Lean and Green – A systematic review of the state of the art literature

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Abstract
The move towards greener operations and products has forced companies to seek alternatives to balance efficiency gains and environmental friendliness in their operations and products. The exploration of the sequential or simultaneous deployment of lean and green initiatives is the results of this balancing action. However, the lean-green topic is relatively new, and it lacks of a clear and structured research definition. Thus, this paper's main contribution is the offering of a systematic review of the existing literature on lean and green, aimed at providing guidance on the topic, uncovering gaps and inconsistencies in the literature, and finding new paths for research. The paper identifies and structures, through a concept map, six main research streams that comprise both conceptual and empirical research conducted within the context of various organisational functions and industrial sectors. Important issues for future research are then suggested in the form of research questions. The paper's aim is to also contribute by stimulating scholars to further study this area in depth, which will lead to a better understanding of the compatibility and impact on organisational performance of lean and green initiatives. It also holds important implications for industrialists, who can develop a deeper and richer knowledge on lean and green to help them formulate more effective strategies for their deployment.

Keywords: Eco-efficiency, eco-sustainability, environment, environmental, green, lean, systematic literature review.

1. Introduction

Lean manufacturing was initially developed in Japan by Toyota, where it was known as Toyota Production System (Herron and Hicks, 2008). After the Second World War, Toyota could not compete with the mass production system adopted by US car manufacturers, especially when considering quality and cost (Abdul Wahab *et al.*, 2013). For this reason, instead of also adopting a mass production approach, Toyota created a new management system focused on the reduction of waste in all aspects of its operations (Herron and Hicks, 2008). Since then, lean manufacturing has been gaining fame in a wide range of industries all around the world (Garza-Reyes *et al.*, 2012), disseminating the concept of waste reduction (Chauhan and Singh, 2012). Nowadays, lean manufacturing is considered the most influential new paradigm in manufacturing (Forrester *et al.*, 2010) as empirical evidence suggests it improves the competitiveness of organisations (Hines *et al.*, 2004) by reducing inventories and lead-times, and improving productivity and quality (Abdul Wahab *et al.*, 2013). In this context, the lean paradigm has not only been in line with historical prevailing organisational objectives such as profitability and efficiency but also contemporary objectives that include customer satisfaction, quality, and responsiveness. However, in order to respond to the growth of customer demands for products and services that are environmentally sustainable

and comply with governmental environmental regulations, companies have now been forced to rethink these objectives and hence how they manage their operations and processes.

Environmental concerns and pressures have contributed to organisations taking a proactive role in designing recyclable products as well as developing cleaner services and manufacturing processes. Thus, the green paradigm has emerged as a philosophy and operational approach to reduce the negative ecological impact of an organisation's products and services as well as improve the environmental efficiency of their operations, while still achieving their financial objectives. The green (environmental) paradigm is operationalised through green initiatives (Digalwar *et al*., 2013), supported by methods and tools that include environmental operations management (EOM), also known as green operations, (Nunes and Bennett, 2010; Gupta and Sharma, 1996), green manufacturing (Kleindorfer *et al.*, 2005; Sarkis, 1998), green supply chains (GSC) (Zhu *et al.*, 2008), reverse logistics (RL) (Sarkis, 2003), eco-design, (Gottberg *et al.*, 2006; Sarkis, 2001), design for environment (DFE), or, green building (Paumgartten, 2003), sustainable value stream mapping (Kurdve *et al.*, 2011) and life cycle assessment (Kainuma and Tawara, 2006). As lean is also an operations management approach that aims at the elimination of waste in every area of design, production, factory management and supplier network (Chauhan and Singh, 2012), its alignment with the green paradigm, and its methods and tools, seems natural. This is reflected through a number of studies that have considered the relationship and investigated the impact of lean and green initiatives on the performance of organisations (see Section 3.6) and their integration as a single combined approach (see Sections 3.2 and 3.3). However, despite these studies, the academic literature and research lines exploring the impact of lean practices on environmental performance, synergies of lean and green initiatives, and their integration as a single and unique approach still remain in early stages. Additionally, it lacks of a clear and structured research definition that may result in difficulties to advance this promising research area.

In order to facilitate further research on the relationship between lean and environmental (green) aspects, this paper presents a comprehensive literature review on the current state of the research on this emerging subject. It is aimed at uncovering gaps and inconsistencies in the literature and finding new research paths. To do this, the paper aims at systematically collecting and critically analysing the existing contributions on lean, with particular interest on its application and linkage with environmental organisational aspects. Considering this, the main research questions addressed in this review are:

- *What are the emerging issues in research on lean and its application and linkage with environmental organisational aspects?*
- *What are the main paths for further research on the lean-green subject area?*

The next sections address the following topics: Section 2 covers the research methodology followed within this paper; the findings and discussion on the different research streams are outlined in Section 3, along with potential directions for further research; and Section 4 provides the conclusions.

2. Research Method

Effectively conducted literature reviews highlight areas where research is needed, resulting in the facilitation of theory development, while also contributing to closing areas where plethora of research exists (Webster and Watson, 2002). Since a literature review consists of a method which is systematic, explicit, and reproducible (Fink, 2005), the research questions presented

in the previous section have been addressed based on a systematic review of the existent literature. A systematic literature review (SLR) is a method that adopts a precise, transparent and explicit approach that includes a series of phases to ensure that an appropriate rigour and transparency is brought to the literature review process (Tranfield *et al.*, 2003; Kitchenham and Charters, 2007). Denyer and Tranfield (2009) consider that a systematic literature review consists of the following five consecutive phases: (1) question formulation, (2) locating studies, (3) study selection and evaluations, (4) analysis and synthesis, and (5) reporting and using the results. The first and fifth phases are respectively reported within Section 1 and Sections 3 and 4 of this paper, while phases two, three and four are addressed in the following sections. According to Saunders *et al.* (2012), for reasons of transparency, it is necessary to explain in detail how the systematic review process was conducted, particularly in relation to the literature section and the choices made regarding the use of specific search terms and databases. This is discussed in the following sub-sections. Fig. 1 illustrates and summarises the phases of the SLR undertaken, the methods and tools used to support every stage as well as the section of the article where these are addressed.

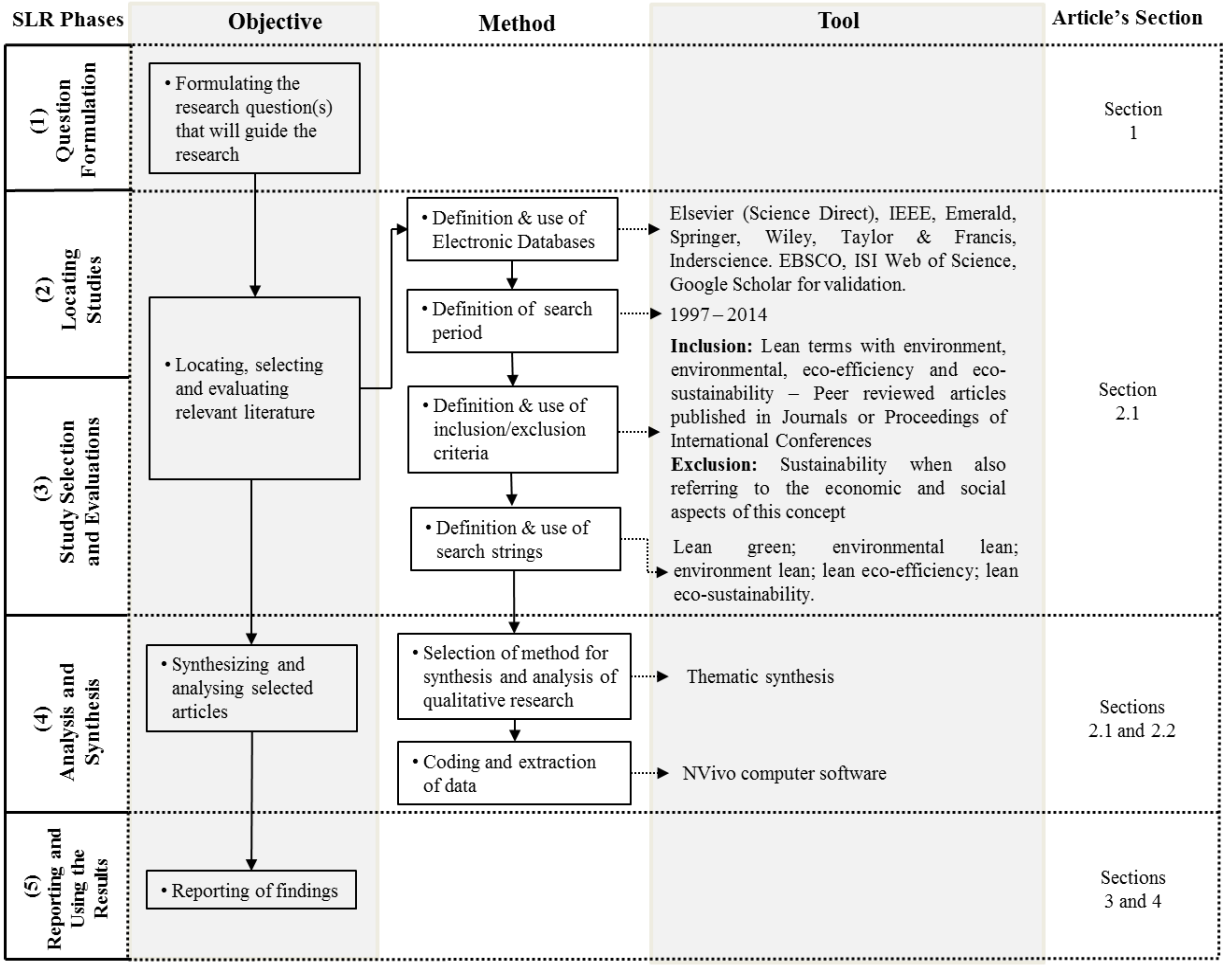


Fig. 1. SLR phases, methods, tools and location within the article

2.1. Location of studies and selection - databases, timing, and search criteria and strings

The location of articles was conducted by considering search strings in numerous publishers' electronic databases (EDs) to find publications relevant to the scope of the review. Electronic databases included Elsevier (sciencedirect.com), Emerald (emeraldinsight.com), Taylor &

Francis (T&F) (tandfonline.com), IEEE (ieeexplore.ieee.org), Springer (springerlink.com), Wiley (onlinelibrary.wiley.com) and Inderscience (inderscience.com). In addition, another set of databases that comprised EBSCO (ebscohost.com), ISI Web of Science (wokinfo.com) and Google Scholar (scholar.google.com) was also used. Although this created an overlap with the previously employed databases, the use of these served as a validation for the preceding searches to ensure that all the relevant articles that fell within the searching criteria were included.

Environmental awareness among businesses can be traced back to the 1970s, when some organisations started to develop their own environmental management systems, mainly to comply with government regulations and minimise risks (Darnall *et al*., 2000). There is also some limited evidence that lean and green have been discussed in the academic literature as complementary strategies since the early 90s (Davids, 1994). However, an important turning point regarding how organisations perceive the environmental dimension of their business can be considered the release of the environmental management standard ISO 14001 in the late 1996 (Darnall *et al*., 2000). Thus, the period for this research was established to comprise from 1997 to 2014, including articles 'in-press' that would be later published in 2015.

In terms of the search strings, they were specified based on the main topics of the phenomena under investigation. The C-I-M-O (context-intervention-mechanism-outcome) (Briner and Denyer, 2012; Rousseau, 2012) framework was followed during this phase of the systematic literature review to determine the inclusion/exclusion criteria of the search strings. Thus, search strings included (lean green), (environmental lean), (environment lean), (lean eco-efficiency) and (lean eco-sustainability). This allowed the definition of a specific search focus and the exclusion of articles when found that these did not refer to the inclusion of both terms and/or presented a relationship between the two. In some cases, some of the search strings resulted in the same articles being found. However, this systematic search and selection approach was necessary to ensure the completeness of the literature exploration. A point of saturation was considered to have been reached when the same articles continue appearing. Additionally, 'manual checks' for all the articles that fell within the search strings criteria were performed based on the abstracts of the papers. This resulted in removing those papers that clearly did not address the topic of lean and green (e.g. because they referred to a 'lean environment' within the context of a place where lean had been implemented, instead of relating lean to a green environmental aspect), or that were outside of the scope, because of, for example, the date or article type. Initially, other search strings such as (sustainability lean) and (sustainable lean) were also considered. However, these were then excluded as they also involved the social and economic perspectives of sustainability (Hosseini and Kaneko, 2012), and hence were not only concerned with the relationship and linkage of lean and the environment. Therefore, lean-sustainability related articles such as those from Martinez-Jurado and Moyano-Fuentes (2014), Chiarini (2014) and Wong and Wong (2014) were not considered within the study.

Search results included peer-reviewed articles, published in academic journals and the proceedings of international conferences only, as according to Saunders *et al.* (2012) these sources are the most useful and reliable for literature reviews. According to this and the searching criteria described in this section, a final sample of 62 articles with reference to lean and green were identified. However, only 59 articles were uploaded to the QSR NVivo software (QSR International, 2013) for analysis as two of them were not full journal articles (i.e. Dhingra *et al.*, 2012; Dhingra *et al.*, 2014) and one (i.e. Davids, 1994) was not within the studied period. QSR NVivo, alongside to data extraction forms, was used to conduct a thematic synthesis as Thorpe *et al.* (2005) and Thomas and Harden (2008) suggest QSR NVivo as the most effective computer software for coding data from full articles.

2.2. Analysis and synthesis

Various methods that include thematic analysis/synthesis, qualitative comparative analysis, qualitative meta-summary, meta-ethnography, qualitative meta-analysis, grounded theory and content analysis can be considered for the synthesis of qualitative research. Due to its effectiveness in identifying important recurring themes and the use of structured ways of dealing with data within each theme (Thomas and Harden, 2008; Barnett-Page and Thomas, 2009), thematic synthesis was considered the most appropriate method for the amalgamation of the results obtained from the systematic review of the literature conducted in this study. Similarly as the analysis approach followed by Ceulemans *et al.* (2014), a preliminary categorisation of the articles selected was made into three main groups, see Fig. 2. Since lean and green initiatives must be operationalised for their deployment, the classification of operations into either supply chain or operation/process, according to their macro or micro level, proposed by Slack *et al.* (2013) was used to identify communalities among the articles. These formed groups two and three, whereas group one involved those articles that discussed lean and green from a conceptual point of view. Sub-categories were also created from groups two and three, based on whether the lean-green environment topic was addressed as a core or additional element either at a supply chain or operation/process level, see Fig. 2. This preliminary classification allowed the coding and individual analysis of the 59 articles as well as their assignment to one of the classification groups, followed by a comparison to the papers in other categories. Consequently, elements applicable to lean-green and synergies among the topics were identified. The number of articles that were classified according every group and sub-group is shown in Fig. 2.

Afterwards, new classifications were made based on the previous classification and coding, finally leading to a concept map, see Fig. 4, representing the different research streams that the lean-green topic has followed and the number of articles dedicated to each research line. The findings of the thematic synthesis are presented in Section 3, which was divided into a descriptive (Section 3.1) and an analytic component (Sections 3.2 to 3.7).

3. Findings and Discussion

3.1. Descriptive analysis of findings

A total number of 59 articles (*n = 59*) complied with the selection criteria. Hence these were all the articles that, to a certain extent, referred to lean and green as well as related topics such as environment, environmental, eco-efficiency and eco-sustainability.

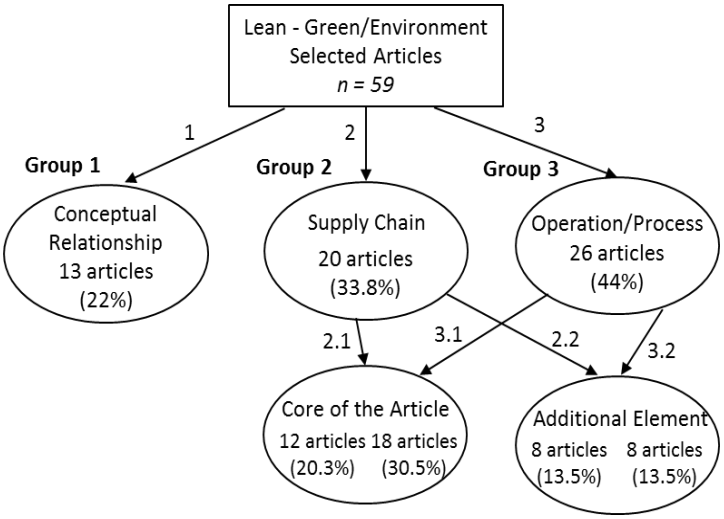
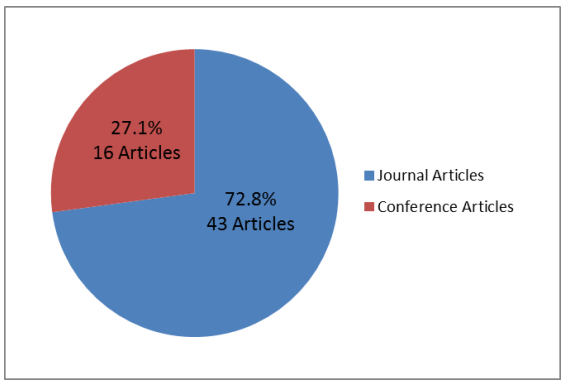


Fig. 2. Preliminary thematic classification of articles included in the literature review

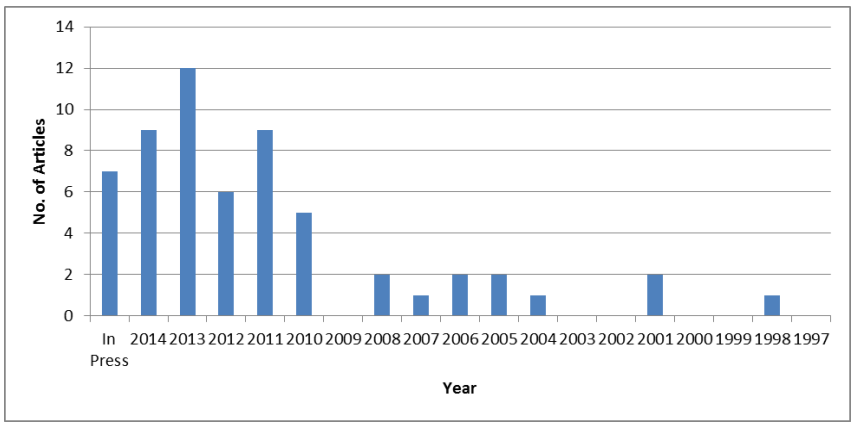
3.1.1. Sources of publication, number of publications per journal/conference and per year

Fig. 3 presents the proportion of the publication sources in relation to whether (a) the articles were published by journals or conference proceedings, (b) number of publications per year, and (c) the specific journal or (b) conference where the articles included in this study were published. Fig 3 also presents the (e) number of articles found per database (individual articles are cross referenced to the database in Table 1). In general, the results indicate that the lean-green topic has gained special interest and popularity within the research community since 2010 as 81% (48 articles) of the publications released in the period from 1997 to 2015 have been made since 2010. This suggests the lean-green topic as a relatively new and emergent research field. As more organisations may be expected to greening their operations due to customer and governmental pressures (Digalwar *et al.*, 2013; Mollenkopf *et al.*, 2010), the trend of lean-green publications may be expected to continue increasing in the next few years. Fig. 3(a) also indicates that although conferences have been used by researchers to disseminate the results of their lean-green investigations, journal publications still represent the main choice of researchers, perhaps because in most of the cases they enjoy a higher status (Freyne *et al.*, 2010).

In terms of the number of publications per journal, *Journal of Cleaner Production* contributes with 20% (12 articles) of the total number of lean-green publications, followed by *Environmental Quality Managemen*t with only 6.7% (4 articles). The highest number of lean-green related articles published by the *Journal of Cleaner Production* is in line with the highest number of articles found in a specific database, see Fig. 3(e), where 28% (17 articles) were found through the Elsevier database. As indicated by Fig. 3(e), all articles where found through the databases of the publishers, except those from Duarte and Cruz-Machado (2011) and Kurdve *et al.* (2011), which were not contained in any of these databases, but which were found through Google Scholar. This shows the importance of having validated the articles search by also employing EBSCO, ISI Web of Science and Google Scholar as indicated in Section 2.1 as these two articles would have otherwise not been considered. Fig. 3(c) also indicates that although the lean-green topic is suitable to be published in a wide range of specialised journals (e.g. *Journal of Cleaner Production* or *Environmental Quality Management* – specialised in environmental topics – or *International Journal of Lean Six Sigma* – specialised on lean topics), it is also suitable for publication in journals with a more general thematic (e.g. *Production and Operations Management*). This may explain the wide range of different journals (i.e. 24) where the lean-green topic has been published.



(a)



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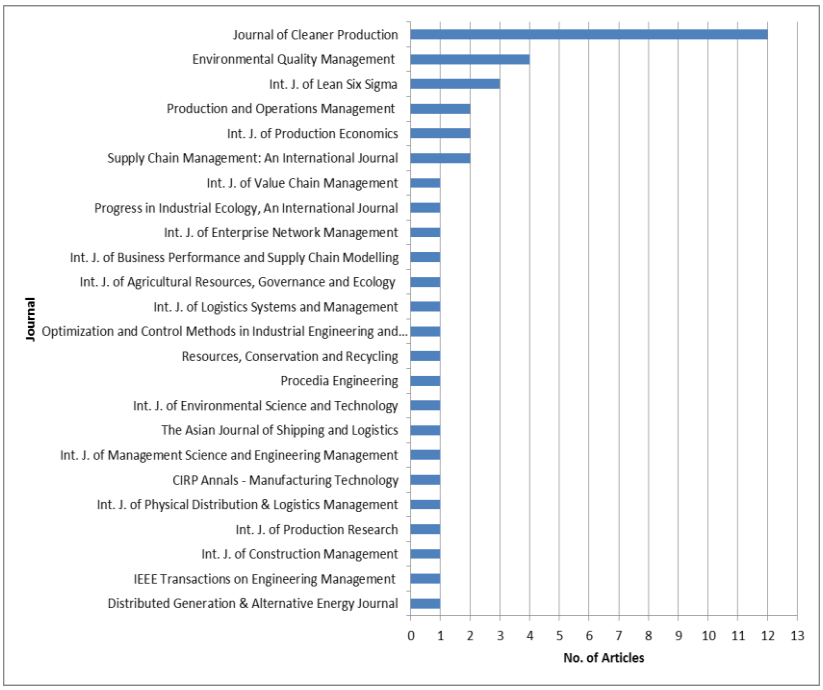

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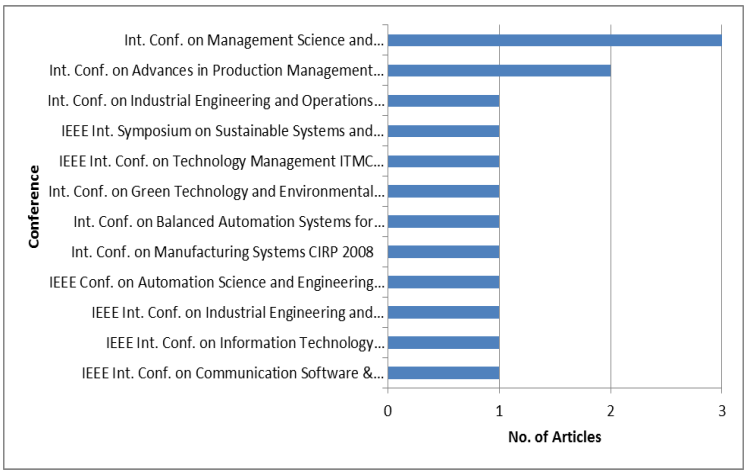

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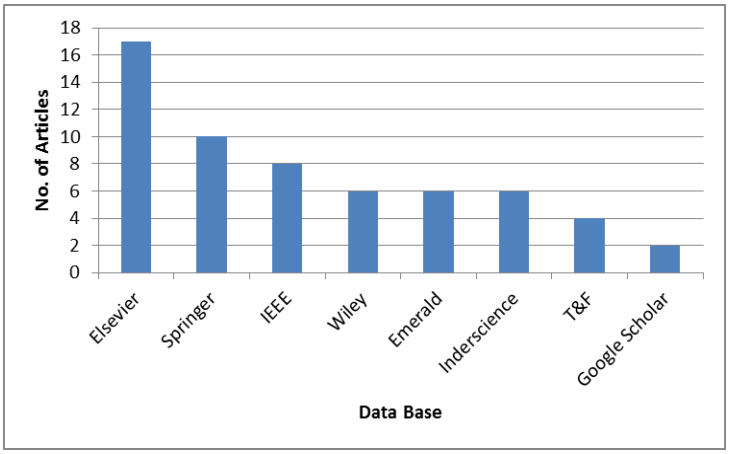

(e)

Fig. 3. Descriptive data – (a) Proportion of journal-conference publication, (b) Year of publication, (c) Number of publications per journal, (d) Number of publication per conference, (e) Number of publications per database

3.1.2. Number of publications per classification group

As described in Section 2.2, the articles were preliminarily classified according to the macro (supply chain) and micro (operation/process) level from which the lean-green theme was reviewed, and then sub-classified into core or additional elements of the articles, see Fig.

2. This was done to identify their similarities and facilitate their analysis. Fig. 2 shows that the topic of lean-green has been studied within the context of both supply chain and operation/process perspectives. Although still more publications have been focused at an operation/process level, this indicates that researchers recognise the potential and need of deploying lean and green not only within organisations but also through their entire supply chain (Mollenkopf *et al.*, 2010; Duarte and Cruz-Machado, 2014a; Dües *et al.*, 2013). Moreover, Fig. 2 also shows that a higher number of articles in both categories (i.e. supply chain and operation/process) covered lean-green as their main topic. In the case of the 16 publications where lean-green were an additional element, this was mainly because other concepts and/or methods such as globalisation (Mollenkopf *et al.*, 2010), innovation (Aguado *et al.*, 2013), resilience (Cabral *et al.*, 2012; Govindan *et al.*, 2013; Cabral *et al.*, 2011a; Cabral *et al.*, 2011b; Espadinha-Cruz *et al.*, 2011; Carvalho *et al*., 2014), agile (Cabral *et al.*, 2012; Sertyesilisik, 2014; Cabral *et al.*, 2011a; Cabral *et al.*, 2011b; Espadinha-Cruz *et al.*, 2011; Carvalho *et al*., 2014), total quality (Salleh *et al.*, 2012), project management (Sertyesilisik, 2014) and Six Sigma (Banawi and Bilec, 2014; Cluzel *et al.*, 2010; Ranky *et al.*, 2012) were considered alongside the lean-green paradigms. This demonstrates that researchers have tried to address the intersection of lean-green with other strategic initiatives to study and take advantage of their synergies through concurrent implementation and address trade-offs that may arise due to their incompatibilities (Mollenkopf *et al.*, 2010).

Finally, 22% (13 articles) referred to the lean-green topic from a conceptual point of view. This is, rather than presenting an empirical research, these articles conceptually discussed, for example, the synergies and divergences between lean and green, possible benefits of their integration in different industries, their impact on organisations and supply chains' performance, and some of their theoretical implementation aspects when tried to be simultaneously deployed. Three articles within the category of 'conceptual relationship', i.e., Carvalho *et al.* (2011), Garza-Reyes *et al*. (2014) and Garza-Reyes (2015), could have been part of the 'additional element' category, because they also consider other concepts and/or methods alongside lean-green. However, since they discuss their interaction from a conceptual point of view, they were included in the 'conceptual relationship' category. This finding indicates an overlap in some of the lean-green research streams, which needs further clarification. Thus, a concept map to show the possible research avenues and interactions of the lean-green topic was developed.

3.1.3. Concept map for lean-green

While all the articles included in the literature review referred to lean-green, the thematic analysis and preliminary categorisation presented in Fig. 2 indicated that they had different focuses, which in some cases overlapped. For this reason, a conceptual map was created inductively to categorise, organise, visualise and structure the discussions and main findings of this systematic literature review. In addition, the articles were 'attached' to every one of the concept map's categories (research streams) according to their thematic focus/content and categorisation structure of the map. This allowed a clear visualisation of the number of articles published per category and/or sub-category, indicating those areas where lean-green research had been concentrated and those where it had been limited.

Fig. 4 presents the concept map with lean-green situated in the centre and from where six research streams emanate. The research streams including (1) compatibility, (2) integration, (3) integration with or study alongside, (4) proposal of an assessment performance method/indicator, (5) impact on organisational performance, and (6) research or empirical application on, were defined based on the thematic content of the articles. In this case, all the articles fell within a minimum of one category, while some of them fell within two or more

categories, showing a multi lean-green focus and overlap with various research streams. Some of the six categories where sub-divided to show with more clarity and detail the lean-green research avenues that the articles had explored. The numbers attached (squares) to the categories and sub-categories represent a cross reference to the articles included in Table 1. For example, Azevedo *et al.* (2012) is article number 5 in Table 1, and has been linked to the sub-categories 'environmental', 'sustainability', 'supply chain', 'production/manufacturing/industrial systems & processes' and 'manufacturing'. This indicates that the Azevedo *et al.* (2012) article encompasses all these thematics. Each research stream and their corresponding sub-categories are discussed in Sections 3.2 to 3.7 (as shown in Figure 4).

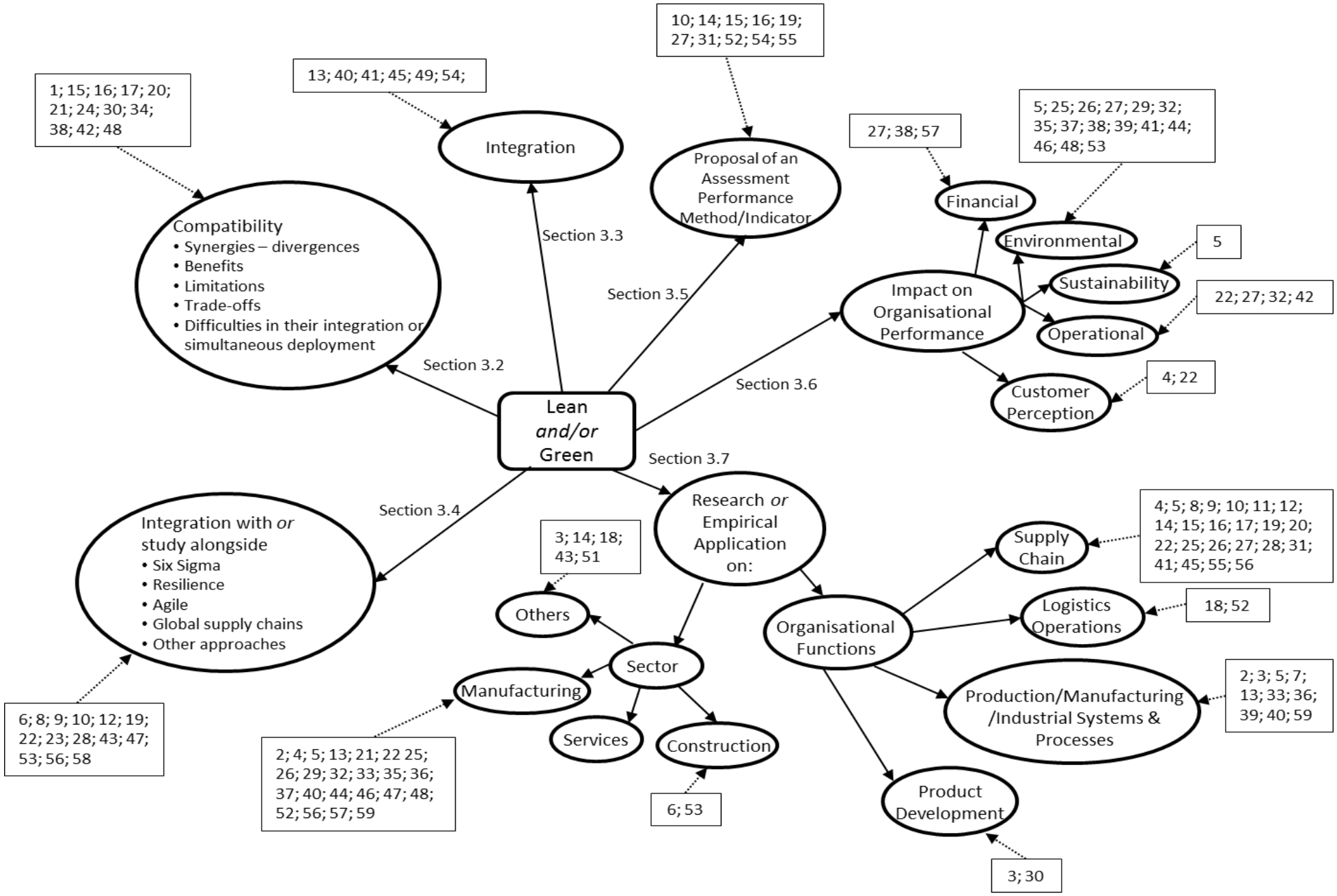

Fig. 4. Concept map of the lean and green literature review showing the different research streams identified

Table 1. Articles included in the literature review

Article No.	Author(s)	Title	Database
1	Lean and Green (2013)	Lean and green	T&F
2	Aguado *et al.* (2013)	Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation	Elsevier
3	Cluzel *et al.* (2010)	Managing the complexity of environmental assessments of complex industrial systems with a lean 6 Sigma approach	Springer
4	Smith (2012)	Green supply chain management and consumer sensitivity to greener and leaner options in the automotive industry	Inderscience
5	Azevedo *et al.* (2012)	Influence of green and lean upstream supply chain management practices on business sustainability	IEEE
6	Banawi and Bilec (2014)	A framework to improve construction processes: integrating lean, green and Six Sigma	T&F
7	Besseris and Kremmydas (2014)	Concurrent multi-response optimization of austenitic stainless steel surface roughness driven by embedded lean and green indicators	Elsevier
8	Cabral *et al.* (2011b)	An information model in lean, agile, resilient and green supply chains	IEEE
9	Cabral *et al.* (2011a)	Modelling lean, agile, resilient, and green supply chain management	IEEE
10	Cabral *et al.* (2012)	A decision-making model for lean, agile, resilient and green supply chain management	T&F
11	Simpson and Power (2005)	Use the supply relationship to develop lean and green suppliers	Emerald
12	Mollenkopf *et al.* (2010)	Green, lean, and global supply chains	Emerald
13	Diaz-Elsayed *et al.* (2013)	Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments	Elsevier
14	Folinas *et al.* (2014)	Greening the agrifood supply chain with lean thinking practices	Inderscience
15	Duarte and Cruz-Machado (2011)	Exploring lean and green supply chain performance using balanced scorecard perspective	Google Scholar
16	Duarte and Cruz-Machado (2014a)	Investigating lean and green supply chain linkages through a balanced scorecard framework	T&F
17	Dües *et al.* (2013)	Green as the new lean: how to use lean practices as a catalyst to greening your supply chain	Elsevier
18	Esmemr *et al.* (2010)	A simulation for optimum terminal truck number in a Turkish port based on lean and green concept	Elsevier
19	Espadinha-Cruz *et al.* (2011)	A model for evaluating lean, agile, resilient and green practices interoperability in supply chains	IEEE
20	Wiengarten *et al.* (2013)	Exploring synergetic effects between investments in environmental and quality/lean practices in supply chains	Emerald
21	Galeazzo *et al.* (2014)	Lean and green in action: interdependencies and performance of pollution prevention projects	Elsevier
22	Govindan *et al.* (2013)	Lean, green and resilient practices influence on supply chain performance: interpretive structural modeling approach	Springer
23	Garza-Reyes *et al.* (2014)	Lean and green – synergies, differences, limitations, and the need for Six Sigma	Springer
24	Wadhwa (2014)	Synergizing lean and green for continuous improvement	Springer
25	Hajmohammad *et al.* (2013a)	Lean management and supply management: their role in green practices and performance	Elsevier

26	Hajmohammad *et al.* (2013b)	Reprint of lean management and supply management: their role in green practices and performance	Elsevier
27	Carvalho *et al.* (2010)	Supply chain performance management: lean and green paradigms	Inderscience
28	Carvalho *et al.* (2011)	Lean, agile, resilient and green: divergences and synergies	Emerald
29	Jabbour *et al.* (2013)	Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing	Elsevier
30	Johansson and Sundin (2014)	Lean and green product development: two sides of the same coin?	Elsevier
31	Kainuma and Tawara (2006)	A multiple attribute utility theory approach to lean and green supply chain management	Elsevier
32	King and Lenox (2001)	Lean and green? an empirical examination of the relationship between lean production and environmental performance	Wiley
33	Kurdve *et al.* (2011)	Use of environmental value stream mapping and environmental loss analysis in lean manufacturing work at Volvo	Google Scholar
34	Larson and Greenwood (2004)	Perfect complements: synergies between lean production and eco-sustainability initiatives	Wiley
35	Bandehnezhad *et al.* (2012)	An empirical study on the contribution of lean practices to environmental performance of the manufacturing firms in northern region of Malaysia	Inderscience
36	Mashaei *et al.* (2011)	Green and lean control of cyclic pallet systems	IEEE
37	Maxwell *et al.* (1998)	Case study: Honda of America Manufacturing, Inc.: can lean production practices increase environmental performance?	Wiley
38	Herrmann *et al.* (2008)	An environmental perspective on lean production	Springer
39	Moreira *et al.* (2010)	Towards eco-efficient lean production systems	Springer
40	Pampanelli *et al.* (2014)	A lean & green model for a production cell	Elsevier
41	Parveen *et al.* (2011)	Integration of lean and green supply chain - impact on manufacturing firms in improving environmental efficiencies	IEEE
42	Puvanasvaran *et al.* (2011)	Principles and business improvement initiatives of lean relates to environmental management system	IEEE
43	Ranky *et al.* (2012)	Sustainable lean six-sigma green engineering system design educational challenges and interactive multimedia solutions	IEEE
44	Sawhney *et al.* (2007)	En-Lean: a framework to align lean and green manufacturing in the metal cutting supply chain	Inderscience
45	Mason *et al.* (2008)	Lean and green supply chain mapping: adapting a lean management tool to the needs of industrial ecology	Inderscience
46	Rothenberg *et al.* (2001)	Lean, green, and the quest for superior environmental performance	Wiley
47	Salleh *et al.* (2012)	Green lean total quality information management in Malaysian automotive companies	Elsevier
48	Sobral *et al.* (2013)	Green benefits from adopting lean manufacturing: a case study from the automotive sector	Wiley
49	Duarte and Cruz-Machado (2013a)	Modelling lean and green: a review from business models	Emerald
50	Tice *et al.* (2005)	Lean production and EMSs: aligning environmental management with business priorities	Wiley
51	Vais *et al.* (2006)	"Green and lean" at a Romanian secondary tissue paper and board mill—putting theory into practice	Elsevier
52	Verrier *et al.* (2014)	Combining organizational performance with	Elsevier

		sustainable development issues: the green and lean project benchmarking repository	
53	Sertyesilisik (2014)	Lean and agile construction project management: as a way of reducing environmental footprint of the construction industry	Springer
54	Duarte and Cruz-Machado (2013b)	Lean and green: a business model framework	Springer
55	Duarte and Cruz-Machado (2014b)	Lean and green supply chain performance: a balanced scorecard perspective	Springer
56	Carvalho *et al.* (2014)	Trade-offs among lean, agile, resilient and green paradigms in supply chain management: a case study approach	Springer
57	Yang *et al*. (2011)	Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms	Elsevier
58	Garza-Reyes (2015)	Green lean and the need for Six Sigma	Emerald
59	Kurdve *et al.* (2014)	Lean and green integration into production system models – experiences from Swedish industry	Elsevier

3.2. Compatibility between lean-green

There is a current need for organisations to not only improve operational but also environmental efficiency. This has prompted research to explore the possible amalgamation of the lean and green approaches, traditionally deployed individually and with different purposes, by delving into their synergies and divergences. Fig. 4 shows the number and the papers that have investigated the compatibility of the lean and green paradigms. It indicates that research in this direction has not only centred on investigating the affinity of lean and green in a general context but also in specific areas such as supply chain (Dües *et al.*, 2013; Wiengarten *et al.*, 2013; Duarte and Cruz-Machado, 2014a), manufacturing (Galeazzo *et al.*, 2014; Sobral *et al.*, 2013) and product development (Johansson and Sundin, 2014). In some other cases, the possible impact of the lean-green compatibility on financial (Herrmann *et al.*, 2008), environmental (Sobral *et al.*, 2013; Herrmann *et al.*, 2008) and operational (Puvanasvaran *et al.*, 2011) performance has also been considered.

In general, research suggests that lean and green are concurrent and thus can effectively work together (Garza-Reyes *et al.*, 2014; Dües *et al.*, 2013; Garza-Reyes, 2015) as they both maintain synergies related to waste reduction, lead time reduction, product design and use of various approaches and techniques to manage people, organisations, and supply chain relations (Garza-Reyes *et al.*, 2014; Dües *et al.*, 2013; Garza-Reyes, 2015; Larson and Greenwood, 2004; Johansson and Sundin, 2014; Wiengarten *et al.*, 2013). For this reason, Galeazzo *et al.* (2014) suggest that sequential or reciprocal interdependencies between lean and green will be generated and prompt these to support each other if their practices are implemented either sequentially or simultaneously.

However, despite maintaining some harmony, authors such as Garza-Reyes *et al.* (2014), Dües *et al.* (2013), Garza-Reyes (2015), Mollenkopf *et al.* (2010) and Johansson and Sundin (2014) suggest that lean and green differ in some dimensions. For example, their primary focus, definition of waste, value construct, process structure, performance metrics, type of customers, and tools/techniques used. Thus, Kleindorfer *et al.* (2005) comment that lean and green practices are distinct and hence they both have a different impact on business performance. These inconsistencies clearly exposed in the literature suggest that further research is needed to explore various aspects regarding the affinity of lean and green. This is highlighted in Section 3.8.

3.3. Integration of lean and green as a consolidated approach

While there are separate streams of established research on lean and green, and a combined stream mainly focused on exploring their compatibility (see Section 3.2), some authors have also addressed the lean-green intersection through the proposal of different approaches to integrate them. According to Mollenkopf *et al.* (2010), focusing on such intersection is critical in order to take advantage of the lean and green synergies available when they are implemented concurrently. Similarly, Pampanelli *et al.* (2014) suggest that it is essential to integrate lean and green strategies into a consolidated approach in order to implement them simultaneously, and in this way, fully exploit the coacting effect. Fig. 4 shows the articles that have been published in the recent lean-green literature intending to integrate these strategic initiatives. Some of these integrating approaches were developed to be applied at an operation/process level in the manufacturing industry (Diaz-Elsayed *et al.*, 2013; Pampanelli *et al.*, 2014), while others have focused on supply chains (Parveen *et al.*, 2011; Mason *et al.*, 2008). Despite these, there seems to be a limited number of approaches or models that integrate lean and green thinking and merge their fundaments and principles (Pampanelli *et al.*, 2014; Kurdve *et al.*, 2011). This suggests that further research is needed not only to investigate different aspects regarding the constitution, effectiveness, applicability and practical implications and challenges of such approaches but also develop other effective integrating frameworks. Paths for further research avenues in relation to the integration of lean and green are highlighted in Section 3.8.

3.4. Integration of lean-green with other approaches

The adoption of lean and green practices in operations/processes and supply chains can contribute to the achievement of corporate profit and market share through the reduction of costs and environmental risks (Carvalho *et al.*, 2011). However, some authors consider that not only the trade-offs between lean and green but also other paradigms such as agile and resilience may help operations/processes and supply chains to become more efficient, streamlined and sustainable. For this reason, authors such as Carvalho *et al.* (2011), Carvalho *et al.* (2014), Cabral *et al.* (2011a), Cabral *et al.* (2011b), Cabral *et al.* (2012), Espadinha-Cruz *et al.* (2011) and Ranky *et al.* (2012) have investigated the concessions of the lean, agile, resilient and green (LARG) paradigms. In particular, information and analytical network process models have been proposed by Cabral *et al.* (2011a), Cabral *et al.* (2011b) and Cabral *et al.* (2012) to support the integration of LARG in supply chains, while Espadinha-Cruz *et al.* (2011) developed a model to evaluate their interoperability. Furthermore, Carvalho *et al.* (2011) and Carvalho *et al.* (2014) investigated the trade-offs of the LARG paradigms and their effect on supply chains. Sertyesilisik (2014) focused on lean and agile construction project management with respect to their contribution to the reduction of environmental footprint and waste.

On the other hand, other authors including Banawi and Bilec (2014), Garza-Reyes *et al.* (2014), Garza-Reyes (2015), Ranky *et al.* (2012) and Salleh *et al.* (2012) have also considered the assimilation of the quality paradigm with the lean and green paradigms. For example, Garza-Reyes *et al.* (2014) and Garza-Reyes (2015) highlighted the need to integrating Six Sigma as part of the green lean approach, while Banawi and Bilec (2014) have proposed a lean-green-Six Sigma integrating method for a construction process. In the case of Salleh *et al.* (2012), the quality dimension is considered through the proposal of a framework that comprises Information Management (IM) in Environmental Management System (EMS) practices, which is integrated to TQM with lean principles.

This research stream within lean and green indicates that authors consider that business performance is multi-dimensionally affected by different factors and hence can be enhanced not only through the adoption of lean and green practices but also by incorporating others related to improving the agility, resilience and quality of operations/processes and supply chains. This provides the opportunity of generating new research avenues regarding the integration of lean and green with other performance enhancement paradigms, see Section 3.8.

3.5. Proposal of a lean-green performance assessment method/indicator

Measurement on continuous basis is crucial to improve operations/processes and supply chains (Cabral *et al.*, 2012). In this context, the concurrent deployment of lean and green practices requires adequate metrics to measure the contribution and effect of both paradigms, and their dependencies, on the performance of organisations. In this case, Carvalho *et al.* (2010) proposed a conceptual model that measures the relationships between lean and green practices and supply chain performance.

However, the research on lean and green performance indicators has gone beyond the study and development of methods to quantify their contribution to performance. For example, authors have also developed frameworks and models to:

- Support decision-making in the selection of the most appropriate key performance indicators (Cabral *et al.*, 2012);
- adapt tools such as value stream mapping (Folinas *et al.*, 2014), balanced score card (Duarte and Cruz-Machado, 2011; Duarte and Cruz-Machado, 2014a; Duarte and Cruz-Machado, 2014b) and theories such as that of multiple attribute utility (Kainuma and Tawara, 2006) to assess environmental performance;
- evaluate the overall business interoperability and establish what measures can reduce interoperability problems in supply chains (Espadinha-Cruz *et al.*, 2011);
- benchmark lean and green practices (Verrier *et al.*, 2014); and
- connect and integrate lean and green principles and tools (Duarte and Cruz-Machado, 2013b).

In most of the cases, the methods and models have been designed to be applicable to supply chains (Cabral *et al.*, 2012; Folinas *et al.*, 2014; Duarte and Cruz-Machado, 2011; Duarte and Cruz-Machado, 2014a; Espadinha-Cruz *et al.*, 2011; Carvalho *et al.*, 2010; Kainuma and Tawara, 2006; Duarte and Cruz-Machado, 2014b), while only the method developed by Verrier *et al.* (2014) was relevant and hence tested in the manufacturing and logistic sectors. This may be explained by a shift in the type of current competition experienced in the market, which has shifted from companies to supply chains (Cabral *et al.*, 2011b), and the fact that supply chains are nowadays a major component of competitive strategies to enhance organisational productivity and profitability (Gunasekaran *et al.*, 2004). This is also in line with the increasing academic and corporate interest in green supply chains noticed by Seuring and Müller (2008). Despite this possible justification and explanation, the results of the literature review suggest that there is a shortage of lean and green research focused, particularly, on developing measurement methods or models for specific processes and industries. Since there is a wide variety, and the characteristics of different industries and processes may vary considerable, specific lean and green measures and metrics may be necessary for specific applications. This is suggested as one of the research avenues that the lean and green theme can explore and that are highlighted in Section 3.8.

3.6. Lean-green impact on organisational performance

Organisational performance is a multifaceted (Yang *et al.*, 2011) condition that is conceptualised through various composite dimensions of performance. In this respect, a significant amount of research has been dedicated to investigate the effect of individual and concurrent lean and green practices on various composite dimensions of organisational performance that include financial, environmental, sustainability, operational and customer perception. Fig. 4 presents the articles which, to a certain extent, have explored such effect. This relatively rich stream of research reflects the constant debate among researchers regarding the potential benefits of sequentially or simultaneously adopting lean and green within organisations, their supply chains and operations/processes (Dües *et al.*, 2013; Larson and Greenwood, 2004; Johansson and Sundin, 2014; Wiengarten *et al.*, 2013).

In general, the studies conducted and presented in Fig. 4 seem to suggest that the adoption of lean and green practices has a beneficial effect on all of the different dimensions of performance illustrated in Fig. 4. This is in line with Kitazawa and Sarkis (2000) and Dües *et al.* (2013), who agree that organisations that jointly implement lean and green achieve higher performance, particularly, environmental and operational. However, similar extensive research has been conducted, for over two decades, into the impact of lean practices on various measures of performance, see Belekoukias *et al.* (2014) for a summary of such research. The complexity and different natures, dimensions and scopes that these types of researches can take as well as the lack of clear and consistent conclusions from these studies may suggest that the research done until now to try to establish the effect of lean-green practices on different aspects of organisational performance is still limited and inconclusive. For this reason, further extensive research needs to be conducted in order to provide more robustness to the results and conclusions that have already been obtained by the articles presented in Fig. 4.

3.7. Lean-green research or empirical application

Fig. 4 illustrates the organisational functions and industrial sectors where lean and green research has focused. Similarly as with the research stream on proposal of lean-green performance assessment method/indicators (see Section 3.5), the majority of the articles (62% – 23 articles) that were able to be classified according to their research focus on specific organisational functions were centred on supply chains. As previously discussed in Section 3.5, this shows the importance and current interest given to the supply chain context (Gunasekaran *et al.*, 2004; Seuring and Müller, 2008). Although logistic operations are an integral part of supply chain activities (Lambert and Pohlen, 2001) and hence articles focused on them could have been generally categorised as part of the supply chain research stream, these were separately classified to show the lean and green research focus with more detail. This indicates that although some lean and green research has centred on the logistic activity of supply chains, this is still very limited, with only two articles (Esmemr *et al.*, 2010; Verrier *et al.*, 2014) considering it. Thus, future lean and green research can concentrate on specific key supply chain activities such as logistics, procurement and materials handling (Slack *et al.*, 2013). Production, manufacturing and industrial systems and processes have also received some attention from lean and green researchers, with 27% (10 articles) considering the study and/or application of lean and green on these. Finally, only two articles (Cluzel *et al.*, 2010; Johansson and Sundin, 2014) have studied lean and green within the ambience of product development, indicating a potential stream for future research.

Manufacturing organisations have been forced, more than companies from other industries, to rethink how they manage their operations and processes in order to respond to governmental environmental regulations and the growth of customer demands for products

and services that are environmentally sustainable (Garza-Reyes, 2015). Thus, it is unsurprising to see that most of the lean and green research, when analysed per industrial sector, has been concentrated in the manufacturing industry, see Fig. 4. Historically, the manufacturing sector has acted as a vital source of innovation, making outsized contributions to research and the development of working practices and organisational models (e.g. lean manufacturing, Six Sigma, Total Quality Management, etc.) that have been later adopted and adapted across a wide range of other industries. In the case of green and lean, the literature review suggests a similar trend where the manufacturing sector, once more, has taken the research lead, followed by a slow transition into other industries such as construction (Banawi and Bilec, 2014; Sertyesilisik, 2014), aluminium electrolysis substations (Cluzel *et al.*, 2010), agrifood (Folinas *et al.*, 2014), ports (Esmemr *et al.*, 2010), education (Ranky *et al.*, 2012) and process (Vais *et al.*, 2006).

3.8. Paths for further research

In the previous sections, six current emerging research streams related to lean and green were identified and discussed. Of these research streams, some have received more attention from the researchers' community, while others still require further research in the future. This can be clearly seen in Fig. 4 by observing the number of articles that have adhered to every category and sub-category.

Although some light has already been provided during the discussion of this research's results in Sections 3.2 to 3.7 regarding potential research paths for future studies, this section presents the research questions that are considered to be crucial for the future development of the lean and green area. According to Bryman and Bell (2011) and Marx (1997), the formulation of research questions is the most effective strategy to highlight and guide future research, while at the same time stopping researchers from going off in unnecessary directions. Thus, the formulation of clear and specific research questions derived from the analyses and discussions made in the previous sections was determined to be the most adequate strategy to highlight the potential paths for future research in the lean and green area. Table 2 presents the research questions that can guide future research paths in the five research streams presented in Sections 3.2 to 3.6.

In relation to the research stream discussed in Section 3.7, more focus could be set on studying lean and green within the context of underreported organisational functions and industries. For this, the five previous research streams can be taken as a basis. For example, Fig. 4 indicates that no research on lean and green has been carried out in the service industry. Considering that the world economy is increasingly classified as a service economy due to the growing importance of this sector (Vago and Lusch, 2008), this can be considered a key under-researched stream. How compatibles, for example, are lean and green in the service sector? (Section 3.2), Can they be integrated to be simultaneously deployed in service organisations? (Section 3.3), Can other paradigms such as agile, resilience and quality be considered alongside lean-green, within the context of service companies, to provide an enhance approach for improvement? (Section 3.4), How can the interrelation and contribution of lean and green to organisational performance be measured in the service sector? (Section 3.5),What is the impact of lean and green initiatives on the performance of service companies? Similar research questions can be formulated to expand the lean and green research in other underreported organisational functions (e.g. logistics, product development, human resources, marketing, etc.) and industries (e.g. construction, healthcare, education, etc.).

Table 2. Research questions to guide further research

Research Questions
Compatibility between lean-green (Section 3.2)
1. How do the lean and green synergies and divergences affect the effectiveness of these initiatives when deployed either sequentially or simultaneously? **2.** Are the lean and green synergies and divergences the same in every industry? **3.** Are the lean and green synergies and divergences the same at any level (i.e. operations/process or supply chain)? **4.** How can the degree of compatibility between lean and green be measured?
Integration of lean and green as a consolidated approach (Section 3.3)
1. What constitutes an effective integrating approach? **2.** Can the current integrating approaches already proposed in the academic literature, see Fig. 4, be adapted to other processes or industries? **3.** In an integrated lean-green approach, what is the individual contribution of lean and green on the performance of an organisation? **4.** What may be the practical implications and challenges of sequentially or simultaneously deploying lean and green as oppose to only deploying one of the two?
Integration of lean-green with other approaches (Section 3.4)
1. Is the integration of lean and green principles enough to achieve the maximum potential of organisational performance improvement? **2.** Can the integration and concurrent implementation of green, lean, agile, resilience and quality practices as well as any other improvement paradigm provide organisations with an enhanced approach to achieve better performance? **3.** What is the individual contribution of every one of the paradigms on the performance of an organisation? **4.** What constitutes an effective integrating approach? **5.** Can the current integrating approaches already proposed in the academic literature, see Fig. 4, be applicable or adapted to different processes or industries? **6.** What may be the practical implications and challenges of integrating lean, green and any other paradigm(s) such as agile, resilience and quality as oppose to only integrating lean and green?
Proposal of a lean-green performance assessment method/indicator (Section 3.5)
1. What are the characteristics of an effective lean-green assessment method or indicator? **2.** Can the current lean and green measurement methods and models already proposed in the academic literature, see Fig. 4, be applicable or adapted to different processes or industries?
Lean-green impact on organisational performance (Section 3.6)
1. What is the effect of the subsequent or concurrent deployment of lean and green practices on contemporary measures of operational performance such as cost, speed, dependability, quality and flexibility (Slack *et al.*, 2013; Belekoukias *et al.*, 2014)? *To further expand this research stream, similar studies can be conducted to investigate such effect in other measures that may include: volume flexibility, product mix flexibility, delivery dependability, JIT delivery, cost investment of a product, productivity, inventory, lead/cycle time, among others - See Belekoukias et al. (2014) for other measures that may also be incorporated into these studies.*

4. Conclusions

Environmental sustainability is nowadays one of the strategic imperatives, for organisations, which must be aligned to their traditional priorities of profitability and efficiency. Different aspects of the lean and green paradigms have been studied as the subsequent or simultaneous deployment of their practices has been considered as a potential approach for achieving such alignment. However, the development of this area is still in early stages, with the majority of the articles in this field published in the last five years. This paper offered a systematic

review of the existing literature that relates lean and green, in order to provide guidance on the topic for scholars and to contribute with the definition of clear paths for further research.

The study has identified and classified six streams of research in the area of lean and green, these being directed to explore: (1) their compatibility, (2) their amalgamation, (3) their integration with other paradigms, (4) methods/indicators to measure their contribution and effect, and their dependencies, on the performance of organisations, (5) their impact on organisational performance, and (6) their application in various organisational functions and industries. For this reason, the concept of lean-green was until now relatively unclear, and many avenues for further research, to continue developing the streams already identified, currently still remain open. All the topics for further research identified can be considered equally important. However, the investigation of lean and green in under-researched organisational functions and industries can be considered critical for the practical advancement of the area. Structuring and defining the potential research topics can stimulate scholars to further study certain issues in depth, leading to a better understanding of the dynamics of deploying lean and green initiatives.

Besides intending to stimulate scientific research, this study also aims at providing industrialists with a general overview of lean and green so they can develop a deeper and richer knowledge on these paradigms, and their practices, to help them formulate more effective strategies for their implementation. This research will also motivate them, and hence their organisations, to operate sustainably.

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