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Analyzing the alignment between the Green Lean and Circular strategies: Towards a Circular Lean approach

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Abstract:

Purpose: Green Lean tools are aligned with the Circular Economy strategy as they aim at reducing waste, however, they miss the creation of value through waste. Therefore, this paper investigates whether the current implementation of the Green Lean strategy promotes the introduction of the Circular philosophy to achieve sustainable management production processes. It analyses how the resources were managed by implementing the different strategies and tools presented in Green Lean case studies under the lens of Circular Economy, and highlights future research paths on the Circular Lean integration.

Design/methodology/approach: An analysis of the implementation of Green Lean case studies, selected through a Systematic Literature Review, from the manufacturing sector is conducted.

Findings: The majority of Green Lean implementations were aimed at minimizing waste, which is aligned with the narrowing strategy of Circular Economy and only a few cases studies aimed at closing the production cycles. Even though the main results indicate that being eco-efficient is a good starting point to move towards sustainability, from a Circular Economy point of view, this approach could remain limited. Therefore, the current contribution of Green Lean to the implementation of circular practices is limited. It can be concluded that introducing the circular philosophy in the Green Lean methodology can be achieved through redirecting Green Lean from waste reduction towards a value creation focus.

Originality: The originality of this paper is that it provides a critical review of the literature on the topic of Green Lean integration and Circular Economy.

Keywords: Green manufacturing; Lean manufacturing; Case studies; Sustainable production

Paper type: Conceptual paper

1. Introduction

One of the most influential operational management paradigms to improve operational performance is Lean Manufacturing (Kurdve and Bellgran, 2020). This business strategy is based on five principles: value, identification of value stream, flow, pull and perfection (Womack and Jones, 2003). These principles lead to the elimination of non-added value activities, known as waste. The lean philosophy identifies seven classic wastes ('mudas') that can be classified as either process wastes, which include over-processing, transportation, inventory and quality defects, or operational wastes that involve unnecessary motion, over-production, and waiting.

To eliminate those mudas, a set of tools and techniques are proposed in the Lean philosophy. The most common tools and techniques include Value Stream Mapping (VSM), 5S, one-piece flow, cellular manufacturing, Total Productive Maintenance (TPM), Single Minute Exchange of Die (SMED), Jidoka, and Total Quality Management (TQM) (Womack and Jones, 2003). By eliminating waste, organizations may increase resource utilization, improve quality and

productivity, and reduce cycle time and lead time. In other words, Lean thinking aims to deliver the most value with the fewest possible resources.

Nevertheless, over the past century, green manufacturing has been introduced to reduce the negative environmental impact caused by industrial activity while efficiently utilising natural resources (Garza-Reyes, 2015). Therefore, in order to improve both the economic and environmental performance of organizations, the Green Lean strategy has been proposed as a potential approach to achieve this (Siegel et al., 2019). The two practices (i.e. Green and Lean) complement each other, being their main focus the reduction and management of waste (Farias et al., 2019; Abualfaraa et al., 2020) and prevention of pollution (Bhattacharya et al., 2019). As extensively found in the literature, Lean thinking is green when it also considers the wastes produced by the flows of materials and energy that are required by production processes (Pampanelli et al., 2015).

The Green Lean strategy allows companies to operate more effectively and efficiently (Thanki and Thakkar, 2019). A large number of studies have proposed frameworks and models to integrate both Lean and Green strategies. In general, these frameworks are focused on improving environmental and economic performance through the implementation of a set of tools (Siegel et al., 2019). However, the implementation of these frameworks in real case studies shows a lack of environmental criteria considered while implementing the Lean tools (Viles et al., 2021).

The literature suggests that the Green and Lean integration could lead to positive results for a triple bottom line impact, especially on the economic and environmental domains (Teixeira et al., 2021). However, the strategies pursued by Green Lean have been generally built based on a linear economic and production model, i.e. take, make, use and dispose. In this context, it has been demonstrated that following this roadmap does not always constitute a sustainable way of producing (Greer et al., 2021). Thus, Circular Economy has been presented as a new direction to achieve sustainability (Bertassini et al., 2021). This economic paradigm aims to close energy and materials loops, facilitate sustainable development and prevent the depletion of resources through its implementation at the micro, meso and macro levels (Prieto-Sandoval et al., 2018).

Extensive literature discussing the Green Lean approach exists. Recently, its focus has moved towards studying the link between Green Lean and sustainability (Teixeira et al., 2021; Abualfaraa et al., 2020; Bhattacharya et al., 2019). In general, the investigation on Green Lean and Sustainability has centered on analysing the impact of Green Lean initiatives on the economic, environmental and social domains (Abualfaraa et al., 2020; Bhattacharya et al., 2019). In this context, the results broadly suggest that the contribution of Geen Lean to sustainability is not clear due to the lack of metrics to measure impact. Additionally, these studies have analysed the integration between both strategies, arguing that an integrative adoption of Green and Lean has a positive impact on sustainability performance, in comparison to an individual adoption of Lean or Green strategies in isolation (Bhattacharya et al., 2019). However, these studies did not consider the integration of Lean with other management strategies to achieve enhanced sustainability results.

Since Circular Economy constitutes a promising path to achieve sustainability, its combination with Lean may present a powerful strategy for companies to address the sustainability challenge. In this regard, some authors have indicated the lack of research on the integration between Lean and Circular Economy (Lim et al., 2022; Kurdve and Bellgran, 2020). Some limited attempts can be found in the literature to fill this gap (Lim et al., 2022; Schmitt et al., 2021; Sartal et al., 2020). However, clear knowledge and understanding of the potential compatibility, benefits and challenges of integrating Green Lean and Circular Economy are still very limited.

Consequently, this paper addresses this gap in the academic literature by investigating whether the current implementation of the Green Lean strategy promotes the introduction of the circular philosophy for the management of production processes. The importance of the analysis is that in terms of practical applications, the combination of both approaches would constitute a powerful approach for increasing industrial systems' resource and environmental performance (Kurdve and Bellgran, 2020) and therefore, move towards sustainability (Lim et al., 2022).

Thus, this study aims to investigate the integration of Green Lean and Circular Economy through the analysis of case studies, identified through a Systematic Literature Review, in the manufacturing sector. The literature review conducted in this paper a) focusses on case studies that have implemented the Lean and Green strategies simultaneously, b) analyses the main strategies and tools implemented in the Green Lean case studies under the lens of Circular Economy, and c) highlights future research paths on the Circular Lean integration.

The rest of the paper is as follows: The following section provides a theoretical background of Green Lean in the manufacturing sector, whereas Section 3 describes the methodology followed to identify Green Lean case studies. Section 4 presents the results and discussion of the case studies as well as proposes a Circular Lean approach. Section 5 presents the theoretical and practical implications of the study. Finally, the last section of the article identifies detailed research gaps and directions for future research. Concluding remarks are also presented in the last section.

2. Theoretical background

2.1 Green Lean strategy

The manufacturing industry is considered the main contributor to environmental damage (Cai et al., 2019) due to the high concentration of CO2 emissions from its processes, the scarcity of energy and natural resources generated, the release of toxic substances and the waste generated during its processes (Thanki et al., 2016). Hence, manufacturing organizations are persistently seeking for solutions to enhance their operational performance while reducing the environmental impact of their processes (Leong et al., 2019).

Various authors have pointed out the emergence of the Green Lean approach as an answer to these problems (Kazancoglu et al., 2020; Cherrafi et al., 2016). The synergy between the Lean and Green strategies is defined by Campos and Vazquez-Brust (2016) as 'the additional effects produced by the implementation of Lean practices and Green practices together' that an individual practice alone cannot bring. Lean organizations are often greener but not necessarily vice-versa since for some authors the green approach is a natural extension of the lean philosophy (Bhattacharya et al.,

2019). However, many challenges of Lean towards Green have been identified in the literature. The most mentioned challenges in the manufacturing sector refer to resistance to change, lack of training to employees and lack of top management commitment (Singh et al., 2020; Tiwari et al., 2020). These are crucial barriers that hinder the Green Lean implementation and that are related to human perceptions towards sustainable manufacturing (Tanco et al., 2021; Cherrafi et al., 2017a). This emphasizes the importance of education and training in disseminating knowledge inside organisations (Tanco et al., 2021).

A literature review conducted by Bhattacharya et al. (2019) on the integration of Lean and Green highlighted that both concepts are based on waste reduction from a direct focus (e.g. pollution prevention projects, higher employee productivity) and an indirect focus (e.g. higher quality, lower scraps). The different interpretations of what waste constitutes are the main conflicting point between Lean and Green practices (Abualfaraa et al., 2020). In a lean context, waste is any activity that does not add value for the customer, and hence should be eliminated. Green strategies consider environmental waste as the result of the inefficient use of resources (Dües et al., 2013). In particular, environmental wastes are related to the flow of mass and energy of production systems (EPA, 2003). Therefore, the main goals of Green Lean tools are to identify and eliminate waste as well as optimize resource utilization (Siegel et al., 2019).

Although Green Lean strategies can be implemented either sequentially or concurrently, scholars have emphasized that an integrated approach is needed for the simultaneous implementation of Green Lean strategies (Viles et al., 2021; Hallam and Contreras, 2016). In this regard, researchers have proposed different models and frameworks to implement Green Lean as an integrated approach (Cherrafi et al., 2017; Alves and Alves, 2015). These models generally follow the Deming's continuous learning and improvement model PDCA (plan-do-check-act). However, companies have found it difficult to integrate and implement both practices simultaneously (Ng et al., 2015).

2.2 Green Lean and Circular Economy

Limited studies are found on how Circular Economy relates to Green Lean (Lim et al., 2022; Kurdve and Bellgran, 2020). In this line, a handful of papers have tried to cover this gap by studying their relationship. For example, Schmitt et al. (2021) identified four characteristics in Lean that can be identified from a circular perspective at a process level. Those potentials include, namely: *waste as resource model*; *identify, evaluate, and quantify material waste and environmental impact*; *educate about circular methods and waste management*; and *digitization of processes and physical tests.*

Moreover, Sartal et al. (2020) conducted a case study in which a reduction in water usage was obtained by improving the water circularity index, after implementing lean tools. This presents some evidence in the literature of the positive results achieved by implementing both strategies.

More recently, Lim et al. (2022) proposed a method that combines both Green Lean with Circular Economy solutions based on the idea that both approaches are complementary. However, there is still a lack of studies integrating Lean and Circular Economy (Kurdve and Bellgran, 2020).

As established in the aforementioned discussion, lean constitutes one of the most influential manufacturing strategies to achieve operational excellence. By also considering green waste, i.e. flow of material and energy, the Lean philosophy has resulted in the development of the Green Lean strategy to reduce the negative environmental impact caused by companies' activities. Although the Green Lean approach is extensively discussed in the literature, the Green Lean integration with sustainability performance is still inconclusive, without a clear insight into how Green Lean contributes to sustainability (Bhattacharya et al., 2019). In this line, most empirical studies have focused on the relationship between Lean and Green practices with organizational and environmental performance, but the role and criticality of sustainability are not significantly represented in the sustainable manufacturing literature (Teixeira et al., 2021; Bhatt et al., 2020).

Circular Economy constitutes a promising path to achieve sustainability. The main principles of Circular Economy, according to the Ellen MacArthur Foundation (2021), are the elimination of waste and pollution, regeneration of nature, and the circularity of products and materials. From these principles, a set of strategies are identified in the literature, namely: narrow, slow, close, and regenerate (Velasco-Muñoz et al., 2021). The narrowing strategy includes eco-efficient solutions that aim to decrease the consumption of resources and the environmental impacts per unit of product or service during the design, production, use and end of life phases (Velasco-Muñoz et al., 2021). Regarding the slowing strategy, it involves using products and components longer (Konietzko et al., 2020). Closing resource loops is achieved by connecting the waste management stage with the resource acquisition stage (Suárez-Eiroa et al., 2019). Finally, the regeneration strategy aims to preserve and enhance natural capital (EMF, 2019).

Combining these strategies with Lean tools can result in a powerful approach for companies to achieve sustainability (Lim et al., 2022; Schmitt et al., 2021). It is beneficial for companies to integrate the circular with traditional strategies used for the management of production processes (Kurdve and Bellgran, 2020). Additionally, for SMEs adopting Green Lean thinking facilitates the implementation of Circular Economy at the level of firms (Caldera et al., 2019). However, the degree to which Lean can enhance Circular Economy practices has not been widely discussed in the literature.

Considering the potential synergies and benefits of combining Lean and Circular Economy as well as the existent gap in the academic literature regarding the simultaneous study of these two strategies, this paper addresses the following research question:

RQ. To what extent does the Green Lean approach facilitate the implementation of Circular Economy strategies for managing production processes?

3. Methodology

The implementation of Green Lean strategies in manufacturing companies is the focus of this review. Therefore, case studies were selected since they are appropriate to test frameworks and examine the 'how' and 'why' of research questions (Yin, 2009), enabling deeper analyses. In order to identify all the potential case studies, a Systematic Literature Review (SRL) was conducted.

A SLR is a method that has gained popularity among researchers in a variety of areas since it provides a reliable approach to get a comprehensive overview of a specific research topic (Farias et al., 2019). In that sense, its main aim is to identify all empirical evidence to answer a certain research question or hypothesis (Snyder, 2019). To organize the relevant information, the SRL should involve several stages (Tranfield et al., 2003), these are illustrated in Figure 1.

After conducting the SLR, a critical analysis was performed to address the RQ proposed. A critical review aims to evaluate, criticize and synthesize the literature on a research subject in such a way that new theoretical constructs and perspectives are developed.

Insert Figure 1.

As Figure 1 indicates, the first stage consisted in establishing the scope of the research by formulating the research question addressed, see Section 2.2. To select and screen the relevant peer-reviewed journal articles in the following stage, the ISI Web of Knowledge (WoS) and Scopus databases were employed.

In regards to the research period, since it was found that the first seminal paper about Green Lean was published by Florida (1996), it was considered between 1996 to 2022. The keywords 'lean-green', lean AND (environmental or sustainability or eco-efficiency) along in combination with 'case study' OR 'implementation' were used. Additionally, a search combining the keywords 'lean-green' AND 'circular economy' was performed. However, only a few studies were found to address both initiatives. This result was in line with Sartal et al. (2020) and Kurdve and Bellgran (2020), who have indicated the very limited simultaneous research on Lean and Circular Economy.

Figure 2 presents the total number of articles found in each database. From the research formulated, see keywords in Figure 1, 675 (WoS) and 760 (Scopus) papers were identified. The original sample of 1,435 was reduced to 796 by removing duplicates during the screening process. A review of the title, abstract, and keywords of each potential article was performed to determine the applicability to the research topic. From this, 138 articles were considered relevant. As the last filtering parameter, the content of the articles was analysed. After this step, the final sample consisted of 47 articles that fell into the category of a case study.

Insert Figure 2.

From the initial sample of 47 case studies, those that implemented only lean tools were excluded from the study. Considering that criteria, 20 case studies claimed to have adopted simultaneously Green and Lean practices. This meant that the implementation of one set of practices was constrained and adjusted by the adoption of the other set of practices, creating reciprocal interdependencies (Galeazzo et al., 2014). Additionally, two case studies linked the Lean approach with Circular Economy (Sartal et al., 2020; Lim et al., 2022). Therefore, the final sample consisted of 22 case studies, see table A1 in Appendix 1.

The 22 case studies were analyzed by looking at the year of publication and journal as presented in Figures 3 and 4. From figure 3, it can be concluded that since this topic is relatively new, most of the articles were published in recent years, but particularly in 2019 (Bhattacharya et al., 2019). The Journal of Cleaner Production has always been a leading publisher in the field of Green Lean,

with seven articles published, followed by five articles published in Production Planning and Control, as depicted in Figure 4. It is also evident that authors used a wide range of journals to publish their articles on Green Lean case studies.

Insert Figure 3.

Insert Figure 4.

Additionally, from the case studies the different practices and tools and the performance measures found were extracted and synthesized, see Table I. These practices have been extracted from and adapted Bhattacharya et. (2019) and Farias et al. (2019). The numbers between brackets in Table I refer to each of the case studies.

The Green Lean practices and tools are presented in the rows of Table I. For example, in the case study (6), it can be concluded that the implementation of a green VSM was presented along in combination with the 3-R practices, life cycle assessment, 5S and kaizen events. On the other hand, the columns in the table represent the different performance measures. Referring to the case study presented in (6), consumption of raw materials, energy and water were measured in the environmental area.

Therefore, from Table I, it can be concluded that environmental VSM was one of the most employed tools and that the strategies were focused on the 3-R framework. Generally, it can also be inferred that in most of the case studies, cost constituted one of the main areas of interest when evaluating economic performance. In the environmental area, the consumption of raw materials, water and energy was measured in most of the case studies. Finally, in the social domain, occupational health and safety were of major interest.

These results indicate an alignment between Green Lean and Circular Economy strategies since the 3R framework is widely mentioned when addressing Circular Economy (De Pascale et al., 2020). However, the deployment of this approach remains limited in Green Lean since other frameworks presented in Circular Economy such as 6R activities include recover, remanufacture and redesign, remain unexplored in Green Lean case studies. The following section deepens on this discussion.

Insert Table I.

4. Results and Discussion

This section aims to address the research question *To what extent does the Green Lean approach facilitate the implementation of Circular Economy strategies for managing production processes?* by analyzing how Green Lean strategies have been implemented in the manufacturing sector.

4.1 Green Lean alignment with Circular Economy

The majority of the case studies analyzed had implemented Green Lean strategies. These results are consistent with Romero and Rossi (2017) and Kurdve and Bellgran (2020), who pointed to the scarcity of studies that focus on the relationship between Lean and Circular Economy strategies.

Table II shows that, in general, Green Lean case studies take a reductionist approach, which is aligned with the narrowing strategy of Circular Economy. This is because most Green Lean case studies have focused on minimizing waste (see Table II) while only a few case studies aimed to close the production cycle by reusing the water or raw material in other processes. Waste reduction is considered one of the major benefits of adopting Green Lean strategies (Shokri and Li, 2020) as it leads companies towards cost reductions. Local reduction of the waste resource constitutes one of the main strategies pursued by companies over the past 100 years (Viles et al., 2020). This result is consistent with Schmitt et al. (2021), who concluded that as companies seek to reduce costs, all the operational focus goes on to the 'reduce' dimension of the (6R) framework, leaving the 'reuse', 'recycle', 'recover', 'remanufacture' and 'redesign' strategies unexplored.

It can also be inferred that Green Lean strategies are implemented under the umbrella of eco-efficiency strategies. Tables I and II show how most strategies were geared towards improving efficiency by reducing consumption without altering the linear flow.

These results confirm the existence of an alignment between Green Lean and Circular strategies. However, local reductions, which are encouraged in the Green Lean approach, prevented companies from obtaining greater results that a more holistic approach would produce. The Green Lean strategy fails to enable eco-effectiveness since it does not take a closed-loop perspective (Schmitt et al., 2021).

Insert Table II.

4.1.1 *How Green Lean strategies were implemented to manage production processes*

On the one hand, the analysis of the case studies showed that most companies implemented Lean tools and subsequently assessed their environmental impact. According to Galeazzo et al. (2014), the simultaneous implementation of Green Lean practices leads to one set of practices being constrained and adjusted by the adoption of the other set of practices, causing reciprocal interdependencies. Our analysis showed that the implementation of Green Lean practices does not fit the aforementioned definition by Galeazzo et al. (2014). In general, the environmental improvements achieved were the result of the positive effect of Lean practices on the environmental performance without taking on board that the impact could have been greater if both strategies had been implemented simultaneously, as some authors have suggested (Teixeira et al., 2021). Therefore, these companies may be missing opportunities for improvement.

On the other hand, as the Lean philosophy is based on the core idea that non-value-added processes consume resources that are valuable from an environmental point of view (Tiwari et al., 2020; Choudhary et al., 2019a), an analysis and discussion of how the green waste – energy, water, material, garbage, transportation and emission – defined by Garza-Reyes et al. (2018) were managed in the 22 case studies is included below.

Energy and Emissions:

Regarding energy management, Lean tools such as SMED were implemented in combination with VSM (Ebrahimi et al., 2021) to reduce set-up times and consequently reduce energy consumption. However, the case study presented by Choudhary et al. (2019b) noted that while an increase in production was obtained as a benefit of implementing Lean strategies, it also led to an increase in energy consumption, which is one of the major potential misalignments between the Lean and Green strategies.

Furthermore, when implementing the SMED tool, the cases failed to adjust it to gather environmental information; a finding which was repeated in several other case studies (Leme et al., 2018; Ebrahimi et al., 2021). Leme et al. (2018), for example, implemented lean tools without considering any environmental criteria during the decision-making process. Thus, by implementing the SMED tool (Leme et al., 2018), machine set-up time was reduced. Once this is achieved, companies are expected to have more time available to convert into value-adding time and, thus, increase production, which in turn, raises carbon emissions. A Green Lean strategy should evaluate both criteria (in this case, the reduction in set-up time *and* the increase in carbon emissions caused by the increase in production facilitated by the shortened set-up time). However, the SMED tool (Leme et al., 2018) only focuses on operational criteria (activities related to the set-up time). Consequently, it does not offer companies optimum solutions in terms of operational and environmental performance.

In the case study presented by Tiwari et al. (2020), which also used the SMED tool, the team in charge recommended installing 'clichés on the liner', which reduced both electricity consumption and the machine set-up time. However, the improvements in environmental performance were presented as a result of the positive impact of implementing lean tools, which can be seen by analyzing the following statements: "*The results show that the proposed framework significantly decreases the machine set-up times and the defect rate in the production line, which leads to the minimization of CO2"* (Tiwari et al., 2020) "*After improvement, the wastes generated from the production line, such as inventory, transportation, and defects, were reduced, and the unnecessary carbon emissions caused by these wastes were eliminated"*(Zhu et al. 2020). By analyzing these statements, it can be concluded that the aim of the strategy was achieved and the environmental impact assessment was only included to show that the expected reduction of the negative environmental impact came solely from implementing the Lean strategy.

In general, the Green Lean case studies mentioned above present the reduction of energy consumption as a benefit of implementing a lean tool without taking into consideration the possible increase in energy consumption that can occur when the non-value-adding time is turned into value-adding time and production is increased.

Furthermore, the concept of redesigning production processes to adopt sustainable and renewable sources of energy was unexplored in the cases studies (Ebrahimi et al., 2021).

Water:

Regarding water management in the production process, Table II suggests that some implementations are aligned with the 3R approach. Under this framework, some case studies (Gholami et al., 2021; Fu et al., 2017) showed how used water was recycled or reused. In order to do so, in the case studies presented by Ben Ruben et al. (2017) and Vinodh et al. (2016), a closed-loop recirculating water system was built into the washing machine, which allowed the water used in the manufacturing process to be reused for longer cycles. These case studies took place in India, where the implementation of reusing and recycling strategies is of great importance as India is considered one of the world's most water-stressed countries (World Bank, 2019).

However, these strategies were unsuitable for some processes because the amount of used water, already minimized to enhance process efficiency, was insufficient. Therefore, the strategies and indicators should take into account that by increasing water consumption throughout the entire process, companies could then recycle it and reduce its overall consumption (the valuable resource) (Viles et al., 2020). This action would lead to better global efficiency in the use of this valuable resource and would mean, for example, that a process that is operationally speaking less efficient under the traditional paradigm (Green Lean) could become more efficient if a more holistic approach was taken (Circular Economy). This would constitute a disruptive and innovative approach in production process management. However, such analysis is under-represented in the case study literature. Only the most recent studies on Green Lean and Circular Economy strategies are more aligned with this type of analysis.

In a similar vein, the case study presented by Sartal et al. (2020) showed that water usage was reduced by about 45% when water circularity was improved, and by implementing the 5S technique at the same time, labour productivity increased by 20%. This case study is consistent with Green Lean studies which aimed to reduce local process water by recycling or reusing it. More recently, the case study presented by Lim et al. (2022) also considered reusing water by installing pipes and using it for watering plants, washing cars and flushing toilets, etc, which led to better global results.

Material waste:

It is common that in an effort to reduce negative environmental impacts, companies focus on minimizing material waste (Fu et al., 2017). However, by introducing the principles of the Circular Economy, this waste can be considered a resource, and therefore, an increase in the amount of 'waste' generated – now a resource – can be beneficial for the company if it can be cascaded either internally or externally into other cycles. Such courses of action can only be considered if companies adopt a holistic view of managing resources. However, the frameworks under which companies are implementing continuous improvement strategies do not encourage them to make such decisions.

More recently, in the case study presented by Lim et al. (2022), which attempted to implement both Green Lean and Circular Economy principles, the company considered selling defective parts (irreducible waste) for subsequent reuse or recycling. In this example, the introduction of Circular Economy strategies complemented the implementation of Lean tools by maximizing the utilization of resources.

From the Green Lean case studies, it can be inferred that organizations focus on reducing the ratio of waste produced per product obtained. However, improvements in this indicator do not always translate directly into a more sustainable approach to production.

Raw materials:

When it comes to selecting raw materials for the production process, some of the case studies maintained that negative environmental impacts can be reduced by using alternative materials (Lim et al., 2022; Ben Ruben et al., 2017), for example, less toxic ones (Galeazzo et al., 2014) or non-degradable plastic packaging (Lim et al., 2022).

Aligned with the idea of extracting value from resources, some case studies, such as the one presented by Choudhary et al. (2019b), incorporated recycled materials, e.g. recycled polymers, which reduced their carbon footprint and subsequently decreased the green waste embedded in the raw material. Similarly, other Green Lean case studies made efforts to incorporate the 6R approach with Lean tools with the aim of converting traditional manufacturing into sustainable manufacturing. Elsewhere, Maqbool et al. (2019) showed that reusable items can be recovered from defective products while unusable (non-recoverable defective components, scrap) material can be recycled, aligning with Circular Economy strategies. This showed that upgrading the 3R framework to a 6R framework created better opportunities for improvement. Joint actions with suppliers were also cited in further case studies. In one case, for example, (Lim et al., 2022; Fu et al., 2017), the suppliers returned the plastic boxes used for the delivery to the manufacturing facilities in order to complete a usage cycle.

These types of actions are more aligned with Circular Economy strategies in the sense that they are aimed at closing production cycles and retrieving more value from resources.

4.1.2 How improvements were assessed

In general, the proposed improvement actions were aimed at reducing negative environmental impacts by minimizing the consumption of resources (Ben Ruben et al., 2017). Therefore, the case studies focused on analyzing the progress of different indicators after Lean tools had been implemented**.** Additionally, it can be concluded that some case studies evaluated the operational, environmental, and social domains separately by considering different indicators for each category. Although some authors defined a set of sustainability indicators (Ebrahimi et al., 2021; Tiwari et al., 2020), they failed to provide integrative results. A further group of case studies implemented combined indicators, in which both operational and environmental parameters were considered (Domingo and Aguado, 2015; Leme et al., 2018; Zhu et al., 2020).

Regarding the financial assessment, Table I shows how cost reduction was the main concern. Regarding how the environmental impact after Lean implementation was evaluated, most of the

case studies referred to the carbon footprint, as shown in Table I. Some case studies combined the carbon footprint with operational parameters such as value-adding time (Zhu et al., 2020; Choudhary et al., 2019; Ng et al., 2015). However, they failed to provide overall results because the indicators were defined to only measure local resource reductions by combining operational and environmental parameters. Additionally, when the improvements involved other companies, the corresponding data was not so easy to obtain (Lim et al., 2022).

As mentioned earlier, some authors also incorporated a set of indicators to evaluate social performance (Ebrahimi et al., 2021; Tiwari et al., 2020). For instance, 'operator waste time' during set-up time, 'skilled operator' and 'teamwork', which measure satisfaction levels and are related to human resources, respectively. Other indicators concerned safety incidents and absenteeism, both of which showed an improvement after Green Lean implementation.

In most of the case studies, the improvements in environmental performance derived directly from the positive impact of eliminating operational waste. The idea of assessing economic and environmental impacts should be directed towards identifying new opportunities for improvement and not only as a means of confirming an expected positive outcome derived from Lean implementation. This analysis should be supported by the use of technology. However, the analysis showed that not many of the Green Lean case studies used technology to measure and optimize sustainable processes. In general, the case studies analyzed did not report making any significant technological changes in order to implement Green Lean tools. In Choudhary et al. (2019b), ERP was used by the company to automate the raw material procurement process. More recently, Lim et al. (2022) mentioned the need to avail real-time data when integrating energy management and production systems. Various researchers have pointed out the importance of implementing Industry 4.0 technologies to improve circularity (Laskurain-Iturbe et al., 2021; Mattos Nascimento et al., 2019) since they facilitate system management and control by taking a holistic approach to managing the entire production operation (Viles et al., 2020).

4.2 Redirecting the focus from Green Lean to Circular Lean

These case studies show the natural progression from lean thinking into Green Lean thinking. This is based on the idea that processes that do not add value consume resources that are valuable for the environment (Choudhary et al., 2019b). Therefore, by eliminating these activities, the environmental impact will be reduced. However, as McDonough and Braungart (2013) pointed out, *why not redesign industrial activities to enhance the environment instead of protecting it from human impact?* This idea was not reflected in the case studies that analyzed the management of resources under a Green Lean approach.

Having analyzed the 22 case studies in this research, Lean and Green tools were seen to have been implemented to address traditional operational and environmental problems such as reducing cycle time and the consumption of water, energy and raw material. From the results presented earlier, it can be inferred that the value creation focus of the Lean strategies transitioned into a waste reduction focus in Green Lean management.

Additionally, it can be inferred that although there is an alignment between Green Lean and Circular strategies as presented in Section 4.1, the development of Lean into the Green Lean

thinking does not encourage the implementation of Circular Economy strategies since the systemic view – even on-site – becomes lost in the implementation process. This result is consistent with the findings of Schmitt et al. (2021) who concluded that Green Lean research has focused mainly on internal corporate operations while the Circular Economy extends beyond organizational boundaries.

The combination of Lean and circularity, on the other hand, could well yield considerable benefits (Schmitt et al., 2021). In other words, by incorporating the concept of circularity into the traditional Lean philosophy of continuous improvement – which could be called Circular Lean, companies commit to a powerful approach that will change how they run their operations and business. The traditional Green Lean strategies and tools need to be redirected towards value-creating proposals in order to incorporate the principles of the Circular Economy. Since the first step for introducing a genuinely sustainable model of production is to consider the three dimensions of the triple bottom line (Hussain et al., 2018), this redirection implies that the environmental and social aspects should not be dealt with as separate and isolated from the financial considerations, but rather as an integral part of the decision-making process.

The main purpose of a Circular Lean approach should be to maximize the flow of value in the use of resources, which means including the stakeholders who are interested in these resources in the decision-making process. This perspective differs from the traditional value definition of Lean, where value is defined by the client and wastes need to be reduced, since it also includes the management of natural resources in such a way that it enables companies to create value across the triple bottom line, therefore allowing it to move towards new value-creating proposals.

The transition to a Circular Economy constitutes a significant strategic change in strategy. This would entail shifting from 'necessity', which means efficient management of resources and waste, to 'opportunity', which involves designing products to transform what is currently waste into a valuable resource for a new production cycle (Muscio and Sisto, 2020).

5. Theoretical and managerial implications

There is scant evidence of Circular Economy notions in the extant literature on Green Lean manufacturing. Although the combination of both ideas has the potential to achieve sustainable manufacturing development, there is a research gap in terms of how to combine them in production operations. This study contributes by laying the foundations for combining Lean and Circular approaches. To the best of our knowledge, no previous research has involved the analysis of Green Lean case studies with the principles of the Circular Economy.

The results of the literature review in this study indicate that although there is an alignment between Green Lean and Circular strategies, the development of Lean into Green Lean thinking does not promote the implementation of Circular Economy strategies since the systemic view becomes lost in the implementation process. These results open the door to integrating both Circular and Lean practices and provide the starting point for academics and researchers by disseminating the way we need to think with a view to combining both approaches.

In terms of the study's practical implications, this study reveals the need to rethink the production process if companies want to simultaneously improve operational and environmental performance and lead to social benefits by adopting Circular Economy principles. The latest studies on the combination of both practices (i.e. Green Lean and Circular Economy) show that more innovative approaches to managing resources lead to better results. Additionally, this analysis also highlights the need to implement Industry 4.0 technologies in order to improve the management of production processes and help industrial managers to optimize operations taking Green Lean and Circular considerations into account.

Therefore, our findings provide inspiration and encouragement for industry professionals who are trying to achieve a new sustainability-oriented mindset in their firms. Furthermore, the case studies which combined Green Lean and Circular Economy strategies will serve as a starting point for managers who want to transition towards more sustainable methods of production.

6. Concluding remarks & future research directions

This study aimed to investigate to what extent traditional Green Lean management strategies facilitate the implementation of Circular Economy strategies. The study also explores the potential integration of both Lean and Circular Economy strategies as a new approach to achieving greater sustainability in organizations, especially those in the manufacturing sector.

From the analysis, it can be concluded that Lean and Green tools have been implemented to address traditional operational and environmental issues, namely reducing cycle times and water, energy and raw material consumption. Most of the case studies analyzed improvements in environmental performance that derived directly from the implementation of a Lean strategy.

While the main results indicate that being eco-efficient is a good starting point when moving towards sustainability, from a Circular Economy point of view, this approach is still limited. Therefore, in response to the posed research question, the current contribution of the Green Lean approach to the implementation of circular practices is limited. As this study suggests, until now, the Green Lean approach has been mainly developed as an extension of the traditional Lean philosophy, which is based on a linear mode of production focused on waste-reduction activities. As a result, the value creation focus of Lean thinking has been redirected towards the waste reduction aim of Green Lean thinking.

A combination of both Lean and Circular strategies would constitute a powerful tool for companies. In order to implement both strategies together and achieve true sustainability improvements, the traditional practices and tools of the Green Lean philosophy should be redirected towards developing actions that create value, one of the core principles of Lean thinking. Additionally, the traditional concept of value should be reoriented towards eco-effectiveness, optimizing the positive environmental impact while obtaining financial and societal benefits. Therefore, we propose that in order to achieve triple bottom line value creation, decisions should be focused on the management of resources from the beginning to the end of their lifecycle.

Future research should focus on how to reformulate Lean tools and indicators to incorporate circular strategies. Additionally, it would be of great practical use to study the different Green

Lean and Circular Economy performance measures and tools/practices in greater depth. As mentioned in the previous section, one of the most widely implemented Lean tools is VSM, to which a green VSM version has been added to incorporate green waste such as materials and energy. However, the design of this tool is based on a linear mode of production. Some authors have pointed out that for the operationalization of the Circular Economy, VSM should be redesigned to consider the value of the product and resources over the entire life cycle in order to develop a circular value stream (Hedlund et al., 2020) to help companies identify new value creation activities.

Most of the case studies analyzed used traditional operational and environmental indicators to assess performance. Additionally, since different authors have used different criteria to measure financial and environmental performance, it is difficult to evaluate the integrative impact of Lean and Green on all three dimensions (Bhattacharya et al., 2019). Therefore, future research should also focus on the redefinition of these indicators in order to assess the global performance of a company's processes. Furthermore, the use of mathematical models or simulations where different scenarios could be tested by analyzing the triple bottom line impact would be helpful in the decision-making process. These types of analyses will require further development in the literature. Table III summarizes the main future research areas derived from the present study.

Insert Table III.

The present research is not exempt from limitations. It focuses on the manufacturing sector; therefore, future work should also include analyses of other sectors. Additionally, some limitations arise from the use of search engines and the type of content available in WoS and Scopus databases, the search string, as well as the inclusion and quality of the criteria used.

Appendix 1

Insert Table IV.

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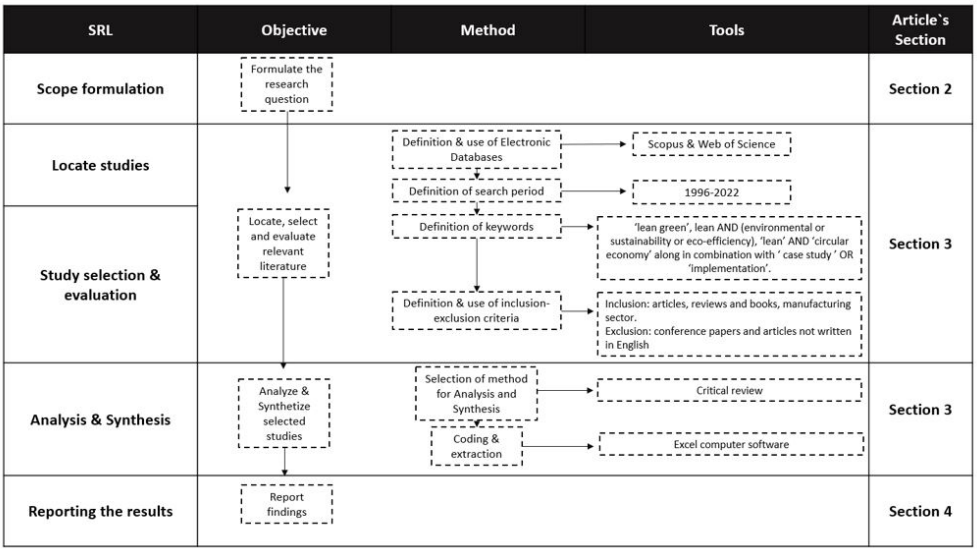

Figure 1. Summary of the stages of systematic literature review adapted from Garza-Reyes (2015).

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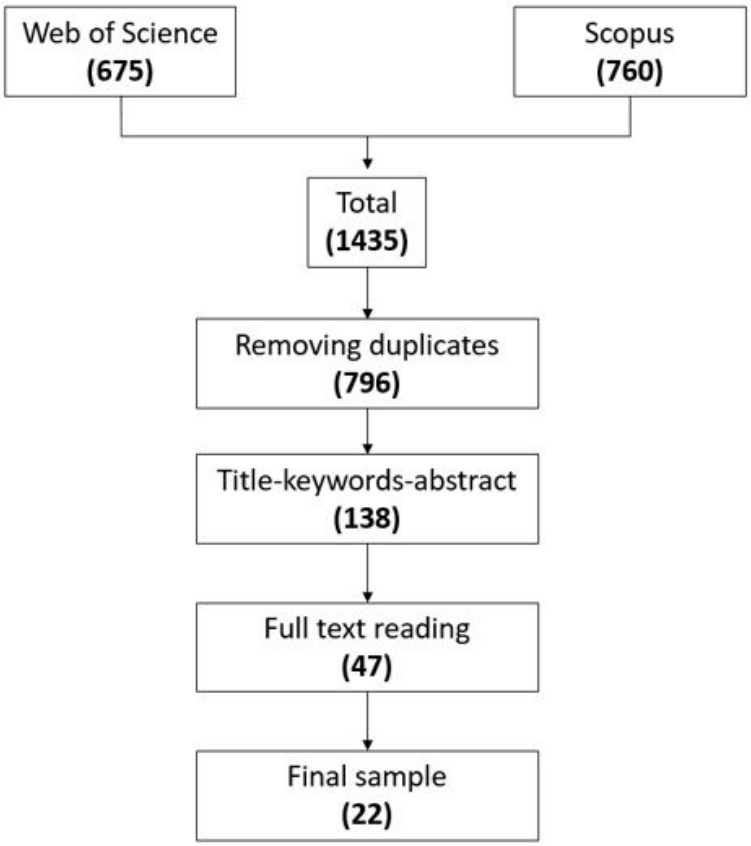

Figure 2. Systematic literature review stages

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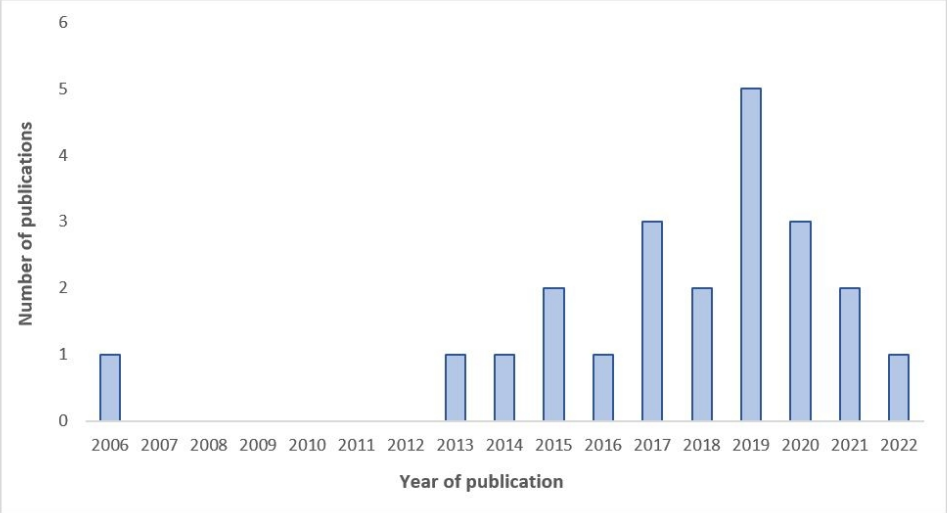

Figure 3. Number of articles published 2006-2022

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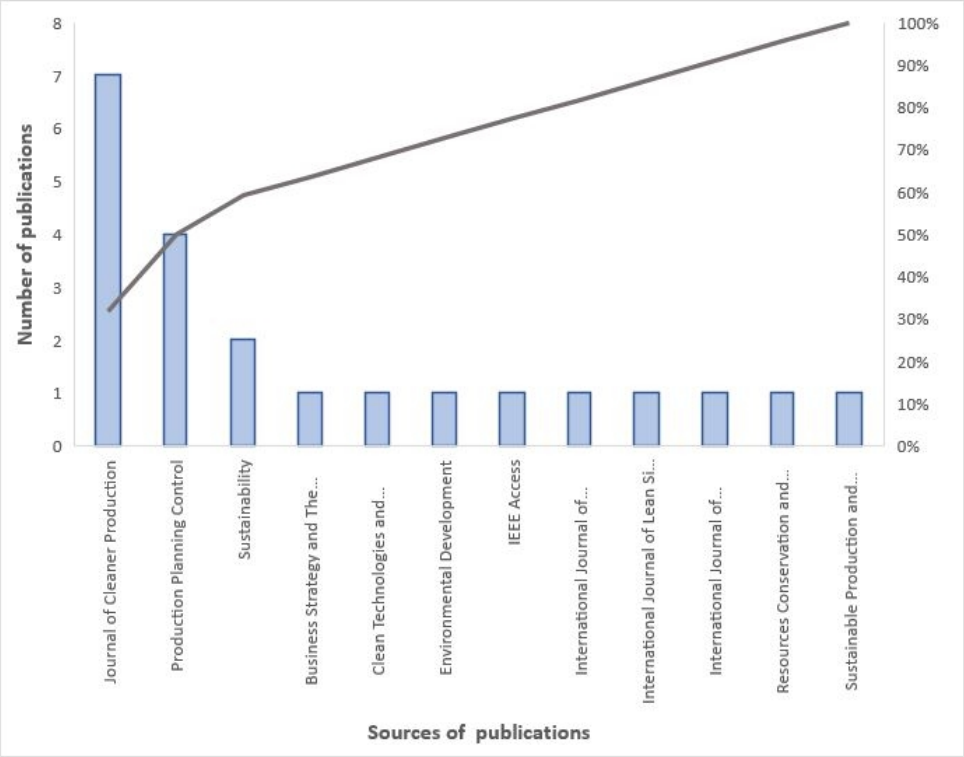

Figure 4. Number of publications by journal

189x148mm (96 x 96 DPI)

Table I. Summary of practices, and performance measures of lean-green case studies

		Performance									
		Economic				Environmental			Social		No performance measure
	Practices and Tools	Costs	Time (lead time, cycle time, value-added time, set up time, process time, speed of delivery, flexibility)	Quality	Inventory levels	Consumption of raw materials, energy and water	Air emissions	Carbon footprint	Employee satisfaction level	Occupational health & safety	
LEAN	VSM - Value Stream Mapping	(7) (8) (16) (21)	(8) (20)	(8)	(20)	(21)				(18)	
	5S - sort, set in order, shine, standardize and sustain	(1)(7) (8) (15)	(18) (14)			(1) (6) (7) (21)	(7)			(7)	
	CM - Cellular manufacturing	(1) (7) (15)	(4)								
	TPM - Total Productive Maintenance	(7) (15)	(17)							(17)	
	SMED - Single Minute Exchange of Die (SMED)	(9) (15) (17)	(4) (9) (10) (18)			(9)		(10)	(21)		
	TQM - Total Quality Management	(1)									
	Gemba walks	(13a-b)							(14)		
	Kaizen events					(1) (6)					

	Poka-Yoke	(13b) (16)	(18)			(16)		(16)			
	JIT - Just in time	(1)(7)									
	SW - Standardize Work	(7)									
GREEN	Change in raw materials	(2) (5) (8)	(2)					(2)			(3)
	LCA - Life Cycle Assessment	(5)	(9)			(6)					
	3R- Reducing, Reusing and Recycling	(1) (9) (17) (22)	(8) (11) (16)	(22)		(6) (11) (16) (22)	(11)	(16)			
	DFE - Design For Environment	(9)									
LEAN-GREEN	Environmental VSM	(9) (7) (8)	(4) (11) (12)			(19) (6) (14)		(12) (15)			
	7S (5S + safety + sustainability)	(9)									

Table II. Summary of Green Lean practices and Circular Economy strategies.

Practices and tools		Main Circular Economy strategies			
		NARROW	CLOSE	SLOW	REGENERATE
LEAN	VSM - Value Stream Mapping	(7) (8) (16) (21)			
	5S - sort, set in order, shine, standardize and sustain	(6) (7) (8) (14) (20)	(20)		
	One-piece flow				
	CM - Cellular manufacturing				
	TPM - Total Productive Maintenance	(7) (17)			
	SMED - Single Minute Exchange of Die (SMED)	(4) (9) (10) (17) (21) (18)			
	TQM - Total Quality Management				
	Gemba walks	(13) (14)			
	Kaizen events		(22)		
	Poka-Yoke	(13) (16)			
	JIT - Just in time	(7)			
	SW - Standardize Work				
GREEN	Change in raw materials	(2) (3) (5)			
	LCA - Life Cycle Assessment				
	3R- Reducing, Reusing and Recycling	(1) (4) (8) (16) (17) (22)	(1) (6) (17)		
	DFE - Design For Environment	(9)			
LEAN-GREEN	Environmental VSM	(6) (7) (9) (11) (12) (14) (15) (19)			
	7S (5S + safety + sustainability)	(9)			

Table III. Summary of future research areas

Current focus of implementations	Future research
Waste reduction	Value creation proposals
Extension of traditional lean tools: green (environmental), sustainable VSM	Redefine existing tools
Traditional indicators: CO2, OEE,…	Propose integrative indicators

Table A1. Green Lean as an integrated approach in case studies

Source	Manufacturing sector	Country of implementation	Authors' Objective		
			Validate Model / Framework	Validate an Indicator	Other (hypotheses / questions)
Vais et al. (2006)	Paper and cardboard mill	Romania			X
Aguado et al. (2013)	Tube manufacturers	Not specified			X
Galeazzo et al. (2014)	Two manufacturing companies (not mentioned) washing and painting	Italy			X
Ng et al. (2015)	Metal stamp parts	Singapore	X	X	
Domingo and Aguado (2015)	Tube manufacturers	Not specified		X	
Vinodh et al. (2016)	Automobile components	India	X		
Cherrafi et al. (2017b)	Agri-food-canned fish	Morocco	X		
Fu et al. (2017)	Food industry (dairy products)	China	X		
Ben Ruben et al. (2017)	Automotive components	India	X		X
Leme Junior et al. (2018)	Metal working	Brazil	X	X	
Garza-Reyes et al. (2018)	Manufacturing of grinding balls	Not specified			X
Choudhary et al. (2019b)	Packaging	UK	X		
Cherrafi et al. (2019)	Aerospace manufacturers	USA	X		
	Injection moulding	Morocco	X		
Tasdemir and Gazo (2019)	Wood	USA		X	
Zhu et al. (2020)	Metal stamp parts	Not specified	X	X	
Mishra et al. (2019)	Car bonnets	India			X
Maqbool et al. (2019)	Fasteners (nuts, bolts, etc)	Not specified	X		
Tiwari et al. (2020)	Cookware	Not specified	X		
Gholami et al. (2021)	Substrates	Malaysia	X		
Sartal et al. (2020)	Food industry	Not specified		X	
Ebrahimi et al. (2021)	Refrigerator	Not specified	X		
Lim et al. (2022)	Automobile	China	X		