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Article

Lean-Green Manufacturing Practices and Their Link to Sustainability

Wadhah Abulafaraa[1,*], Konstantinos Salonitis[1], Ahmed Al-Ashaab[1], Maher Ala'raj[2]

[1] School of Aerospace, Transport and Manufacturing, Cranfield University, Bedford MK43 0AL, UK

[2] Department of Information Systems, College of Technological Innovation, Zayed University, Dubai 19282, UAE;

* Correspondence: w.abualfaraa@cranfield.ac.uk

Abstract: The current rapidly changing and highly competitive market has put companies under a great pressure not only to be successful, but also to sustain their success into the future. In addition, in recent years, companies have become more aware of the fact that it is no longer enough to take care of economic aspects, being crucial to also take care of environmental and social aspects in order to actually succeed and lead in the current and future markets. In this context, companies are urged to move towards more innovative manufacturing practices that maintain a healthy balance among economic, environmental and social performances, which are the three pillars of the sustainability performance. To give some insight into this issue, a Systematic Literature Review (SLR) is conducted in this paper regarding the current trends in the field, doing special focus on the link between lean-green manufacturing and the different sustainability aspects. The SLR concluded that lean and green implementations as stand-alone systems are usually not enough to ensure the required balance between the three pillars of sustainability, suggesting further combining them into a single approach. Researchers expect to achieve further improvements in the sustainability performance moving towards the next level of sustainability.

Keywords: Lean manufacturing; Green manufacturing; Lean-green manufacturing; sustainability.

1. Introduction

The triple bottom line of sustainability requires companies to not only focus on their financial performance, but also to be proactive when it comes to their environmental and social stance. This is further reinforced by the external environment's stakeholders scrutiny in the current digital era. In this context, companies are urged to move towards novel and innovative manufacturing practices that can maintain a healthy balance among economic, environmental and social performances, which are the three pillars of the sustainability performance.

Lean practices have widely been adopted by companies all over the world, even by ones in other sectors [1], [2], for the sake of developing an efficient approach by increasing value to customers while reducing the resources consumption via waste elimination. By nature, lean practices are mainly focused on economic issues, nevertheless, they can also positively contribute (to a certain extent) to initiatives related to environmental [3], [4], and social [5], [6], issues. Moreover, in recent years, several efforts have been reported towards evaluating to what extent lean practices can fulfil the current environmental requirements [7], [8] as well as towards extending, modifying and updating lean practices so that they can address social and environmental aspects more efficiently [9], [10], [11]. Based on these results, several researchers argue that sustainability is an evolution of lean practices [5], [12], [4]. On the other hand, there are studies that argue that lean practices have not reached yet the maturity level required to ensure sustainability [5], suggesting that a more holistic approach, including health and safety is required [13]. In this line, many companies' leaders have realised that, since lean practices are not always capable of fulfilling neither the environmental requirements

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imposed by international standards and government regulations, nor the required social responsibility level, the implementation of green practices should be considered instead at least for sorting out the environmental ones. Green practices are focused on reducing hazardous emissions, getting rid of the consumption of wasteful resources, recycling, and minimising health risks throughout the entire manufacturing process, by minimising the environmental footprint during the whole product life cycle [14]. In this way, the implementation of green practices is expected to lead to improvements in the companies' environmental performance as well as their public image. In addition, in recent years, several studies in the literature have shown that green practices can also lead to improvements in the whole companies' sustainability performance [15], [16], [17]. Nevertheless, despite these promising results, the relationship between green practices and the economic performance remains unclear, being not straightforward and often called into question by practitioners and researchers arguing that they can be a burden for reaching improvements regarding design and production processes. In this sense, the actual capability of green practices towards reaching sustainable improvements is still highly questioned.

In this context, researchers have recognised that, on one hand, although lean practices, which are mainly focused on economic aspects [18] , [19] do have a positive impact on environmental [20], [4] , and social [5], [6] aspects, these positive impacts are not always enough to reach the sustainability level required by the highly competitive market. On the other hand, green practices are mainly focused on environmental aspects [7], [21] and do have a great impact on social [22], [21] aspects, but their positive impact on the economic performance has largely been questioned [23], [24]. In this conflicting situation, researchers and practitioners have realised that neither lean nor green practices seem to be completely suitable to keep the expected balance among economic, environmental and social aspects towards reaching the required level of sustainability. In this line, integrating both manufacturing approaches into a single combined framework seems promising [1], [25]. In that way simultaneous advantage can be taken of the operational, financial and (to a lesser extent) social benefits obtained by lean practices, as well as of the environmental and social benefits obtained by green practices. In particular, researchers expect that to implement both practices together could generate a complementary atmosphere leading to concurrent enhancement of operational, financial, environmental and social performances, by complementing lean benefits, such as, cost and lead time reduction and increased product quality, with green practices aimed at reducing the environmental impact of the whole manufacturing process, while working in a socially enhanced environment where employees are not only well-trained and engaged but also enjoy a cleaner, safer and healthier environment.

Although research regarding the individual implementation of lean and green manufacturing approaches abounds, there is still much research to be conducted regarding their integration into a single approach [26], [10]. Moreover, in a recent literature review study [27], conflicting results have been reported regarding whether green and lean practices are actually suitable to work together. On one hand, there are the ones who favour their integration [26], [25], arguing that they can support each other, whenever implemented together, generating a synergetic effect, in the sense that their strengths can be enhanced while their weaknesses can be disguised. On the other hand, there are the ones who do not favour their integration [28], [29], arguing that both approaches differ in their main objectives, so they are likely to have different impacts on the overall company's performance, making it not always a good choice to combine them. In this conflicting context, further research needs to be conducted towards evaluating the actual possibility of integrating the lean and green approaches, the potential of the combined approach and its influence on operational, financial, environmental and social performances towards reaching the next level of sustainability. In this context, the main motivation for the present study is to fill the research gaps regarding the actual lean-green combined approach implementation in order to provide researchers and practitioners creative tools towards achieving the currently required levels of sustainability keeping the balance among economic, environmental and social performances.

2. Lean manufacturing

The lean concept, which is based on the infamous TPS philosophy [30] promotes the waste reduction (ideally, elimination) in all the organizations' aspects [31], being waste understood as any non-value-added activity. Lean manufacturing is aimed at increasing the value delivered to customers by eliminating waste, that is to say, by eliminating any non-value-added activity [30]. Different definitions of lean manufacturing can be found in the literature: Womack et al. [32] see the lean concept as a manufacturing way of thinking that is able to decrease the time from customer order to the time when the product is already finished and shipped by reducing any waste. Liker and Lamb [33] on the other hand define lean as a system aimed at eliminating waste based on the concurrent reduction or minimisation of supplier, costumer, and internal variabilities.

2.1. Lean manufacturing: Tools and Techniques

Several techniques have been proposed in the literature within the framework of lean manufacturing in order to address costs reduction as well as productivity and quality improvements in order to fulfil customers' needs [3]. Among them, Just-in-time (JIT) [34], Standardisation of Work [35], Cellular Manufacturing (CM), Workplace Organisation-The Five S (5S) [36], Value Stream Mapping (VSM) [37], Total Preventive Maintenance (TPM) [38], Visual Management [39], Production Smoothing (Levelling) [40], and Quality at the Source or Do it Right the First Time, are the most popular ones. In [41], a recent and detailed review on such techniques is presented.

2.2. Lean manufacturing and its link to sustainability

The well-known Triple-Bottom-Line (TBL) sustainability conceptualisation, shown in Figure 1, is adopted within the context of this paper. In particular, the TBL sustainability model, first introduced in [7], suggests that a firm would be able to achieve sustainable results provided it is capable of improving environmental, social and economic performances simultaneously. Then, in order to analyse lean practices and their link with sustainability, it is necessary to analyse to what extent companies currently implementing lean practices are taking into concern not only economic but also environmental and social aspects.

Figure 1. The three pillars of sustainability performance defined in [42].

In order to fulfil today's society demands for sustainable solutions, lean manufacturing has become to be considered with a renewed interest as a starting point for becoming "greener" by extending, modifying and updating lean methodologies, in the sense of improving economic aspects by reducing cost and increasing the profit; environmental aspects by reducing waste and optimising resource usage; and social aspects by improving the working environment and occupant health. This lean approach towards sustainability can be seen in Figure 2. Several studies have demonstrated that lean practices can actually yield sustainability improvements, even if they have not been particularly aimed at doing so [42].

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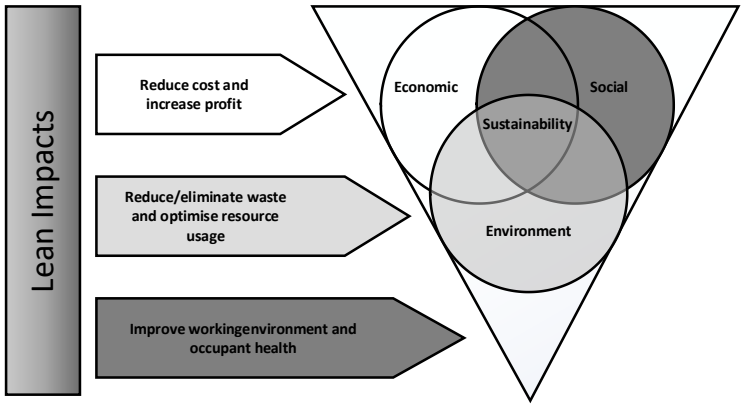

Figure 2. Lean contributions towards sustainability

It is important to highlight that, despite the promising greener results obtained by lean practices [43], [4], [11], it is possible that the achieved benefits in other aspects than the economic one would be not enough to meet the current sustainability requirements. In this line, researchers agree that, in order to achieve a higher sustainability level, green practices should also be adopted. In next section a theoretical background about green manufacturing is provided and its main techniques are described.

3. Green manufacturing

The concept of green manufacturing was first introduced in Germany in the early 1990s to fulfil the market's greener expectations by extending the "waste reduction" idea proposed by lean manufacturing, in the sense of reducing waste and pollution as well as optimising the use of raw material and energy in order to minimise the environmental and health risks [45], [46]. Although the literature about green manufacturing is not as vast as in the case of the lean manufacturing, different definitions of green manufacturing can be found. Dilip Maruthi and Rashmi [47] defined green manufacturing as a sustainable approach that makes special focus on product development and operations to decrease the impact on the environment. Atlas and Florida [48], extended this definition by presenting green manufacturing as a set of practices aimed at integrating the different companies' tasks within different productive areas, such as, designing, manufacturing and planning in such a way that the flow of environmental waste can be identified, quantified, assessed, and managed so that the environmental impact can be reduced.

3..1 Green manufacturing: tools and techniques.

Green manufacturing faces challenges regarding both product and process perspectives. Regarding the product perspective, green manufacturing should be able to meet customer demands for environmentally friendly products, minimise resources use, and select materials that do not harm the environmental. Regarding the process perspective, green manufacturing aims at minimising the use of materials and the energy consumption, eliminating the use of hazardous substances, and reducing the waste generation. Within the green framework, both perspectives (product and process) should be addressed in an integrated way in an attempt to ensure the reduction of the product environmental footprint throughout its entire life cycle.

Generally speaking, green manufacturing tools can be classified into two groups of methods, namely, assessment oriented or improvement-oriented methods. Methods belonging to the first group, such as the mass balance (also known as eco-balance) and the Life Cycle Assessment (LCA), conduct a conscious evaluation regarding the company's environmental impact in order to give an insight of the company's environmental efficiency. Based on this analysis, methods belonging to the second group, such as EOL strategies and DfE can be applied in order to achieve improvements in the environmental efficiency of the whole company.

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3.2. Green manufacturing and its link to sustainability

Green manufacturing is mainly aimed at reducing the companies' environmental footprint by minimising the use of materials and the energy consumption, eliminating the use of toxic substances, and reducing the waste generation. According to [49], taking into account the widely accepted definition of sustainability introduced in [15] where sustainability is defined as fulfilling the needs of the current generation without having compromise future generations and being able to fulfil their needs as well, any eco-friendly approach aimed at taking care of the environmental resources can be interpreted as sustainable. In addition, although green manufacturing is mainly focused on solving environmental issues, social and economic aspects are also usually considered within the framework of green practices. Then, green manufacturing could be interpreted as a strategy to keep balance economically, environmentally and socially within a manufacturing framework. In this line, in [50], the relationship between green manufacturing and sustainability is summarised by defining green manufacturing as a "sustainable" approach aimed at designing and planning the product development and the process flow in such a way that the environmental footprint of the whole system is minimised. Finally, it is also important to say that this tight relationship between the sustainability concept and the green manufacturing methodology has led some researchers to use both terms interchangeably [15], as in the cases of [49], [51]. In general, researchers agree that green manufacturing can lead to sustainability, having a positive impact not only on environmental but also on economic and social aspects. Some researchers have conducted different experimental case studies in order to evaluate the link between green manufacturing and sustainability, in an attempt to fill the gap in the literature regarding practical and real-life evidence [16], [17].

Some researchers give an insight into the link between green manufacturing and sustainability by analysing different aspects of the green practices and proposing new approaches to implement them [52], [53]. In [54] authors state that DfE practices optimise the interaction of the economic and the environmental systems, producing a sustainable development and enterprise integration. On the other hand, in [55], it is stated that DfE practices are not enough to ensure sustainability, suggesting that EOL strategies should be integrated from the beginning in order to reach sustainability. Researchers in [56] and [57] focus their attention in the link between GSCM practices and sustainability performance proposing an environmental collaboration referred to as "environpreneurship" to facilitate this link in a Malaysian manufacturing industry. The proposed model in [58] is shown in Figure 3.

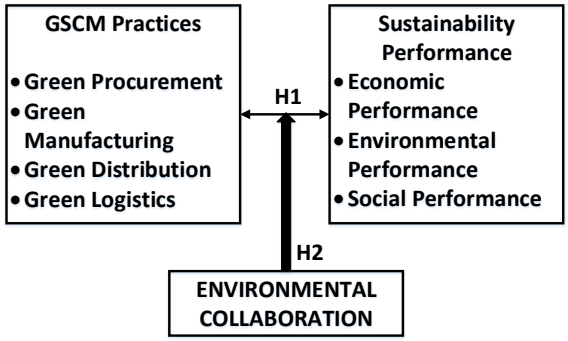

Figure 3. Green collaboration to enhance the relationship between GSCM practices and sustainability performance (based on [57])

Thoo et al. [57] agree with the observations in [18] and [58] regarding the influence of GSCM with respect to sustainability aspects. Moreover, they suggest that the green supply chain should be extended to include green purchasing and marketing for the sake of sustainability. In this line, they propose the network approach shown in Figure 4, which considers the different stakeholders as interdependent actors within this network, suggesting that a novel and joint view of green manufacturing would lead to sustainable organisations and eventually to sustainable societies.

Despite the promising economic green perspective, the relationship between green practices and the economic performance remains unclear. In this line, being green practices highly environment-oriented and lean practices highly economic-oriented, researchers have suggested combining them towards achieving the required balance among the different aspects of sustainability. Such integration has demonstrated to be a complex and challenging task. In the next section the actual possibility of combining lean and green practice into a single approach is evaluated and the available theoretical as well as practical methods towards implementing it are studied by conducting an exhaustive Systematic Literature Review (SLR).

4. Lean-Green manufacturing approach

In recent years, companies have recognised that, in order to lead in the current and future markets, it is mandatory to move towards the next level of sustainability. The current trends in lean and green manufacturing practices, respectively, as well as their link with the different sustainability aspects have been discussed, showing that several efforts have been undertaken in order to reach further improvements in the sustainability performance, either from the lean [44], [5], [12], [4], [11], [59] perspective or from the green [60], [16], [17], [53], [52], [57], [58], [61], [55], [62] one. Nevertheless, despite these great efforts as well as the promising results reported in the literature regarding lean practices leading to environmental improvements [18], [4], [11] and green practices leading to economic improvements [5], many researchers have concluded that, due to the fact that neither lean nor green practices have particularly been aimed at addressing the three pillars of sustainability simultaneously, their contributions towards these three sustainability aspects would not be enough when implemented individually, being necessary to implement them in a combined framework.

In general, researchers agree that the integration of lean and green practices into a combined approach is a quite complex and challenging task [46], [26], [25]. In order to give some insight in this direction, in this section an exhaustive literature review is conducted in order to study the different combination strategies of lean and green practices proposed in the literature, their potential and their capability of keeping the balance among economic, environmental and social performances towards achieving a superior level of sustainability.

4.1 Research questions and search methodology

The present systematic literature review (SLR) is aimed at giving an insight into the current research in the field regarding the integration of lean and green approaches, making special focus on the potential such combination can have towards improving the whole company's sustainability performance. In this line, the following questions should be answered:

1. Which are the actual possibilities of integrating lean and green practices into a combined approach?
2. Which are the currently proposed strategies to implement the combined lean-green approach?
3. What is the actual (and expected) impact of implementing the combined lean-green approach in the sustainability performance?

Each of these research questions will be addressed in the coming sections. The search for the relevant contributions related to these research questions has been carried by focusing the attention on the contributions published in the last two decades, taking as initial research points the following topics:

- Compatibility between lean and green manufacturing practices: similarities, differences and synergy,
- Main strategies towards implementing the combined lean-green approach,
- The lean-green approach and its actual potential towards achieving further improvements in the sustainability performance

4.2. Thematic Synthesis

A total of 45 contributions to the field have been selected. Among them, 35 (77.7%) are from international journals (being 11 (24.4%), while only one (2.2%) is from a book, and 10 (22.2%) are from Proceedings of International Conferences.

In order to better analyse the selected articles in the SLR, a thematic synthesis is performed to identify and study the most relevant contributions addressing the main concerns regarding the integration of lean and green practices into a combined approach. Table 1 shows the resulting SLM based on this thematic synthesis. In particular, the 45 selected articles are thematically synthesised considering the following categories:

- Conceptual Analysis: Articles in this category address the lean and green practices integration from a theoretical point of view. In general, these kinds of analyses are found in books.
- Literature Review: Literature reviews focus on collecting and discussing the main and most recent contributions regarding integrating lean and green practices. In particular, they can address the integration issues either by performing a lean vs. green analysis, or by proposing strategies to implement it.
- Research Application: This category includes articles where authors propose different models and approaches to actually implement the lean-green approach.
- Case Study/Empirical Study: These types of studies are held within the companies' manufacturing context. Some of them resort to surveys, while some others perform experimental tests.
- Lean vs. Green Analysis: Articles classified in this category study the actual possibility of combining lean and green practices based on their main similarities and differences.
- Lean and Green Synergy: These articles evaluate to what extent lean and green practices can actually be implemented together within a synergetic environment, in the sense that their strengths can be enhanced while their weaknesses can be disguised.
- Lean-green Implementation: This category aims to gather the proposed approaches to practically implement the lean-green combination.
- Impact on Performance: This category shows which are the main pursued objectives behind implementing the combined lean-green approach.
- Sustainability: In this category, it is intended to include articles that evaluate the actual impacts of the combined approach to the sustainability performance and to what extent (and how) further improvements can be achieved when the combination approach is implemented.

Table 1. SLR for the lean-green approach

Ref	Conceptual analysis	Lit. Review	Research app.	Case study/ Empirical appl.	Lean vs. Green analysis	Lean and green synergy	Lean-green implementation	Impact on Performance	Sustainability
[64]		x			x	x			
[65]			x				x		X
[66]				x				x	X
[67]		x		x				x	x
[68]			x				x	x	
[69]				x			x	x	X
[70]			x				x		x
[9]		x			x	x			x
[71]	x			x			x		x
[72]		x	x	x			x		x
[73]				x			x		x
[28]				x	x	x		x	
[27]				x			x	x	x
[74]			x	x			x		
[75]	x				x				
[76]			x				x		x
[77]				x					
[26]		x			x	x	x		x
[78]			x	x			x		
[79]	x				x				

Ref	Conceptual analysis	Lit. Review	Research app.	Case study/ Empirical appl.	Lean vs. Green analysis	Lean and green synergy	Lean-green implementation	Impact on Performance	Sustainability
[80]				x			x	x	x
[26]		x			x	x			x
[8]	x				x				x
[7]			x				x		x
[81]		x				x			x
[82]			x				x		x
[83]			x				x	x	x
[84]		x			x	x			
[85]			x				x		
[86]	x				x	x			
[25]		x			x	x			x
[87]		x							x
[63]			x	x			x	x	x
[88]	x				x				
[89]	x			x		x			
[29]		x			x				
[90]	x				x				
[91]				x	x				
[92]				x					x
[93]			x	x				x	x
[94]	x			x		x			x
[95]				x		x	x		x
[96]	x					x			x
[97]				x			x		
[98]				x			x		

5. Towards a lean-green approach

The conducted SLR confirms that, in recent years, researchers have focused their efforts towards understanding the actual possibility of integrating lean and green practices in order to reach a higher level of sustainability. In fact, the 45 (100%) articles in the SLM of Table 4-1 have been published after 2000, while 40 (88.8%) of them have been published after 2010. Here, it is important to highlight that, despite the great efforts reported in the literature towards investigating the combined approach, only 45 articles have been found in the literature explicitly addressing this issue which, in comparison with the 73 and 67 articles gathered in the SLRs for lean and green practices, respectively, demonstrates that too much research has still to be conducted in this direction [27], [26], [25].

Among the 45 selected articles, the majority (24 (53.3%)) study the integration of lean and green practices from a general and theoretical point of view (being 14 (31.1%) of them literature reviews and 10 (22.2%) conceptual analyses). On the other hand, 12 (26.6%) articles address the combination issue from a more practical point of view, proposing integration frameworks and approaches based on simulations and (when available) benchmark data, while 19 (42.2%) conduct empirical case studies. The lack of further practical analyses is probably due to the fact that, since the idea of implementing lean and green practices together is relatively new, there are not many companies that have already adopted such a combined approach, making researchers to resort to simulations, theoretical analyses and pilot experiments to test their research hypotheses and proposals.

The integration of lean and green practices into a combined approach is a quite complex and challenging task [63], [26], [25], [27]. In order to be able to propose a combination strategy capable of integrating lean and green practices in such a way that they can work in a synergetic environment, in the sense that their strengths can be enhanced while their weaknesses can be disguised, it becomes crucial to understand the main similarities and differences between them. From the SLR conducted here, it can be seen that several researchers have focused their attention on studying lean and green practices concurrent and divergent points in order to provide a suitable starting point for developing their combination strategy. In particular, 16 (35.5%) from the 45 articles have been published with this purpose. These contributions are discussed in the next section. In addition, to be aware of lean and green similarities and differences makes researchers to be able to better evaluate whether both practices can actually be implemented together as well as to study which are the potential benefits of

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such integration. In fact, several researchers have focused their attention in analysing to what extent lean and green practices, with their similarities and differences, are compatible and can yield improved results when being combined. Contributions in this direction have been found in 15 (33.3%) of the articles selected in the SLR, and are discussed in Section 3.2.

5.1. Lean vs green manufacturing: similarities and differences

The SLM of Table 1 shows that several works (16 (35.5%)) have been presented in the literature studying the main similarities and differences between lean and green practices, concluding (most of them) that both practices are complementary and, to some extent, overlapping. In general, researchers agree that, although lean and green practices do differ in their main objectives, being the former mainly focused on adding value to customers while reducing the resource and time consumptions, and the latter focused on reducing the environmental footprint throughout the whole product life, their main similarity, which is waste reduction, appears to be obvious [63], [25]. In fact, according to [29], both practices are aimed at minimising (ideally eliminating) waste, no matter what type of waste they are focused on. Researchers in [29] and [64] agree with the observations reported in [84] and [25]. Nevertheless, they further suggest that the different methods for reducing such wastes and, even more important, the different definitions of what wastes are, are indeed the main conflicting points between lean and green practices. In the same line, authors in [29] state that green practices go further than lean ones being concerned not only in waste reduction but also in process efficiency and optimization of raw material consumption. Researchers in [29] also highlight that the main difference between lean and green practices is the waste definition, arguing that while lean practices are focused on workforce and space reduction as well as increasing flexibility and capacity utilisation, green practices are aimed at reducing, reusing, recycling, reworking, returning, and remanufacturing. On the other hand, in [84] it is argued that, although lean and green wastes definition can differ, lean non-value added activities can be considered as energy and natural resources wastage, associating, in this way, the seven lean wastes with the ones defined within the green manufacturing context.

According to the articles selected in the SLR conducted here, most researchers in the field highlight waste reduction philosophy [82], resource productivity, organisational change and source reduction [29], among the main similarities between both practices, while identify their main focus [88], the waste definition [88], the type of customer, the manufacturing strategies, some adopted methods and practices [29] and the EOL strategies [64], as their main differences. Finally, in order to further visualise and understand the main similarities and differences reported in the literature, they are summarised in Figure 5 and Table 2, respectively.

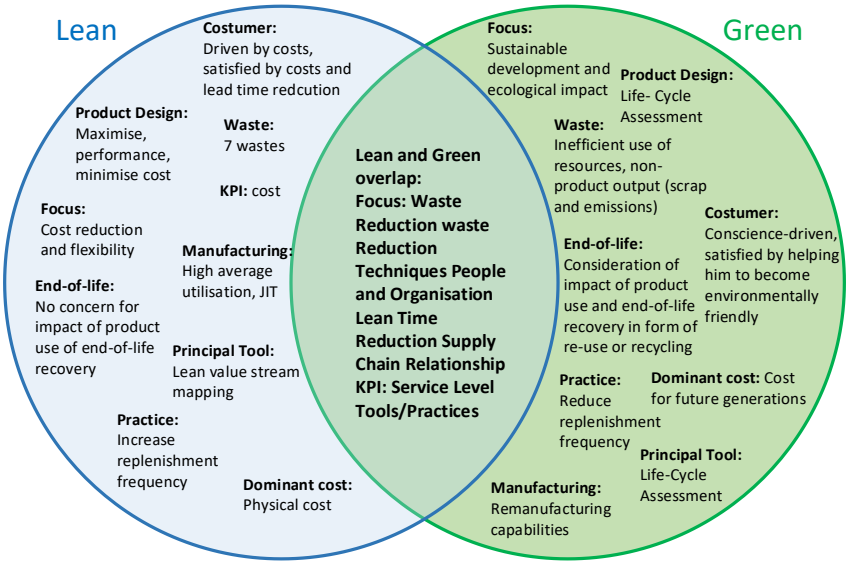

Figure 5. Lean and green common points [72]

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Table 2. Lean vs. Green manufacturing

Manufacturing philosophy	Lean	Green
Main focus	Increase value to customers while reducing the resource and time consumptions via waste elimination [72].	Reduce environmental footprint and minimise health risks throughout the entire product life cycle [64].
Basic principles	Lean principles [15]: • Long-term thinking • Elimination of wastes • People commitment • Continuous improvements	Green principles are mainly focused on [32]: • Pollution prevention • Reduction of toxic substances • DfE
Waste	Lean 7 wastes [29]: • Transport • Inventory • Motion • Waiting • Over-processing • Over-production • Defects	• Green wastes [32]: • Solid wastes • Hazardous wastes • Air emissions • Wastewater discharges
Methods/tools	Well-defined, documented and widely used standard methods and tools [65].	Although different tools, such as, LCA, DfE and EOL strategies are widely used, green practices are usually based on customised approaches [65].
Product design	Design is focused in increasing the quality and performance, while reducing costs [49].	Design, including tools such as DfE, focuses on decrease scrap in many areas of the product life cycle by planning waste reduction from the first stages of the production [82].
Inventory	Replenishment frequencies are increased [82].	High replenishment frequencies imply higher emissions, so replenishment frequencies need to be reduced [82].
Pollution	CO2 emission is not reduced [100].	Reduces any pollution that happens during the production process [99].
Supply chain	Close cooperation with suppliers [99].	Suppliers' involvement is crucial since environmental footprint should be minimised throughout the entire product life cycle including its EOL.
Product EoL	No concern for product use impact or EOL recovery [64].	Includes EOL strategies into the product life cycle for which the company is responsible [64].
Costumers	Customers are focused on high quality and low priced services and products [101], [64].	Customers are focused on services and products that are produced in an eco-friendly way [65], [64].

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5.2. Lean vs green manufacturing: towards an integrated approach

The different opinions discussed in Section 3.1, show that the discussion about which are the common and conflicting points between lean and green practices is still open. Consequently, so it is the discussion regarding whether they are actually compatible and suitable to work together. In addition, not only too little empirical evidence of successful cases adopting lean-green approaches can be found in the literature [65], [25], but also the results that can currently be found are conflicting [63]. On one hand, there are researchers that argue that lean and green practices can work together since they can be concurrent generating a synergy regarding waste reduction, energy, material and time consumption, supply chain management and product life cycle optimisation [26], [89], [81], [25], [10], [64], [28]. On the other hand, there are the ones that state that lean and green practices are not always compatible, existing some areas where combining them can be particularly hard [68], [29], [102]. For example, the inventory level is one of the most critical aspects when combining lean and green approaches. In this case, while lean practices focus on producing, transporting and packing small lot sizes to fulfil customers' requirements, the high replenishment frequency can imply higher emissions and more packaging wastes, contradicting green principles.

In the SLR conducted here, 15 (33.3%) articles evaluate whether lean and green practices can be implemented together. On one hand, researchers who are reluctant to combine both approaches are concerned about whether lean practices, which are focused on waste reduction from the customers' added value perspective, optimising cost, quality and lead times, will still be profitable after incorporating green practices towards environmental objectives which are not always in line with lean objectives. In this line, authors in [88], suggest that the main strategic challenge consists in deciding how to implement green practices in combination with lean ones, without diminishing the potential profitability achieved by the latter, while being able to keep the balance between economic, environmental and social performances. Moreover, in [103] it is stated that, within a combined framework, lean practices will not always be able to limit the negative impact on operational aspects that green practices could have, being also true the other way around. Finally, in [10], authors also state that lean-green approaches will have to face the same challenges that lean and green practices have to face when implemented individually. For instance, in [25], it is highlighted that, as it is usually the case of green practices, in order to implement the lean-green approach, practitioners should have to resort to customised approaches, while in [89], it is stated that one of the main barriers for the implementation of the lean-green approach is the fact that a huge investment in equipment is required.

On the other hand, there are many researchers that agree that, although lean and green manufacturing approaches are not completely compatible and do differ in their main focus, to be aware of their similarities and differences and, even more important, to be capable of handling them, can indeed give practitioners the opportunity to improve both methods so that they can efficiently match. Moreover, in [104], a case study conducted on a Brazilian large multinational company, shows that synergetic effects can emerge even if lean and green practices are applied in different areas, with no joining strategy. In Figure 6, the synergetic model introduced in [81] is shown. Then, taking into account that, according to [81], lean and green practices can be synergetic even when being implemented without a combination strategy, researchers who favour the integration have further studied their compatibility (beyond their similarities and differences), evaluating to what extent lean and green practices can be synergetic, in such a way that they can obtain better performance when being implemented together than when summing their individual performances. In this way, researchers intend to be able to propose joining strategies capable of generating the synergetic effect, taking advantage of it, and further potentiating its results.

According to [81], the synergetic hypothesis is suitable since there exist a similar structure for the implementation of successful lean and green practices. In this line, in the SLR conducted here 14 (31.1%) articles address the compatibility from the synergetic point of view. In [83], authors state that companies looking for being lean will have more success if they also seek green objectives. In the same line, several researchers in the field who have largely discussed about "how green can be lean", such as the ones in [68] and [9], have concluded that, since lean practices are not aimed at green

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objectives, they cannot replace green practices towards achieving green results, but they can provide a continuous improvement, flexible and employees' engagement culture creating a suitable and highly favouring environment for the implementation of green initiatives. Authors in [100], agree with them, stating that the lean culture can be a catalyst for green practices, facilitating the adoption of environmental practices. Moreover, a particular example of such catalytic effect can be found in [64], where it has been proved that the impact of lean practices on operational supply chain performance can be improved by preventing pollution and recycling. According to [94], lean and green practices can generate sequential or reciprocal interactions, supporting each other, working in a complementary and synergetic environment. In [28], the synergetic effect generated by lean and green practices has proved to achieve several benefits, such as, fostering innovations and reducing the production costs of eco-friendly products. Finally, in [89], empirical evidence shows that, in order to actually reach the beneficial synergetic effect between lean and green practices, it is necessary to customise some operational aspects of the company as well as to ensure fluent collaboration with suppliers.

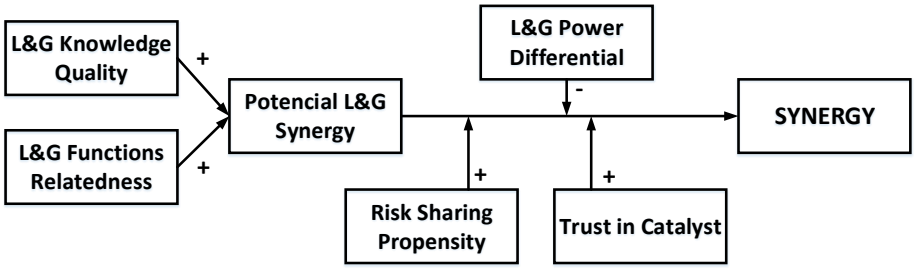

Figure 6. Synergetic model in [81]

6. Green-Lean approach: stare-of-the art implementations

Although the synergetic effects of implementing lean and green practices in an integrated environment have been demonstrated by several researchers in the field [89], [104], [96], [81], [25], the practical implementation of such a combined approach is a quite complex and challenging task that has not been yet investigated deeply enough [105], [26], [27], [25]. In fact, although several researchers recommend the integration of lean and green practices towards reaching further sustainability improvements, they also agree that there is a lack in the literature of suitable integration and combination strategies [63]. In particular, according to authors in [27], the research gap is still deeper due to the lack of sustainability metrics. In addition, most of the current proposed approaches in the literature are customised since, as in the case of green practices being implemented individually, lean-green approaches are also aimed at fulfilling particular needs of the companies, related with local culture, policies and regulations.

In order to fill the above-mentioned research gaps and provide some insight towards the actual implementation of lean-green combined approaches, several efforts have been done in recent years to develop and implement these kinds of manufacturing approaches. The SLR conducted here, confirms this tendency including 21 (46.6%) articles where different approaches have been proposed to implement the combination of lean and green practices. In general, researchers agree that different combination schemes, such as, sequential and parallel, can be adopted to integrate lean and green practices [27]. In this line, there are the ones that propose to combine them into a new, single and stand-alone lean-green approach [28], [65].

while there are others that, based on the fact that lean practices are not only well-documented but also widely (and successfully) adopted all over the world, as well as that the lean culture do favour the implementation of green initiatives, propose to use an already stablished lean environment as a catalyst to the adoption and further incorporation of green practices [79], [70], [71].

Within the first group, waste management methods, like Waste Reducing Techniques (WRT), are the most used strategies to perform the combination [64], [68], [65], [85], [89]. In [79], a combined approach based on the Theory of Inventive Problems-Solving tools, is presented. Researchers in [65], assume that green and lean practices have mutually exclusive design requirements, and propose to

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combine them into the same system based on a waste contradiction matrix. In [65], a waste minimisation framework based on an advanced 3R (Reduction-Reuse-Recovery) method, is proposed. In addition, although there is a strong tendency of using waste management methods, some other approaches have been proposed to address the combination from the first group's perspective. In [85], the multiple attribute utility theory method is used for assessing a lean-green supply chain. In [106], a Green Lean Total Quality (GLTQ) Information Management System, which is an Information Management (IM) system within the context of an Environmental Management System (EMS), integrated to TQM and lean principles, is proposed. In this way, authors in [97] intend to achieve total communication efficiency based on a green-lean TQM system, demonstrating that the proposed approach allows generating more revenues and also providing Research & Develop facilities. In [97], a combined lean-green approach based on the integration of management systems, such as ISO 9001 and 14001, is proposed. In [27], an Analytical Hierarchical Process (AHP) is used to integrate TPM and ISO 14001principles into a lean-green combined framework. In [98], a case study is conducted on different Alsatian industrial companies in order to develop a lean-green management framework based on lean indicators as well as green performance and intentions indicators.

Within the second group, several researchers have proposed to incorporate green practices to manufacturing processes that have already adopted a lean philosophy. In this line, one of the most frequently proposed approaches consists in taking advantage of the flexible nature of lean practices by modifying and adapting them so that they can work in combination with green practices towards the same objectives. In particular, the most frequently reported adapted lean tools are VSM ([73], [69], [70]) and Continuous Improvements principles [74]. In [95], the implementation of lean and green practices combined within a continuous improvement culture in a SME foundry is studied. In [95], VSM is adapted to address environmental and production wastes. In [69], the VSM tool is proposed for determining waste, in terms of measuring the carbon dioxide emissions particularly across organisational boundaries within the context of a food industry. In [74], a green-lean business model based on five principles, viz., stable value stream, identification of environmental impacts, measurement and improvement of the environmental value streams, and CIs, is developed for a global engineering company. In [70], a novel metric integrating metrics derived from lean and green implementations. Experimental results in [72] show that the proposed approach is capable of reducing the carbon footprint by improving not only the Carbon-Value Efficiency but also the production lead time.

In Figure 7, the most relevant contributions towards the integration of lean and green practices, in terms of the main proposed approaches, their objectives and their main impacts on the companies' performance, are shown. Here, it is important to highlight that, although lean as well as green practices do include activities that can be implemented throughout different areas of the company, addressing different stages of the productive process, the articles selected in the SLR show a strong tendency of implementing and evaluating the lean-green approach within the context of supply chain management [72], [64]. In fact, although there are the ones that reports the combination of both practices to address other manufacturing issues, such as, metrics [74], [73], quality [73], [27], safety [106], lead time [27], customer service [106], cost [106], inventory [106] and transportation [83], there exists the necessity for more research regarding the different production stages [83]. Finally, in [69] and [25] it is stated that there is a lack in the literature regarding empirical evidence of practical implementation of the combined lean-green approach. In order to fill this gap, among the 21 (46.6%) articles proposing strategies for implementing the lean-green combination, 9 (20%) have report results obtained by the lean-green implementation within real manufacturing scenarios from different countries all over the world, such as, construction projects [63], metal stamped parts production [69], Swedish industry [72], food industry [27], part production in the automotive sector [74], Chinese Fashion AutoParts industry [78] and SME foundry [105]. In [95], authors go even further, presenting the results obtained by implementing the proposed lean-green approach in different companies, with different sizes and operating in a different business area, giving researchers in the field benchmark data allowing them to expand their approaches to other companies and manufacturing sectors.

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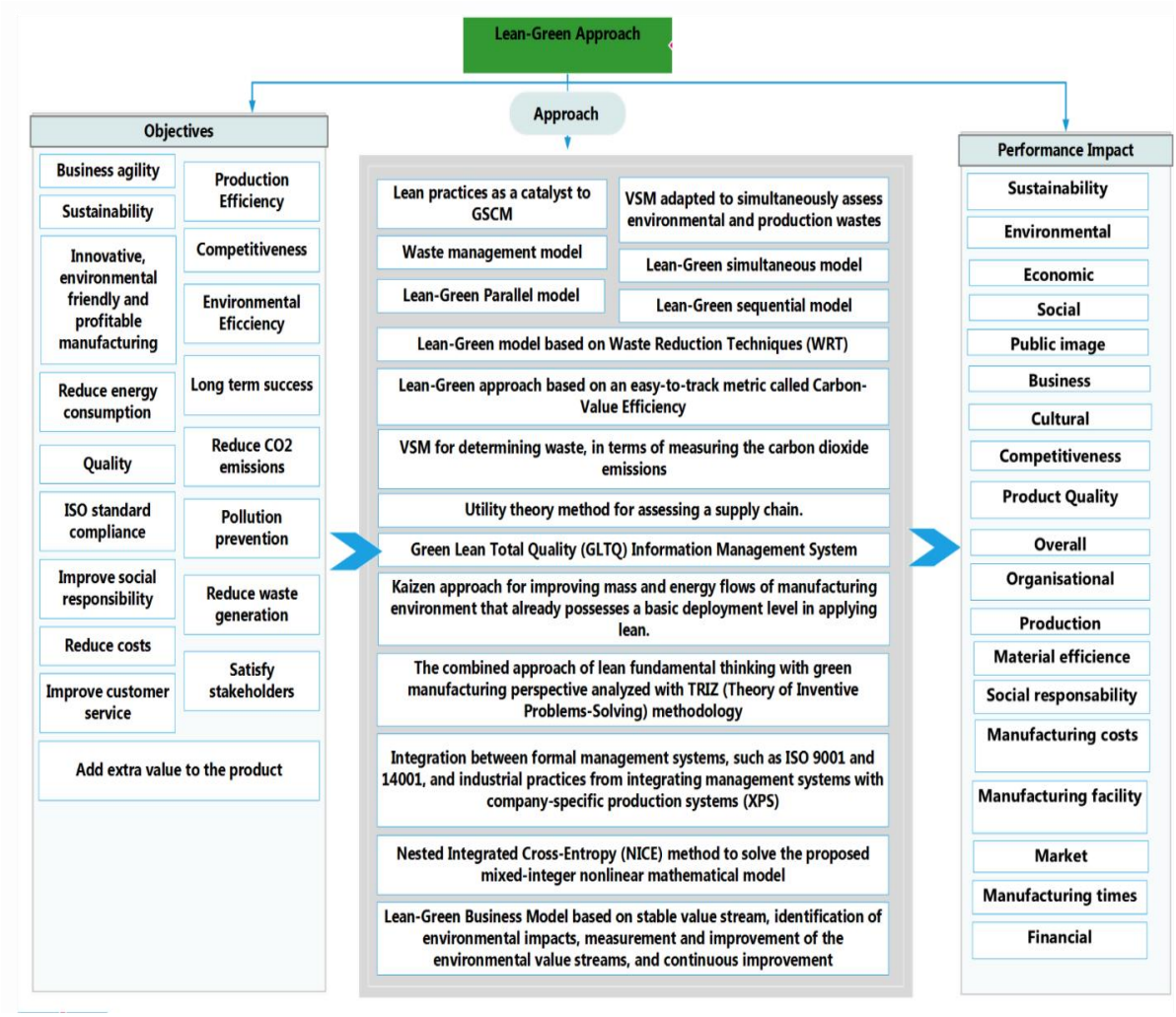

Figure 7. Summary of the proposed lean-green approaches in the SLR: Main concerns, proposed approaches, and their performance impact

7. Green-Lean approach and its link with sustainability

In recent years, companies have tried to move towards more sustainable manufacturing practices, in terms of economic, environmental and social aspects. Researchers analyses have shown that lean practices are, by nature, mainly focused in operational [63], [19], [107] and financial [108], [109] aspects, while being capable (to some extent) of contributing towards environmental [20], [4], [11] and social [5], [6], [110] performances. On the other hand, green practices are, also by nature, highly focused on environmental aspects [7], [21], [57], as well as capable of reaching improvements in the social performance [22], being their impact on economic aspects highly called into question, existing the ones that consider green practices can actually lead to economic improvements [23], [111], and the ones that consider them as a burden for operational and financial aspects. In this context, although several efforts have been done towards improving sustainable aspects from the lean [1], [5], [12], [4], as well as from the green [60], [16], [17], perspective, several researchers agree that neither lean nor green practices are enough to ensure sustainable results when being implemented individually [18], [90], [13], [63]. Then, the need for new strategies towards reaching a superior level of sustainability arises. In this line, several researchers have proposed the idea of integrating lean and green practices, taking simultaneous advantage of their positive impacts on each of the three pillars of sustainability, while smoothing their negative impacts (if any), as the natural next step towards a higher level of sustainability.

Based on the above discussion, it can be noticed that, unlike lean practices, that are mainly aimed at operational and financial aspects, and green practices, that are mainly aimed at environmental

aspects, the idea of a lean-green approach has indeed been born to address the three pillars of sustainability simultaneously. In this way, it can be said that the lean-green concept is tightly linked with sustainability, being sustainability its main focus and objective. In this line, it seems natural that most of the works in the literature addressing the lean-green approach measure their performances in terms of sustainability improvements. In particular, in the SLR conducted here, most of the selected articles (30 (66.6%) out of the 45) explicitly report results in terms of the companies' sustainability performances. In general, the authors of these articles agree that, provided the synergetic effect is achieved, the green-lean approach can lead to improvements on economic, environmental and social performances simultaneously [14], [70], [71], [72], Moreover, in [92] it is stated that the integration of lean and green practices into a combined approach is the key aspect towards achieving a superior sustainability performance.

In [63], it is stated that, to fully address sustainability aspects, it is crucial to develop standard and benchmark sustainability metrics. In fact, only 3 (6.6%) of the 30 selected articles explicitly reporting results in terms of sustainability performance, address the performance analysis from a quantitative perspective by defining new metrics related with sustainability aspects [27], [72], [106]. In [73], a carbon-value efficiency metric is defined to measure the performance of a metal stamped parts production process, showing improvements in terms of the carbon-value efficiency, production lead time and carbon footprint. In [72], the multiple attribute utility theory method is proposed to measure the performance of supply chains in terms of managerial and environmental performances. In [106], a lean-green management framework is developed on the basis of lean and green indicators, allowing companies to benchmark their lean and green practices. Finally, in [73] it is further highlighted that, for the sake of succeeding in the implementation of lean-green approaches, companies not only need to have access to benchmark sustainability metrics, but they also to fully consider operational, cultural and business opportunities.

The SLR conducted here shows that, in recent years, promising sustainability results have been reported in the literature when implementing the combined approach. Moreover, many of these results have been obtained within the context of real manufacturing scenarios, suggesting that several efforts have been done towards filling the research gap highlighted in [27] and [25] regarding the lack of empirical evidence of successful lean and green integration cases in the real manufacturing scenario. In this line, in the SLR conducted here, 19 (42.2%) articles evaluate the potential and actual sustainability performance improvements that the lean-green approach implementation can achieve within real manufacturing scenarios, such as, the construction of a hospital, within the particular application of a structural concrete work stage [63], an European motorcycle component manufacturer [69], a Swedish industry [71], a food industry supply chain [27], an Indian automotive sector [74], a Chinese Fashion Auto Parts suppliers [78], a metal stamped parts processes [105], Alsatian industrial companies [72], a Portuguese automaker [73] and a SME foundry industry [93], among others, reporting many successful cases. In particular, articles in the SLR report results either from literature reviews based on case studies, surveys and empirical research evaluating the synergetic effect between lean and green practices, or from empirical evidence obtained from the actual implementation of novel proposed lean-green approaches. Among the literature reviews, studies conducted within the Indian automotive SME industry have reported improvements regarding productivity, by constantly enhancing the business efficiency and effectiveness, when combining lean and green practices [95]; while studies conducted within the context of foundry SMEs, suggest that lean and green management strategies should be implemented in a continuous improvement context in order to achieve sustainable continuous improvements [67]. Regarding the survey case studies, in [95], empirical results evaluating the lean and green synergetic effects within the supply chain are reported based on survey data collected by the *Global Manufacturing Research Group* (https://gmrg.org/) in European countries. In [94], the analysis of three pollution-prevention projects implemented by two large multinational companies have been conducted, concluding that lean and green practices can generate a synergetic effect. In [28], semi-structured interviews with interdisciplinary teams responsible of integrating lean and green practices in two manufacturing companies in the UK, are conducted, showing that, to achieve synergetic effects, it is usually required

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to customise the companies' operational profile as well as to ensure collaboration with suppliers. In addition, authors in [89], highlight that environmentally-friendly products are easier and cheaper to produce when applying the lean-green approach. In Table 2, the main success factors pointed out by researchers reporting the promising results discussed here regarding sustainability performance based on the implementation of the lean-green approach are summarised.

Table 2. Success factors towards achieving sustainability performance by implementing the green-lean approach.

Success factor	Source
The lean-green approach implementation should be gradual, allowing companies to set priorities, and identify key goals.	[89]
Operational roles and responsibilities need to be broadened to include sustainability issues.	[63]
Sustainability metrics should be developed.	[27]
There is a need for openness of employees, stakeholders, customers, leaders and suppliers towards innovation.	[27]
Effective information management is crucial towards reaching sustainability improvements.	[97]
Management commitment is crucial for achieving sustainability standards.	[97])
A lean working environment, consisting in trained, engaged and committed employees, as well as continuous improvements culture, favours the implementation of green initiatives in combination with lean practices towards sustainability.	[64]
Customer focus and integration is crucial to achieve sustainable results.	[97] , [65]
A key aspect towards implementing innovative lean-green approaches is to ensure system and process change management.	[65]
Effective planning is needed towards combining lean and green practices in a synergetic way.	[89]
Team and end-to-end supply chain integration is crucial to achieve sustainable results.	[89], [64], [106], [7], [81], [29], [94]
It is usually needed to customise the lean-green approach in order to fulfil the particular needs of the companies.	[74], [89]
The adoption of a continuous improvement culture is crucial towards implementing a lean-green approach and obtaining sustainable results.	[72]
Benchmarking of suppliers against each other can help to implement lean-green strategies more efficiently.	[104]
Strong communication and coordination between different sectors are crucial for being able to implement the lean-green approach.	[73]
Evaluation and review of performance and progress towards targets can lead to improvements in the sustainable results.	[97], [27]
Wide understanding, acceptance and adoption of lean and green concepts are needed towards being able to actually implement them together in a synergetic way.	[72], [26], [29], [64], [84]
Understanding of lean contributions towards implementation of green initiatives helps to take advantage of lean culture as a catalyst for green practices.	[100], [64],[90]

8. Conclusions and remarks

Along with the important contributions of lean and green practices towards sustainability, respectively, researchers have concluded that lean and green implementations as stand-alone systems are usually not enough to ensure the required balance between the three pillars of sustainability, suggesting further combining them into a single approach. In this way, researchers expect to achieve further improvements in the sustainability performance moving towards the next

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level of sustainability. In this paper, the actual possibility of implementing the lean-green approach has been evaluated. On one hand, the analysis of the concurrent and divergent points between both practices as well as the synergetic effects they can achieve when being implemented together have been analysed. On the other hand, the main challenges reported in the literature regarding their combination have also been discussed. Then, the main currently proposed strategies to actually implement the lean-green approach within a combination framework have been introduced and, finally, the link of the combined lean-green approach with sustainability has been explored by analysing the different sustainability performance results reported in the literature, in terms of economic, environmental and social performances. In general, despite the great challenges faced by practitioners when practically implementing the lean-green combined approach, the theoretical and empirical promising results reported in the literature demonstrate that lean and green practices can generate a synergetic atmosphere when being implemented together, in the sense that their strengths can be enhanced and their weaknesses can be disguised, suggesting that the lean-green combined approach is the natural step towards achieving more sustainable manufacturing systems capable of keeping the balance among the three sustainability pillars, viz., economic, environmental and social, simultaneously.

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