A bibliometric and network analysis of Lean and Clean(er) production research (1990/2017)

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Abstract

In recent years, the renewed interest in environmental issues has gradually required manufacturers to simultaneously pursue a more rational use of resources and a reduction in wastes production. New strategies, technologies and organisational innovations must be therefore conceived to "create more value with less impact" (WBCSD, 2010). An interesting and promising perspective for achieving internal efficiency, market effectiveness and environmental eco-efficiency is that of integrating the environmental variable in the Lean Production (LP) paradigm. Scholars and practitioners have been working for some years in this direction of eco-innovation. The present article aims at obtaining a quali/quantitative overview of Lean and Clean(er) production (L&C) research through a bibliometric and network analysis, by using a scientific literature database; in particular, it investigates how Clean(er) Production research and publications are progressively embedded in the field of LP, what are the main topics in this sub-field and common research themes. A comprehensive picture was made by analysing data concerning publications, authors, affiliations, and the countries of origin. Evolutionary profiles, major topics investigated, leading authors and collaborations have been reported. The results also reveal promising space for the development of L&C production research, in order to achieve economic and environmental benefits.

Keywords: Lean Production; Lean Manufacturing; Cleaner Production; Green Manufacturing; Bibliometric analysis; Social Network Analysis.

1. Introduction

Lean Production (LP) is a management approach that considers the use of resources for any goal other than the creation of value for the end customer as a target for elimination (Womack and Jones, 1996). Moving from incorporating the Just-In-Time and Total Quality Control principles, LP extended them to production processes, logistics and finally to supply chain systems (Crute et al., 2003; Kojima and Kaplinsky, 2004). The Lean approach introduces a key variable into manufacturing, i.e., the concept of "waste" (W), which derived from the Ohno study (1978) in the Toyota Production System, who used the term *Muda* to indicate non-value activities. The relevance of Muda is based on its direct connection with quality, time and cost variables. By removing a Muda, a synergistic and positive effect on the competitiveness of the whole system is enhanced, being able to manage prices or provide a higher level of performance in products or services (Rother and Shook, 1999).

The ever-increasing attention towards the issue of sustainability has progressively led to the involvement of another management variable in manufacturing studies, the natural environment. More specifically, the most

promising approaches concern such preventive strategies that consider the efficient use of resources as a source of all technical, economic and environmental benefits (Porter and Van de Linde, 1995). In this article, we briefly call all of them "Clean(er) Production" (CP) approaches. Their purpose represents an important opportunity for companies in order to introduce new solutions that enhance environmental performances of products and processes and improve business competitiveness. The first efforts in this direction focused on the technological dimension of innovations for the development of the so-called cleaner technologies (e.g., Ausubel and Sladovich, 1989), and more recently, the organisational eco-innovations have been gaining increasing relevance (Florida, 1996). A great part of them is developed within the field of the LP studies. The scientific community has progressively welcomed this view and multiple studies and practical experiences have been conducted in this regard. However, the need for a well-defined framework of study and for specific methods and tools of analysis is still recognised.

In the light of what was stated above, the present article aims at obtaining an overview about Lean and Clean(er) production (L&C) research, by addressing the following questions: *i) How have research and publications on L&C production evolved in the last years? ii) How are CP research and publications embedded in the field of LP? iii) What are the most promising common themes of research?* In order for these questions to be answered, a bibliometric and network analysis were performed to analyse the scientific literature. The article starts by showing the methods used, the data acquisition and management. After that, the quantitative results are presented, both for the LP field and for the L&C sub-field. Through a keyword-based analysis, the core literature and journals, research areas, and author profile are presented. In the second part of the article, a more detailed discussion about the L&C studies is conducted using social network analysis tools. A qualitative analysis of the most relevant contributions was carried out, as well. Finally, the results are outlined with an emphasis on the leading topics (studies) and the potential perspectives for the research on L&C production.

2. Approach and methods

A bibliometric study was carried out. Bibliometrics is used to measure the qualitative and quantitative research, to investigate the research trends in a subject and to measure and assess the research impact of individuals, groups of individuals or institutions (Nilaranjan and Pushpanjali, 2014; Yu et al., 2013).

The data for the study are retrieved from the Scopus database. Scopus is the main world multidisciplinary bibliographic database, produced by Elsevier and accessible online after subscription; it covers nearly over 21,500 peer-reviewed journals, from more than 5,000 international publishers (Elsevier, 2017). The Scopus database is used for many bibliographic fields of research, including citation information (author(s), document title, year, source title, volume, issue, pages, citation count, source and document type), fund details (number, acronym and sponsor), references, other information (trade names and manufacturers, accession numbers and chemicals and conference information) and bibliographical information (affiliations, serial identifiers (e.g., ISSN), DOI, PubMed ID, publisher, editor(s), language of original document, correspondence address and abbreviated source title).

The search was limited to the period from 1990 to 2017. We selected this period because after analysing the contributions before 1990 (13), none was found in the Scopus database concerning the area of interest. The collected data were then classified by using spreadsheets in order to analyse the types of research data. All types of different data are presented in a tabular form or different types of figures are used to present different research characteristics. Part of the collected data has been loaded into the UCINET software (a software package for social sciences) for the additional purposes of the analysis. We used the truncated search * to identify variation terms, plural form and singular form.
The search was structured in two phases: the first focused on studies related to LP; the second -with the integration of contributions- on CP. The analysis was developed as follows.

2.1 Key-concept selection

The first addressed issue was the choice of the key concepts for data acquisition and selection. Within the Lean studies, we firstly decided to investigate the origins and use of the three most recognised key concepts: *lean production*, *lean manufacturing* and *lean thinking*. The term *lean production* was first used in a MIT Sloan Management Review article by John Krafcik, titled "The triumph of the lean production system" (1988). The term "lean" was later popularised in the best-selling book, co-authored by three MIT researchers Jim Womack, Daniel Jones, and Daniel Roos, by the title "The Machine That Changed the World" (1990). This book encouraged the dissemination of lean principles and is universally considered as the contribution that gave rise to this new field of study. The term *lean thinking* was coined by Womack and Jones in 1996 in the book entitled "Lean thinking: banish waste and create wealth in your corporation". This expression refers to a new way of thinking for any activities finalised to the systematic elimination of waste and to the real implementation of LP. *Lean manufacturing* is often used as synonym for LP, although someone claims a slight difference between the two (Barlotti, 2013), considering manufacturing as a very specific form of production with organised labour and tools in order to achieve tangible outputs (e.g., automobiles).
In the end, given the tendency to use the three concepts interchangeably, it was decided to use all of them (in the search), using LP as a referential concept of the article.
Regarding the key concepts in the field of CP, the terms *green*; *environment** and *sustainab** were chosen to be used in addition to *clean**.

2.2 Aspects investigated

The aspects that were investigated quantitatively are the following:

i) Historical evolution of the field (number of publications covered by the field of research and published over the years);
ii) Sources (documents that have published the contributions);
iii) Themes (most recurring themes/topics in the field);
iv) Authorship (most recurring authors based on the number of publications);
v) Subject areas (research area of the publications);

vi) Documents (type of documents in which the contributions have been published);

vii) Affiliation and country (bodies/institutions and countries of origin of the authors).

The data obtained were used both for a representation using charts and diagrams and for Social Network Analysis (SNA).

On the other hand, the qualitative analysis was developed by selecting the most relevant contributions in the fields of LP and L&C production; the selection was based on the citation analysis (Pilkington and Meredith, 2009). Figure 1 summarises the main concepts and steps of the research activities (Fig.1)

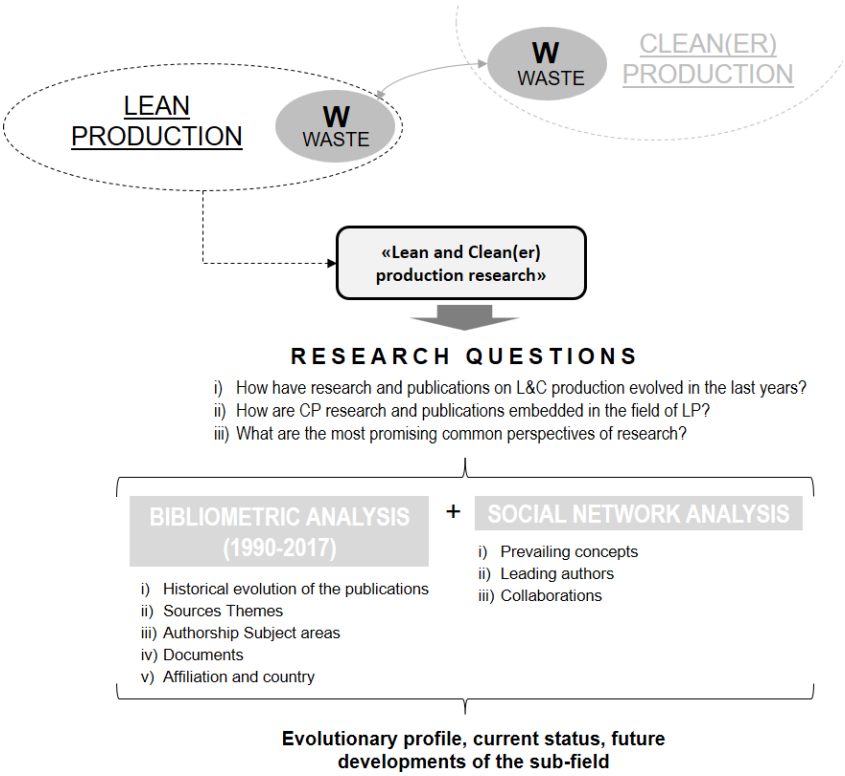


Fig.1. Research design

2.3 Bibliometric and clean-up methods

We used the literature exported from the Scopus database to create a first data set for LP and a sub-dataset for L&C research. The results obtained by searching for the keywords "*lean production*" or "*lean manufacturing*" or "*lean thinking*" in the article titles and keywords were firstly considered. In this way, the inclusion of terms with different meanings such as those contained in the abstracts can be limited. The information selected for the dataset includes title, author data, keywords, and citations. Manual techniques were used in order to clean-up the data (duplications; keywords listed in articles that do not adhere to the main theme; etc.). The first search generated 6,008 results. A time filter was then imposed, limiting the search to the period 1990-2017, because the analysis of the contributions before 1990 (13) results in no contributions concerning the area of interest in the Scopus database. Subsequently, all the results not related to the areas of interest of the research were excluded manually. This step reduced the results to 5,943. This considered the reference database I) of the study and it was analysed quantitatively.

The basis of reference of research activities in the field of LP was analysed in order to select contributions in the field of CP research. For this purpose, a sub-dataset was created, containing the results related to all the contributions that in the *title* or within the *keywords* presented the terms "clean*" OR "green" OR "sustainab*" OR "environment*". The overall obtained contributions were selected in order to eliminate duplications and contributions of topics. The basis of reference II) thus obtained includes 281 contributions; they were then subject to a quali-quantitative and a network analysis.

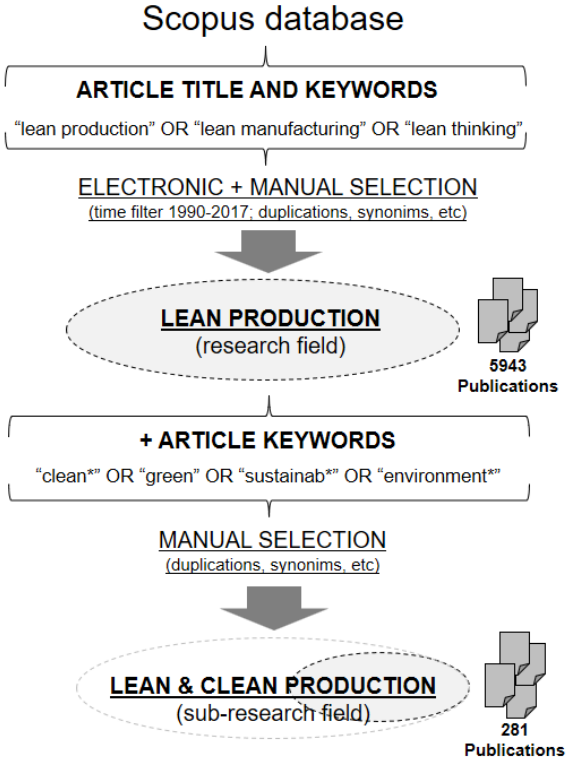


Fig.2 The main steps of the bibliometric analysis

2.4 Social Network Analysis (SNA) aims

Network research focuses on relations among interacting units (e.g., individuals or organisations). By contrast with traditional organisational studies, which examine individual units in isolation by focusing on their attributes, from the network perspective, units are embedded within networks of interconnected relationships that provide opportunities for -and constraints on- behaviour (Wasserman and Faust, 1994). SNA allows researchers to characterise and describe the networks and the position of units. Specifically, the use of methods and tools offered by SNA allow researchers to map and measure the relationships among units and serve as a lens on the insights that underly a network of nodes and links through which information or social relationships travel (Yu et al., 2013).

In this study, we applied SNA to a network established with the nodes that represented articles, keywords, or authors to evaluate the importance and influence of a node by means of graphically investigating the centrality of a node in the network. By definition, units in the centre of a network are more connected than

those on the periphery (Borgatti and Halgin, 2011). The larger its centrality, the more important the node is and the more it can play the role of a "hub" (Wasserman and Faust, 1994). In addition, we applied SNA to describe i) how certain ties correlate with other ties and with the attributes of units, and ii) how the degree of similarity in the network configurations is associated with different types of relations (Borgatti and Halgin, 2011; Stevenson and Greenberg, 2000).

3. Results

a) Bibliometric analysis

This section shows the results of the quantitative analysis conducted.

3.1 Evolution of the literature

The evolution of the literature on LP and L&C production gradually evolved over the years. As regards the LP evolution, four phases can be identified (Fig. 3). The first, from the early '90s until the beginning of 2000s, with an average number of not exceeding 50 publications per year. The second, from the early 2000s until 2005, with an exponential growth of publications, followed by a decline up to 2007 and a new growth until 2011, with over 500 contributions published on average per year until now. Concerning the L&C evolution, it can be noted that the first contributions retrieved in Scopus database are published in the middle of the '90s, progressively increasing from 2000 to 2017 (over 25 contributions published on average during the last 5 years), with a peak in 2016 (41 contributions published).

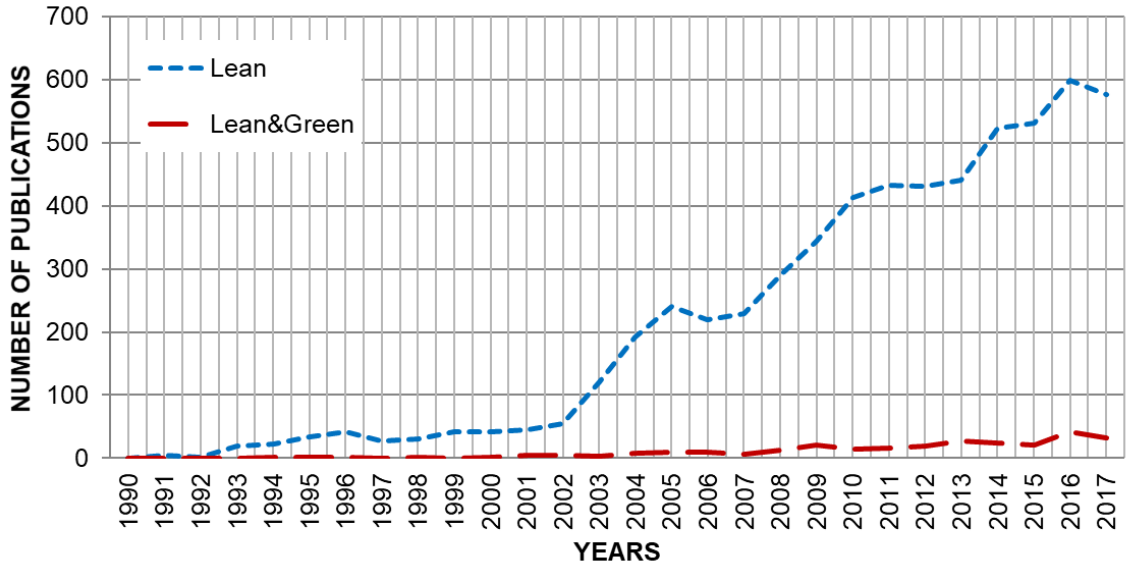


Fig.3. Documents by year. (Data source: Scopus database).

A word-cloud (or tag-cloud) analysis (Halvey and Keane, 2007) has been also conducted on the keywords of the articles (excluding the terms lean manufacturing, lean production, lean thinking). The word cloud is employed to visualise the importance of keywords. The bigger the font size of a tag is, the more frequently

this keyword appears. The cloud confirms that the issues connected to the environmental dimension of manufacturing have still little relevance and, instead, terms more closely related to managerial and operational aspects of manufacturing prevail (Fig.4).

Fig.4. The most recurring keywords in LP research. (Data source: Scopus database).

3.2 Core journals

The analysis carried out has shown that currently the core journals in LP studies are the *SAE Technical papers* (127 articles) and *International Journal of Production Research* (119 articles) (Fig.2a); almost the only two reference journals from 1991 to 2001, which was the first period of publication in this field. As the academic community of LP has evolved, the range of journals has considerably extended; at present, over 100 sources of publications can be recognised. The top 10 journals published 831 papers during the analysed period (1990/2017), about 14% of the total amount. With regard to the L&C articles and during the analysed period, the top 10 journals published 57 papers, the 20% of the total amount. In this case, the core journals are the *Journal of Cleaner Production* (16 articles) and *Food Manufacture* (7 articles) (Fig. 2b). By comparing the field and the sub-field, we can note the presence of three common journals amongst the top 10, underlined in Figure 5 a) and b).

a) Lean **b) Lean and Clean(er)**

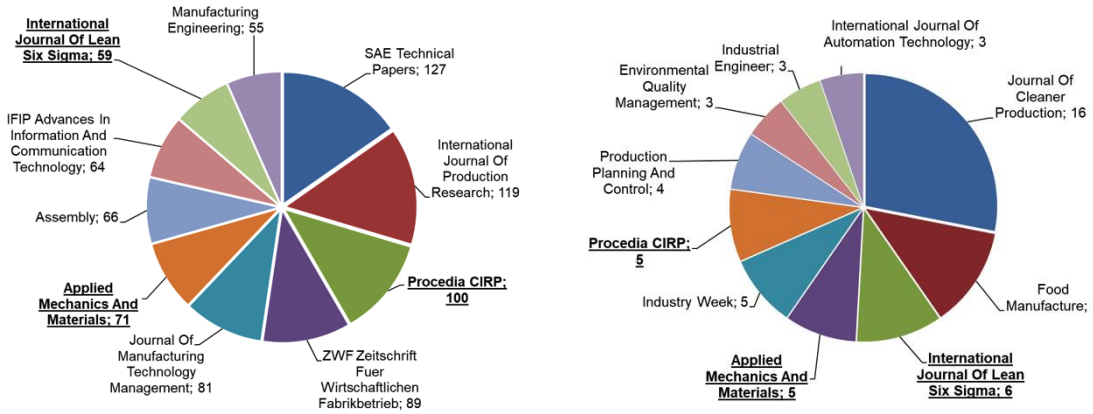


Fig.5 a-b. Documents by source (top10). (Data source: Scopus database).

3.3 Authorship Analysis

As far as the Authorship analysis is concerned, the research has highlighted that over 300 different authors have resulted in the LP studies, with a maximum number of 56 publications (Dombrowski, U.) and over 15 authors with more than 20 publications on the topic (Fig. 6a). This aspect shows a specific degree of "concentration" of the studies. The top cited article received 1089 (Shah and Ward, 2003), 793 (Ben Naylor et al., 1999), 793 (Shah and Ward, 2007), 700 (Hines et al., 2004) and 503 (Holweg M., 2007) citations. In the case of L&C, the community of authors is composed of more than 150 members; the maximum number of publications was18 (Cruz-Machado, V.), and only 15 authors exceeded 3 publications (Fig. 6b). The top 5 cited articles received respectively 388 (King and Lenox, 2001), 375 (Florida, 1996), 230 (Simpson and Power, 2005), 212 (Mollenkopf et al., 2010) and 210 (Rothenberg et al., 2001) citations.

a) Lean **b) Lean and Clean(er)**

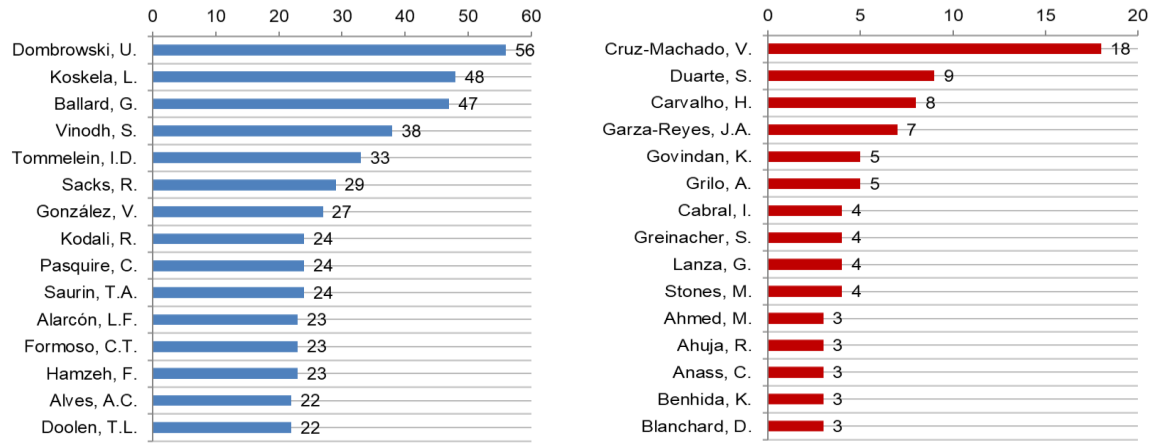


Fig.6 a-b. Documents by author (top15). (Data source: Scopus database).

3.4 Document type

In the case of LP research, the analysis of Document type highlighted that the contributions published in journals (about 45% of the total) and conference papers (43.5%) are significantly predominant. Over 350 contributions were classified as reviews (blocks in red in Fig.5). Similar results were obtained in the case of L&C, with 44% of the contributions published in journals and 33% in conference papers; 19 contributions were classified as reviews (blocks in blue in Fig.7); among them, some are relatively recent (Garza-Reyes, 2015; Martínez-Jurado and Moyano-Fuentes, 2014).

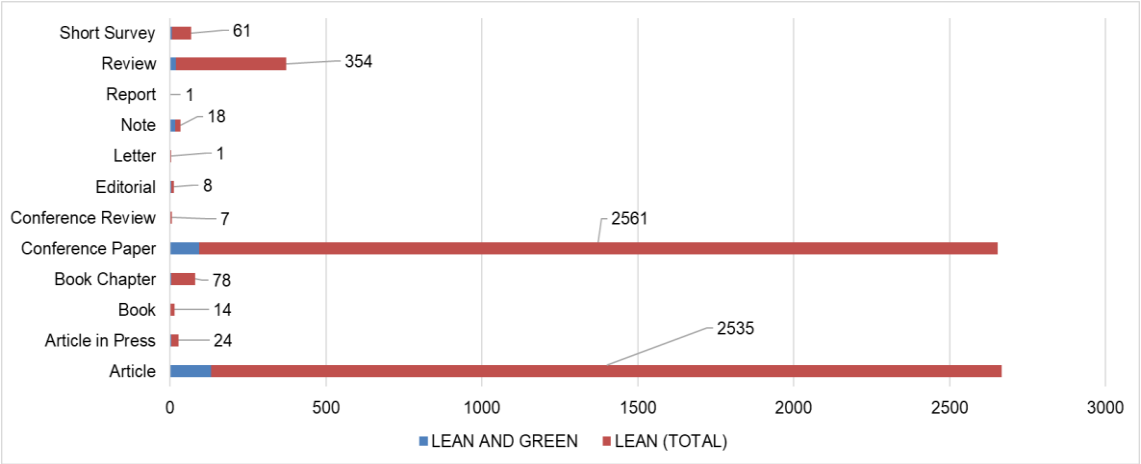


Fig.7. Documents by type. (Data source: Scopus database).

3.5 Subject area

As regards the results of the investigation in the Subject area, Scopus classification clearly shows that over 2/3 of the LP contributions are related to the Engineering area, followed by Business and Management and Accounting research (about 28%), Computer Science (18%) and Decision Science (16%) (Fig. 8a). In the case of L&C research, most contributions are also in the Engineering area (61%), followed by Business, Management and Accounting area (30%) and Environmental Science (13.5%) (Fig. 8b).

a) Lean **b) Lean and Clean(er)**

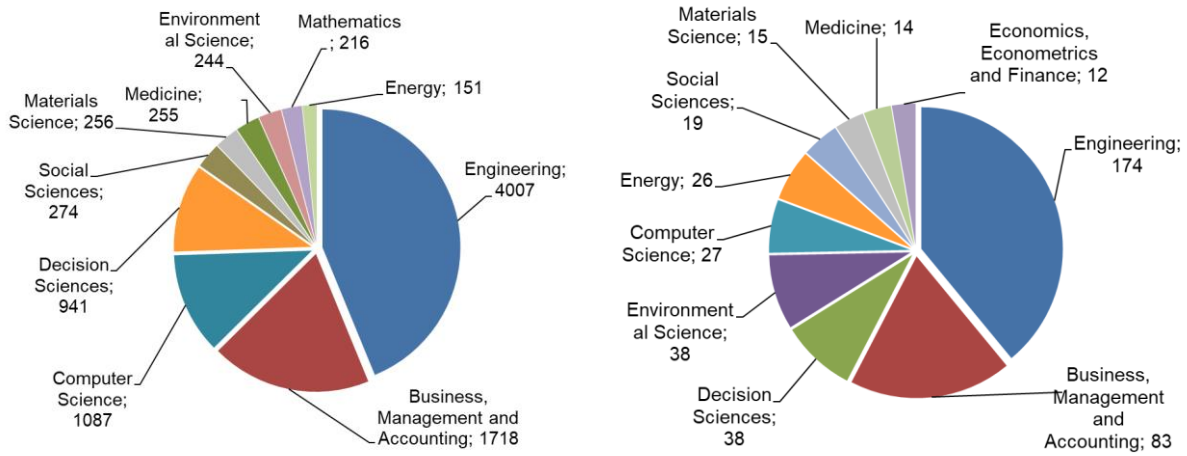
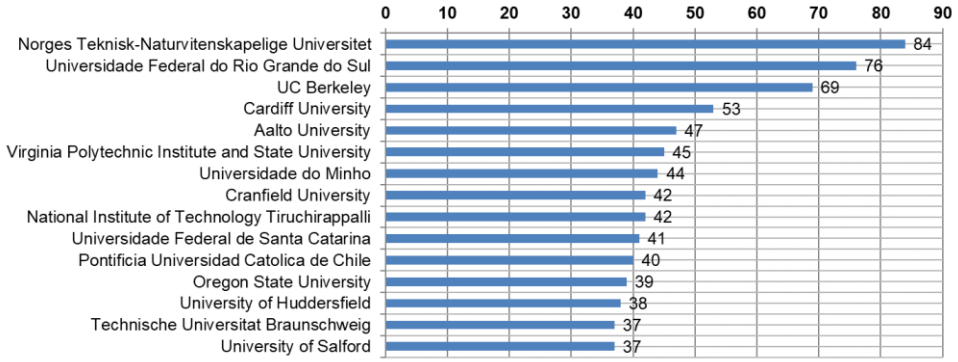


Fig.8 a-b. Documents by subject area. (Data source: Scopus database).

3.6 Affiliations

The Norges Teknisk-Naturvitenskapelige Universitet (NTNU) followed by the Universidade Federal do Rio Grande do Sul and the UC Berkeley have been the most productive institutions, with 84 and 76 and 69 publications in the field of LP respectively. The average of the top 15 institutions is 49 publications (Fig. 9a). More interesting is the geographical origin, with a clear dominance of Anglo-Saxon (US and UK) and South American contexts. A significant diffusion of LP studies is observed also in the Asian and Middle Eastern countries (China, India, Malaysia) and in the European Union. In the case of L&C research, results in Affiliation analysis identified the New University of Lisbon (PT), followed by the University of Derby (UK), as the most productive institutions, with 17 and 7 publications respectively (Fig. 9b). The average of the top 15 institutions is about 5 publications. Also in this case, the geographical origin shows a clear dominance of Anglo-Saxon contexts (US and UK). A significant diffusion of L&C studies is observed also in Latin regions such as Portugal and Brazil (Fig. 9b).

a) Lean



b) Lean and Clean(er)

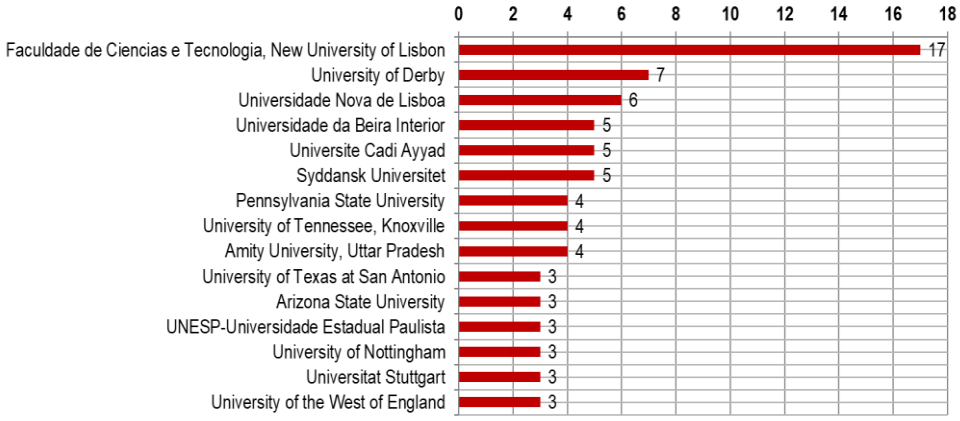


Fig.9 a-b. Documents by affiliation (top15). (Data source: Scopus database).

b) Network analysis

This section shows the results of the network analysis conducted by elaborating the Scopus database. Both following figures were created with NetDraw, a program for drawing social networks included in the UCINET software package version 6.620 (Borgatti et al., 2002).

3.7 Key concepts

Figure 10 shows which are the most important research topics and how they are linked together. The graph was obtained through the construction of a two-mode matrix articles (rows) x key concept (columns), in which the authors classified all the articles included in the Scopus database. The key concepts emerged in terms of their occurrence (excluding those present once) in the title and keywords. In order to make the graph more readable, such key concepts were then grouped in macro-categories. Five main categories were identified: "Operations" (*Production/Product, Engineering/Design, Operations, Logistics, Supply Chain/Suppliers, Machines*); "Business" (*Business/Company/Firms/Enterprise, SME's, Performance/Indicators/Results, Value, Flows, Efficiency/Synergies, Management, Costs, Agile*); "Lean techniques" (*Quality/TQM, Six Sigma Improvement/Kaizen*); "Sustainability aspects" (*Energy, Industrial Ecology, LCA, Waste/Emission, Resilient, Social*); "Technology" (*ICT, Innovation, Technology/Technique*).

The macro categories were individually selected by the authors starting from the list of the key concepts and then jointly discussed and validated.

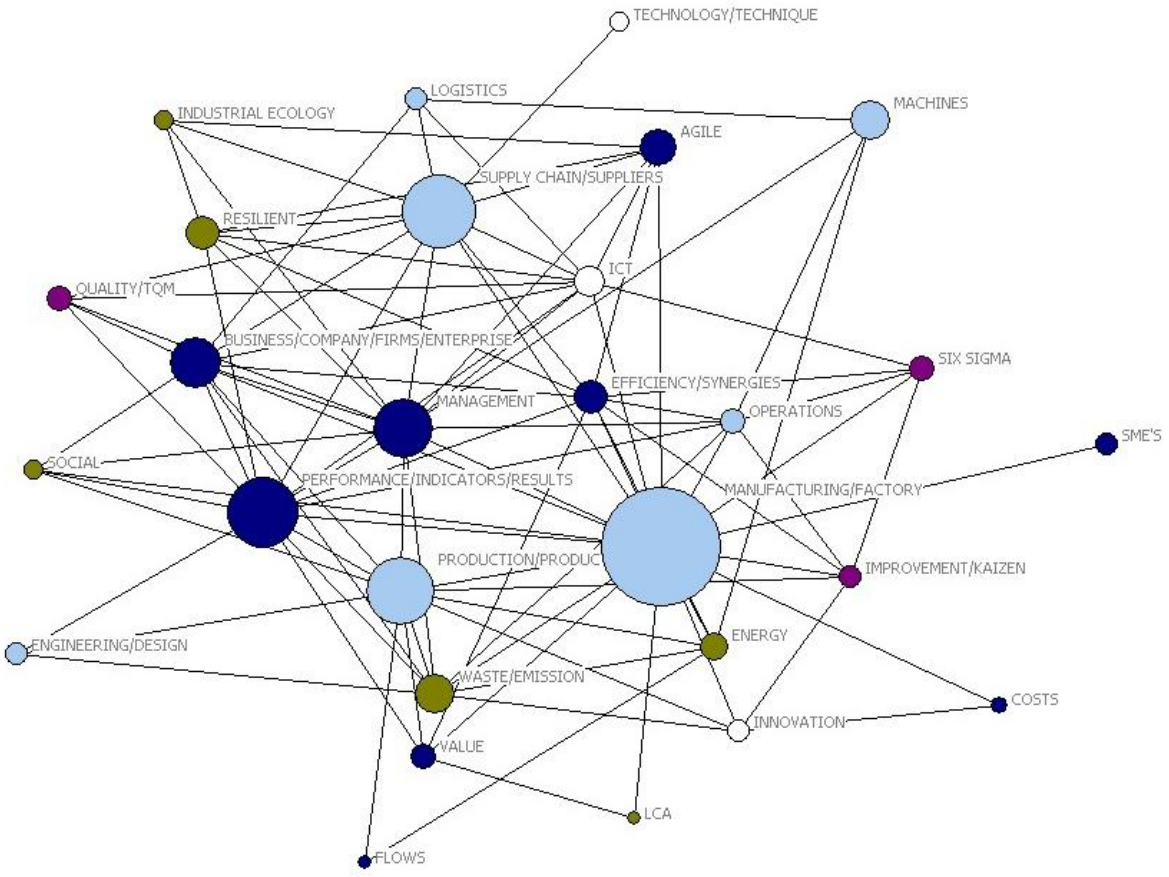


Fig.10. Visualisation of the key concepts network. (Data source: Scopus database).

Note: Each node represents one concept and each link represents the co-occurrence of concepts among node pairs. The locations of the nodes are determined by using a spring-embedding heuristic, multidimensional scaling algorithm, with proximity indicating the extent to which two concepts are connected directly and indirectly through mutual concepts. Node dimension is proportional to the number of articles title and keywords in which each given key concept is mentioned. The light blue colour identifies the macro category "Operations"; the blue colour the category "Business"; the purple colour the category "Lean techniques"; the green colour the category "Sustainability aspects" and finally in white the category "Technology".

Larger size nodes represent trend-topics and describe the most recurrent key concepts in the literature (e.g., *manufacturing/factory*). The nodes placed at the centre of the graph represent the key concepts at the centre of debate on L&C production, capable of linking more arguments among themselves (e.g., *management* or *efficiency/synergies*). Moving away from the central part of the graph, the more "niche concepts" can be found (e.g., *SMEs; costs*). It should be noted that, alongside "basic" terms and concepts (e.g., production, manufacturing) emphasis is placed on performance aspects and on perspectives of study focusing on supply chains.

3.8 Collaborations

Figure 11 shows collaborations (i.e., co-authorships) in the L&C field literature. We employ data that derived from Scopus to build a relational matrix. Each row and column reports all the authors of the articles included in our dataset. Intersecting cells contain 1 if the couple of authors wrote an article together, 0 otherwise. Aside from just showing the network in a graph, the size of the nodes was used to indicate scientific productivity, meaning that larger nodes are authors who published more articles in this sub-field.

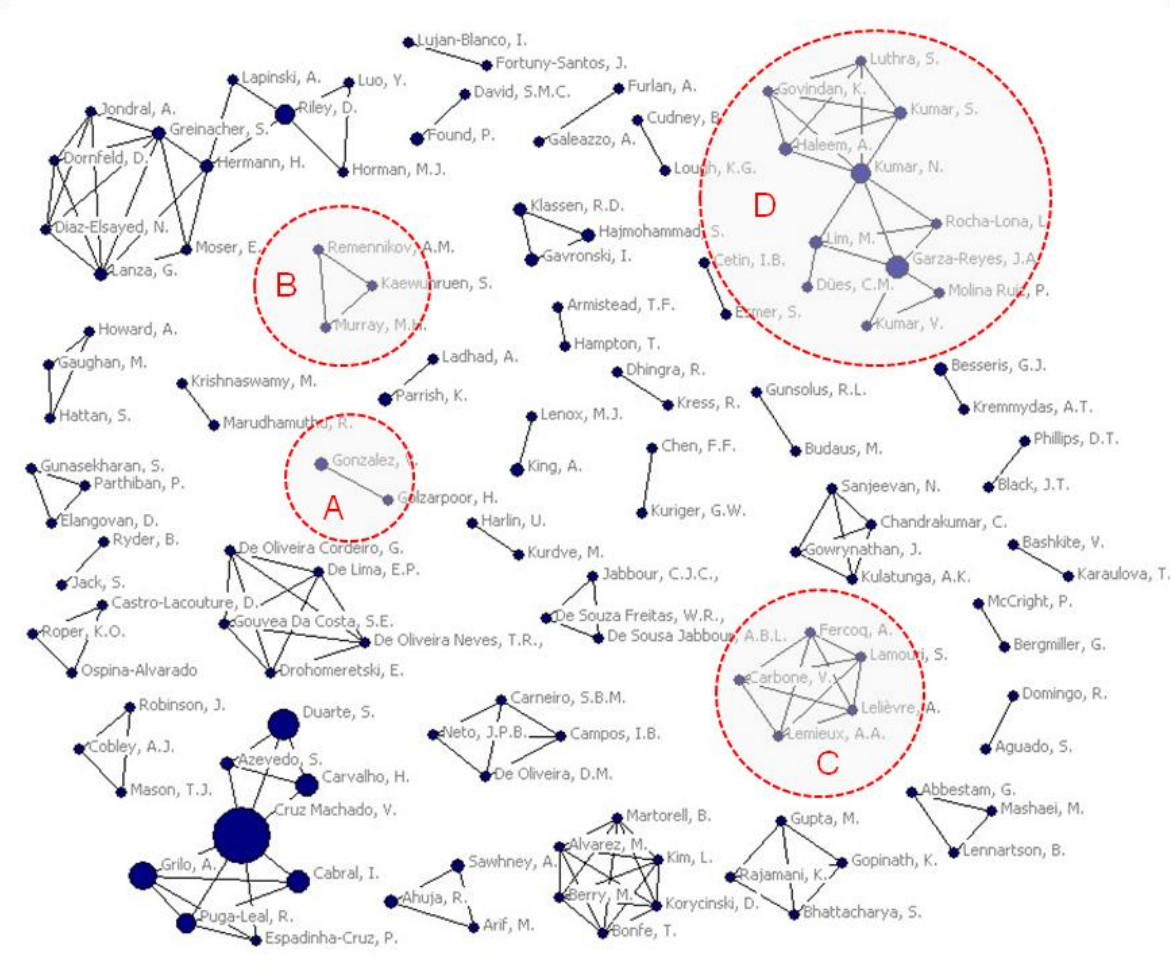


Fig.11. Collaborations *(co-authorships)* in the L&C research. (Data source: Scopus database).

Note: Each node represents one author and each link represents the co-authorships. Node dimension is proportional to the number of published articles. Isolates are not included in the illustration.

By analysing Fig. 11, we can find three different relational patterns occurring more frequently: dyads (see for an example circle A), triads/small groups (see for examples circles B and C), and large groups (see for example circle D). More specifically, in the sociogram we count 19 isolated dyads formed by pairs of co-authors who have not published even with other researchers, and 15 triads/small groups consisting of 3 up to 6 authors. This result is quite expected as it reflects the average number of authors for each article. It is interesting however to note as ties are created among authors who have similar levels of productivity.

Of great interest there are also the 3 largest groups (D is an example composed by 11 authors, the others respectively by 8 and 11 researchers) located in the upper right, upper left, and lower left of the graph. For example, circle D shows that there are 2 authors named Kumar, N. and Garza-Reyes, J.A. playing a very important role in the network because they act as "bridges" that connect authors that otherwise would have been unconnected between them. In social network literature, the absence of ties among those to whom one is connected is named "structural hole" (Burt, 1992). The central argument of structural holes theory is that ties are redundant to the degree to which they lead to the same people and provide the same informational benefits. On the other hand, networks that are rich in structural holes imply access to mutually unconnected partners and, consequently, to many distinct and non-redundant flows of information and resources (Burt, 1992). Structural holes offer opportunities to broker the flow of information. People are better informed of opportunities, see new opportunities created by the needs in one group that could be served by the skills in other groups and have more options of bringing together diverse individuals when it is rewarding (Burt, 2000).

The same relational patterns can be seen for the author Cruz Machado in the group of co-authors placed in the lower left part (as highlighted in section 3.3). The particularity, in this case, is that researchers who published a lot together and reached a scientific production amount greater than all other groups in the network form the group. This can definitely be considered as the leading group of co-authors, and within it, definitely Cruz Machado plays a role of fundamental pivot. We can also highlight that the group in the circle D is characterised by international collaborations by involving authors from different countries (UK, Brazil, Mexico, India, and Denmark), while the lower left large group includes authors with affiliations from the same country (Portugal).

3.9 Leading authors and articles

On the basis of the principle according to which, more frequently cited an article is, the greater the impact it has (Garfield, 1979), a summarising table of the top 10 cited articles in the sub-field of the L&C production research has been built (Tab.1). This shows the number of citations obtained from their publication until 2017, the journals and the year in which they were published, the keywords, and the major concepts discussed; it thus provides an idea about the authors and the topics that have led this field of research until now.

1 **Table 1** Analysis of the top 10 cited articles in L&C production studies.

2

Author	Year	Title	Journal	Citiations	Keywords	Major concepts
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	388	Lean Production; Environmental Performance; ISO 9000; ISO 14000	*The companies that adopt the ISO9000 standards were more likely to adopt the ISO14000 standards.*
Florida, R.	1996	Lean and Green: The move to environmentally conscious manufacturing	California Management Review	375	-	*The adoption of manufacturing process innovations creates incentives for adoption of environmentally conscious manufacturing strategies.*
Simpson, D.F.; Power, D.J.	2005	Use the supply relationship to develop lean and green suppliers	Supply Chain Management: An international Journal	230	Supplier relations; Lean Production; Environmental management	*A conceptual framework to investigate the relationship between a supplier and the firm's level of environmental management activity and the customer-supplier manufacturing relationship is proposed.*
Mollenkopf, D.; Stolze, H.; Tate, W.L.; Ueltschy, M.	2010	Green, lean, and global supply chains	International Journal of Physical Distribution & Logistics Management	212	Globalization; Sustainable development; Supply chain management; Environmental management; Lean Production	*The relationship among green, lean, and global supply chain strategies is examined in order to develop a research agenda to guide theoretically based future research that informs managerial decision-making.*
Rothenberg, S.; Pil, F.K.; Maxwell, J.	2001	Lean, Green, and the quest for superior environmental performance	Production and Operations Management	210	Lean Manufacturing; Environmental performance; High-involvement work; Resource use	*Some mechanisms, through which the three aspects of lean management (buffer minimisation, work systems, and human resource management) may be related to environmental management practices and performance, are described.*
Lewis, M.A.	2000	Lean production and sustainable competitive advantage	International Journal of Operations & Production Management	199	Lean production; Competitive advantage; Case studies	*The impact of lean production on the overall competitive positions of adopter firms is analysed.*
Kainuma, Y.; Tawara, N.	2006	A multiple attribute utility theory approach to lean and green supply chain management	International Journal of Production Economics	198	Supply Chain management; Life Cycle Assessment; Lean and Green Supply Chain	*The multiple attribute utility theory method for assessing a supply chain is proposed and used to evaluate the performance of a supply chain both from a managerial and from an environmental performance viewpoint.*
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	149	Green; Sustainability; Environment; Lean; Supply chain management	*The article suggests that Lean is beneficial for Green practices and the implementation of Green practices in turn also has a positive influence on existing Lean business practices.*
Lapinski, A.R.; Horman, M.J.; Riley, D.R.	2006	Lean processes for sustainable project delivery	Journal of Construction Engineering and Management	117	Delivery; Sustainable development; Construction industry	The presence of value and waste in a sustainable building project is identified.
Hajmohammad, S.; Vachon,S.; Klassen, R.D.; Gavronski, I.	2013	Lean management and supply management: their role in green practices and performance	Journal of Cleaner Production	98	Environmental performance; Environmental management; Supply management; Lean management	*The conceptual model proposed suggests that supply management as well as Lean management activities provide means by which environmental actions can be encouraged.*

4) Discussion: current state of L&C production research

Through the conducted bibliometric and network analysis, interesting considerations emerge in the analysis of the evolution of L&C production research.

- *Structural and relational features of the sub-field:* Considering that studies on LP are relatively recent with respect of other managerial research field (the first publications date back to the early '90s), it should be noted that the environmental aspects (Clean(er)) were included just from the first years of its occurrence (1994). The number of publications has generally grown over time, reaching a share between 4 and 7% of total publications in the field. There is a clear tendency to use the term "green" (rather than e.g., clean or sustainable) to indicate the environmental dimension of these studies; therefore, it appears that the sub-field should be formally identified as "Lean and Green" production research. With respect to the publication sources, apart from the referential journal of this sub-field (Journal of Cleaner Production), the remaining (that have embedded articles from L&C studies) are the journals of the LP field; four are indeed the common journals amongst the top 10 (*International Journal of Lean Six Sigma; Industrial Engineering; Advanced Materials Research; Applied Mechanics and Materials).* It is also evident that the studies within the Lean paradigm have a predominantly Anglo-Saxon origin and this finding is confirmed in L&C studies. The articles coming from the USA and the UK are always higher in numbers than the 2/3 of the total, although the presence of a significant community of authors in South America (Brazil), Europe (Portugal, Germany and Italy) and Asia (India, China and Malaysia) should be noted. The role of the Portuguese community seems to be particularly relevant in L&C studies (third place), especially considering its placement in the LP studies (15th). The authors of the examined articles do not show a particular tendency to work in a team; indeed, single-name (about 40%) or two-name publications are currently prevalent, except for some networks of authors from the most prolific countries (Fig.9). Regarding affiliations, American and British universities prevail amongst the first 15, although the first place is for a Portuguese University (New University of Lisbon); always amongst the top 15, the Cardiff University and Chalmers University of Technology are the only ones with active researchers, who are simultaneously present in the two fields of the LP and L&C. Conference papers and articles are the most preferred forms of documents for publication (more than 80% of the total). Regarding the main themes of research, by a comparison of the obtained results in subject areas and key concept analysis, it clearly emerges that in L&C studies the most closely-related topics to production and operations are the most processed (especially with an engineering profile), followed by the issues of management and accounting. The most strictly environmental issues (*industrial ecology; life cycle assessment; energy; wastes/emissions*) are often found in association with technical issues, whilst the social ones (*resilience, social*) with the performance indicators. As emerged also from the results of Table 1 and network analysis, a number of articles use a supply chain-based perspective in their studies (Simpson and Power, 2005; Mollenkopf et al., 2010; Kainuma and Tawara, 2006; Dües et al., 2013); this can be considered in line with the most relevant approaches of sustainability studies (e.g., the life cycle-based ones).

- *Leading articles and themes:* A more careful analysis of the contents of the leading articles gives the opportunity to make a few final comments on the current state (and limits) of this sub-field.

A gap, which emerges, lies in the ability of businesses to integrate the two perspectives of LP and CP at an operational level. One of the first contributions in this sense was the one proposed by Florida (1996), who emphasised the links between the concepts of lean and clean manufacturing by exploring the relation between advanced production practices and innovative approaches to environmentally conscious manufacturing. He was the first to suggest that the L&C approaches be considered as organisational eco-innovations. In 2001, King and Lenox, after having conducted an empirical analysis of the environmental performance of more than 17,000 manufacturing companies during the period 1991-1996, found that those companies that adopt the ISO 9000 standards were more likely to adopt the ISO 14000 standards, as well. This aspect was considered by the authors as a promising way also for the adoption of L&C approaches. Mollenkopf et al. in 2010, showed that some aspects of the LP approaches, such as the reduction in the flow of materials through the supply chain, have undeniable positive effects on the environment (reduction in materials extracted, produced, packaged, handled and transported). On the other hand, Just-In-Time methods, which are based on the reduction of lot-sizing and frequent shipments, may affect it negatively. The authors highlight the need to develop tools to solve such conflicts and help the managerial decision making to find solutions that take into account Lean, Green and Supply chain management goals. With regard to this, studies have been published trying to reproduce these different perspectives in a comprehensive model. Hajmohammad et al. (2013) hypothesised a model suggesting that supply management as well as LP activities provide means through which, environmental actions can be encouraged. More recently, Simboli et al. (2014) and Ioppolo et al. (2014), proposed integrating Industrial Ecology (Erkman, 1997) methods and tools of analysis in the L&C studies. These, if developed in a life-cycle-based perspective, could be integrated for a joint assessment of environmental, economic and social performance and would be also capable of including the various actors and stakeholders of the supply chains (Ioppolo et al., 2018). The one of performance measurement is certainly one of the most promising areas for future development for the L&C research field.

Conclusions

Lean Production is considered one of the most relevant paradigms in manufacturing, which is able to increase the competitiveness of companies by reducing all of the non-value activities, thus improving productivity and quality. In recent decades, the growing and widespread interest in environmental issues has been prompting companies to rethink both their objectives and how they manage their operations and processes. This has gradually led to the development of a sub-field of studies that attempts to integrate the two perspectives of competitiveness and sustainability, by acting on organisational and management variables. We called them Lean and Clean(er) production research activities. This article analysed the

research evolution in this sub-field by means of Scopus scientific literature database. The main objectives were to understand how are CP research and publications embedded in the field of LP and what are the most promising common perspectives of research. A bibliometric analysis of the scientific literature integrating the two approaches was conducted. A comprehensive picture was made by analysing data concerning publications, authors, affiliations, and countries of origin, using quantitative and qualitative tools, such as the Social Network Analysis. Evolutionary profiles, major topics investigated, leading authors and collaborations were reported. The results suggest that the literature regarding L&C production research will increase in the coming years and point out that the two perspectives have enough things in common to develop synergies in achieving economic and environmental benefits. Another issue that emerges is that the sub-field is already quite independent, in terms of both leading authors, relevant journals and topics and is progressively acquiring its own physiognomy, as "Lean and Green". The integrated analysis and the decision-support tools will be probably the areas that the L&C studies will have to cover in the next few years in order to ensure the diffusion of such an innovative approach in the world of production.

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