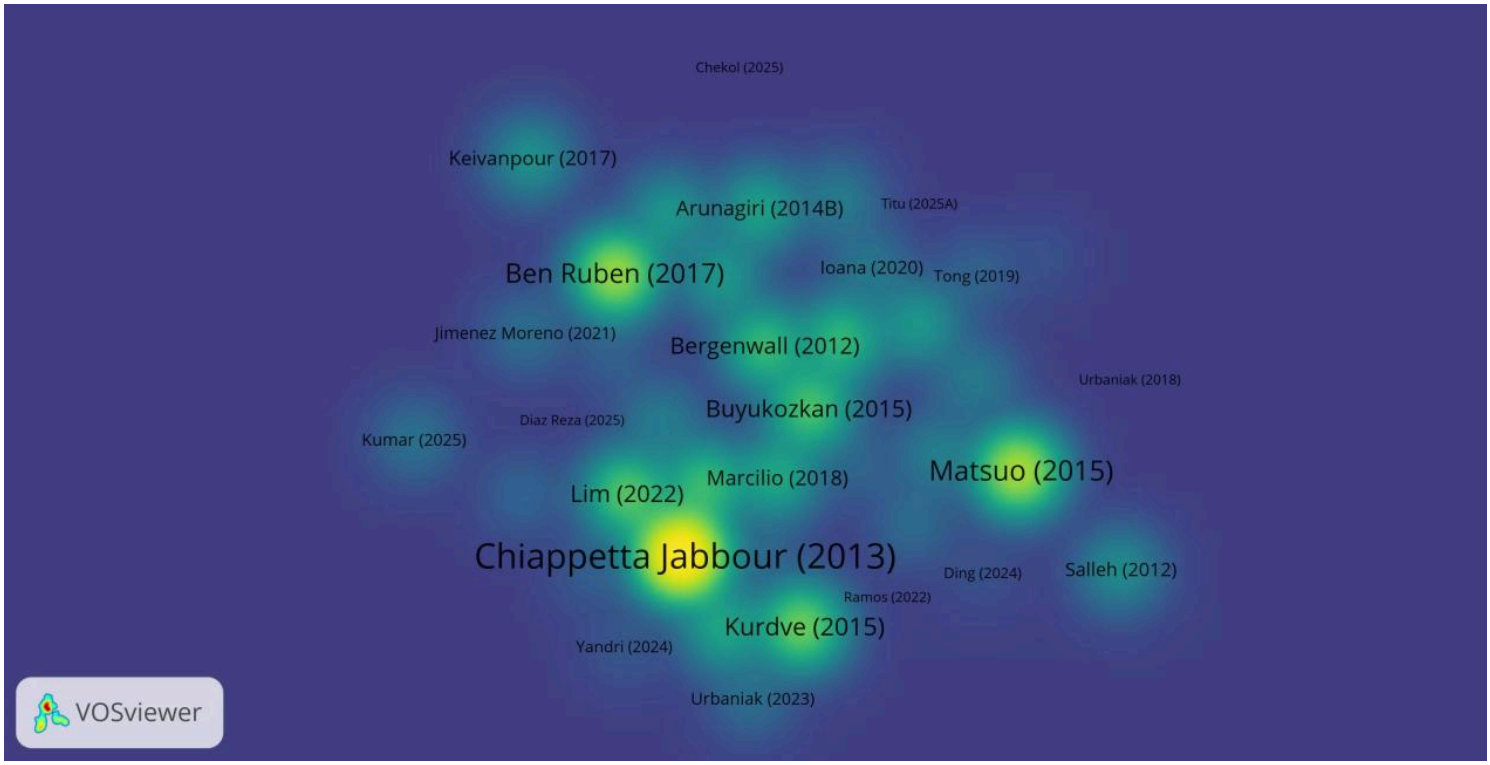



**Figure 8**

Figure 3.7: Co-Citation Density Map

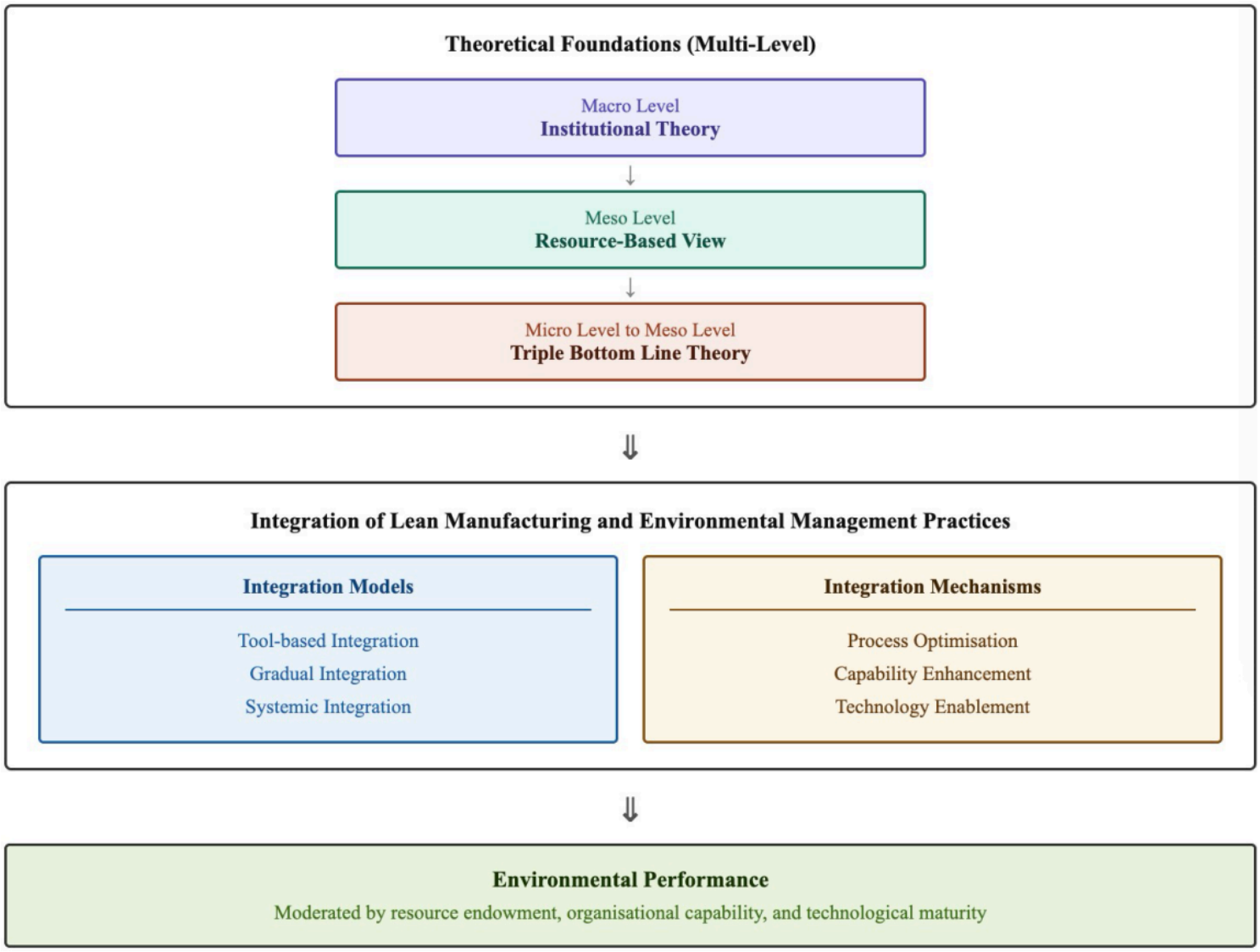



**Figure 9**

Figure 4.1: Multi-theoretical Integration Framework For Lean Manufacturing and Environmental Management Practices in the Automotive Industries