

1 Article

2 Lean-Green Manufacturing Practices and Their Link 3 to Sustainability

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

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

25

26 1. Introduction

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

33 Lean practices have widely been adopted by companies all over the world, even by ones in other
34 sectors [1], [2], for the sake of developing an efficient approach by increasing value to customers while
35 reducing the resources consumption via waste elimination. By nature, lean practices are mainly
36 focused on economic issues, nevertheless, they can also positively contribute (to a certain extent) to
37 initiatives related to environmental [3], [4], and social [5], [6], issues. Moreover, in recent years,
38 several efforts have been reported towards evaluating to what extent lean practices can fulfil the
39 current environmental requirements [7], [8] as well as towards extending, modifying and updating
40 lean practices so that they can address social and environmental aspects more efficiently [9], [10], [11].
41 Based on these results, several researchers argue that sustainability is an evolution of lean practices
42 [5], [12], [4]. On the other hand, there are studies that argue that lean practices have not reached yet
43 the maturity level required to ensure sustainability [5], suggesting that a more holistic approach,
44 including health and safety is required [13]. In this line, many companies' leaders have realised that,
45 since lean practices are not always capable of fulfilling neither the environmental requirements

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

60 In this context, researchers have recognised that, on one hand, although lean practices, which
61 are mainly focused on economic aspects [18], [19] do have a positive impact on environmental [20],
62 [4], and social [5], [6] aspects, these positive impacts are not always enough to reach the sustainability
63 level required by the highly competitive market. On the other hand, green practices are mainly
64 focused on environmental aspects [7], [21] and do have a great impact on social [22], [21] aspects, but
65 their positive impact on the economic performance has largely been questioned [23], [24]. In this
66 conflicting situation, researchers and practitioners have realised that neither lean nor green practices
67 seem to be completely suitable to keep the expected balance among economic, environmental and
68 social aspects towards reaching the required level of sustainability. In this line, integrating both
69 manufacturing approaches into a single combined framework seems promising [1], [25]. In that way
70 simultaneous advantage can be taken of the operational, financial and (to a lesser extent) social
71 benefits obtained by lean practices, as well as of the environmental and social benefits obtained by
72 green practices. In particular, researchers expect that to implement both practices together could
73 generate a complementary atmosphere leading to concurrent enhancement of operational, financial,
74 environmental and social performances, by complementing lean benefits, such as, cost and lead time
75 reduction and increased product quality, with green practices aimed at reducing the environmental
76 impact of the whole manufacturing process, while working in a socially enhanced environment
77 where employees are not only well-trained and engaged but also enjoy a cleaner, safer and healthier
78 environment.

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

96 2. Lean manufacturing

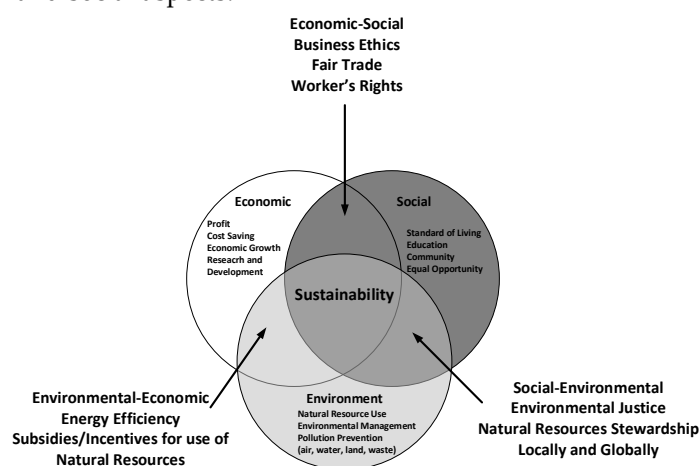
97 The lean concept, which is based on the infamous TPS philosophy [30] promotes the waste
 98 reduction (ideally, elimination) in all the organizations' aspects [31], being waste understood as any
 99 non-value-added activity. Lean manufacturing is aimed at increasing the value delivered to
 100 customers by eliminating waste, that is to say, by eliminating any non-value-added activity [30].
 101 Different definitions of lean manufacturing can be found in the literature: Womack et al. [32] see the
 102 lean concept as a manufacturing way of thinking that is able to decrease the time from customer order
 103 to the time when the product is already finished and shipped by reducing any waste. Liker and Lamb
 104 [33] on the other hand define lean as a system aimed at eliminating waste based on the concurrent
 105 reduction or minimisation of supplier, costumer, and internal variabilities.

106 2.1. Lean manufacturing: Tools and Techniques

107 Several techniques have been proposed in the literature within the framework of lean
 108 manufacturing in order to address costs reduction as well as productivity and quality improvements
 109 in order to fulfil customers' needs [3]. Among them, Just-in-time (JIT) [34], Standardisation of Work
 110 [35], Cellular Manufacturing (CM), Workplace Organisation-The Five S (5S) [36], Value Stream
 111 Mapping (VSM) [37], Total Preventive Maintenance (TPM) [38], Visual Management [39], Production
 112 Smoothing (Levelling) [40], and Quality at the Source or Do it Right the First Time, are the most
 113 popular ones. In [41], a recent and detailed review on such techniques is presented.

114 2.2. Lean manufacturing and its link to sustainability

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



122

123

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

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

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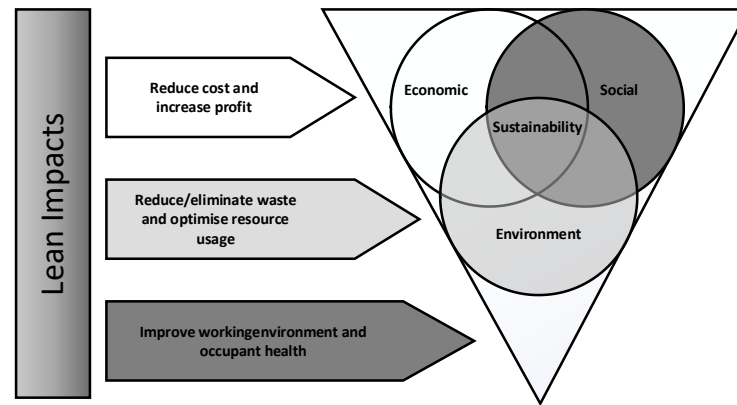


Figure 2. Lean contributions towards sustainability

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134

135 It is important to highlight that, despite the promising greener results obtained by lean practices
 136 [43], [4], [11], it is possible that the achieved benefits in other aspects than the economic one would
 137 be not enough to meet the current sustainability requirements. In this line, researchers agree that, in
 138 order to achieve a higher sustainability level, green practices should also be adopted. In next section
 139 a theoretical background about green manufacturing is provided and its main techniques are
 140 described.

141 3. Green manufacturing

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

154 3.1 Green manufacturing: tools and techniques.

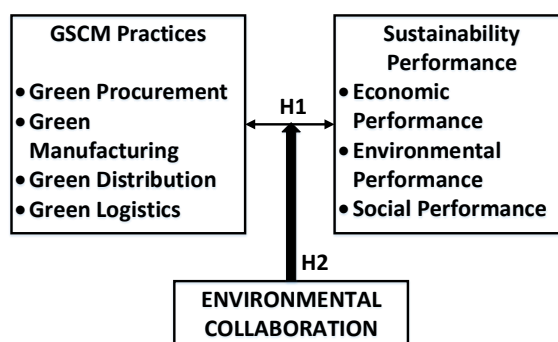
155 Green manufacturing faces challenges regarding both product and process perspectives.
 156 Regarding the product perspective, green manufacturing should be able to meet customer demands
 157 for environmentally friendly products, minimise resources use, and select materials that do not harm
 158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

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

170 3.2. Green manufacturing and its link to sustainability

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

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



201

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

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

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

218 4. Lean-Green manufacturing approach

219 In recent years, companies have recognised that, in order to lead in the current and future
220 markets, it is mandatory to move towards the next level of sustainability. The current trends in lean
221 and green manufacturing practices, respectively, as well as their link with the different sustainability
222 aspects have been discussed, showing that several efforts have been undertaken in order to reach
223 further improvements in the sustainability performance, either from the lean [44], [5], [12], [4], [11],
224 [59] perspective or from the green [60], [16], [17], [53], [52], [57], [58], [61], [55], [62] one. Nevertheless,
225 despite these great efforts as well as the promising results reported in the literature regarding lean
226 practices leading to environmental improvements [18], [4], [11] and green practices leading to
227 economic improvements [5], many researchers have concluded that, due to the fact that neither lean
228 nor green practices have particularly been aimed at addressing the three pillars of sustainability
229 simultaneously, their contributions towards these three sustainability aspects would not be enough
230 when implemented individually, being necessary to implement them in a combined framework.

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

237 4.1 Research questions and search methodology

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

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

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

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

256 4.2. Thematic Synthesis

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

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

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

288

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		

289 5. Towards a lean-green approach

290 The conducted SLR confirms that, in recent years, researchers have focused their efforts towards
 291 understanding the actual possibility of integrating lean and green practices in order to reach a higher
 292 level of sustainability. In fact, the 45 (100%) articles in the SLM of Table 4-1 have been published after
 293 2000, while 40 (88.8%) of them have been published after 2010. Here, it is important to highlight that,
 294 despite the great efforts reported in the literature towards investigating the combined approach, only
 295 45 articles have been found in the literature explicitly addressing this issue which, in comparison
 296 with the 73 and 67 articles gathered in the SLRs for lean and green practices, respectively,
 297 demonstrates that too much research has still to be conducted in this direction [27], [26], [25].

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

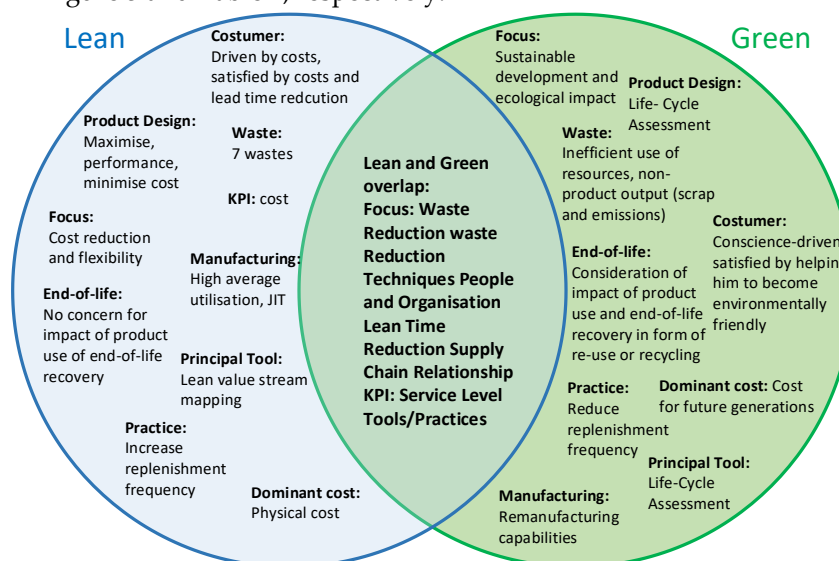
307 The integration of lean and green practices into a combined approach is a quite complex and
 308 challenging task [63], [26], [25], [27]. In order to be able to propose a combination strategy capable of
 309 integrating lean and green practices in such a way that they can work in a synergetic environment,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

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

322 5.1. Lean vs green manufacturing: similarities and differences

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

344 According to the articles selected in the SLR conducted here, most researchers in the field
 345 highlight waste reduction philosophy [82], resource productivity, organisational change and source
 346 reduction [29], among the main similarities between both practices, while identify their main focus
 347 [88], the waste definition [88], the type of customer, the manufacturing strategies, some adopted
 348 methods and practices [29] and the EOL strategies [64], as their main differences. Finally, in order to
 349 further visualise and understand the main similarities and differences reported in the literature, they
 350 are summarised in Figure 5 and Table 2, respectively.



351
 352

Figure 5. Lean and green common points [72]

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]: <ul style="list-style-type: none"> • Long-term thinking • Elimination of wastes • People commitment • Continuous improvements 	Green principles are mainly focused on [32]: <ul style="list-style-type: none"> • Pollution prevention • Reduction of toxic substances • DfE
Waste	Lean 7 wastes [29]: <ul style="list-style-type: none"> • Transport • Inventory • Motion • Waiting • Over-processing • Over-production • Defects 	<ul style="list-style-type: none"> • 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].

355 5.2. Lean vs green manufacturing: towards an integrated approach

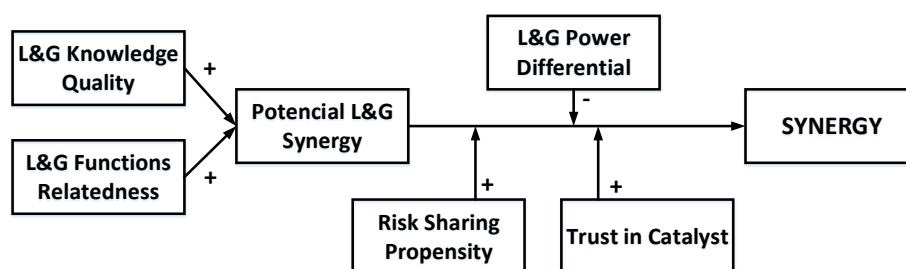
356 The different opinions discussed in Section 3.1, show that the discussion about which are the
357 common and conflicting points between lean and green practices is still open. Consequently, so it is
358 the discussion regarding whether they are actually compatible and suitable to work together. In
359 addition, not only too little empirical evidence of successful cases adopting lean-green approaches
360 can be found in the literature [65], [25], but also the results that can currently be found are conflicting
361 [63]. On one hand, there are researchers that argue that lean and green practices can work together
362 since they can be concurrent generating a synergy regarding waste reduction, energy, material and
363 time consumption, supply chain management and product life cycle optimisation [26], [89], [81], [25],
364 [10], [64], [28]. On the other hand, there are the ones that state that lean and green practices are not
365 always compatible, existing some areas where combining them can be particularly hard [68], [29],
366 [102]. For example, the inventory level is one of the most critical aspects when combining lean and
367 green approaches. In this case, while lean practices focus on producing, transporting and packing
368 small lot sizes to fulfil customers' requirements, the high replenishment frequency can imply higher
369 emissions and more packaging wastes, contradicting green principles.

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

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

401 According to [81], the synergetic hypothesis is suitable since there exist a similar structure for
402 the implementation of successful lean and green practices. In this line, in the SLR conducted here 14
403 (31.1%) articles address the compatibility from the synergetic point of view. In [83], authors state that
404 companies looking for being lean will have more success if they also seek green objectives. In the
405 same line, several researchers in the field who have largely discussed about "how green can be lean",
406 such as the ones in [68] and [9], have concluded that, since lean practices are not aimed at green

407 objectives, they cannot replace green practices towards achieving green results, but they can provide
 408 a continuous improvement, flexible and employees' engagement culture creating a suitable and
 409 highly favouring environment for the implementation of green initiatives. Authors in [100], agree
 410 with them, stating that the lean culture can be a catalyst for green practices, facilitating the adoption
 411 of environmental practices. Moreover, a particular example of such catalytic effect can be found in
 412 [64], where it has been proved that the impact of lean practices on operational supply chain
 413 performance can be improved by preventing pollution and recycling. According to [94], lean and
 414 green practices can generate sequential or reciprocal interactions, supporting each other, working in
 415 a complementary and synergetic environment. In [28], the synergetic effect generated by lean and
 416 green practices has proved to achieve several benefits, such as, fostering innovations and reducing
 417 the production costs of eco-friendly products. Finally, in [89], empirical evidence shows that, in order
 418 to actually reach the beneficial synergetic effect between lean and green practices, it is necessary to
 419 customise some operational aspects of the company as well as to ensure fluent collaboration with
 420 suppliers.



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Figure 6. Synergetic model in [81]

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

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

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

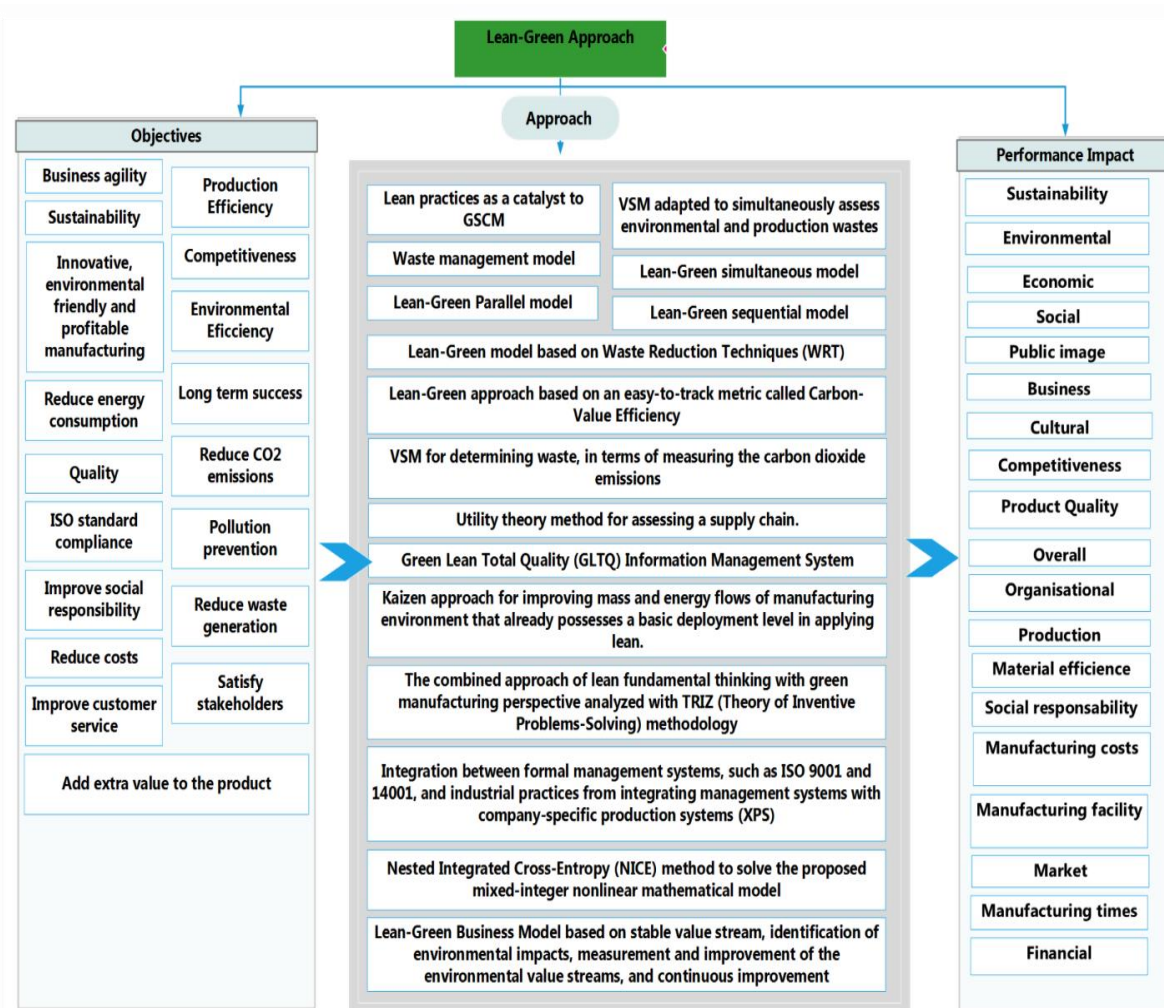
443 while there are others that, based on the fact that lean practices are not only well-documented
 444 but also widely (and successfully) adopted all over the world, as well as that the lean culture do
 445 favour the implementation of green initiatives, propose to use an already established lean
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

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

451 combine them into the same system based on a waste contradiction matrix. In [65], a waste
452 minimisation framework based on an advanced 3R (Reduction-Reuse-Recovery) method, is proposed.
453 In addition, although there is a strong tendency of using waste management methods, some other
454 approaches have been proposed to address the combination from the first group's perspective. In
455 [85], the multiple attribute utility theory method is used for assessing a lean-green supply chain. In
456 [106], a Green Lean Total Quality (GLTQ) Information Management System, which is an Information
457 Management (IM) system within the context of an Environmental Management System (EMS),
458 integrated to TQM and lean principles, is proposed. In this way, authors in [97] intend to achieve
459 total communication efficiency based on a green-lean TQM system, demonstrating that the proposed
460 approach allows generating more revenues and also providing Research & Develop facilities. In [97],
461 a combined lean-green approach based on the integration of management systems, such as ISO 9001
462 and 14001, is proposed. In [27], an Analytical Hierarchical Process (AHP) is used to integrate TPM
463 and ISO 14001 principles into a lean-green combined framework. In [98], a case study is conducted on
464 different Alsatian industrial companies in order to develop a lean-green management framework
465 based on lean indicators as well as green performance and intentions indicators.

466 Within the second group, several researchers have proposed to incorporate green practices to
467 manufacturing processes that have already adopted a lean philosophy. In this line, one of the most
468 frequently proposed approaches consists in taking advantage of the flexible nature of lean practices
469 by modifying and adapting them so that they can work in combination with green practices towards
470 the same objectives. In particular, the most frequently reported adapted lean tools are VSM ([73], [69],
471 [70]) and Continuous Improvements principles [74]. In [95], the implementation of lean and green
472 practices combined within a continuous improvement culture in a SME foundry is studied. In [95],
473 VSM is adapted to address environmental and production wastes. In [69], the VSM tool is proposed
474 for determining waste, in terms of measuring the carbon dioxide emissions particularly across
475 organisational boundaries within the context of a food industry. In [74], a green-lean business model
476 based on five principles, viz., stable value stream, identification of environmental impacts,
477 measurement and improvement of the environmental value streams, and CIs, is developed for a
478 global engineering company. In [70], a novel metric integrating metrics derived from lean and green
479 implementations. Experimental results in [72] show that the proposed approach is capable of
480 reducing the carbon footprint by improving not only the Carbon-Value Efficiency but also the
481 production lead time.

482 In Figure 7, the most relevant contributions towards the integration of lean and green practices,
483 in terms of the main proposed approaches, their objectives and their main impacts on the companies'
484 performance, are shown. Here, it is important to highlight that, although lean as well as green
485 practices do include activities that can be implemented throughout different areas of the company,
486 addressing different stages of the productive process, the articles selected in the SLR show a strong
487 tendency of implementing and evaluating the lean-green approach within the context of supply chain
488 management [72], [64]. In fact, although there are the ones that reports the combination of both
489 practices to address other manufacturing issues, such as, metrics [74], [73], quality [73], [27], safety
490 [106], lead time [27], customer service [106], cost [106], inventory [106] and transportation [83], there
491 exists the necessity for more research regarding the different production stages [83]. Finally, in [69]
492 and [25] it is stated that there is a lack in the literature regarding empirical evidence of practical
493 implementation of the combined lean-green approach. In order to fill this gap, among the 21 (46.6%)
494 articles proposing strategies for implementing the lean-green combination, 9 (20%) have report
495 results obtained by the lean-green implementation within real manufacturing scenarios from
496 different countries all over the world, such as, construction projects [63], metal stamped parts
497 production [69], Swedish industry [72], food industry [27], part production in the automotive sector
498 [74], Chinese Fashion AutoParts industry [78] and SME foundry [105]. In [95], authors go even further,
499 presenting the results obtained by implementing the proposed lean-green approach in different
500 companies, with different sizes and operating in a different business area, giving researchers in the
501 field benchmark data allowing them to expand their approaches to other companies and
502 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

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7. Green-Lean approach and its link with sustainability

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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

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

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

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

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

583 **Table 2.** Success factors towards achieving sustainability performance by implementing the green-
 584 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]

585 8. Conclusions and remarks

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

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

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