The relationship between Lean practices and environmental performance: practices and measures

Abstract

Lean production has emerged in the past decades as one of the most popular themes in the business and manufacturing literature as it is the most extended production paradigm currently applied in industry. The lean approach is characterized by five principles (value, mapping the value stream, flow, pull and continuous improvement) that facilitate the reduction of waste (*muda*). In parallel, the environmental performance of a company in terms of pollution prevention, reduction and use/waste of resources is an issue increasingly concerning companies and customers in recent years. The focus on these issues has spurred an area of research that is commonly known as green production. Lean and green production concepts are both focused on waste reduction, and several authors have studied their relationships (commonalities and divergences) and the synergic effects of integrating these two management approaches. This research conducts a literature review in order to: (1) identify if firms which have applied lean principles and methods have improved their environmental measures; (2) highlight the environmental measures that are positively affected by lean practices adoption; and finally (3) underline the most important lean practices in relation to impacting environmental performance. The results are condensed in a final matrix that links some key lean practices to specific environmental measures. This matrix is of great interest for both researchers and practitioners since it suggests some possible relationships between various lean practices and the improvement of specific green performances. The findings give light regarding the state-of-the-art relationships between the lean and green production approaches.

Keywords: Lean production, Green production, Environmental performance, Practices, Measures.

1. Introduction

Lean production system (Womack and Jones, 1996) is the most extended production paradigm nowadays as it pursues the reduction of non-value-added activities in the entire processes of organisations, identifying seven types of waste, also known as *muda* in lean environments (Ohno, 1988).

In parallel, environmental sustainability is nowadays a strategic imperative for organisations, which must be aligned to their traditional priorities of profitability and efficiency (Garza-Reyes, 2015). Limiting the environmental sustainability concept, arises the notion of green production (Berkel et al., 1997), which "aims a continuous integration of environmental improvements of

industrial processes and products to reduce or prevent pollution to air, water and land; to reduce waste at source; and to minimize risks to humans and other species".

Recently, several academics have studied the possible relationships between the adoption and the outcomes of both lean and green production. Some scholars argue that it is possible for lean companies to achieve environmental performance improvements since lean and green may have elements in common as both are focused on reducing waste and increasing efficiency of production processes (Cherrafi et al., 2017b; Florida, 1996; King and Lenox, 2001). However, the results achieved to date are not always consistent with themselves as some studies strongly highlight the existence of a positive relationship while others are more cautious by suggesting that lean practices' implementation does not necessarily enable green performances in firms (Carvalho et al., 2017; Dües et al., 2013; Rothenberg et al., 2001; Simons and Mason, 2003).

Regardless of the results obtained, the study of the relationships between lean and environmental performance has also encouraged various scholars to explore new areas of research within this field. Some of these academics have developed joint models for the implementation of both paradigms (Ng et al., 2015; Pampanelli et al., 2014; Kurdve et al., 2014; Verrier et al., 2016), have designed assessment frameworks (Gupta et al., 2017; Helleno et al., 2017; Thanki and Thakkar, 2016) and studied the barriers that may counter the implementation and assessment of lean and green paradigms (Cherrafi et al., 2017a; Mittal et al., 2016). Other authors have investigated the relationship between both paradigms in different sectors besides manufacturing and with special characteristics such as construction, consumer goods industry, logistics and foundry industry (Bae and Kim, 2018; Colicchia et al., 2017; Ugarte et al., 2016; Garza-Reyes et al., 2016; Prasad et al., 2016). Additionally, the analysis of these relationships within diverse national contexts such as India, China, Sweden and Brazil has also been studied by several academics (Thanki et al., 2016; Zhan et al., 2016; Kurdve et al., 2014; Jabbour et al., 2013).

Therefore, the purpose of this paper is to develop a literature review aimed first and foremost at knowing which environmental measures are used more frequently in the literature and the possible effects of lean practices on them. Secondly, deepen on the identification of the possible relationships between various lean practices and environmental performance using the well-known lean practice bundles proposed by Shah and Ward (2003). The paper also presents a final matrix which links some lean practices to specific environmental measures. The final sections are reserved to the conclusions regarding this research.

The originality of this study lies in the investigation of the connections between lean practices and environmental measures found in literature, resulting in the identification of various possible positive impacts of each practice in each indicator. This contribution facilitates the general understanding of the specific effects of lean practices on each measure so far investigated in literature, regrouping them and giving them a numerical value in order to emphasize their importance.

In addition, two research gaps and various future research recommendations are acknowledged in this manuscript since the study of the relationships described is of interest to academics in the operations and waste management and sustainability areas; as well as to business managers designing lean and environmentally sustainable operations and to policy advisors. Moreover, it is useful for companies in general to improve brand image and increase demand, since

environmental damage is a problem worrying more and more customers, which are requesting cleaner products and raw materials, less waste and reduced pollution.

2. Research methodology

The recent attention paid to the relationship between lean and green production and the effects on environmental performance have attracted authors to explore its implications in different dimensions.

This research primarily analyses the published literature utilising a systematic literature review (SLR) adapted from Garza-Reyes (2015). Figure 1 shows an overview of the SLR by describing its phases, objectives, methods adopted and their setting within the article.

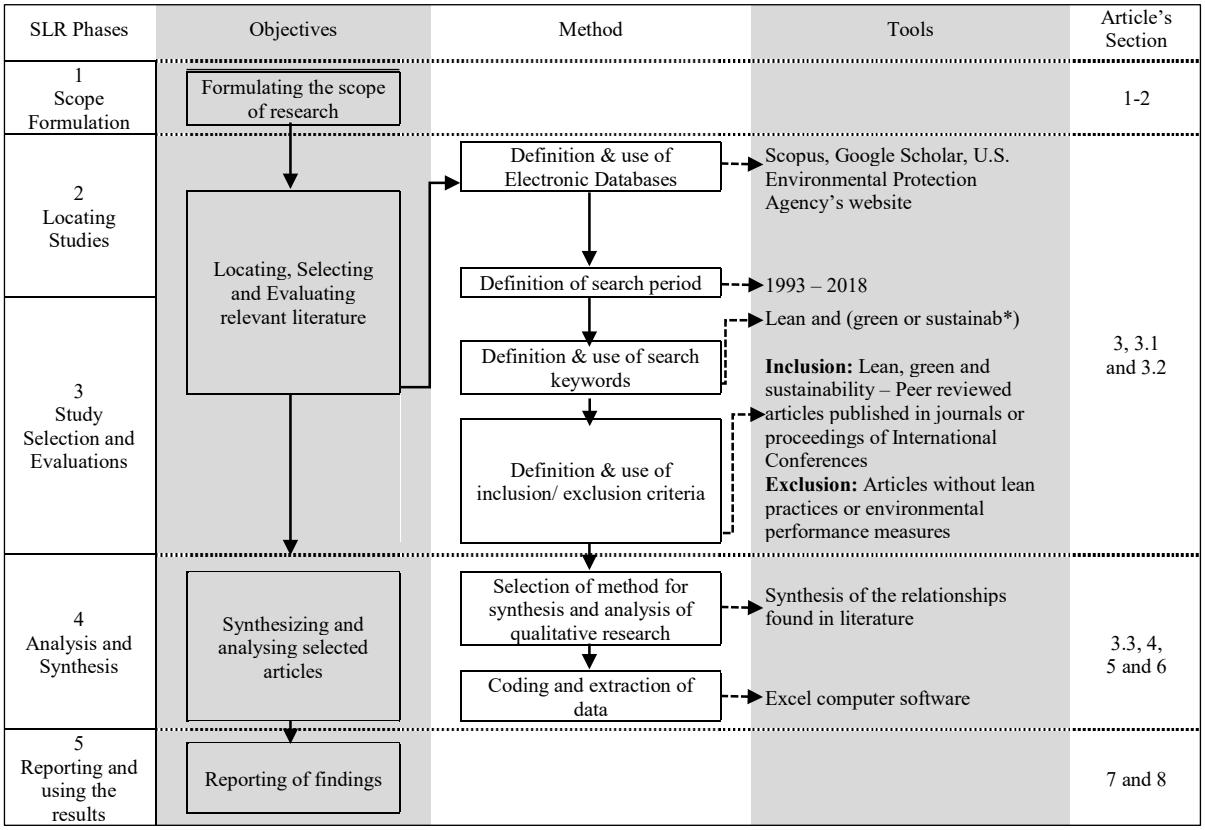

Figure 1. SLR phases, objectives, methods and setting within the article (adapted from Garza-Reyes, 2015).

From the foregoing, in phase 1 the scope of the research was formulated as "the identification of the effects and relationships between various relevant lean practices and environmental performance measures". The reminder of the paper presents the phases 2-5 starting with phase 2 (in Section 3). In it, the whole analysis is provided starting with the description of the selection method of the papers and the SLR continues following the phases noted in Figure 1.

3. Literature review

3.1. Paper selection method

In order to examine the relationship between lean production and environmental performance, the web literature databases Scopus and Google Scholar and the U.S. Environmental Protection Agency's website (EPA) were consulted. The EPA website was included because this agency has researched extensively in this area and has published a range of relevant reports. Moreover, to find the documentation and articles needed for the literature review, the following keywords were searched: lean and (green or sustainab*). Using the asterisk in "sustainab", the database would take all the keywords which start with this word, not discarding those referencing the same concept although they are not written equally as the keyword, for example, "sustainability" or "sustainable". These keywords were searched in the title, abstract and keywords. The article and the time interval selected started from 1993 and concluded in 2018, containing in this way the most relevant preliminary publications about this topic and the most recently released. 1993 was selected as initial date for the search due to the publication of a novel and relevant article in this field written by Corbett and Wassenhove (1993), which studies various analogies between environmental programs and successful practices in current use in operations management (including lean techniques).

The results obtained searching the keywords mentioned are shown in Figure 2. In summary, 3,081 articles resulted from the database research.

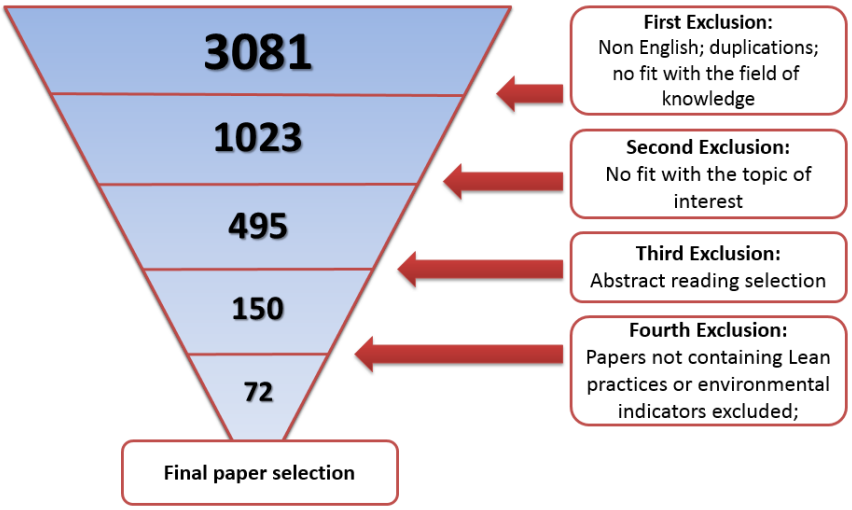

Figure 2. Article selection criteria

Applying the exclusions detailed in Figure 2, from the preliminary results found in the database, 72 documents were selected for the elaboration of this literature review study. The selected articles are listed in Appendix A (Table A.1).

3.2. Paper classifications

The 72 papers selected were then assorted according to various criteria, i.e. publication dates, source and research methods. These are presented in Figure 3, which shows the sorting of documents emerging from the selection detailed in Appendix A (Table A.1) based on their date of publication. The papers were grouped in five-year periods starting from 1993, except the last interval that included 6 years until 2018.

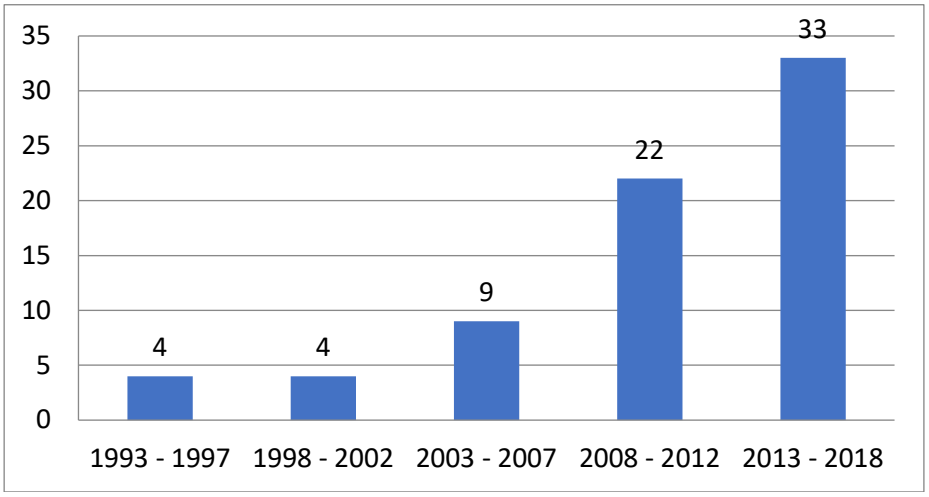

Figure 3. Publication dates of the documents

The data highlighted the growing significance in literature of the topic regarding the relationship between lean and environmental performance, particularly from 2008 onwards.

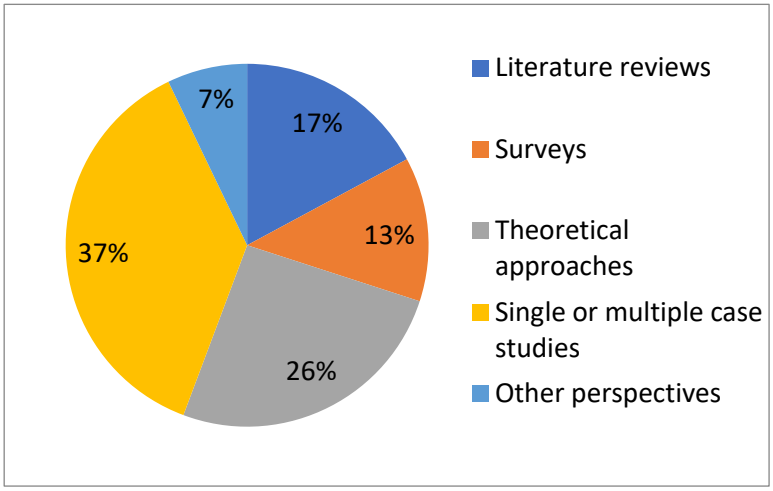

Figure 4. Research methodologies adopted

Figure 4 shows the breakdown of the papers considering the research methodology adopted excluding the two books (Dornfeld et al., 2012; Zokaei et al., 2013). In particular, thirty-seven of the articles (26 papers) had used a single or multiple case study methodology. For example, in this category, the work of Campos and Vazquez-Brust (2016) conducted an in-depth case study of the Brazilian subsidiary of a large multinational company using interviews, in-plant observations and document analysis. Carvalho et al. (2017) presented a case study from an automotive supply chain and demonstrated that not all companies belonging to the same supply chain can be lean or green. Another important work was developed by Galeazzo et al. (2014), making the analysis of three pollution-prevention projects undertaken by two manufacturing plants of two large multinational firms. Finally, Piercy and Rich (2015) used a longitudinal multi-year case study approach to analyse the sustainable benefits of lean operations.

Twenty-six percent of the papers (i.e. 18) were based on theoretical approaches. In this category, it is noteworthy the work conducted by Bergmiller and McCright (2009b), which

indicated that lean and green programs lead to improved business results and integrated both paradigms in a single model. Additionally, Verrier et al. (2016) analysed the synergies between lean and green wastes and the tools used for their elimination, the results were highlighted in a lean and green house model. Vinodh et al. (2011) explored various issues of sustainability using lean initiatives and studied the techniques that would facilitate sustainability objectives with a theoretical approach.

Seventeen percent of the articles developed (i.e. 12) are based on a literature review analysis. In recent research, Chugani et al. (2017) stated that lean and Six Sigma can support the conservation of resources, combat global warming and save energy. Dües et al. (2013) explored and evaluated previous work focussing on the relationship and links between lean and green supply chain management practices. Furthermore, Garza-Reyes (2015) developed a concept map identifying six research streams from literature and suggested various valuable research questions for future research in this field.

Thirteen percent of the papers (i.e. 9) investigated the topic through a survey-based approach. In this case, Hajmohammad et al. (2013) confirmed the impact of lean and supply management on environmental performance, mediated by environmental practices through a survey collected from a sample of Canadian manufacturing plants. Rothenberg et al. (2001) examined the relationship between lean manufacturing practices and environmental performance in terms of air emissions and resource use, drawing on two surveys of 31 automobile assembly plants in Japan and North America.

Finally, the remaining seven percent of articles (i.e. 5) were labelled as "other perspectives" in Figure 4. Fercoq et al. (2016) studied the integration of lean and green strategies focused on waste reduction via the design of experiments methodology. Similarly, Hong et al. (2012) used structural equation modelling to demonstrate if lean practices are an important mediator to achieve excellent environmental performance, whereas King and Lenox (2001) conducted an empirical analysis of the environmental performance of 17,499 U.S. manufacturing firms throughout the time period 1991-1996. In addition, Venkat and Wakeland (2006) used a simulation model to measure the emissions of various generic lean supply chains. As a final point, Yang et al. (2011) studied the impact of lean manufacturing and environmental management on business performance of 309 international manufacturing firms using database information.

3.3. The lean and environmental performance relationship in literature

The articles identified were classified in order to understand whether there is a positive relationship between lean practices adoption and environmental measures improvement. Nevertheless, before doing this, it was considered that 6 articles from the set did not suggest, within their findings, the existence of a positive, negative or mixed relationship, consequently they were not included in the following Figure 5. Conversely, literature review (i.e. 10) and theoretical approaches (i.e. 17) publications were included in the analysis since they were valuable to get a deeper understanding and give further importance and consistence to the conclusions drawn from the analyses. These papers "confirm" the suggestions of previous scholars, or even conclude that certain practices may be positive, negative or mixed; perhaps without proving empirical evidence but by providing examples of application and arguments that contribute to the discussion of the topic.

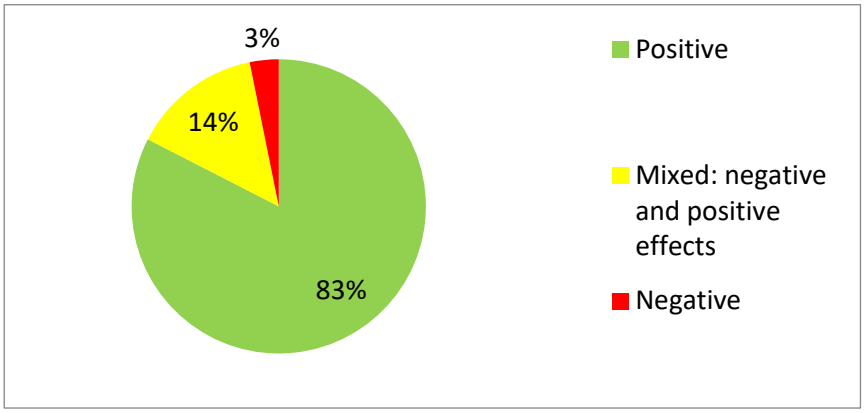

Figure 5. Relationships between lean and environmental performance

The vast majority of the studies in literature suggests that lean has positive effects in the environmental performance of companies. More precisely, the overwhelming majority of literature sustains that both lean and environmental performance activities have a waste reduction focus. On one hand, lean manufacturing seeks the reduction of non-value-added activities and the improvement of efficiency (Womack and Jones, 1996). On the other hand, environmental sustainability and green manufacturing have an ecologist point of view: banish waste in order to achieve pollution and emissions prevention as it is mentioned in one of the three pillars of the Triple Bottom Line (3BL). In particular, authors such as Garza-Reyes et al. (2018), Chiarini (2014), Helleno et al. (2017), King and Lenox (2001) and Piercy and Rich (2015) verify that the application of some practices composing the lean transformation path go beyond economic results and lean waste (*muda*) reduction: these techniques additionally enable the improvement of diverse environmental measures.

However, applying lean techniques some *blind spots* can arise during their implementation. This means that in addition to the lean waste reduction and continuous improvement concepts, which frequently produce implicit environmental performance, there are further "hidden" opportunities to achieve this purpose (EPA, 2003). Moreover, some practices as source reduction, production process improvements and facility downsizing, which imply pollution prevention can be enclosed in a lean thinking view, even if they are traditionally framed in the environmental management field.

Nevertheless, not all authors agree that there are only positive relationships between lean production practices and environmental measures. For instance, 14% of the papers analysed concluded that lean may have both positive and negative environmental effects; depending on the practices applied and the indicators measured. As it was affirmed, for example, by Carvalho et al. (2017), Dües et al. (2013), Rothenberg et al. (2001) and Simons and Mason (2003), lean and green production are in some cases divergent. Among the causes of this contrast, some authors suggest that the search for greater levels of productivity and efficiency is not consistent with environmental sustainability in manufacturing. Additionally, business growth generally implies more production, transportation, deliveries and stock; these additional activities mean extra wastes in the normal functioning of the company. For example, integration with suppliers via *kanban* (Monden, 1983) requires more frequent deliveries and therefore greater fuel consumption for transport. An additional point of reflection is that the financial savings gained by environmental management techniques are not always significant or even non-existent.

A minor part of the sample rejected, in some way, this positive relationship between the two paradigms. Cusumano (1994) affirms that lean has the limitation of producing increased negative product impacts and may intensify the emissions produced by just-in-time and kanban. Moreover, Venkat and Wakeland (2006) similarly suggest that carbon dioxide levels may increase, and suggest that lean supply chains are not necessarily green, remarking distance as main impediment to enhance environmental performance.

As a final point, it is worth noting that from this general analysis of the relationships in literature between lean and environmental performance and returning to Figure 4, from those articles that highlighted that lean may have mixed results, 3 were literature reviews, 2 were empirical studies, 2 were surveys and 2 theoretical models. One article using simulation and another a theoretical model considered negative the lean and environmental performance relationship. At this stage, it is important to remark that this analysis is the first and general classification of the papers. These documents will be analysed point by point in the forthcoming sections, relating first lean and environmental performance measures (EPA, 2007), secondly linking lean bundles (Shah and Ward, 2003) and environmental performance, to end up with the relationships between practices and measures.

4. Environmental measures presence and performance in literature

In this section, the attention is focused on the environmental performance measures that have been considered in the extant literature when analysing the relationships between lean implementation and environmental improvements. For this aim, the list of measures and the categories proposed by the U.S. Environmental Protection Agency were used as they are a summary of basic measures directed to waste reduction goals and many leading enterprises already use them in their reports (EPA, 2007).

Within the sample of 72 papers analysed, the EPA indicators most used to measure the environmental performance of companies adopting lean practices were air emissions, energy use, solid waste, water pollution, toxic/hazardous chemicals use, water use and materials use (see Figure 6, the indicators are listed in descending order of quotations).

For each indicator, Figure 6 shows the number of studies suggesting that the adoption of lean practices has improved its value (green colour), worsened its value (red colour), and in some cases, both improved and worsened its value (yellow colour). In addition, the grey colour indicates the number of studies that used that measure among their checklists for testing lean's environmental performance, but that at the same time did not provide values of improvement or worsening (i.e. Faulkner and Badurdeen, 2014; Taubitz, 2010; Vinodh et al., 2011). The measure of cost savings and the qualitative measures (i.e. further environmental improvements that cannot be directly or accurately quantified) were removed since they can cause confusion in the interpretation of the findings. For this reason, measures referred to inputs used, non-product outputs released and downstream/product measures were only considered.

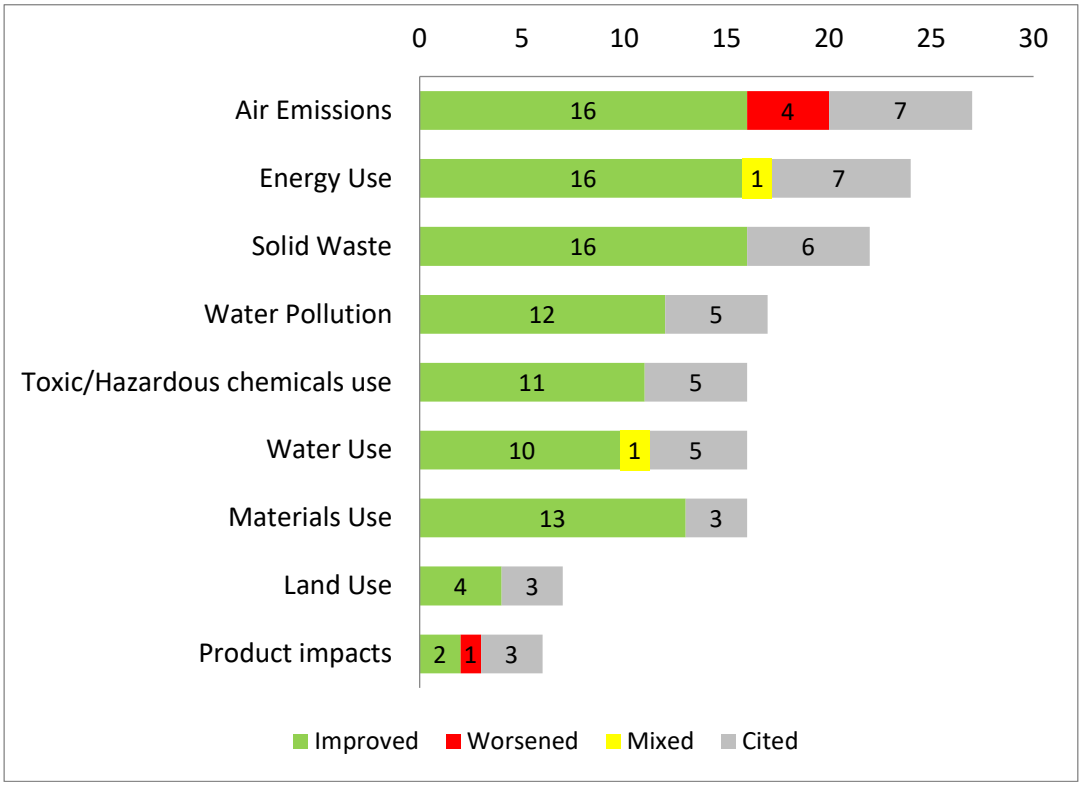

Figure 6. Distribution of the results of the environmental measures.

As shown in Figure 6, the indicators that are most positively affected by the implementation of lean practices, according to the literature, are air emissions, energy use and solid waste (Garza-Reyes et al., 2018; Deif, 2011; EPA, 2007; Fliedner, 2008; Gustashaw and Hall, 2008; Hajmohammad et al., 2013; Wiese et al., 2015). These results held by these and other papers strongly sustain the affirmation of a direct relationship between lean and green.

However, it is interesting to note that for the air emissions measure, there are four papers that suggest that this relationship is not positive and that some lean practices can be harmful to the environment (Cusumano, 1994; Rothenberg et al., 2001; Simons and Mason, 2003; Venkat and Wakeland, 2006). Similarly, product impacts (Cusumano, 1994) has one article sustaining negative results. In addition, energy use (Chiarini, 2014) and water use (Rothenberg et al., 2001) present one mixed outcome each, which can also conflict with environmental performance, since both positive and negative relationships between these measures and lean can neither be confirmed nor rejected.

Additionally, but to a lesser extent, materials use, water pollution, toxic/hazardous chemicals use and water use (Chapman and Green, 2010; EPA, 2013; Pampanelli et al., 2014; Vais et al., 2006) are also strongly related with lean practices. Land use (Aguado et al., 2013; EPA, 2007) and product impacts (EPA, 2007; Fliedner, 2008) are the indicators that have less positive evidence in the literature.

As it was stated before, the cost saving indicator was removed to present a clear analysis. However, the importance of lean practices leading to significant economic savings for companies it is not denied, gained from efficiency and waste and materials use reduction (Galeazzo et al., 2014; Miller et al., 2010; Pampanelli et al., 2011).

5. The relationship between lean practice bundles and environmental performance

The purpose of this section is to understand which of the commonly associated groups/bundles of lean practices are most closely related to green performance. The lean approach is a multi-dimensional concept that is characterized by a number of practices aimed at accomplishing the objectives of "doing more with less" and increasing value deliverance to customers. Through their work, Shah and Ward (2003) proposed a model that categorizes these practices into four bundles. Other works have proposed similar classifications, e.g. Chan et al. (1990), Flynn et al. (1995), Netland et al. (2015) and Panizzolo (1998), but Shah and Ward's (2003) model was used to compare the company's environmental effects because of its relevance in the operations management literature and its internal consistency between practices. Moreover, these bundles are the most generally accepted in the academic literature (see Figure 7):

- Just In Time (JIT): flow production, pull systems, cellular manufacturing, supply chain management (SCM including supply integration and monitoring), value stream mapping (VSM), quick changeover techniques i.e. single minute of exchange of die (SMED).
- Total Quality Management (TQM): statistical process control, continuous improvement (*kaizen*), standard operation procedures, 5S, visual management.
- Total Preventive Maintenance (TPM): preventive maintenance, autonomous maintenance.
- Human Resource Management (HRM): multifunctional workers, training, team decision-making, worker's autonomy.

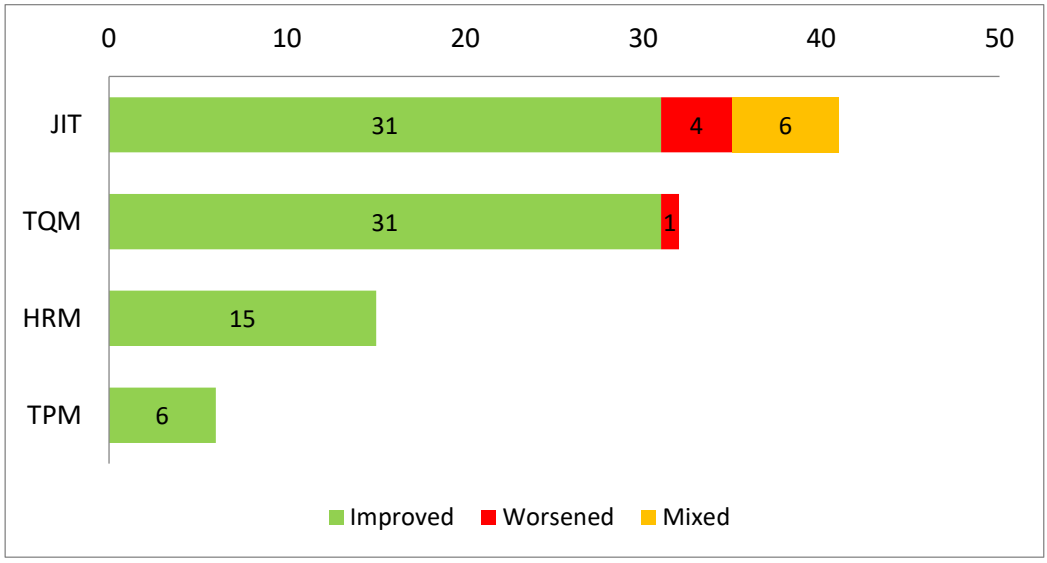

Figure 7. Distribution of the results of the practice bundles.

Within the set of articles selected, JIT techniques are the most utilized and evaluated in order to study their relationships with environmental performance, followed by the TQM bundle. HRM and TPM practices are the fewer cited in literature referring to environmental performance.

In addition, JIT seems to be one of the most positive bundles after the review of the literature. This bundle includes the VSM tool, which is typically used by lean practitioners to see environmental wastes in processes (Aguado et al., 2013; EPA, 2007; Gustashaw and Hall, 2008; Simons and Mason, 2003). Similarly, Cherrafi et al. (2017), Hajmohammad et al. (2013), Piercy

and Rich (2015) and Wiese et al. (2015) suggest that SCM provides means like consolidation of orders and improved fill rates, for example, by which environmental actions can be encouraged leading them to superior environmental performance.

In the same way, TQM and the lean practices included in this bundle enhance environmental performance according to the literature analysed. Kaizen is considered in literature as an important mediator to achieve environmental performance (Hong et al. 2012). For instance, through continuous improvement teams, kaizen enhances mass and energy flows in manufacturing environments (Pampanelli et al., 2014), identifying wastes and learning how to eliminate them along the value stream (Chapman and Green, 2010). Similarly, 5S is considered a good starting point for learning how to identify and eliminate waste (Taubitz, 2010), produces higher productivity and less defects to enhance better environmental performance at the source (Miller et al., 2010; Vais et al., 2006).

With less importance in the literature, but with remarkable positive results, the HRM bundle, which includes practices such as employee training (Sobral et al., 2013) and people commitment techniques, improves lean success. Lean success drives firms towards sustainable operations management and facilitates avoiding failures, during the production process, which might lead to rework or unnecessary use of resources (Rothenberg et al., 2001; Wong and Wong, 2014).

To conclude with the positive effects of lean and in regards to the TPM bundle, authors such as Garza Reyes et al. (2018), Cherrafi et al. (2017b), Chiarini (2014) and Fliedner (2008) concluded that preventive and proactive maintenance are environmental improvement facilitators as they reduce numerous machine-associated impacts, e.g. air emissions, noise pollution and oil leakage. They also eliminate process failures that generate rework, scraps and unnecessary resource consumption.

In opposition, the JIT bundle seems to be the most problematic since small lot deliveries might produce additional wastes and emissions (Rothenberg et al., 2001; Venkat and Wakeland, 2006). Some authors consider it as the principal area where lean and green cannot be combined (Dües et al., 2013; Zhu and Sarkis, 2004). JIT practices may cause further degradation of environmental performance and companies should take care, from an environmental perspective, when implementing them (Zhu and Sarkis, 2004). Cusumano (1994) describes that in Japan, plants have altered their JIT systems to reduce air pollution. Furthermore, frequent delivery practices may result in an increase of transportation, which rises CO_2 emissions, contradicting the air emission reduction principles of green practices. Dües et al. (2013) explain that companies have to find new solutions to minimise the impact of JIT practices on the environment. They suggest that this can be done by, for example, selecting suppliers from a certain geographic area to enable truckload sharing for delivering or, when small amounts have to be delivered, managing the routes in order to supply multiple customers in the same area. Other scholars affirm that there may exist positive and negative effects at the same time, for example, reduction of hazardous inventories versus the need of extra packaging (Corbett and Wassenhove, 1993). Moreover, Rothenberg et al. (2001) suggest that the focus on JIT principles, waste minimization and buffer minimization can conflict with some features of environmental performance, in particular, with the VOC (Volatile Organic Compounds) emissions. In addition, some SCM objectives which are included in this bundle can conflict with environmental interests as distances increase along the supply chain (Simons and Mason,

2003; Venkat and Wakeland, 2006) and can produce mixed positive and negative outcomes. These are the so-called trade-offs since not all companies belonging to the same supply chain can be absolutely lean or green and some strategies do not seem naturally synergistic. Some authors remark the benefits of understanding these trade-offs and their possible optimization may enhance performance in the future (Carvalho et al. 2017; Mollenkopf et al. 2010). Finally, the TQM bundle presents one negative impact. Rothenberg et al. (2001) explain that goals like superior quality of products, for example, may lead to greater consumption to achieve the desired quality levels. Rothenberg et al. (2001) suggest that the use of water, for example, in some processes is critical to product quality, consequently lean plants may have greater water consumptions for the achievement of superior quality.

6. Relating single lean practices and environmental indicators

Table 1 illustrates the positive relationships found in literature between the EPA environmental categories and various relevant lean practices included in Shah and Ward's (2003) bundles. The value inside the cells show the number of papers that suggest a positive relationship between the practice in the row and the environmental measure of the column within their studies and examples of implementation. In addition, the rightmost column in Table 1 shows the degree of importance of each lean practice. Similarly, the last row indicates the green measures that most benefit from the implementation of lean practices.

		Energy Use	Land Use	Materials Use	Toxic/Hazardous chemicals use	Water Use	Air Emissions	Water Pollution	Solid Waste	Product impacts	Money Saved	Most impactful practice
JIT	**SCM**	4	1	4	4	1	6	2	5	1	2	30
	VSM	7	3	8	6	5	9	5	7	2	8	60
	SMED	2	0	1	0	0	2	1	1	0	1	8
	5S	5	2	5	3	2	3	2	4	1	3	30
TQM	**Kaizen**	3	2	4	6	5	5	4	4	2	5	40
	KPIs	1	0	1	0	1	2	0	1	0	1	7
	Visual management	2	1	2	1	1	2	0	1	0	0	10
TPM		2	0	1	1	0	2	1	3	0	1	11
HRM		2	0	1	0	2	1	0	1	0	0	7
Most impacted measure		28	9	27	21	17	32	15	27	6	21	

Table 1. Lean practices and environmental measures

The results shown in Table 1 suggest that VSM, with its waste identification techniques, positively improves the values of the measures corresponding to air emissions, money saved and energy use (Cherrafi et al., 2017b; Deif, 2011; EPA, 2007). The indicators materials, solid waste and toxic/hazardous chemicals use are also benefited by the VSM implementation (Pampanelli et al., 2014; Fliedner, 2008; Chapman and Green, 2010). Moreover, but with less effect, water use and water pollution are also positively affected (EPA, 2007; Pampanelli et al., 2014).

Secondly, continuous improvement, or kaizen, uncovers and eliminates hidden wastes, waste generating processes and significantly enhances the measures corresponding to toxic/hazardous chemicals use, water use, money saved, water pollution, solid waste (EPA, 2007; Pampanelli et al., 2011; Pampanelli et al., 2014), materials use and air emissions (Garza Reyes et al., 2018; EPA, 2013). Less evidence of a positive relationship between kaizen and energy use was found (Fliedner, 2008).

Furthermore, the literature suggests that SCM reduces air emissions, solid waste and toxic/hazardous chemicals use (Hajmohammad et al., 2013; Zhu and Sarkis, 2004). In addition, packaging wastes and other unnecessary materials might be reduced using SCM (EPA, 2003) and strategies integrated in this practice. For instance, supplier selection could be useful in order to achieve energy saving gains as was remarked by Cherrafi et al. (2017b).

A number of studies affirm that 5S can assist in maintaining an orderly workplace and using its principles to reduce energy consumption by evidencing, for example, those machines which should or should not be operating (EPA, 2007; Torielli et al., 2011). Additionally, other studies have also suggested that 5S can contribute to enhance productivity by facilitating the reduction of materials utilization (EPA, 2003; Vais et al., 2006), improve solid waste treatment processes (Cherrafi et al., 2017b), reduce the consumption and utilization of toxic/hazardous chemicals (Fliedner, 2008) and increase money savings through its implementation in some projects (Miller et al., 2010).

As a final point, it is noteworthy that the numbers in Table 1 are not identical to the numbers included in Figures 6 and 7. The reason is that in this table direct relationships present in the literature are analysed, which denotes that if a paper uses two different indicators in the same study, in this chart the article will be taken into account twice and in the previous figures once.

7. Discussion and conclusions

The literature demonstrates that lean leads to green, and even more, that it facilitates a cultural organisational background that drives the formulation and achievement of green objectives like waste elimination and pollution prevention, which are mandatory for environmental performance (EPA, 2003). Thus, previous conclusions suggested in the literature in regards to lean leading to green are confirmed by the present work, hence those businesses that are following a lean transformation process might improve resource efficiency and therefore will increase their ecological outcomes (King and Lenox, 2001).

On the other hand, there are some existing divergences between lean and green that may result in negative implications for the environment. These are known as trade-offs in the literature and were highlighted in this article. The results of the study suggested JIT as the most

conflictive bundle. JIT confronts low inventory levels and more frequent transportation with additional pollution and reduced environmental performance (CO_2 emissions or additional package for example). In addition, the longer the distance of transportation is, or the more the production lines involved, the less environmentally friendly the process becomes (Venkat and Wakeland, 2006; Zhu and Sarkis, 2004). Still, recent researches from Carvalho et al. (2017), Chiarini (2014) and Dües et al. (2013) do not seem to agree with the suggestion that JIT practices lead to environmental benefits.

Furthermore, from the analysis of the indicators, it is possible to elucidate which are the most used and the most positive measures considered in the literature, and in which indicators companies shall pay attention when applying lean practices in order to improve their environmental performance. In relation to this, this paper concludes that companies have to pay extra attention to the air emissions produced, which is the main measurable divergence between lean and environmental performance (Venkat and Wakeland, 2006; Rothenberg et al., 2001; Simons and Mason, 2003). Thus, companies have to effectively manage their JIT activities as they might be a relevant factor of air pollution increments. However, studies relating lean and environmental performance frequently use "traditional" lean and supply chain tools and technologies which are obviously between those most widely implemented in industry. In this sense, it could be challenging to carry out newer studies to empirically review the effects that JIT, SCM and logistics activities have with the incorporation of the newest technologies. Consequently, a need to develop green-JIT methods and tools might be identified as a potential future area for research and practice.

Simultaneously, another important point emerges from the need to analyse the effects of lean considering newer views, practices and tools of lean thinking. Lean practices have evolved and for instance, now lean practitioners have more soft tools such as operational development, coaching leadership, safety at work, competence planning, etc. This kind of practices have not yet been studied in depth and their investigation may provide new ways to enhance environmental performance.

In any way, the results from this analysis need to be contextualized in order to take into consideration firms' specific characteristics. In other words, the cause-effect relationships between the use of a technique and the expected result of a specific environmental measure depends on the contextual conditions that are internal and external to organizations.

Nevertheless, the majority of lean practices may be beneficial (Cherrafi et al., 2017b; EPA, 2007) and most of the environmental-improving practices can be framed within the JIT and TQM bundles. In addition, the bundles of HRM and TPM did not present an elevated number of publications relating them to environmental performance objectives. The literature demonstrates that these bundles may not negatively affect the environment (Garza Reyes et al., 2018; Piercy and Rich, 2015; EPA, 2003; Florida 1996). However, it might be interesting to obtain more evidence about which practices comprised in these bundles may improve the environmental performance of companies and in which indicators concur the major impact.

The last analysis gives details about the possible effects of every single lean practice to each single measure. This contribution may be useful to understand the order of application of the practices to obtain specific environmental outcomes from lean production. Moreover, the study gives light about which techniques companies shall use to improve specific measures. For example, if a lean company has high air emissions, it might be advantageous to apply VSM if

it is not already applied or even adapt it to unveil environmental opportunities and/or complement it with other practices like SCM, kaizen and 5S as well. Again, the rest of the relationships regarding both lean techniques SMED and KPIs and bundles TPM and HRM with environmental measures are less present in the literature. This is because there maybe not be an easy and direct connection between these practices and the environmental categories. Another explanation of these lower grade relationships is that the literature research streams are more oriented towards the study of the trade-offs of lean and green strategies. This means that the study of the most conflictive areas between these two paradigms has been studied deeper both theoretically and empirically than those practices that presumably do not seem problematic to the environment.

In parallel, two clear gaps were also identified through the present literature review, besides the conclusions outlined first in this and previous sections. The first gap refers to the need for a clear empirical identification of the effects of individual lean practices on specific environmental indicators. This an issue introduced in this paper and that requires further investigation. The second gap relates to the study of the relationships between lean and environmental performance observed within a period of time. Researches present in literature are often punctual analyses in time while a medium-long term vision is lacking considering the evolution of the process of lean transformation in companies.

The results outlined in this article, and especially those included in Table 1, provide interesting insights into the effects of lean practices on environmental performance. These may encourage firms not completely committed to environmental performance to contemplate the possible benefits of lean in their environmental performance, and guide their managers in the design of lean and environmentally sustainable operations to achieve the reduction of raw materials consumption, less waste and reduced environmental damage in general. Moreover, the relationships showed in this article may be useful to academics for the development of joint lean and green models looking for their simultaneous implementation, or for further and necessary qualitative and empirical studies about their relationships.

8. Summary

The present literature review contributes to the clarification and delimitation of the lean and green relationships. In particular, the study has explained the lean and environmental performance concepts and presented the current issues belonging to their relationships. As a matter of fact, it is noticeable that in both academic and industrial-managerial fields there is a growing interest to understand the effects achieved in the process of lean implementation regarding to environmental performance, this paper contributes by providing light into this phenomenon.

From the analyses conducted, it can be concluded that firms have to pay attention to the environmental wastes produced, taking into consideration not only lean objectives but also ecological targets. In this regard, it was suggested that lean practices can improve single environmental measures. Furthermore, there are some practices that enhance some measures more than others. For example, the following measures are those that might be more positively affected by the deployment of lean practices: air emissions, energy use, solid waste, materials use, toxic/hazardous chemicals use and money saved.

The results of this research are important for academics in the operations, waste management and sustainability fields and for practitioners and managers who are in charge of the design of business operations. Scholars may be able to develop, with the novel information outlined in this paper, new deployment schemes and roadmaps for simultaneously implementing lean and green strategies, or for transforming their operations from lean to green, and vice-versa. Furthermore, this research can also provide the opportunity to develop a KPI tool to control the use of lean practices. Additionally, this paper may be useful for companies in general to attract demand, since environmental damage is a concerning problem for customers, who are requesting cleaner products and raw materials, less waste and reduced environmental damage.

An important discussion point emerging from the literature analysis concerns the need to involve customers and suppliers in the process of implementing lean practices. As stated by Dhingra et al. (2014), manufacturers should encourage suppliers and customers to collaborate in waste reduction activities in order to facilitate extra environmental performance and arrive to maximum environmental sustainability levels.

References

Aguado, S., Alvarez, R., Domingo, R., 2013. Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation. Journal of Cleaner Production 47, 141-148.

Bae, J.W., Kim, Y.W., 2008. Sustainable value on construction projects and lean construction. Journal of green building 3(1), 156-167.

Bergmiller, G., McCright, P., 2009. Are lean and green operations synergistic?, Proceedings of the 2009 Industrial Engineering Research Conference, Miami, FL.

Bergmiller, G.G., McCright, P.R., 2009a. Lean manufacturers' transcendence to green manufacturing, Proceedings of the 2009 industrial engineering research conference.

Bergmiller, G.G., McCright, P.R., 2009b. Parallel models for lean and green operations, Proceedings of the 2009 industrial engineering research conference. University of South Florida and Zero Waste Operations Research and Consulting, pp. 1138-1143.

Berkel, R., Willems, E., Lafleur, M., 1997. The relationship between cleaner production and industrial ecology. Journal of Industrial Ecology 1(1), 51-66.

Caldera, H., Desha, C., Dawes, L., 2017. Exploring the role of lean thinking in sustainable business practice: A systematic literature review. Journal of Cleaner Production 167, 1546-1565.

Calia, R.C., Guerrini, F.M., de Castro, M., 2009. The impact of Six Sigma in the performance of a Pollution Prevention program. Journal of cleaner production 17(15), 1303-1310.

Campos, L.M., Vazquez-Brust, D.A., 2016. Lean and green synergies in supply chain management. Supply Chain Management: An International Journal 21(5), 627-641.

Carvalho, H., Govindan, K., Azevedo, S.G., Cruz-Machado, V., 2017. Modelling green and lean supply chains: An eco-efficiency perspective. Resources, Conservation and Recycling 120, 75-87.

Chan, J.S., Samson, D.A., Sohal, A.S., 1990. An integrative model of Japanese manufacturing techniques. International journal of operations & production management 10(9), 37-56.

Chapman, C.D., Green, N.B., 2010. Leaning toward green. Quality Progress 43 (3), 19e24.

Cherrafi, A., Elfezazi, S., Garza-Reyes, J.A., Benhida, K., Mokhlis, A., 2017a. Barriers in Green Lean implementation: a combined systematic literature review and interpretive structural modelling approach. Production Planning & Control 28(10), 829-842.

Cherrafi, A., Elfezazi, S., Govindan, K., Garza-Reyes, J.A., Benhida, K., Mokhlis, A., 2017b. A framework for the integration of Green and Lean Six Sigma for superior sustainability performance. International Journal of Production Research 55(15), 4481-4515.

Chiarini, A., 2014. Sustainable manufacturing-greening processes using specific Lean Production tools: an empirical observation from European motorcycle component manufacturers. Journal of Cleaner Production 85, 226-233.

Chugani, N., Kumar, V., Garza-Reyes, J.A., Rocha-Lona, L., Upadhyay, A., 2017. Investigating the green impact of Lean, Six Sigma and Lean Six Sigma: A systematic literature review. International Journal of Lean Six Sigma 8(1), 7-32.

Colicchia, C., Creazza, A., Dallari, F., 2017. Lean and green supply chain management through intermodal transport: insights from the fast moving consumer goods industry. Production Planning & Control 28(4), 321-334.

Corbett, C.J., Klassen, R.D., 2006. Extending the horizons: environmental excellence as key to improving operations. Manufacturing & Service Operations Management 8(1), 5-22.

Corbett, C.J., Van Wassenhove, L.N., 1993. The green fee: internalizing and operationalizing environmental issues. California Management Review 36(1), 116-135.

Cusumano, M.A., 1994. The limits of "Lean". Sloan management review 35(4), 27.

de Freitas, J.G., Costa, H.G., Ferraz, F.T., 2017. Impacts of Lean Six Sigma over organizational sustainability: A survey study. Journal of cleaner production 156, 262-275.
Deif, A.M., 2011. A system model for green manufacturing. Journal of Cleaner Production 19(14), 1553-1559.
Dhingra, R., Kress, R., Upreti, G., 2014. Does lean mean green? Journal of Cleaner Production 85, 1-7.
Diaz-Elsayed, N., Jondral, A., Greinacher, S., Dornfeld, D., Lanza, G., 2013. Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments. CIRP Annals-Manufacturing Technology 62(1), 475-478.
Dornfeld, D.A., 2012. Green manufacturing: fundamentals and applications. Springer Science & Business Media.
Duarte, S., Cabrita, R., Machado, V.C., 2011. Exploring lean and green supply chain performance using balanced scorecard perspective, Proceedings of the 2011 international conference on industrial engineering and operations management. pp. 520-525.
Duarte, S., Cruz-Machado, V., 2013. Modelling lean and green: a review from business models. International Journal of Lean Six Sigma 4(3), 228-250.
Dües, C.M., Tan, K.H., Lim, M., 2013. Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain. Journal of cleaner production 40, 93-100.
EPA, 2003. Lean Manufacturing and the Environment.
EPA, 2007. The Lean and Environment Toolkit. Washington D.C.
EPA, 2013. The Environmental Professional's Guide to Lean & Six Sigma.
Faulkner, W., Badurdeen, F., 2014. Sustainable Value Stream Mapping (Sus-VSM): methodology to visualize and assess manufacturing sustainability performance. Journal of cleaner production 85, 8-18.
Fercoq, A., Lamouri, S., Carbone, V., 2016. Lean/Green integration focused on waste reduction techniques. Journal of Cleaner production 137, 567-578.
Fliedner, G., 2008. Sustainability: a new lean principle, Proceedings of the 39th annual meeting of the decision sciences institute, Baltimore, Maryland. pp. 3321-3326.
Florida, R., 1996. Lean and green: the move to environmentally conscious manufacturing. California management review 39(1), 80-105.
Flynn, B.B., Sakakibara, S., Schroeder, R.G., 1995. Relationship between JIT and TQM: practices and performance. Academy of management Journal 38(5), 1325-1360.
Franchetti, M., Bedal, K., Ulloa, J., Grodek, S., 2009. Lean and Green: Industrial engineering methods are natural stepping stones to green engineering. Industrial Engineer 41(9), 24-30.
Galeazzo, A., Furlan, A., Vinelli, A., 2014. Lean and green in action: interdependencies and performance of pollution prevention projects. Journal of Cleaner Production 85, 191-200.
Garza-Reyes, J.A., 2015. Lean and green–a systematic review of the state of the art literature. Journal of Cleaner Production 102, 18-29.
Garza-Reyes, J.A., Kumar, V., Chaikittisilp, S., Tan, K.H., 2018. The effect of lean methods and tools on the environmental performance of manufacturing organisations. International Journal of Production Economics.
Garza-Reyes, J.A., Villarreal, B., Kumar, V., Molina Ruiz, P., 2016. Lean and green in the transport and logistics sector–a case study of simultaneous deployment. Production Planning & Control 27(15), 1221-1232.
Gupta, V., Narayanamurthy, G., Acharya, P., 2018. Can lean lead to green? Assessment of radial tyre manufacturing processes using system dynamics modelling. Computers & Operations Research 89, 284-306.
Gustashaw, D., Hall, R.W., 2008. From Lean to Green: Interface, Inc. Association for

Manufacturing Excellence's Target Magazine 24(5).
Hajmohammad, S., Vachon, S., Klassen, R.D., Gavronski, I., 2013. Reprint of Lean management and supply management: their role in green practices and performance. Journal of Cleaner Production 56, 86-93.
Helleno, A.L., de Moraes, A.J.I., Simon, A.T., 2017. Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes: Application case studies in Brazilian industry. Journal of cleaner production 153, 405-416.
Ho, S.K., 2010a. Integrated lean TQM model for global sustainability and competitiveness. The TQM Journal 22(2), 143-158.
Ho, S.K., 2010b. Integrated lean TQM model for sustainable development. The TQM Journal 22(6), 583-593.
Hong, P., Jungbae Roh, J., Rawski, G., 2012. Benchmarking sustainability practices: evidence from manufacturing firms. Benchmarking: An International Journal 19(4/5), 634-648.
Ioppolo, G., Cucurachi, S., Salomone, R., Saija, G., Ciraolo, L., 2014. Industrial ecology and environmental lean management: Lights and shadows. Sustainability 6(9), 6362-6376.
Jabbour, C.J.C., de Sousa Jabbour, A.B.L., Govindan, K., Teixeira, A.A., de Souza Freitas, W.R., 2013. Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. Journal of Cleaner Production 47, 129-140.
Johansson, G., Winroth, M., 2009. Lean vs. Green manufacturing: Similarities and differences, Proc. of the 16th International Annual EurOMA Conference, Implementation realizing Operations Management knowledge, June. pp. 14-17.
Kainuma, Y., Tawara, N., 2006. A multiple attribute utility theory approach to lean and green supply chain management. International Journal of Production Economics 101(1), 99-108.
King, A.A., Lenox, M.J., 2001. Lean and green? An empirical examination of the relationship between lean production and environmental performance. Production and operations management 10(3), 244-256.
Klassen, R.D., Whybark, D.C., 1999. Environmental management in operations: the selection of environmental technologies. Decision sciences 30(3), 601-631.
Kleindorfer, P.R., Singhal, K., Wassenhove, L.N., 2005. Sustainable operations management. Production and operations management 14(4), 482-492.
Kurdve, M., Zackrisson, M., Wiktorsson, M., Harlin, U., 2014. Lean and green integration into production system models–experiences from Swedish industry. Journal of Cleaner Production 85, 180-190.
León, H.C.M., Calvo-Amodio, J., 2017. Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective. Journal of cleaner production 142, 4384-4402.
Miller, G., Pawloski, J., Standrigde, C.R., 2010. A case study of lean, sustainable manufacturing. Journal of industrial engineering and management 3(1), 11-32.
Mittal, V.K., Sindhwani, R., Kapur, P., 2016. Two-way assessment of barriers to Lean–Green Manufacturing System: insights from India. International Journal of System Assurance Engineering and Management 7(4), 400-407.
Mollenkopf, D., Stolze, H., Tate, W.L., Ueltschy, M., 2010. Green, lean, and global supply chains. International Journal of Physical Distribution & Logistics Management 40(1/2), 14-41.
Monden, Y., 1983. Toyota production system, an Integrated Approach to Just-In-Time.
Netland, T.H., Schloetzer, J.D., Ferdows, K., 2015. Implementing corporate lean programs: The effect of management control practices. Journal of Operations Management 36, 90-102.

Ohno, T., 1988. Toyota production system: beyond large-scale production. crc Press.
O'Rourke, D., 2014. The science of sustainable supply chains. Science 344(6188), 1124-1127.
Ng, R., Low, J.S.C., Song, B., 2015. Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric. Journal of Cleaner Production 95, 242-255.
Pampanelli, A.B., Found, P., Bernardes, A.M., 2011. A lean and green Kaizen model, POMS annual conference, Reno, Nevada, USA.
Pampanelli, A.B., Found, P., Bernardes, A.M., 2014. A Lean & Green Model for a production cell. Journal of cleaner production 85, 19-30.
Panizzolo, R., 1998. Applying the lessons learned from 27 lean manufacturers.: The relevance of relationships management. International journal of production economics 55(3), 223-240.
Piercy, N., Rich, N., 2015. The relationship between lean operations and sustainable operations. International Journal of Operations & Production Management 35(2), 282-315.
Porter, M., van der Linde, C., 1995. Green and competitive: ending the stalemate. The Dynamics of the eco-efficient economy: environmental regulation and competitive advantage 33.
Powell, D., Lundeby, S., Chabada, L., Dreyer, H., 2017. Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer. International Journal of Lean Six Sigma 8(1), 53-64.
Prasad, S., Khanduja, D., Sharma, S.K., 2016. An empirical study on applicability of lean and green practices in the foundry industry. Journal of Manufacturing Technology Management 27(3), 408-426.
Qureshi, M.I., Rasli, A.M., Jusoh, A., Kowang, T.O., 2015. Sustainability: A new manufacturing paradigm. Journal Teknologi 77(22), 47-53.
Rothenberg, S., Pil, F.K., Maxwell, J., 2001. Lean, green, and the quest for superior environmental performance. Production and operations management 10(3), 228-243.
Shah, R., Ward, P.T., 2003. Lean manufacturing: context, practice bundles, and performance. Journal of operations management 21(2), 129-149.
Simons, D., Mason, R., 2003. Lean and green:'doing more with less'. International Commerce Review: ECR Journal 3(1), 84.
Sobral, M.C., Sousa Jabbour, A.B.L.d., Chiappetta Jabbour, C.J., 2013. Green benefits from adopting lean manufacturing: a case study from the automotive sector. Environmental Quality Management 22(3), 65-72.
Soltero, C., Waldrip, G., 2002. Using kaizen to reduce waste and prevent pollution. Environmental Quality Management 11(3), 23-38.
Taubitz, M.A., 2010. Lean, green & safe. Professional Safety 55(5), 39.
Thanki, S., Govindan, K., Thakkar, J., 2016. An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. Journal of Cleaner Production 135, 284-298.
Thanki, S.J., Thakkar, J.J., 2016. Value–value load diagram: a graphical tool for lean–green performance assessment. Production Planning & Control 27(15), 1280-1297.
Torielli, R., Abrahams, R., Smillie, R., Voigt, R., 2011. Using lean methodologies for economically and environmentally sustainable foundries. China Foundry 8(1), 74-88.
Ugarte, G.M., Golden, J.S., Dooley, K.J., 2016. Lean versus green: The impact of lean logistics on greenhouse gas emissions in consumer goods supply chains. Journal of Purchasing and Supply Management 22(2), 98-109.
Vais, A., Miron, V., Pedersen, M., Folke, J., 2006. "Lean and Green" at a Romanian

secondary tissue paper and board mill—putting theory into practice. Resources, Conservation and Recycling 46(1), 44-74.
Venkat, K., Wakeland, W., 2006. Is lean necessarily green?, Proceedings of the 50th Annual Meeting of the ISSS-2006, Sonoma, CA, USA.
Verrier, B., Rose, B., Caillaud, E., 2016. Lean and Green strategy: the Lean and Green House and maturity deployment model. Journal of cleaner production 116, 150-156.
Verrier, B., Rose, B., Caillaud, E., Remita, H., 2014. Combining organizational performance with sustainable development issues: the Lean and Green project benchmarking repository. Journal of Cleaner Production 85, 83-93.
Vinodh, S., Arvind, K., Somanaathan, M., 2011. Tools and techniques for enabling sustainability through lean initiatives. Clean Technologies and Environmental Policy 13(3), 469-479.
Wiese, A., Luke, R., Heyns, G.J., Pisa, N.M., 2015. The integration of lean, green and best practice business principles. Journal of Transport and Supply Chain Management 9(1), 1-10.
Womack, J.P., Jones, D.T., 1996. Lean thinking: Banish waste and create wealth in your organisation. Simon and Shuster, New York, NY 397.
Wong, W.P., Wong, K.Y., 2014. Synergizing an ecosphere of lean for sustainable operations. Journal of Cleaner Production 85, 51-66.
Yang, M.G.M., Hong, P., Modi, S.B., 2011. Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. International Journal of Production Economics 129(2), 251-261.
Zhan, Y., Tan, K.H., Ji, G., Tseng, M.-L., 2018. Sustainable Chinese manufacturing competitiveness in the 21st century: green and lean practices, pressure and performance. International Journal of Computer Integrated Manufacturing 31(6), 523-536.
Zhu, Q., Sarkis, J., 2004. Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. Journal of operations management 22(3), 265-289.
Zokaei, K., Lovins, H., Wood, A., Hines, P., 2013. Creating a lean and green business system: techniques for improving profits and sustainability. CRC Press.

Appendix A

Authors	Title	Year	Type	Relationship	Publication
Aguado et al.	Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation	2013	Single or multiple case study	Positive	Journal
Bergmiller and McCright	Parallel Models for Lean and Green Operations	2009	Theoretical model	Positive	Conference
Bergmiller and McCright	Lean Manufacturers Transcendence to	2009	Survey	Positive	Conference

	Green Manufacturing				
Bergmiller and McCright	Are Lean and Green Programs Synergistic	2009	Survey	Positive	Conference
Caldera et al.	Exploring the role of lean thinking in sustainable business practice: A systematic literature review	2017	Literature review	Positive	Journal
Calia et al.	The impact of Six Sigma in the performance of a Pollution Prevention program	2009	Single or multiple case study	Positive	Journal
Campos and Vazquez-Brust	Lean and green synergies in supply chain management.	2016	Single or multiple case study	Positive	Journal
Carvalho et al.	Modelling green and lean supply chains: An eco-efficiency perspective	2017	Single or multiple case study	Mixed	Journal
Chapman and Green	Leaning-toward-green	2010	Single or multiple case study	Positive	Journal
Cherrafi et al.	A framework for the integration of Green and Lean Six Sigma for superior sustainability performance	2017	Single or multiple case study	Positive	Journal
Chiarini	Sustainable manufacturing-greening processes using specific Lean production tools: an empirical observation from European motorcycle component manufacturers	2014	Single or multiple case study	Positive	Journal
Chugani et al.	Investigating the green impact of Lean, Six Sigma and Lean Six Sigma: A	2017	Literature review	Positive	Journal

	systematic literature review				
Corbett and Klassen	Extending the horizons Environmental excellence as key to improving operations	2006	Literature review	Positive	Journal
Corbett and Wassenhove	The Green Fee: Internalizing and Operationalizing Environmental Issues	1993	Theoretical model	Mixed	Journal
Cusumano	The limits of lean	1994	Theoretical model	Negative	Journal
de Freitas et al.	Impacts of Lean Six Sigma over organizational sustainability: A survey study	2017	Survey	Positive	Journal
Deif	A system model for green manufacturing	2011	Single or multiple case study	Positive	Journal
Dhingra et al.	Does lean mean green?	2014	Literature review	Positive	Journal
Diaz-Elsayed et al.	Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments	2013	Single or multiple case study	Positive	Journal
Dornfeld et al.	Green Manufacturing: Fundamentals and Applications	2012	-	-	Book
Duarte and Cruz-Machado	Modelling lean and green a review from business models	2013	Literature review	Positive	Journal
Duarte et al.	Exploring Lean and Green Supply Chain Performance Using Balanced Scorecard Perspective	2011	Theoretical model	Positive	Conference
Dües et al.	Green as the new Lean how to use	2013	Literature review	Mixed	Journal

	Lean practices as a catalyst to greening your supply chain				
EPA	Lean and environmental toolkit	2007	Theoretical model	Positive	Report
EPA	The Environmental Professional's Guide to Lean & Six Sigma	2013	Theoretical model	Positive	Report
EPA	Lean Manufacturing and the environment	2003	Theoretical model	Positive	Report
Faulkner and Badurdeen	Sustainable Value Stream Mapping (Sus-VSM) methodology to visualize and assess manufacturing sustainability performance	2014	Single or multiple case study	Positive	Journal
Fercoq et al.	Lean/Green integration focused on waste reduction techniques	2016	Quantitative experimental study	Positive	Journal
Fliedner	Sustainability: a new lean principle	2008	Theoretical model	Positive	Conference
Florida	Lean and green to move to environmentally conscious manufacturing	1996	Survey	Positive	Journal
Franchetti et al.	Lean and green: Industrial engineering methods are natural stepping stones to green engineering	2009	Theoretical model	Positive	Journal
Galeazzo et al.	Lean and green in action: interdependences and performance of pollution prevention projects	2014	Single or multiple case study	Positive	Journal
Garza-Reyes	Lean and green - a systematic review of the state of the art literature	2015	Literature review	-	Journal

Garza-Reyes et al.	The effect of lean methods and tools on the environmental performance of manufacturing organizations	2018	Survey	Positive	Journal
Gustashaw and Hall	From Lean to Green Interface, Inc.	2008	Single or multiple case study	Positive	Journal
Hajmohammad et al.	Lean management and supply management their role in green practices	2013	Survey	Positive	Journal
Helleno et al.	Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes: Application case studies in Brazilian industry	2017	Single or multiple case study	Positive	Journal
Ho	Integrated lean TQM model for global sustainability and competitiveness	2010	Theoretical model	Positive	Journal
Ho	Integrated TQM for sustainable development	2010	Theoretical model	Positive	Journal
Hong et al.	Benchmarking sustainability practices evidence from manufacturing firms	2012	Structural equation modelling	Positive	Journal
Ioppolo et al.	Industrial Ecology and Environmental Lean management: lights and shadows	2014	Theoretical model	-	Journal
Johansson and Winroth	Lean vs green manufacturing	2009	Literature review	Mixed	Conference
Kainuma and Tawara	A multiple attribute utility theory approach to lean and green supply chain management	2006	Single or multiple case study	-	Journal

King and Lenox	Lean and green? An empirical examination of the relationship between lean production and environmental performance	2001	Empirical analysis	Positive	Journal
Klassen and Whybark	Environmental Management in Operations The Selection of Environmental Technologies	1999	Survey	-	Journal
Kleindorfer et al.	Sustainable operations management	2005	Literature review	Positive	Journal
León and Calvo-Amodio	Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective	2017	Literature review	-	Journal
Miller et al.	A case study of lean, sustainable manufacturing	2010	Single or multiple case study	Positive	Journal
Mollenkopf et al.	Green, lean, and global supply chains	2010	Literature review	Mixed	Journal
O'rourke	The science of sustainable supply chains	2014	Theoretical model	Positive	Journal
Pampanelli et al.	A Lean and Green Kaizen Model	2011	Single or multiple case study	Positive	Conference
Pampanelli et al.	A Lean & Green Model for a production cell	2014	Single or multiple case study	Positive	Journal
Piercy and Rich	The relationship between lean operations and sustainable operations	2015	Single or multiple case study	Positive	Journal
Porter and van der Linde	Green and Competitive: ending the stalemate	1996	Theoretical model	Positive	Journal

Powell et al.	Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer	2017	Single or multiple case study	Positive	Journal
Qureshi et al.	Sustainability a new manufacturing paradigm	2015	Literature review	Positive	Journal
Rothenberg et al.	Lean, green and the quest for superior environmental performance	2001	Survey	Mixed	Journal
Simons and Mason	Lean and green: "doing more with less"	2003	Single or multiple case study	Mixed	Journal
Sobral et al.	Green benefits from adopting lean manufacturing a case study from the automotive sector	2013	Single or multiple case study	Positive	Journal
Soltero and Waldrip	Using kaizen to reduce waste and prevent pollution	2002	Theoretical model	Positive	Journal
Taubitz	Lean, green & safe Integrating safety into the lean, green and sustainability movement	2010	Single or multiple case study	Positive	Journal
Torielli et al.	Using lean methodologies for economically and environmentally sustainable foundries	2011	Theoretical models	Mixed	Journal
Vais et al.	Lean and green at a romanian secondary tissue paper and board mill - putting theory into practice	2006	Single or multiple case study	Positive	Journal
Venkat and Wakeland	Is lean necessarily green?	2006	Simulation	Negative	Conference
Verrier et al.	Lean and green strategy: the Lean and Green House and maturity deployment model	2016	Theoretical model	Positive	Journal

Verrier et al.	Combining organizational performance with sustainable development issues: the lean and green project benchmarking repository	2014	Single or multiple case study	Positive	Journal
Vinodh et al.	Tools and techniques for enabling sustainability through lean initiatives	2011	Theoretical model	Positive	Journal
Wiese et al.	The integration of lean, green and best practice business principles	2015	Single or multiple case study	Positive	Journal
Wong and Wong	Synergizing an ecosphere of lean for sustainable operations	2014	Single or multiple case study	Positive	Journal
Yang et al.	Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms	2011	Research database	Positive	Journal
Zhu and Sarkis	Relationships Between Operational Practices and Performance Among Early Adopters of Green Supply Chain management practices in Chinese manufacturing enterprises	2004	Survey	Mixed	Journal
Zokaei et al.	Creating a Lean and Green Business System: Techniques for Improving Profits and Sustainability	2013	-	Positive	Book

Table A.1. List of references within the sample