The International Journal of Advanced Manufacturing Technology (2025) 136:4025–4044
https://doi.org/10.1007/s00170-024-13215-5

ORIGINAL ARTICLE

Investigating the influence of lean manufacturing approach on environmental performance: A systematic literature review

Matteo Ferrazzi[1] · Stefano Frecassetti[1] · Alessia Bilancia[1] · Alberto Portioli-Staudacher[1]

Received: 3 February 2024 / Accepted: 5 February 2024 / Published online: 28 February 2024

Abstract
The growing emphasis on environmental sustainability has drawn considerable attention from both academia and industry practitioners. Factors such as escalating energy costs, heightened environmental degradation, and a burgeoning market demand for eco-friendly practices have compelled businesses to reassess their strategies through a green lens. Given that Lean principles are rooted in optimising operations to minimise waste across design and production processes, their synergy with the green paradigm is evident. However, despite the intuitive connection between Lean methodologies and environmental sustainability, the scholarly exploration of their impact remains largely underdeveloped. This research seeks to bridge this gap by conducting a comprehensive systematic literature review to dissect the current understanding of Lean manufacturing practices and their influence on environmental sustainability performance. The selected papers were meticulously screened and grouped into three clusters using the PRISMA diagram methodology. The primary objective was to discern the tangible effects of Lean practices on eco-efficiency performance and explore integrating Lean manufacturing principles with broader sustainable manufacturing approaches. A structured matrix was created to categorise and visualise the identified impacts gleaned from the initial articles. Nevertheless, the review revealed significant gaps in understanding, particularly regarding the factors that shape the efficacy of Lean manufacturing tools in enhancing eco-efficiency performance. The findings underscore the need for further research to unravel these complexities and delineate the mechanisms through which Lean practices contribute to environmental sustainability. Several avenues for future research have been delineated, focusing on how Lean manufacturing practices can be leveraged to support eco-efficiency performance effectively. While the preliminary findings shed light on the promising intersection between Lean principles and environmental sustainability, they also underscore the imperative for continued scholarly inquiry to unlock the full potential of Lean methodologies in fostering a greener industrial landscape.

Keywords Sustainability · Eco-efficiency · Lean practices

1 Introduction

Lean manufacturing was developed in Japan under the name Toyota Production System [1]. The general concept became famous with the publication of the article "The machine that changed the world" in 1990 [2]. One of the main goals of Lean is to implement a continuous improvement philosophy that enables companies to reduce costs, improve processes, and eliminate waste to increase customer satisfaction [3]. Nowadays, the lean manufacturing approach is considered the most influential paradigm in manufacturing [4]; empirical evidence suggests the increased competitiveness of organisations [5] by reducing inventory and lead times and improving productivity. In this context, the lean paradigm has not only been in line with historically prevalent organisational goals, such as profitability and efficiency, but also with contemporary goals, which include improving productivity, quality, and responsiveness.

Over the decades, the lean manufacturing approach has been able to adapt to different contexts and be used for various problems in companies worldwide [6]. In recent years, many researchers [7, 8] have investigated whether, in addition to productivity goals, the lean manufacturing approach was also useful for environmental sustainability goals in manufacturing companies. Environmental sustainability is

✉ Matteo Ferrazzi
matteo.ferrazzi@polimi.it

[1] Department of Management, Economics and Industrial Engineering, Politecnico Di Milano, Milan, Italy

increasingly at the centre of issues both in academia and in the interest of practitioners. In recent decades, managing operations following a logic aimed at environmental sustainability has become the managers' mission in many manufacturing companies. Effects such as rising energy prices, increasing environmental pollution and market demand for green practices have prompted companies to rethink their strategies from a green perspective [9]. Environmental sustainability initiatives consider business improvements, which aim to transform an input into an output using as few resources as possible [10]. The first and most important positive outcome for companies that apply green thinking is reducing their environmental impact.

This is evidenced by several studies that have considered the relationship and investigated the impact of green initiatives on the performance of organisations. Green manufacturing management methods influenced by the lean manufacturing approach are as diverse as; Green manufacturing [11, 12], a manufacturing process that helps to minimise environmental impact to protect and maintain the natural environment and resources. A circular economy [13] is a set of strategies that, in combination with the lean approach, generates new value from waste or production waste. Eco-design [14] is a methodology for designing products and their production systems with minimal environmental impact. Since Lean is an operations management approach that aims to eliminate waste in every area of factory design, production and management, its alignment with the green paradigm and its methods seem natural [15]. Some studies relate the lean manufacturing approach to green manufacturing paradigms [16]. Despite this, the big question that the academic community is asking is how an approach which has revolutionised the management of operations in manufacturing can support one of the biggest challenges facing society in recent decades; that is, empowering manufacturing companies to continue to be profitable while at the same time going about managing and limiting their environmental impact.

Indeed, despite the academic interest, also manifested by the growing number of publications on these topics and various studies investigating how lean manufacturing interacts with environmental sustainability, there are still open questions. Lines of research that explore the impact of lean manufacturing practices on environmental performance or eco-efficiency and those that explore the influence of lean manufacturing on environmental sustainability and the green manufacturing paradigm are still in primordial stages. The concept of eco-efficiency is developed in the industrial world because its practical approach makes it possible to balance environmental and economic benefits in an integrated way. Its goals are to reduce resource consumption and impact on nature while maintaining or increasing production volume. The environmental performance of a company or industry is becoming an important criterion of evaluation, as evidenced by environmental standards (ISO 14000 series). Eco-efficiency indicators are tools used to know how resources are used in a process and its impact on the environment. Indicators are defined for the manufacturing sector as the value of the output of manufactured products and the amount of resources used or pollution generated [17]. This research aims to facilitate further research on the influence of lean manufacturing on environmental sustainability performance. This paper presents a literature review of the current state of research on this emerging topic. The goal is to identify gaps in today's literature and find future lines of research. To this end, the paper aims to systematically collect and critically analyse existing contributions on using lean manufacturing practices in manufacturing settings and the effect on environmental sustainability performance. Two main questions are proposed to guide the research:

- What are the emerging topics in today's literature on lean manufacturing practices and their influence on environmental sustainability performance?
- What are the main tracks for future research on lean manufacturing and environmental sustainability?

In the following sections, the article is structured to answer the research questions proposed above. In Section 2, researchers critically analyse the search method used to select articles from the existing literature. Section 3, through a literature review, debates the main outcome. In Section 4, the systematic literature review results are discussed for the development of future lines of research. Finally, Section 5 will present the answers to the research question of this article and show the limitations and future developments of this research.

2 Research method

Through the literature review proposed below, this article aims to analyse the state of the art of interaction between the two macro research topics. In particular, it seeks to investigate how the operation management approach of lean manufacturing can positively influence the sustainable performance of manufacturing organisations. An effectively conducted literature review can highlight areas where research is still primordial. Once areas are highlighted, it is easier to develop theories and, at the same time, identify areas where vague concepts still exist [18]. The literature review uses a systematic, explicit, reproducible method [19]. The research questions presented in the previous chapter were formulated to address a systematic review of the existing literature. A systematic literature review is a method that takes a precise, transparent and explicit approach that includes a series of steps to ensure appropriate rigour and

transparency in the literature review process [20]. Denyer and Tranfield (2009) believe that a systematic literature review consists of the following five consecutive steps: (1) formulation of the question, (2) identification of studies, (3) selection and evaluation of studies, (4) analysis and synthesis, and (5) communication and use of results. All of these stages will be analysed in this paper [21].

According to Saunders et al. [22], for transparency, it is necessary to explain in detail how the systematic review process was conducted, particularly regarding the selection of literature and the choices made regarding the use of search terms. The next section will explore this in more detail; the steps, methods and tools used in the systematic literature review approach will be analysed.

2.1 Articles selection

The search for articles was conducted through a search string on the Scopus electronic database. The choice to use Scopus arose from the fact that this database conveys within itself the most authoritative and certified contributions from the various journals of reference in this research field. The search string used for searching in Scopus is the result of several refinements and iterative tests to be able to find the right query for the database to ensure the same time completeness and specificity. By using a systematic approach to the literature search, it was possible to have complete information on the research topic. Through a systematic search, one is assured of the current knowledge of the research topic. In this way, one can ensure that important contributions are not overlooked. The empirical context of the research is defined as Lean manufacturing and environmental sustainability, while the analysis of the environmental performance of manufacturing companies defines the theoretical lens. This research investigates how lean manufacturing practices and tools can influence environmental performance. Next, undertaking a systematic literature search means finding relevant keywords related to the topics under analysis. In this case, the choice was to capture the keywords of the two macro topics, Lean management and environmental sustainability, and consider their intersection.

In fact, on the one hand, there are some keywords which refer to the area of Lean management ("lean practices", "lean tools", "lean manufacturing", "lean production", "lean management"). In order not to exclude the contribution of significant articles dealing with manufacturing and production areas, in addition to general terms such as "lean management" and "lean production," more specific terms such as "lean practices" and "lean tools" have been added. The same approach was used for keywords in the area of environmental sustainability. The selected keywords are "environmental sustainab*," "eco-efficiency," and "eco-sustainability." Again in combination with more general terms, such as "environmental sustainab*," more specific terms dealing with environmental performance, "eco-efficiency", and "eco-sustainability," were added. Once these keywords were identified, they were linked through logical constructs, creating the reference search query for this search. The query through the logical construct "AND" collects studies that are part of the intersection of the two sets of keywords described previously.

To better organise the item selection phase, the PRISMA was used. The PRISMA diagram visually summarises the screening process (Fig. 1). It initially identifies the number of articles found with the search query. Subsequently, it makes the screening process transparent by reporting the decisions made at the various stages of the systematic review. Once the search string was identified, filters were applied to ensure specificity and consistency with respect to the topic to be investigated by selecting only certain articles. First, no restriction was added on the studies' publication years. According to the research, the publication years of the papers are between 2007 and 2022. Evidence shows that lean and environmental sustainability have been discussed in the academic literature since the early 1990s [23]. However, a major turning point in how organisations perceive their business's environmental dimension can be considered the release of the ISO 14001 environmental management standard in late 1996 [24]. So, the years of research done through the database fit into this time frame. The filters were included in the sub-areas to identify the relevant scientific communities. The sub-areas of business management and engineering were included. The reason is related to the fact that industrial engineers may be interested in the benefits that lean can bring to new operational solutions to solve some sustainability problems. At the same time, managers may benefit from this research to explore new sustainable business possibilities using the influence of lean.

The research results included only articles, peer-reviewed published in academic journals and international conference proceedings. According to Saunders et al. [22], these sources are the most useful and reliable for literature reviews. In addition, it was decided not to exclude a priori papers not published in Q1 journals. This is because it was considered important not to exclude even minor contributions, as environmental sustainability is dynamic and constantly evolving, and excluding some papers, a priori could result in missing important information.

The final search QUERY, including keywords and filters, is written below:

TITLE-ABS-KEY ((“lean practice”OR“lean tools”OR“lean manufacturing”OR“lean production”OR“lean management”)AND(“environmental sustainab*”OR“eco-efficiency”OR“eco efficiency”OR“eco-sustainability”OR“eco sustainability”)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE,

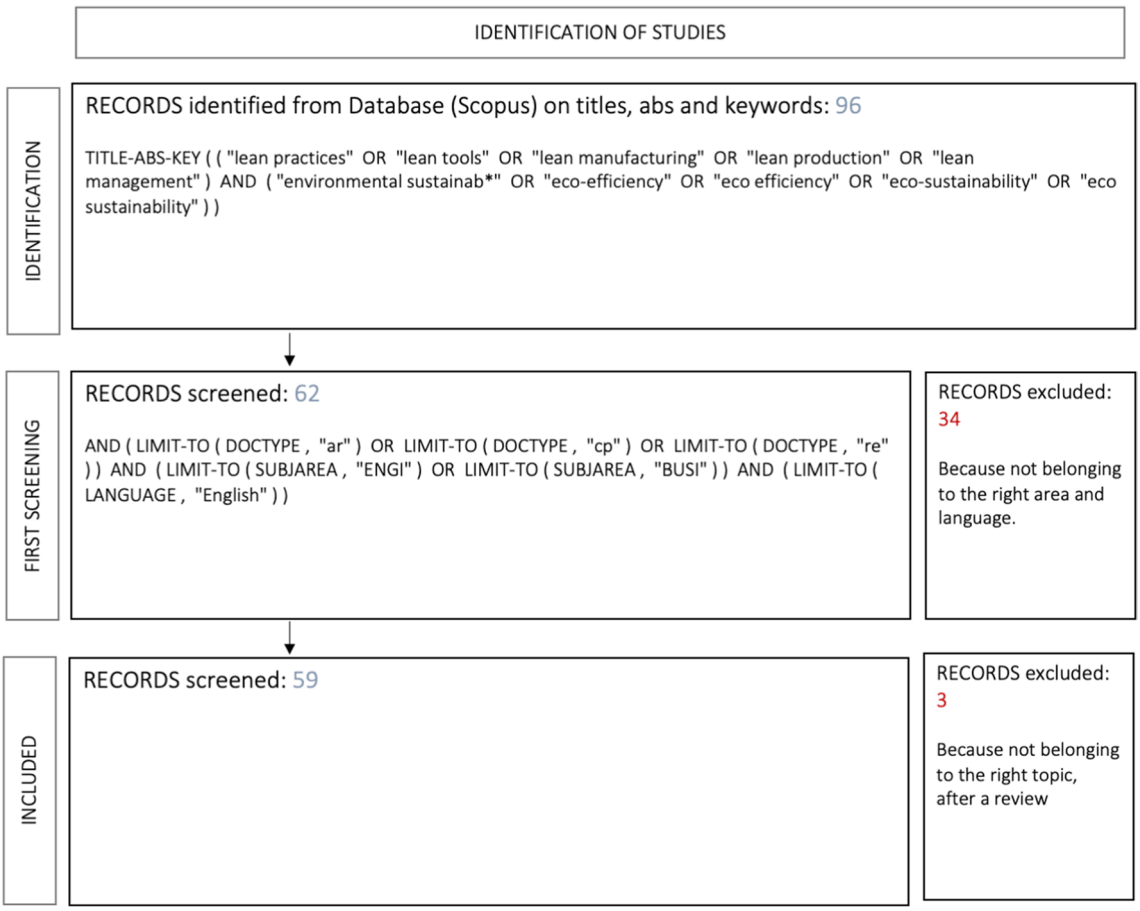


Fig. 1 PRISMA diagram-systematic search

"re")) AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "BUSI")) AND (LIMIT-TO (LANGUAGE, "English")).

2.2 Analysis and synthesis

Through the full reading, three articles [25–27] were discarded because they were out of the research objective of this paper as they dealt with the use of the lean approach. Still, the focus on environmental sustainability was a topic that was not central to the article. Many approaches exist to qualitatively synthesise the research developed through the proposed QUERY, including thematic/synthesis analysis, qualitative comparative analysis, and content analysis. This study presents an initial thematic analysis of the selected articles by reading them. Thematic synthesis was considered the most appropriate method to analyse the results obtained from the systematic literature review conducted in this study [28]. The Lean manufacturing approach to have better sustainable performance was not only used in manufacturing and operations areas. The research query returned several articles encapsulated into a first set through thematic synthesis. Twenty-two articles (37%) were identified, dealing with the lean manufacturing approach to environmental sustainability performance in supply chain/logistics, construction, and agriculture contexts. These articles fall under the systematic literature search but are considered low contribution because they deal with research in areas not inherent to the manufacturing and operations domain. The second thematic group of 19 articles (32%) encompasses studies showing the impact of the lean approach, particularly lean practices, on eco-efficiency performance. This study presented empirical evidence of how Lean manufacturing practices influence environmental sustainability or eco-efficiency performance. This thematic group of articles is the only part that can contribute the greatest to this research because it perfectly targets the research questions above. Finally, the last thematic group represents that group of 18 articles (30%) that show a pattern or conceptual relationship between environmental sustainability and the Lean manufacturing approach. These articles have a medium contribution to this research. On the one hand, they express the interaction between Lean manufacturing and environmental sustainability, but through studies that express very holistic

conceptual models that include other types of sustainability or propose models for a transition to green manufacturing processes.

3 Findings

Through the full reading of the articles, 59 articles entered the literature review. As anticipated in the previous chapter, these articles were divided the three thematic groups: Group A.1, Group A.2, and Group B (the characteristics of these groups will be developed in the next sections). The articles in the literature review deal with the relevant topic, i.e., the Lean manufacturing approach and its influence on environmental sustainability and eco-efficiency performance concepts.

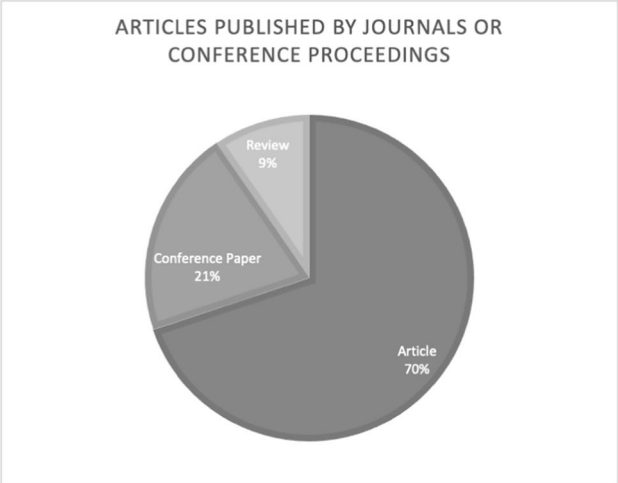


Fig. 2 Types of articles published

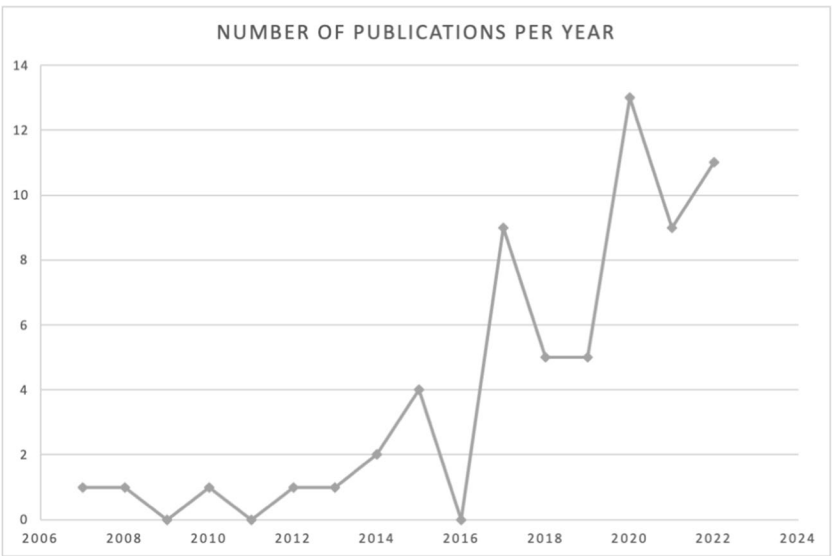
3.1 Sources of publication

In the graphs presented in this session, the results of the systematic literature search are represented synthetically with respect to various analyses: articles published by journals or conference proceedings (Fig. 2), number of publications per year (Fig. 3), specific journal (Fig. 4) and most cited authors (Fig. 5).

First of all, it can be stated that the topic covered by this study is of great topicality and interest to the relevant academics. This is first demonstrated in Fig. 3. It can be analysed how Lean manufacturing approach for environmental sustainability is a topic of great interest from the referenced academic communities mentioned above in recent years. From the graph, it can be seen that in the time frame of publication of the selected articles (2007–2022), there is a positive trend of publication growth. In particular, it can be noted that from 2017 onward, 88% (52 articles) of total publications were concentrated. This suggests that this topic is on the rise and can grow further in the coming years and attract the interests of both practitioners and academics.

Figure 2 shows that conferences have been an important medium for disseminating studies on this topic (21%) but still represent a minority of publications. Most of the studies (70%) are articles published in journals. This is likely because, in most cases, these studies enjoy depth and status suitable for journal publication. Through Fig. 4, the number of citations per journal is shown. The research found that journal publications are distributed across 37 different journals. The total number of articles published in the 37 journals is 51; despite this fact, as many as 21 articles are enclosed in only seven. This analysis makes it possible to identify which journals are the reference journals for this particular topic. Figure 4 shows seven publications from the *Journal of Cleaner Production* and four from the *Journal*

Fig. 3 Number of publications yearly trend



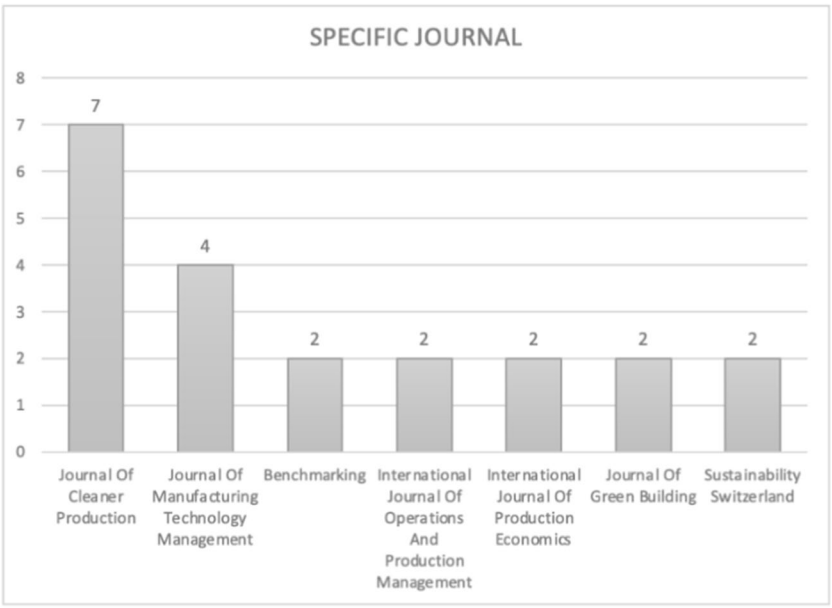


Fig. 4 Journals with the highest number of publications

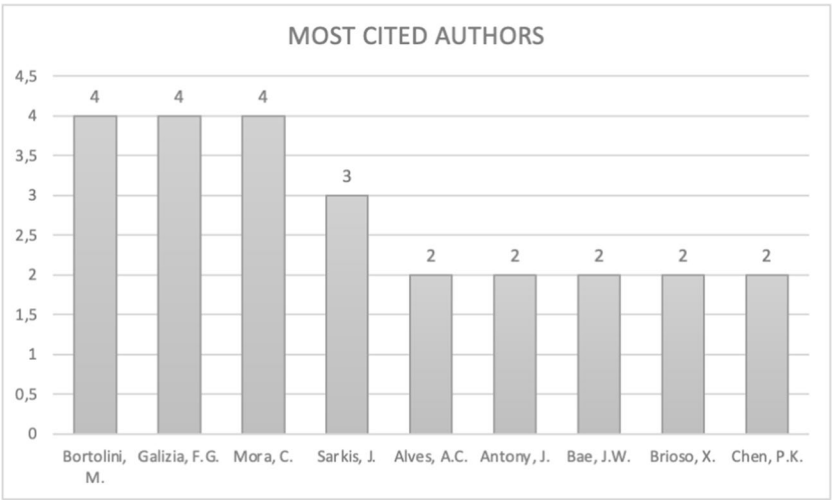


Fig. 5 Most cited authors

of Manufacturing Technology Management. In comparison, they have two publications each from *Benchmarking*, *International Journal of Operations and Production Management*, *International Journal of Production Economics*, *Sustainability Switzerland*, and *Journal of Green Building*.

Finally, Fig. 5 represents the number of publications per author. This kind of analysis is useful for identifying the leading scholars regarding this topic. In particular, it is possible to see how Bortolini, M., Mora, C. and Galicia, F.G. have four publications each, while Sarkis, J. has 3.

3.2 Systematic literature review

The systematic literature review will answer the first research question in the first chapters. Then, this paper will investigate the emerging themes in today's literature on lean manufacturing practices and their influence on environmental sustainability performance. The future lines of research related to the literature review will be presented, thus answering the second research question.

The articles selected for the systematic literature review all refer to the impact of lean manufacturing on environmental sustainability. Despite this, a preliminary thematic classification of the various articles was necessary. This was very useful in identifying the main themes covered in the set of selected articles and detecting the contribution/relevance of multiple articles. As preliminarily presented earlier, the articles were divided into three classes (Table 1). First, the collected articles were divided with respect to the empirical context of

reference. Group A of articles deals with lean management and environmental sustainability in manufacturing/operation contexts.

In contrast, group B of articles deals with the same topic in non-manufacturing contexts, such as supply chain/logistics, construction, and agriculture. Then, the articles in group A were divided into two subgroups (group A.1 and A.2). Group A.1 collected all the articles that deal with the impact of lean manufacturing on environmental sustainability by going to show how lean manufacturing practices had an impact on companies' eco-efficiency performance. Group A.2, on the other hand, collects the remainder of the articles that deal with the topic of research in manufacturing/operation sectors, proposing models and studies that show how the relationship between green production paradigm integrated with the lean manufacturing approach can be effective in arriving at more sustainable production models (Fig. 6).

The three groups of articles presented within the systematic literature review have different relevance. The three groups are categorised by importance according to the following scheme:

- Group A.1 - High Significance/Impact: papers that focus on analysing the impact of lean manufacturing practices on eco-efficiency performance in manufacturing settings and analysing variables that influence the effect of lean manufacturing on environmental sustainability performance. They have greater significance because they clearly show the impact of lean manufacturing on environmental sustainability performance.
- Group A.2 - Medium Significance/Impact: papers that theoretically integrate lean manufacturing techniques with green manufacturing paradigms. These papers explain how lean manufacturing practices have been modified and integrated with environmental sustainability practices to generate more sustainable manufacturing environments. These papers have medium relevance within this literature review because they show the impact of lean manufacturing on environmental sustainability at a holistic level.
- Group B - Low Significance/Impact: papers that address the impact of lean manufacturing on environmental sustainability in contexts other than manufacturing. These papers have low relevance within this literature review because they do not fully address the research objective but may be useful in developing future lines of research.

In the following paragraphs, the literature will be divided into thematic groups, mainly groups A.1 and A.2, to answer the research questions in the first chapter.

3.3 Matrix: Lean practices — eco-efficiency performance

The first step in the systematic literature review starts with article group A.1. Although all the articles in this group deal with the impact of Lean manufacturing practices on eco-efficiency performance, it is necessary to create a structure to understand how this impact manifests itself. For this reason, it was decided to develop a matrix to categorise, visualise, and structure the impacts shown by each article in group A.1 (Fig. 7). This visualisation tool is intended to convey a discussion of the main findings of the systematic literature review. To create the matrix for categorising the impacts of lean manufacturing practices on eco-efficiency performance, it is necessary to identify the variables that will make up the vertical and horizontal axis of the matrix. For the vertical axis of the matrix, a set of variables representing lean manufacturing practices were identified. The variables identified to express the Lean manufacturing approach, which emerges from the literature reviewed in this group of articles, are related to the lean practices made explicit by Shah and Ward in 2003 in one of the most important articles on the Lean approach, "Lean manufacturing: context, practice bundles, and performance" [87]. This article was taken as a reference for identifying variables that represented lean manufacturing practices because it is considered by scholars to be one of the masterpieces in the literature dealing with topics related to lean philosophy. The practices can be summarised in 18 variables. They are listed below: Just-in-time (JIT), Kanban, 5S, Single Minute Exchange of Die (SMED), Value Stream Map (VSM), Customer engagement, Supplier collaboration, Total Productive Maintenance (TPM), Kaizen, Total Quality Management (TQM), Bottleneck removal (production smoothing), Human Resource Management (HRM), Cellular manufacturing, Continuous improvement programs, Cycle time reductions, Customer engagement, Supplier collaboration, Employee involvement, Visual management, 9th type of muda.

For the horizontal axis, variables related to eco-efficiency performance were identified to represent the impact of Lean manufacturing on environmental sustainability. Eco-efficiency performance variables were identified to complete the horizontal axis of the matrix. In order to do this, there is no single reference study recognised by the scientific community that can unambiguously guide the identification of such variables. However, studies that have already addressed the issue of eco-efficiency performance can be exploited. Indeed, it is possible to identify matrix variables related to eco-efficiency performance through the studies of Garza-Reyes & Kumar [88] and Maxime et al. [17]. Eco-efficiency metrics can be grouped according to four macro variables: natural resource use, pollution emissions, material use/consumption, and non-productive

Table 1 List of articles included in the revision

Article number	Article group	Authors	Title	Year
1	A.1	Estrada-González I.E., Taboada-González P.A., Guerrero-García-Rojas H., Márquez-Benavides L. [29]	Decreasing the environmental impact in an egg-producing farm through the application of LCA and lean tools	2020
2	A.1	Gaikwad L., Sunnapwar V. [9]	Development of an integrated framework of LGSS strategies for Indian manufacturing firms to improve business performance: an empirical study	2021
3	A.1	Resta B., Dotti S., Gaiardelli P., Boffelli A. [30]	How lean manufacturing affects the creation of sustainable value: An Integrated model	2017
4	A.1	Bai C., Satir A., Sarkis J.N [31]	Investing in lean manufacturing practices: an environmental and operational perspective	2018
5	A.1	Ball P., Lunt P. [32]	Lean eco-efficient innovation in operations through the maintenance organisation	2020
6	A.1	Antomarioni S., Bevilacqua M., Ciarapica F.E. [33]	More Sustainable Performances Through Lean Practices: A Case Study	2018
7	A.1	Farrukh A., Mathrani S., Sajjad A. [34]	Managerial perspectives on green-lean-six sigma adoption in the flexible packaging industry: empirical evidence from an emerging economy	2022
8	A.1	Wu P. [35]	Monitoring carbon emissions in precast concrete installation through lean production – A case study in Singapore	2015
9	A.1	Maia L.C., Alves A.C., Leão C.P. [36]	Sustainable work environment with lean production in textile and clothing industry	2013
10	A.1	Gholami H., Jamil N., Mat Saman M.Z., Streimikiene D., Sharif S., Zakuan N. [37]	The application of Green Lean Six Sigma	2021
11	A.1	Sadiq S., Amjad M.S., Rafique M.Z., Hussain S., Yasmeen U., Khan M.A. [38]	An integrated framework for lean manufacturing in relation with blue ocean manufacturing—A case study	2021
12	A.1	Yadav V., Gahlot P., Rathi R., Yadav G., Kumar A., Kaswan M.S. [39]	Integral measures and framework for green lean six sigma implementation in manufacturing environment	2021
13	A.1	Agyabeng-Mensah Y., Ahenkorah E., Afum E., Owusu D. [40]	The influence of lean management and environmental practices on relative competitive quality advantage and performance	2020
14	A.1	Chen P.-K., Lujan-Blanco I., Fortuny-Santos J., Ruiz-De-arbulo-lópez P. [41]	Lean manufacturing and environmental sustainability: The effects of employee involvement, stakeholder pressure and iso 14,001	2020
15	A.1	Chen P.-K., Fortuny-Santos J., Lujan I., Ruiz-de-Arbulo-López P. [42]	Sustainable manufacturing: Exploring antecedents and influence of Total Productive Maintenance and lean manufacturing	2019
16	A.1	Muñoz-Villamizar A., Santos J., Garcia-Sabater J.J., Lleo A., Grau P. [43]	Green value stream mapping approach to improving productivity and environmental performance	2019
17	A.1	Leme R.D., Júnior, Nunes A.O., Message Costa L.B., Silva D.A.L. [44]	Creating value with less impact: Lean, green and eco-efficiency in a metalworking industry towards a cleaner production	2018
18	A.1	Simboli A., Taddeo R., Morgante A. [45]	Value and wastes in manufacturing. An overview and a new perspective based on eco-efficiency	2019
19	A.1	Belayutham S., González V.A. [46]	A lean approach to manage production and environmental performance of earthwork operation	2015
20	A.2	Marques T.L., Giusti G., de Paula E Silva M.H., Mendes J.V., de Figueirêdo M.C.B., Silva D.A.L. [47]	Monitoring and Evaluating Eco-efficiency by Three Different Ways in a Beverage Company: A Lean-Green Approach	2022

Table 1 (continued)

Article number	Article group	Authors	Title	Year
21	A.2	Shokri A., Antony J., Garza-Reyes J.A. [48]	A new way of environmentally sustainable manufacturing with assessing transformation through the green deployment of Lean Six Sigma projects	2022
22	A.2	Abreu M.F., Alves A.C., Moreira F. [49]	Lean-Green models for eco-efficient and sustainable production	2017
23	A.2	Sajan M.P., Shalij P.R., Ramesh A., Biju A.P. [50]	Lean manufacturing practices in Indian manufacturing SMEs and their effect on sustainability performance	2017
24	A.2	Ghaithan A., Khan M., Mohammed A., Hadidi L. [51]	Impact of industry 4.0 and lean manufacturing on the sustainability performance of plastic and petrochemical organisations in saudi arabia	2021
25	A.2	Wu P., Low S.P. [52]	Lean management and low carbon emissions in precast concrete factories in Singapore	2012
26	A.2	Raj D., Ma Y.J., Gam H.J., Banning J. [53]	Implementation of lean production and environmental sustainability in the Indian apparel manufacturing industry: a way to reach the triple bottom line	2017
27	A.2	Colombo B., Gaiardelli P., Dotti S. [54]	Overcoming barriers of green transformation through the adoption of lean manufacturing: A case study	2020
28	A.2	Yusup M.Z., Wan Mahmood W.H., Salleh M.R., Ibrahim N. [55]	Structural model of lean and cleaner production on manufacturing sustainability performance: Malaysian manufacturers' perspectives	2021
29	A.2	Longoni A., Cagliano R. [56]	Cross-functional executive involvement and worker involvement in lean manufacturing and sustainability alignment	2015
30	A.2	Kaswan M.S., Rathi R., Reyes J.A.G., Antony J. [57]	Exploration and Investigation of Green Lean Six Sigma Adoption Barriers for Manufacturing Sustainability	2021
31	A.2	Lobo Mesquita L., Lizarelli F.L., Duarte S., Oprime P.C. [58]	Exploring relationships for integrating lean, environmental sustainability and industry 4.0	2022
32	A.2	Saetta S., Caldarelli V. [59]	Lean production as a tool for green production: The Green Foundry case study	2020
33	A.2	Menon A.P., Lahoti V., Gunreddy N., Chadha U., Selvaraj S.K., Nagalakshmi R., Jayakumar K., Karthikeyan B. [60]	Quality control tools and digitalisation of real-time data in sustainable manufacturing	2022
34	A.2	Tseng M.-L., Tran T.P.T., Ha H.M., Bui T.-D., Lim M.K. [61]	Sustainable industrial and operation engineering trends and challenges Toward Industry 4.0: a data driven analysis	2021
35	A.2	Hallam C.R.A., Contreras C. [62]	The interrelation of Lean and green manufacturing Practices: A case of push or pull in implementation	2016
36	A.2	Jum'a L., Zimon D., Ikram M., Madzík P. [63]	Towards a sustainability paradigm: the nexus between lean green practices, sustainability-oriented innovation and Triple Bottom Line	2022
37	A.2	Ferrazzi M., Frecassetti S., Portioli-Staudacher A. [64]	A Lean approach for improving workers' ergonomics: a case study	2022
38	B	Pandey P., Shah B.J., Gajjar H. [65]	A fuzzy goal programming approach for selecting sustainable suppliers	2017
39	B	Barth H., Melin M. [66]	A Green Lean approach to global competition and climate change in the agricultural sector – A Swedish case study	2018
40	B	de Oliveira Rezende M., Saade M.R.M., Nunes A.O., da Silva V.G., Moris V.A.S., Silva D.A.L. [67]	A Lean and Green approach for the eco-efficiency assessment on construction sites: description and case study	2022
41	B	Bortolini M., Calabrese F., Galizia F.G., Mora C. [68]	A three-objective optimisation model for mid-term sustainable supply chain network design	2022

Table 1 (continued)

Article number	Article group	Authors	Title	Year
42	B	Fahimnia B., Sarkis J., Eshragh A. [69]	A tradeoff model for green supply chain planning: A leanness-versus-greenness analysis	2015
43	B	Navarro P. [70]	Applying quality concepts to achieve environmental sustainability in the freight transport sector – reviewing process management and lean	2021
44	B	Zhu X.-Y., Zhang H. [71]	Construction of lean-green coordinated development model from the perspective of personnel integration in manufacturing companies	2020
45	B	Bortolini M., Galizia F.G., Mora C. [72]	Current research trend in lean and green supply chain management	2017
46	B	Bortolini M., Galizia F.G., Mora C. [73]	Efficiency & Sustainability Model to Design and Manage Two-stage Logistic Networks	2017
47	B	Jeffers P.I. [74]	Embracing sustainability: Information technology and the strategic leveraging of operations in third-party logistics	2010
48	B	Bortolini M., Galizia F.G., Gamberi M., Mora C., Pilati F. [75]	Enhancing stock efficiency and environmental sustainability goals in direct distribution logistic networks	2019
49	B	Francis A., Thomas A. [76]	Exploring the relationship between lean construction and environmental sustainability: A review of existing literature to decipher broader dimensions	2020
50	B	Hazzouri M., Thoumy M. [77]	Internal stakeholders' perspective on lean energy and environmental sustainability: The case of Notre Dame University—Louaize	2020
51	B	Singh P. [78]	Lean in healthcare organisation: an opportunity for environmental sustainability	2019
52	B	Martínez-Jurado P.J., Moyano-Fuentes J. [79]	Lean management, supply chain management and sustainability: A literature review	2014
53	B	Zhu Q., Johnson S., Sarkis J. [80]	Lean six sigma and environmental sustainability: A hospital perspective	2018
54	B	Brioso X., Cruzado-Ramos F. [81]	Model of evaluation of sustainability performance in building projects integrating lean, through the Delphi method	2020
55	B	Nabhani F., Bala S., Evans G., Shokri A. [82]	Review of implementing Lean Six Sigma to reduce environmental wastes of internal supply chains in food industry	2017
56	B	Mekhum W. [83]	Role of green supply chain management strategies in sustainability: Evidence from manufacturing industry of Thailand	2020
57	B	Bae J.-W., Kim Y.-W. [84]	Sustainable value on construction project and application of lean construction methods	2007
58	B	Bae J., Kim Y. [85]	Sustainable value on construction projects and lean construction	2008
59	B	Marcilio G.P., Rangel J.J.D.A., Souza C.L.M.D., Shimoda E., Silva F.F.D., Peixoto T.A. [86]	Analysis of greenhouse gas emissions in the road freight transportation using simulation	2018

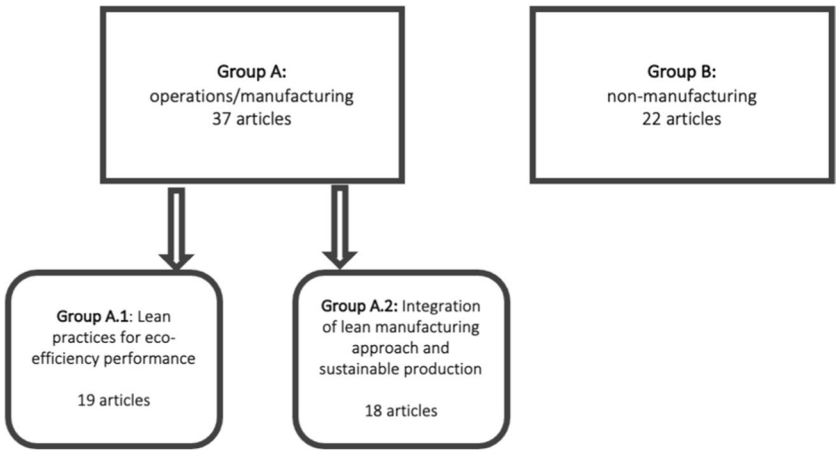


Fig. 6 Overview scheme of article groups

outputs [16]. These four macro variables were then divided into sub-variables according to the nature of each eco-efficiency performance. The subdivision into sub-variables is presented below:

- Use of natural resources: Energy, water, oil
- Pollution emissions: carbon footprint, CO2 emissions
- Material use/consumption: raw materials, auxiliary materials, packaging
- Non-productive outputs: production waste, defects, auxiliary production materials

Once the variables for lean practices (vertical axis) and variables for eco-efficiency performance (horizontal axis) were identified, the matrix was populated by the items included in group A.1. The matrix below also shows a colour code to identify the various effects of Lean practices on eco-efficiency performance. Numbers in black represent a positive impact, numbers in red have a negative effect, and numbers in blue have a null effect.

Each cell of the matrix expresses the impact of one variable of lean practices on one variable of eco-efficiency performance. First, it should be emphasised that in most cases analysed during this literature review, the impact of lean practices on eco-efficiency performance is positive. Only two articles present studies showing negative or null impact on eco-efficiency performance. The study by Chen et al. [42] highlights the negative effect of continuous improvement programs on water and energy consumption. The article by Resta et al. [30] presents both a negative effect of TPM on energy consumption and a null effect of Human Resource Management on energy consumption, raw material utilisation, and waste generation reduction [30]. The matrix shows how, within the systematic literature review, the effect of lean practices, identified by Shah and Ward, on eco-efficiency performance is present in many ways. Some examples represented in the matrix are SMED for carbon footprint reduction [34, 44], VSM for energy consumption [29, 33] for CO_2 reduction [35, 43], and TQM for reduction of non-productive outputs such as production waste [42].

The first reflection from this review is that the matrix created shows how the lean manufacturing approach positively affects eco-efficiency performance and, consequently, environmental sustainability. Once this is consolidated, one can go deeper with the literature review.

First, a preliminary consideration is, which lean practices are most widely used to solve problems related to improved eco-efficiency performance (Fig. 8). The lean practices that feature most in this literature review are Value Stream Map (in 9 out of 19 articles), Total productive maintenance (in 6 out of 19 articles), Continuous improvement programs & Kaizen (in 4 out of 19 articles) and Just-in-time & 5 s (in 3 out of 19 articles). Some of these practices are also presented in the articles as modified or adapted to solve problems related to environmental sustainability. The lean practice most prone to this phenomenon is the Value Stream Map [37, 43]. This leads to the idea that this lean practice is one of the most effective and mature practices in improving eco-efficiency performance.

It is also interesting to identify which eco-efficiency performances are most subject to the intervention of the lean approach to be improved (Fig. 9). The eco-efficiency performances that were most featured in this literature review are reduction of energy consumption (in 12 out of 19 articles), reduction of carbon footprint (in 10 out of 19 articles), reduction of raw material consumption (in 8 out of 19 articles), and reduction of production waste (in 6 out of 19 articles). The eco-efficiency performances are most subject to improvement in the literature review; those that companies consider the most critical or the most sensitive can be analysed to have a concrete improvement in the company's environmental sustainability.

Another interesting point to make about the proposed matrix is identifying areas not covered in the literature. In fact, on the one hand, lean management practices such as Kanban, Supplier collaboration, and Customer engagement

	Consumption of natural resources			Pollution releases		Material consumption			Non-production outputs		
	Water	*Oil*	*Energy*	*Carbon footprint*	*CO2 emission*	*Raw materials*	*Auxiliary materials*	*Packaging*	*Production waste*	*Defects*	*Auxiliary material*
Just-in-time (JIT)						9;14	14	14	3;14		
Kanban											
5S	9;12	9	9;12			7;12					
Single Minute Exchange of Die (SMED)				7;17	7						
Value Stream Map (VSM)	9	9	1;6;9;10;11;16	8;9;11;16;19	8;16	7;16	10;16	16	16		
Total productive maintenance (TPM)		9	5	9,15	15	3;7;14	14	14	3,14,15		
Kaizen	9;12	9	6;9;12	7;9	7	7;12					
Total Quality Management (TQM)			3	15	15				3;15		
Human Resource Management (HRM)			3			3			3		
Bottleneck removal (production smoothing)	15		15	15	15	14	14	14	14;15		
Cellular manufacturing	15		15	15	15				15		
Continuous improvement programs	15		4;11;15	4;11;15	4;15				2;15		
Cycle time reductions			13			13			13		
Customer engagement											
Supplier collaboration											
Employee involvement		9		8;9	8	14	14	14	14		
Visual management	9		9								
9th type of muda				18	18	18	18	18			18

LEGENDA	
black	POSITIVE
blue	NULL
red	NEGATIVE

Figure 7 Article classification matrix group A.1

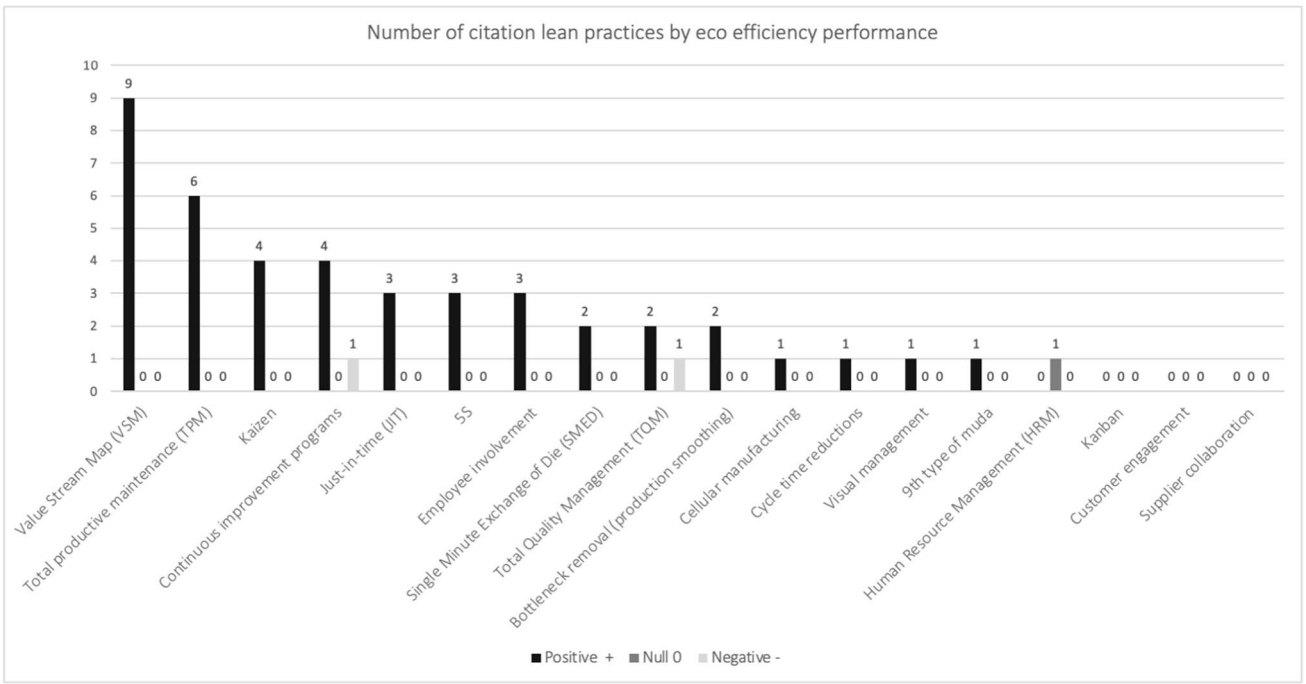


Fig. 8 Number of citations for Lean practices by eco-efficiency performance

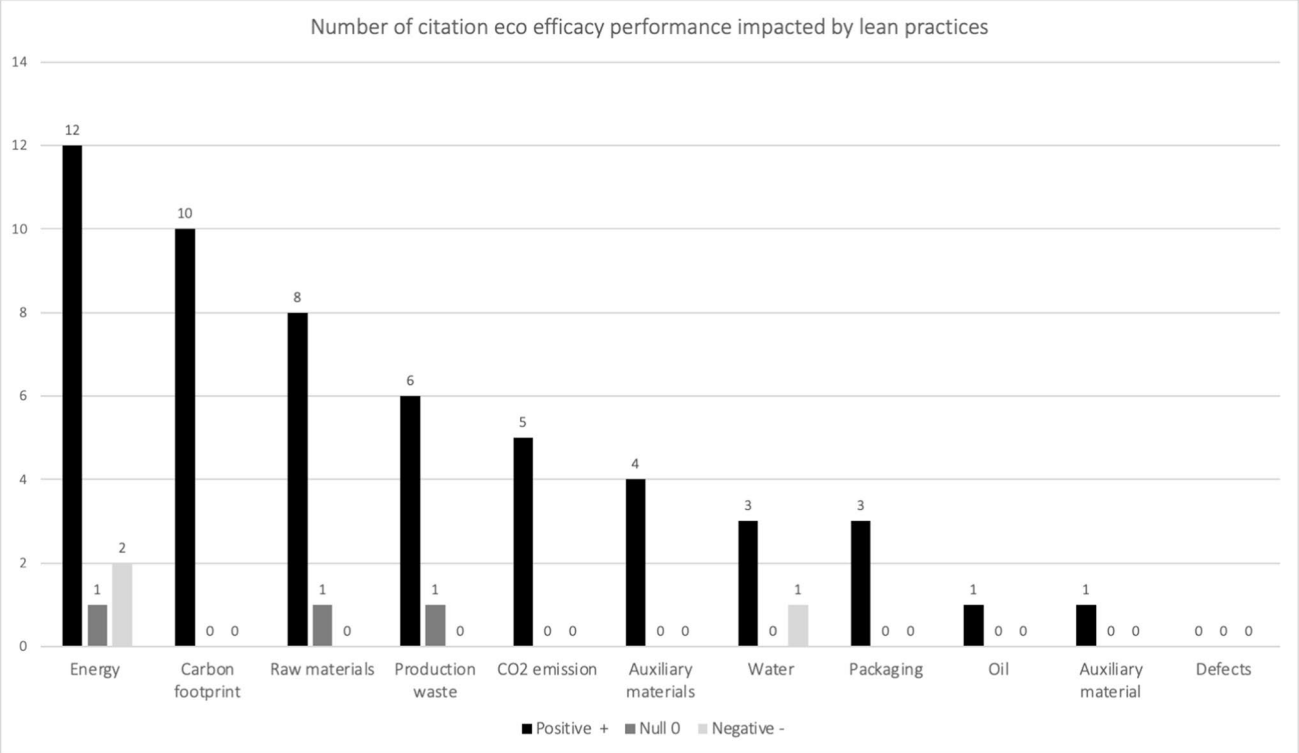


Fig. 9 Number of citations for eco-efficiency performance impacted by lean practices

are never mentioned. While regarding eco-efficiency performance, there still seems to be little literature that analyses performance, such as defect reduction for environmental sustainability, packaging consumption reduction, and auxiliary material consumption reduction.

3.4 Integration of the lean manufacturing approach with sustainable production models

The next stage of the systematic literature review is developed by analysing the articles included in group A.2. The systematic review of these articles highlights a strong relationship between lean manufacturing and environmental sustainability. All articles in this thematic group explore the integration of lean manufacturing with sustainable production approaches. For a better critical analysis of this group of articles, it was decided to divide them into four macro sub-clusters: (1) Effective decision-making tools, (2) Overcoming barriers, (3) The Triple Bottom Line Concept and (4) Industry 4.0.

(1) This thematic group offers studies that develop models/frameworks for creating environmentally sustainable manufacturing models. The integration between lean manufacturing-based production models and green production paradigms are concepts developed in several articles. Studies such as Bai et al. highlight the lack of effective decision-making tools that help implement lean practices for better environmental sustainability. This study, therefore, seeks to develop a new decision-making model for evaluating lean practices. The results of this study identify a set of investments in developing the lean approach to direct companies toward green production models [31].

(2) Implementing lean and green productions share common goals, so integration between these paradigms is natural. Despite this, some scholars highlight that manufacturing companies often face barriers to implementing green production processes. This implementation involves several challenges and requires appropriate actions to overcome internal and external barriers. Some articles propose lean manufacturing as a suitable approach to support the transformation to green production systems. In particular, the article by Colombo et al. presents an inductive analysis of a textile manufacturing company that, while operating according to lean manufacturing principles, has recently initiated a green transformation project [54]. The results confirm that green transformation is an ongoing process of gradually adopting green management practices. In addition, the study suggests that the distinctive features of lean manufacturing can help organisations overcome spe-

cific barriers that arise at different stages of the green transformation process. Another example of a study for overcoming barriers to green transition is reported by Kaswan et al. [57]. This article proposes a decision-making model to help companies prioritise barriers and manage important and causal relationships among them. The results reveal that management-related barriers are ranked first, followed by environmental and organisational ones. The review of this group of articles brought out additional interesting aspects.

(3) Several authors study the integration between lean and environmental sustainability by considering different issues. Some proposed studies do not limit the integration of lean manufacturing to environmental sustainability but introduce a more holistic concept of sustainability. These studies consider a Triple Bottom Line concept; environmental sustainability is linked to social and economic sustainability principles. Jum'a L. et al. [63] provide a model that holistically relates lean manufacturing practices to develop sustainable production processes. Another example is the article by Longoni A. & Cagliano R. [56]. This research aimed to study the involvement of multiple functions in formulating and implementing the operational strategy for supporting lean manufacturing for sustainability. The results of this study are related to the development of operational strategies and social and environmental sustainability, taking advantage of lean manufacturing support. Finally, the study written by Ferrazzi et al. [64] analyses a case study that, through the utilisation of the lean management approach, succeeded in impacting the social sustainability of the company taken into consideration. In fact, through the reconfiguration of the operations of some operators on an assembly line, the company, taking into analysis, managed to achieve better ergonomic performance for its workers [64]. These studies highlight how some authors consider lean manufacturing not only closely related to environmental sustainability. In fact, according to these studies, social and economic sustainability are inescapable and must be viewed as a fundamental factor when it comes to lean manufacturing.

(4) Another interesting aspect that emerged in the literature review is the introduction of the concept of Industry 4.0. Articles such as Ghaithan et al. [51] expose how the paradigms of lean manufacturing, Industry 4.0 and environmental sustainability over the years are increasingly interconnected. These studies aim to identify the forms of integration between Lean, Industry 4.0, and environmental sustainability by examining the relationships among these three constructs, deepening the understanding of the topic, and evolving the construction of a framework that can help the management of industrial production processes. As presented by the authors, these studies investigate promising research areas that have not been explored. The operational contribution of such studies is that they can help managers understand the integrations between Lean practices and I4.0 technologies to achieve better operational and environmental outcomes.

4 Discussion

The literature indicates that scholars and academics are increasingly investigating the link between environmental sustainability and lean manufacturing [10]. As analysed in the literature review, on the one hand, the influence of lean manufacturing practices with the green manufacturing paradigm and how these two paradigms have been integrated over the years are being studied [45]. From another perspective, empirical evidence is expressed in the literature showing that lean manufacturing approaches positively affect eco-efficiency performance [7]. However, the literature review showed that there are still many unexplored spaces in this area of research. Following are proposed some future lines of research that can still be explored. Finally, new research questions related to the lines of research that emerged from the literature review are proposed.

4.1 Critical analysis and open issues

The systematic literature review of article group A.1 clearly showed the influence of lean practices on eco-efficiency performance. In most cases, a positive influence of lean practices is shown in the summary matrix. Despite this, it is unclear what factors influence the effect of the Lean manufacturing approach on improving eco-efficiency performance. In particular, an analysis of the current state of the literature on this topic reveals some lines of research yet to be explored. Some possible factors not yet explored in depth in the literature will be outlined below. Cherrafi et al. [89] explain that factors such as "lack of communication and cooperation," "lack of kaizen culture," and "poor corporate culture separating environmental and continuous improvement decisions" are barriers to greater "environmental awareness" and consequently harm sustainable performance. Studies such as Longoni A. & Cagliano R. [56] also highlight how alignment across functions and alignment of goals between top management and operators are key factors in achieving better results for environmental sustainability. These factors can be expressed as soft lean practices; they are a set of practices developed to act on the behaviours of individuals in organisations that take advantage of the lean approach [90]. Despite the great potential of soft lean practices, few studies examine how soft lean practices can

achieve eco-efficiency performance. Some studies show that increased adoption of soft lean practices may be a key factor in amplifying the benefits of lean tools [91]. Future studies could investigate how lean soft practices may be a factor that fosters the positive effect of lean tools on eco-efficiency performance. Another factor that may impact the influence of lean tools on eco-efficiency performance is the company's degree of Lean maturity. Analysis of the literature, especially in group A.1, has shown that companies with lean manufacturing systems have higher eco-efficiency performance. To date, research is unable to determine how much and how maturity in using the lean approach affects environmental performance. Some studies show that lean maturity is a factor in achieving better operational performance [92]. From this perspective, it is reasonable to think that the maturity of lean adoption may also be a determinant of better environmental performance; in fact, there are empirical studies that show that through the use of lean tools in manufacturing settings, both operational and environmental performance have benefited [93]. For these reasons, it is necessary to investigate further the role of maturity in using the Lean approach to achieve improved eco-efficiency performance.

Over the past two decades, the great push toward digitisation has also led to enormous changes in the lean manufacturing approach. Digitisation and introduction of Industry 4.0 practices have profoundly changed the use of the lean approach [94]. The literature review presents how Industry 4.0 can be a factor, through synergy with lean tools, for an impact on environmental sustainability [51]. Despite this, in the literature review, there appears to be a lack of studies showing how integrating Industry 4.0 techniques can amplify the benefit of lean practices for better eco-efficiency performance. Therefore, a line of research investigating this aspect becomes essential. As presented earlier, during the literature review, some articles present how lean practices have been modified and adapted to address environmental sustainability issues [43].

On the other hand, most articles included in the matrix expose the use of lean practices that have not been adapted and modified [29]. The literature reveals that it is unclear how some lean practices can be adjusted while others cannot. It is unclear why some lean practices have not yet been adapted for environmental sustainability issues. Above all, it is not yet clear whether the adaptation of lean practices can be a factor that affects eco-efficiency performance, especially compared to a situation where lean practices have not been modified.

Another factor to be considered for future research is contextual factors. In fact, during the systematic search of articles, no filter was added to select studies that analysed the lean approach for sustainability in predetermined context areas. This consequently led to a heterogeneity of studies showing the positive effect of lean practices on eco-efficiency performance. At this time, however, it is unclear how contextual factors, such as the company's size or the industry where it operates, could influence lean practices' impact on eco-sustainability performance. Studies in very different sectors and from companies of very different sizes are presented in the matrix. In possible future lines of research, it is interesting to study how contextual factors of companies may influence the impact of lean practices on eco-efficiency performance.

Another area of investigation for future research is related to group A.2 The current literature does not understand the relationships between various lean tools, sustainable environmental practices, and eco-efficiency performance [16]. This is clear from reviewing the articles in group A.2. The studies propose models that relate to the lean approach and green production practices but do not show how this integration manifests in environmental sustainability performance. Moreover, some scholars argue that it is necessary to study a relational model that shows which and to what extent lean tools impact various eco-efficiency performances [8, 16]. It is unclear what the relationships are between various lean practices and eco-efficiency performance and what the interactions among them can bring higher benefits in improving eco-efficiency performance.

As a final output, a set of research questions for future lines of research related to the analysis just described are presented below.

- Understanding what influences the impact of lean practices on eco-efficiency performance.

  How do the soft lean factors influence the impact of lean practices on eco-efficiency performance?
  How does the maturity grade of lean practices influence eco-efficiency performance?
  How does the synergy between I4.0 and lean practices influence eco-efficiency performance?
  How can lean practices be modified to influence eco-efficiency performance?
  How can lean practices be influenced by contextual factors (such as company size and sector) for eco-efficiency performance?
  How can lean practices interact with each other to lead to better eco-efficiency performance?
  Which lean practices have the greatest impact on eco-efficiency performance?

- Understand how integrating various lean manufacturing and sustainability practices influences eco-efficiency performance.

How can integrating Lean practices with green manufacturing paradigms improve eco-efficiency performance?

What are the lean practices that influence different eco-efficiency performances? Furthermore, what is their interaction?

How can the lean manufacturing approach holistically affect the sustainability of manufacturing companies (Triple bottom line concept)?

How can the Lean approach help manufacturing companies overcome barriers to green production models?

5 Conclusion

5.1 Discussion and contribution to theory

This study is further evidence of how environmental sustainability, one of organisations' goals, must align with their traditional profitability and efficiency priorities. This paper has studied several aspects linking the Lean manufacturing approach and environmental sustainability, particularly how lean manufacturing practices positively impact eco-efficiency performance. Through a systematic review of the literature, the authors were able to answer the two research questions proposed in the introduction section.

In particular, to answer the first research question, the systematic literature review identified two macro areas of investigation. The first area is how the influence of Lean practices on eco-efficiency performance is manifested. To clarify this, a matrix was created to summarise and visualise the effects of lean practices on eco-efficiency performance. The second macro area is related to integrating the Lean Manufacturing approach with sustainable production models.

A series of future research lines were developed to answer the second research question. The future research questions are related to macro areas of investigation that emerged from the literature. Specifically for the first research area, it is interesting to investigate which factors impact the influence of Lean manufacturing practices on eco-efficiency performance. The factors that develop future lines of research are (1) the implementation of soft lean practices, (2) the lean maturity level of the company, (3) the implementation of Industry 4.0 practices, (4) the adaptation of Lean practices for environmental sustainability goals, and (5) the contextual factors of organisations. While related to the second area of investigation, this study proposes to investigate how the integration of Lean practices with green production paradigms can improve eco-efficiency performance and also what the interactions among various Lean practices can bring higher benefits in improving eco-efficiency performance (i.e., if there are synergetic effects).

In conclusion, the presented research can stimulate and foster the research for the relevant scientific communities, and aims to provide practitioners with information that is extremely necessary to compete in today's market. Indeed, this study provides a comprehensive overview of how Lean manufacturing can address environmental sustainability issues. In this way, practitioners can develop a deeper understanding of these issues. This study can help them formulate strategies to compete in a market increasingly focused on sustainable product development. This research may help organisations select and exploit new production models based on Lean manufacturing with better eco-efficiency performance.

5.2 Limitations and further research

Even though this paper contributes substantially to enriching the existing knowledge on the topics, it presents its limitations and pitfalls. The first limitation is that the researchers used specific keywords to identify the papers. Thus some precious contributions could have been lost in this phase or the following screening phases in which the number of articles have been selected. Also, the classification in groups of the papers has been done according to the authors' thoughts. Thus, it presents a certain grade of subjectivity, which could be a pitfall.

Then, this study does not consider the context variables (e.g., companies' sector, dimension, etc.) of the papers analysed. For instance, the dimension of a company or the industry in which it operates can have a huge impact on eco-efficiency performance, as well as other factors such as the presence of corporate sustainability programs massive presence of digital technologies or incentives. Thus, the researchers suggest further research, both from a theoretical and an empirical perspective, focusing on the effect brought by these elements or their inclusion in similar studies.

Another main limitation of this paper is the absence of a weighting system for the eco-efficiency variables. Here, all the variables in this paper have the same weight. For further research, studies that analyse and rank each Lean practice's impact on eco-efficiency performance are strongly encouraged. In that way, weight and thus the importance in terms of effects on eco-efficiency performance can be given to each Lean practice.

A pitfall could also be the complete absence of the economic and time dimension. In fact, the impact on eco-efficiency of using Lean practices is considered but did not contemplate the company's effort in terms of implementation time and monetary expenditures. It could be possible, for instance, that to achieve good results, companies have to spend a huge amount of resources before some good results are obtained. Thus, the researchers propose future research to take into consideration these factors.

A last limitation of this work is the absence of a reference seminal paper related to the eco-efficiency variables. In fact, unlike the Lean practices, where the reference paper was the one by Shah & Ward [6], no reference paper has been used for the eco-efficiency variables. The eco-efficiency variable has been a subjective choice based on screening several papers on eco-efficiency performance. Thus, further research in developing a model with the most relevant variables for eco-efficiency in manufacturing is suggested.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Matteo Ferrazzi and Alessia Bilancia. The first draft of the manuscript was written by Matteo Ferrazzi and all authors commented on previous versions of the manuscript. Stefano Frecassetti was responsible for the final review. Alberto Portioli supervised the entire project. All authors read and approved the final manuscript.

Funding Open access funding provided by Politecnico di Milano within the CRUI-CARE Agreement.

Declarations

Competing interests The authors declare no competing interests.

References

1. Herron C, Hicks C (2008) "The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents." Robot Comput-Integr Manuf 24(4):524–531 (Elsevier BV)
2. Womack JP, Jones DT, Roos D (2007) The machine that changed the world: how lean production revolutionised the Global Car Wars. Simon & Schuster, London
3. Womack JP, Jones DT (1997) Lean thinking—banish waste and create wealth in your corporation. J Oper Res Soc 48(11):1148–1148
4. Forrester PL, Kazumi Shimizu U, Soriano-Meier H, Arturo Garza-Reyes J, Fernando Cruz Basso L (2010) Lean production, market share and value creation in the agricultural machinery sector in Brazil. J Manuf Technol Manage 21(7):853–871 (Emerald)
5. Hines P, Holweg M, Rich N (2004) Learning to evolve. Int J Oper Prod Manage 24(10):994–1011 (Emerald)
6. Shah R, Ward PT (2007) Defining and developing measures of lean production. J Oper Manage 25(4):785–805 (Wiley)
7. Ramos AR, Ferreira JCE, Kumar V, Garza-Reyes JA, Cherrafi A (2018) A lean and cleaner production benchmarking method for sustainability assessment: a study of manufacturing companies in Brazil. J Clean Prod 177:218–231 (Elsevier BV)
8. Hartini S, Ciptomulyono U (2015) The relationship between lean and sustainable manufacturing on performance: literature review. Procedia Manuf 4:38–45 (Elsevier BV)
9. Gaikwad LM, Sunnapwar VK (2021) Integrated lean-green-six sigma practices to improve the performance of the manufacturing industry. In Concepts, Applications and Emerging Opportunities in Industrial Engineering. IntechOpen. https://doi.org/10.5772/intechopen.93276
10. Benabdellah AC, Zekhnini K, Cherrafi A, Garza-Reyes JA, Kumar A (2021) Design for the environment: an ontology-based knowledge management model for green product development. Bus Strat Environ 30(8):4037–4053 (Wiley)
11 Digalwar AK, Tagalpallewar AR, Sunnapwar VK (2013) Green manufacturing performance measures: an empirical investigation from Indian manufacturing industries. Meas Bus Excell 17(4):59–75 (Emerald)
12 Gandhi NS, Thanki SJ, Thakkar JJ (2018) Ranking of drivers for integrated lean-green manufacturing for Indian manufacturing SMEs. J Clean Prod 171:675–689 (Elsevier BV)
13. Kalemkerian F, Santos J, Tanco M, Garza-Reyes JA, Viles E (2022) Analysing the alignment between the Green Lean and Circular strategies: towards a Circular Lean approach. J Manuf Technol Manage 33(6):1059–1079 (Emerald)
14 Gottberg A, Morris J, Pollard S, Mark-Herbert C, Cook M (2006) Producer responsibility, waste minimisation and the WEEE Directive: case studies in eco-design from the European lighting sector. Sci Total Environ 359(1–3):38–56 (Elsevier BV)
15. Thanki S, Govindan K, Thakkar J (2016) An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. J Clean Prod 135:284–298 (Elsevier BV)
16 Garza-Reyes JA (2015) Lean and green – a systematic review of the state of the art literature. J Clean Prod 102:18–29 (Elsevier BV)
17 Maxime D, Marcotte M, Arcand Y (2006) Development of eco-efficiency indicators for the Canadian food and beverage industry. J Clean Prod 14(6–7):636–648 (Elsevier BV)
18. Watson RT, Webster J (2020) Analysing the past to prepare for the future: writing a literature review a roadmap for release 2.0. J Decis Syst 29(3):129–147
19 Gray MA (2000) "Media reviews. conducting research literature reviews by A. Fink. Sage Publications, Thousand Oaks, 1998, 265 pages, F14.99 (paperback) F32.00 (hardback), ISBN 0 761 90904 4." J Adv Nurs 32(3):764–764
20 Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br J Manage 14(3):207–222 (Wiley)
21. Schinckus C, Akbari M, Clarke S (2019) Corporate social responsibility in sustainable supply chain management: an econo-bibliometric perspective. In: Theoretical Economics Letters, Scientific Research Publishing, Inc. 9(1):247–270. https://doi.org/10.4236/tel.2019.91020
22. Saunders M, Lewis P, Thornhill A (2012) Research methods for business students, 6th edn. Pearson Education Ltd, Essex
23 Davids M (1994) Environmental strategies: lean and green. J Bus Strat 15(2):18e20
24 Darnall N, Rigling Gallagher D, Andrews RNL, Amaral D (2000) Environmental management systems: opportunities for improved environmental and business strategy? Environ Qual Manage 9(3):1–9 (Wiley)

25 Ghobakhloo M, Fathi M (2019) Corporate survival in Industry 4.0 era: the enabling role of lean-digitised manufacturing. J Manuf Technol Manage 31(1):1–30 (Emerald)

26. Sudarsan JS, Abhyankar AA, Parashar A, Krishna SV (2022) Analysing construction and demolition waste practices: an indian case study. In: Lecture Notes in Civil Engineering, Springer Nature, Singapore, pp 481–490. https://doi.org/10.1007/978-981-16-8433-3_41

27. Cruzado-Ramos F, Brioso X (2020) Sustainability performance evaluation in building projects by integrating lean and sustainable management using the delphi method. In Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC). 28th Annual Conference of the International Group for Lean Construction (IGLC). International Group for Lean Construction. https://doi.org/10.24928/2020/0132

28 Thomas J, Harden A (2008) Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Med Res Methodol 8:1 (Springer Science and Business Media LLC)

29. Estrada-González IE, Taboada-González PA, Guerrero-García-Rojas H, Márquez-Benavides L (2020) Decreasing the environmental impact in an egg-producing farm through the application of LCA and lean tools. Appl Sci 10(4):1352 (MDPI AG)

30 Resta B, Dotti S, Gaiardelli P, Boffelli A (2017) How lean manufacturing affects the creation of sustainable value: an integrated model. Int J Autom Technol 11(4):542–551 (Fuji Technology Press Ltd)

31. Bai C, Satir A, Sarkis J (2018) Investing in lean manufacturing practices: an environmental and operational perspective. Int J Prod Res 57(4):1037–1051 (Informa UK Limited)

32 Ball P, Lunt P (2020) Lean eco-efficient innovation in operations through the maintenance organisation. Int J Prod Econ 219:405–415 (Elsevier BV)

33. Antomarioni S, Bevilacqua M, Ciarapica FE (2018) "More sustainable performances through lean practices: a case study," 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Stuttgart, Germany, pp 1–8. https://doi.org/10.1109/ICE.2018.8436263

34. Farrukh A, Mathrani S, Sajjad A (2022) Managerial perspectives on green-lean-six sigma adoption in the flexible packaging industry: empirical evidence from an emerging economy. J Manuf Technol Manage 33(7):1232–1255 (Emerald)

35. Wu P (2014) Monitoring carbon emissions in precast concrete installation through lean production – a case study in Singapore. J Green Build 9(4):191–211 (College Publishing)

36. Costa Maia L, Carvalho Alves A, Leão CP (2013) Definition of a protocol for implementing lean production methodology in textile and clothing case studies. In Volume 2B: Advanced Manufacturing. ASME 2013 International Mechanical Engineering Congress and Exposition. Am Soc Mech Eng. https://doi.org/10.1115/imece2013-64739

37. Gholami H, Jamil N, Mat Saman MZ, Streimikiene D, Sharif S, Zakuan N (2021) The application of Green Lean Six Sigma. Bus Strat Environ 30(4):1913–1931 (Wiley)

38. Sadiq S, Amjad MS, Rafique MZ, Hussain S, Yasmeen U, Khan MA (2021) An integrated framework for lean manufacturing in relation with blue ocean manufacturing - a case study. J Clean Prod 279:123790

39. Yadav V, Gahlot P, Rathi R, Yadav G, Kumar A, Kaswan MS (2021) Integral measures and framework for green lean six sigma implementation in manufacturing environment. Int J Sustain Eng 14(6):1319–1331 (InformaUK)

40. Agyabeng-Mensah Y, Ahenkorah E, Afum E, Owusu D (2020) The influence of lean management and environmental practices on relative competitive quality advantage and performance. J Manuf Technol Manage 31(7):1351–1372 (Emerald)

41. Chen P-K, Lujan-Blanco I, Fortuny-Santos J, Ruiz-de-Arbulo-López P (2020) Lean manufacturing and environmental sustainability: the effects of employee involvement, stakeholder pressure and ISO 14001. Sustainability 12(18):7258 (MDPIAG)

42. Chen P-K, Fortuny-Santos J, Lujan I, Ruiz-de-Arbulo-López P (2019) Sustainable manufacturing: exploring antecedents and influence of total productive maintenance and lean manufacturing. Adv Mech Eng 11(11):168781401988973 (SAGEPublications)

43. Muñoz-Villamizar A, Santos J, Garcia-Sabater JJ, Lleo A, Grau P (2019) Green value stream mapping approach to improving productivity and environmental performance. Int J Prod Perform Manage 68(3):608–625 (Emerald)

44 LemeJúnior RD, Nunes AO, Message Costa LB, Silva DAL (2018) Creating value with less impact: lean, green and eco-efficiency in a metalworking industry towards a cleaner production. J Clean Prod 196:517–534 (ElsevierBV)

45 Taddeo R, Simboli A, Di Vincenzo F, Ioppolo G (2019) A bibliometric and network analysis of lean and clean(er) production research (1990/2017). Sci Total Environ 653:765–775 (Elsevier BV)

46. Belayutham S, González V (2015) A lean approach to manage production and environmental performance of earthwork operation, 23rd Annual Conference of the International Group for Lean Construction, pp 743–752

47. Marques TL, Giusti G, de Paula'e Silva MH, Mendes JV, de Figueirêdo MCB, Silva DAL (2022) Monitoring and evaluating eco-efficiency by three different ways in a beverage company: a lean-green approach. Smart Sustain Manuf Syst 6(1):20220006 (ASTM International)

48. Shokri A, Antony J, Garza-Reyes JA (2022) A new way of environmentally sustainable manufacturing with assessing transformation through the green deployment of Lean Six Sigma projects. J Clean Prod 351:131510 (Elsevier BV)

49 Abreu MF, Alves AC, Moreira F (2017) Lean-Green models for eco-efficient and sustainable production. Energy 137:846–853 (Elsevier BV)

50. Sajan MP, Shalij PR, Ramesh A, Biju AP (2017) Lean manufacturing practices in Indian manufacturing SMEs and their effect on sustainability performance. In J Manuf Technol Manag 28(6):772–793. https://doi.org/10.1108/jmtm-12-2016-0188

51. Ghaithan A, Khan M, Mohammed A, Hadidi L (2021) Impact of Industry 4.0 and lean manufacturing on the sustainability performance of plastic and petrochemical organizations in Saudi Arabia. Sustainability 13(20):11252 (MDPIAG)

52. Wu P, Low SP (2012) Lean management and low carbon emissions in precast concrete factories in Singapore. J Archit Eng 18(2):176–186 (American Society of Civil Engineers (ASCE))

53. Raj D, Ma YJ, Gam HJ, Banning J (2017) Implementation of lean production and environmental sustainability in the Indian apparel manufacturing industry: a way to reach the triple bottom line. Int J Fash Des Technol Educ 10(3):254–264 (Informa UK Limited)

54. Colombo B, Gaiardelli P, Dotti S (2020) Overcoming barriers of green transformation through the adoption of lean manufacturing: A case study. ... SUMMER SCHOOL FRANCESCO TURCO. PROCEEDINGS, 1–7

55 Yusup MZ, Mahmood WHW, Salleh MR, Ibrahim N (2021) Structural model of lean and cleaner production on manufacturing sustainability performance: Malaysian manufacturers' perspectives. Int J Agile Syst Manage 14(1):1 (InderscienceEPublishers)

56. Longoni A, Cagliano R (2015) Cross-functional executive involvement and worker involvement in lean manufacturing and sustainability alignment. Int J Oper Prod Manage 35(9):1332–1358 (Emerald)

57. Kaswan MS, Rathi R, Reyes JAG, Antony J (2023) Exploration and investigation of green lean six sigma adoption barriers for manufacturing sustainability. IEEE Transactions on Engineering

Management. Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/TEM.2021.3108171
58. Lobo Mesquita L, Lizarelli FL, Duarte S, Oprime PC (2021) Exploring relationships for integrating lean, environmental sustainability and industry 4.0. Int J Lean Six Sigma 13(4):863–896 (Emerald)
59 Saetta S, Caldarelli V (2020) Lean production as a tool for green production: the Green Foundry case study. Procedia Manuf 42:498–502 (Elsevier BV)
60. Menon AP, Lahoti V, Gunreddy N, Chadha U, Selvaraj SK et al (2022) Quality control tools and digitalization of real-time data in sustainable manufacturing. International Journal on Interactive Design and Manufacturing (IJIDeM). Springer Science and Business Media LLC. https://doi.org/10.1007/s12008-022-01054-1
61. Tseng M-L, Tran TPT, Ha HM, Bui T-D, Lim MK (2021) Sustainable industrial and operation engineering trends and challenges Toward Industry 4.0: a data driven analysis. J Ind Prod Eng 38(8):581–598 (InformaUKLimited)
62. Hallam CRA, Contreras C (2016) The interrelation of Lean and green manufacturing Practices: a case of push or pull in implementation. 2016 Portland International Conference on Management of Engineering and Technology (PICMET). Presented at the 2016 Portland International Conference on Management of Engineering and Technology (PICMET), IEEE. https://doi.org/10.1109/picmet.2016.7806669
63. Jum'a L, Zimon D, Ikram M, Madzík P (2022) Towards a sustainability paradigm; the nexus between lean green practices, sustainability-oriented innovation and Triple Bottom Line. Int J Prod Econ 245:108393 (ElsevierBV)
64. Ferrazzi M, Frecassetti S, Portioli-Staudacher A (2022) A lean approach for improving workers' ergonomics: a case study., ... SUMMER SCHOOL FRANCESCO TURCO. PROCEEDINGS
65. Pandey P, Shah BJ, Gajjar H (2017) A fuzzy goal programming approach for selecting sustainable suppliers. Benchmark An Int J 24(5):1138–1165 (Emerald)
66. Barth H, Melin M (2018) A green lean approach to global competition and climate change in the agricultural sector – a Swedish case study. J Clean Prod 204:183–192 (Elsevier BV)
67. de Oliveira Rezende M, Saade MRM, Nunes AO, da Silva VG, Moris VAS, Silva DAL (2022) A lean and green approach for the eco-efficiency assessment on construction sites: description and case study. Clean Technol Environ Policy 24(5):1535–1552 (SpringerScience and Business Media LLC)
68. Bortolini M, Calabrese F, Galizia FG, Mora C (2022) A three-objective optimisation model for mid-term sustainable supply chain network design. Comput Ind Eng 168:108131 (Elsevier BV)
69 Fahimnia B, Sarkis J, Eshragh A (2015) A tradeoff model for green supply chain planning: a leanness-versus-greenness analysis. Omega 54:173–190 (Elsevier BV)
70. Navarro P (2021) Applying quality concepts to achieve environmental sustainability in the freight transport sector – reviewing process management and lean. Int J Qual Serv Sci 13(4):545–562 (Emerald)
71. Zhu X, Zhang H (2020) Construction of lean-green coordinated development model from the perspective of personnel integration in manufacturing companies. Proc Inst Mech Eng, Part B: J Eng Manuf 234(11):1460–1470 (SAGE Publications)
72. Marco B, Galizia FG, Cristina M (2017) Current research trend in lean and green supply chain management. In Proceedings of the XXII Summer School" Francesco Turco", vol. 2017, pp 16–20
73. Bortolini M, Galizia FG, Mora C (2017) Efficiency and sustainability model to design and manage two-stage logistic networks. Procedia Manuf 11:2170–2177 (Elsevier BV)
74 Jeffers PI (2010) Embracing sustainability. Int J Oper Prod Manage 30(3):260–287 (Emerald)
75. Bortolini M, Galizia FG, Gamberi M, Mora C, Pilati F (2019) Enhancing stock efficiency and environmental sustainability goals in direct distribution logistic networks. Int J Adv Oper Manage 11(1/2):8 (Inderscience Publishers)
76. Francis A, Thomas A (2020) Exploring the relationship between lean construction and environmental sustainability: a review of existing literature to decipher broader dimensions. J Clean Prod 252:119913 (ElsevierBV)
77. Hazzouri M, Thoumy M (2020) Internal stakeholders' perspective on lean energy and environmental sustainability: the case of Notre Dame University - Louaize. World Rev Entrep, Manage Sustain Dev 16(5):492 (Inderscience Publishers)
78 Singh P (2019) Lean in healthcare organisation: an opportunity for environmental sustainability. Benchmark An Int J 26(1):205–220 (Emerald)
79 Martínez-Jurado PJ, Moyano-Fuentes J (2014) Lean management, supply chain management and sustainability: a literature review. J Clean Prod 85:134–150 (Elsevier BV)
80 Zhu Q, Johnson S, Sarkis J (2018) Lean six sigma and environmental sustainability: a hospital perspective. Supply Chain Forum: An Int J 19(1):25–41 (Informa UK Limited)
81. Brios X, Cruzado-Ramos F (2020) Model of evaluation of sustainability performance in building projects integrating lean, through the delphi method. Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC). Presented at the 28th Annual Conference of the International Group for Lean Construction (IGLC), International Group for Lean Construction. https://doi.org/10.24928/2020/0039
82. Nabhani F, Bala S, Evans G, Shokri A (2017) Review of implementing lean six sigma to reduce environmental wastes of internal supply chains in food industry. Adv Manuf Technol XXXI 6:327–332 (IOS Press)
83. Mekhum W (2020) Role of green supply chain management strategies in sustainability evidence from manufacturing industry of Thailand. Int J Supply Chain Manage 9:1
84. Bae JW, Kim YW (2008) Sustainable value on construction projects and lean construction. Journal of green building 3(1):156–167
85 Bae J-W, Kim Y-W (2008) Sustainable value on construction projects and lean construction. J Green Build 3(1):156–167 (College Publishing)
86. Marcilio GP, de Rangel JJA, de Souza CLM, Shimoda E, da Silva FF, Peixoto TA (2018) Analysis of greenhouse gas emissions in the road freight transportation using simulation. J Clean Prod 170:298–309 (Elsevier BV)
87 Shah R, Ward PT (2002) Lean manufacturing: context, practice bundles, and performance. J Oper Manage 21(2):129–149 (Wiley)
88 Garza-Reyes JA, Kumar V, Chaikittisilp S, Tan KH (2018) The effect of lean methods and tools on the environmental performance of manufacturing organisations. Int J Prod Econ 200:170–180 (Elsevier BV)
89 Cherrafi A, Elfezazi S, Garza-Reyes JA, Benhida K, Mokhlis A (2017) Barriers in green lean implementation: a combined systematic literature review and interpretive structural modelling approach. Prod Plan Control 28(10):829–842 (InformaUKLimited)
90. CheMamat R, MdDeros B, Ab Rahman MN, Khalil Omar M, Abdullah S (2015) Soft lean practices for successful lean production system implementation in Malaysia automotive SMES a proposed framework. J Teknol 77:27 (Penerbit UTM Press)
91. Costa F, Lispi L, Staudacher AP, Rossini M, Kundu K, Cifone FD (2019) How to foster sustainable continuous improvement: a cause-effect relations map of lean soft practices. Oper Res Perspect 6:100091 (Elsevier BV)
92. Rossini M, Costa F, Tortorella GL, Portioli-Staudacher A (2019) The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers. Int J Adv Manuf Technol 102(9–12):3963–3976 (Springer Science and Business Media LLC)

93. Ng R, Low JSC, Song B (2015) Integrating and implementing lean and green practices based on proposition of carbon-value efficiency metric. J Clean Prod 95:242–255 (ElsevierBV)
94 Torri M, Kundu K, Frecassetti S, Rossini M (2021) Implementation of lean in IT SME company: an Italian case. Int J Lean Six Sigma 12(5):944–972 (Emerald)