Sustainability and digitalization in supply chains: A bibliometric analysis

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CHRONICLE	ABSTRACT
	Digitalization is impacting almost every aspect of people's life and is greatly affecting supply chain processes. At the same time, supply chains are becoming progressively more aware of their impacts on people, the planet and profits (triple bottom line perspective) and the concept of sustainable supply chain has received increasing attention among scholars and practitioners. In this context, this article aims to analyze scientific research on supply chain management in the field of sustainability and digitalization using a bibliometric approach. To this end, this article analyses 484 papers from Scopus database according to the following parameters: chronology, discipline, source, center, country and citations. The dataset consisted of articles from scientific journals published over the period 2002–2018. In addition, VOSviewer software is used to map the bibliographic material using the co-occurrence of keywords and most influential journals. The analysis reveals that: sustainability and digitalization are important emerging fields within supply chains that have increased significantly during the last ten years; the USA is the most influential country; and the topic is structured around 2 clusters (1) Supply chain management, concepts and practices and (2) energy related technologies. The results may facilitate the planning, designing, running and publishing of future research on this topic. © 2019 by the authors; licensee Growing Science, Canada.

1. Introduction

Supply chains can be defined as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Mangan & Lalwanii, 2016, p.10). In the present global environment, these organizational structures operate in complex and dynamic markets (Yang et al., 2011) mainly affected by technological developments (Büyüközkan & Göçer, 2018). The accelerated pace in digitalization of processes has transformed the business dynamic and market structure (Kayikci, 2018; Waluyo, 2019), affecting supply chain management (Ward et al., 2017; Büyüközkan & Göçer, 2018; Naway et al., 2019). The confluence of internet, wireless, predictive

analytics and cloud technologies (i.e., digitalization) have changed the entire supply chain operations and has brought more value out of it (Yang et al., 2011).

At the same time, supply chain management is confronted by the constant growth of capital and consumer goods in the global demand by persistently verifying overall interests for social, environmental and economic aspects (Manavalan & Jayakrishna, 2019; Sabara et al., 2019). Therefore, in addition to technological and digital parameters, social and environmental dimensions are considered as important for supply chain performance (Dossou, 2018). As an example, digitalization has the immense opportunity to reduce emissions from logistics as much as 10 to 12% by 2025 and to help decarbonize the global economy (World Economic Forum, 2016). Consequently, the aim with the digitalization of supply chains should be considered to a transformative change towards 'sustainability' (Kayikci, 2018).

The term 'sustainability' can be defined as expanding the corporate perspective to one that considers environmental, social and economic aspects (i.e., triple bottom line) (Abdul-Rashid et al., 2017). This concept, first introduced in 1987 (Brundtland, 1987), has been witnessed in the subsequent emergence and adoption of environmental practices and standards, either in relation to production (life cycle analysis, green building standards, etc.) or to management procedures (environmental management system) in business and supply chains (Muñoz-Villamizar et al., 2018). Hence, beginning from the 1990s, new terms, such as reverse logistics, green logistics, and green supply chain, have appeared (Hou et al., 2015). Therefore, the increasing focus on sustainable practices and information and communications technology tools has led academia and industry to address sustainable and digital supply chains in different ways (Papetti et al., 2019). For example, Sabat (2002) described how emerging mobile wireless were unleashing the potential of the value chain in early 2002. Nunes et al. (2006) discussed the opportunities for a supply chain optimization in the automotive industry using Radio Frequency Identification (RFID) technology. Shrouf et al. (2014) discussed the role of the Internet of Things in sustainable supply chains with the objective of achieving energy efficiency. Hazen et al. (2016) studied the nature of big data analytics impact on supply chain sustainability. Kayikci (2018) highlighted the benefits of the digitalization of logistics process and examined the sustainability impact of digitalization in logistics. More recently, Manavalan and Jayakrishna (2019) presented a literature review of Internet of Things, sustainable supply chains and Industry 4.0. Based on this investigation, the authors prosed a framework for assessing the preparedness of supply chains for a sustainable growth to meet industry 4.0.

Although the abovementioned literature review, as well as other works, provides valuable information on the state of the literature on sustainable and digital supply chains, there is still much need for a bibliometric approach for analyzing this literature (Amirbagheri et al., 2018). Bibliometric studies are becoming very popular in the scientific literature, strongly motivated by access to bibliographic information (Merigó et al., 2018). To the best of our knowledge, there are no studies that have analyzed sustainable and digital supply chains research from a bibliometric analysis perspective. In that sense, this paper aims to fulfill this gap in the literature.

The major contributions of the paper are highlighted as follows: 1) A detailed bibliometric analysis of sustainability and digitalization in supply chains has been conducted using the most widely used database (i.e., Scopus); 2) the research growth of sustainability and digitalization in supply chains is documented from 2002 to 2018; 3) the most common parameters (e.g., highly productive authors, most influential authors, most cited discipline, countries, and highly prolific institutions, etc.) are discussed; 4) the conceptualization of this topic over the years is presented using the most common keywords used in the field; and 5) the main two research clusters for this topic are defined.

The rest of this paper is organized as follows. Section 2 describes the proposed research method. Section 3 presents the analysis of the papers we identified from our bibliometric approach. Finally,

section 4 concludes the paper by presenting some concluding remarks in addition to guidelines for future research.

2. Methodology

Bibliometrics is usually defined as a collection of research techniques that studies quantitatively the bibliographic material (Pritchard 1969; Merigó et al., 2018; Pourkhani et al., 2019). These bibliometric analyses are based on quantitative and reliable data (i.e., indexed publications). Therefore, the bibliometric analysis is based on a stable foundation of knowledge and not (for example) on the hardly verifiable opinions of expert groups (Zemigala, 2019). This method has been used in management research to improve the understanding of theoretical structures in logistics and supply chain management but also in various other fields (e.g., management information systems, operations management, international management, etc.) (Bensalem & Kin, 2019).

From an academic point of view, it is important that the published material in a specific research field, such as sustainability and digitalization in supply chains, could be classified so that researches and practitioners can follow all the field's advances and trends (Gaviria-Marin et al., 2019). In recent years, technological advances have also facilitated the development of bibliometric analysis, which has become an increasingly popular technique among researchers (Ding et al., 2014).

The summary of the methodology for conducting the search is shown in Table 1. Our bibliometric analysis is based on literature recorded in the Scopus citation database (www.scopus.com). The decision to choose this database is based on the fact that "Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings." (Elsevier, 2019). Scopus indexes many serial and non-serial publications and millions of conference papers, including the majority of the most important journals in the field of operations management research as listed in Barman et al. (2001), Olson (2005) and Theoharakis et al. (2007).

Table 1
Summary of used methodology

Unit of analysis	Relevant books and articles whose main content focuses on the links between supply chains, sustainability and digitalization
Type of analysis	Qualitative and quantitative
Period of analysis	2002 – 2018
Search engines	Scopus
Query string	Using the keywords that were associated with each of the concepts of this research, the following query string was created: TITLE-ABS-KEY (("supply chain" OR "supply chains" OR scm OR "supply chain management") AND (sustainable OR sustainability) AND (digitalization OR smart OR digital OR digitalisation OR digitization OR "Communication Technologies" OR "industry 4.0")) AND (EXCLUDE (PUBYEAR , 2020) OR EXCLUDE (PUBYEAR , 2019))
Total number of articles evaluated	484

In the first stage, the keywords 'supply chain' and 'digitalization' and 'sustainability' were entered in the search tool of Scopus to obtain a first list of works combining these three terms in the title, abstract or keywords. Using keywords of these early results, a new and complete search equation (i.e., query string) was defined (see Table 1). The results were then filtered by subject area, keywords and year using tools within Scopus. Text mining software called VOSviewer, developed by van Eck and Waltman (2010) was also applied to detect nonrelevant repeating terms and exclude them from the list. A continuous combination of text mining and Scopus filtering tools narrowed down the number of hits until text mining no longer showed any irrelevant clusters of terms.

This generic search identified 484 publications published between 2002 and 2018. Although, the year 1987 can be defined as the starting point for the concept sustainability (Brundtland, 1987), it is important to note that digitalization was enabled by the diffusion of Internet-based information and communication technologies at the beginning of the years 2000 (Bicocchi et al., 2019). Consequently, first publication on sustainability and digitalization in the supply chain is dated on 2002. Finally, results from 2019 (and 2020) are excluded in the chart to avoid showing partial statistics (see Table 1). It is to note that in the remainder of this article, the documents identified by Scopus are generally referred to as papers and articles, even though some of them are book chapters.

3. Results

According to Noyons et al. (1999), bibliometrics combines two main procedures: performance analysis and science mapping. Within performance analysis, there is descriptive bibliometrics (that is used for trend analysis in scientific research based primarily on research centers, journals or regions); and evaluative bibliometrics that is used to assess academic centers or researchers, based primarily on citation indexes of articles (Zemigala, 2019). The study of these statistics allows one to grasp the trends of the research field including the most influential authors and the most cited references (Bensalem & Kin, 2019). On the other hand, science mapping is a spatial representation of how different scientific actors are related to one another (Small, 1999). In this sense, this bibliometric component shows the structural and dynamic aspects of scientific research using, for example: the co-occurrence of keywords in documents, the co-citation analysis using pairs of documents that are commonly cited together, the most important journals, etc. (Gaviria-Marin et al., 2019). This section presents both analysis with their corresponding elements.

3.1. Annual citation and scientific disciplines

As mentioned before, the very first paper on sustainability and digitalization in supply chain management was published in 1992. Since then, the number of published papers on this topic has grown, especially in 2017. To better understand this trend, Table 2 reports the number of published papers and their total citations. Additionally, Table 2 identifies the range of highly cited papers relative to those with one or five citations.

Table 2
Annual citation

Years	TP	≥ 100	≥50	≥ 20	≥10	≥5	≥1	TC
2002	1	0	0	0	0	0	1	1
2003	3	0	0	0	0	1	1	6
2004	9	0	0	0	3	3	3	50
2005	8	0	0	0	1	3	5	30
2006	3	1	1	1	1	1	2	869
2007	10	1	2	3	3	3	6	205
2008	10	0	0	1	3	4	6	73
2009	2	1	1	1	1	1	2	153
2010	16	0	0	0	1	3	12	43
2011	18	0	1	1	2	4	6	79
2012	20	1	1	3	4	6	11	293
2013	27	1	2	2	3	9	16	219
2014	32	2	3	5	7	8	17	446
2015	35	0	0	4	5	10	23	152
2016	38	0	2	5	9	14	26	306
2017	159	0	0	7	12	21	60	404
2018	93	0	0	3	5	12	44	238
Total	**484**	**7**	**13**	**36**	**60**	**103**	**241**	**3567**
%	**100%**	**1%**	**3%**	**7%**	**12%**	**21%**	**50%**	

Explanation. TP= Total papers; ≥100 ≥50,≥20, ≥10, ≥5, ≥1 = Number of papers with equal or more than 100, 50, 20, 10, 5 and 1

During the first 8 years of the time period studied in this paper, the number of published papers on sustainability and digitalization in supply chains had not exceeded 10. After this period, there had been a slight growth in the number of published papers on this topic, with a maximum of 38 papers in 2016.

However, in 2017, the number of published papers had a huge increase compared to previous years. The amount of published research articles in 2017 was 159 (i.e., 33% of total sample). Regarding citations, it should be noted that only 1% of the papers have received more than one hundred citations, that are 7 out of 484 papers. In addition, 3% of the papers have received more than 50 citations and 7%, 12%, 21% and 50% of the papers have received more than twenty, ten, five and one citations, respectively. It is also important to highlight that recently published articles (those published in the last 5 years) represent about 43% of total cites (1546 out of 3567 citations).

The next step is to analyze the most important scientific disciplines. In order to define areas of science are focused on research on sustainability and digitalization in the supply chain, the taxonomy of scientific areas considered by Scopus database was used. In the general set, articles have been assigned to 14 different disciplines (see Table 3). Engineering clearly occupied the first place due to the nature of the considered topics (i.e. sustainability, digitalization and supply chains). The scientific disciplines from positions 1–4 were considered as leading and the rates in each of these areas were similar dozen percent of the total general dataset. It is important to highlight that Energy discipline represents 15% of the total sample. A thorough analysis of the results in section 3.3 allows a surmise that future research in the Energy field is going to be a leading one. The disciplines from items 5–7 obtained interest rates in the general set of half dozen or so percent. Positions 8-13 represent the less important disciplines. The differences between these disciplines were not significant, as they reached similar percent. Finally, unimportant disciplines as Physics and Astronomy, Biochemistry, Genetics and Molecular Biology, Chemistry, etc., are groped in other categories, as they only represent 2.9% of total share.

Table 3
Research on sustainability and digitalization in the supply chain according to scientific disciplines

Rank	Subject area	Papers	%
1. Leading, large, several dozen percent share	Engineering	239	25.3%
	Energy	142	15.0%
	Computer Science	134	14.2%
	Business, Management and Accounting	110	11.6%
2. Significant, medium, several percent share	Environmental Science	71	7.5%
	Decision Sciences	60	6.3%
	Social Sciences	52	5.5%
3. Less important, small, at most a few percent share	Agricultural and Biological Sciences	24	2.5%
	Materials Science	22	2.3%
	Mathematics	20	2.1%
	Economics, Econometrics and Finance	19	2.0%
	Chemical Engineering	15	1.6%
	Medicine	10	1.1%
4. Unimportant, minimal, at most	Others	27	2.9%

3.2. Leading journals, authors, institutions and countries

Table 4 shows the top 14 journals. The journal with the largest number of articles is "IFIP Advances in Information and Communication Technology" (TP=20 documents). However, the most important journal that was focused on sustainability and digitalization in the supply chains was the "Journal of Cleaner Production", as it has the highest number of citations from the general dataset appeared there (TC=446) and the highest average citation per document (C/D = 26.2). In addition, this title had the highest impact factor SJR (Scimago Journal & Country Rank, 2019) among the reported sources. Other journals with important average citations per document are "Supply Chain Management" and "International Journal of Production Research". Although "IFIP Advances in Information and Communication Technology" and "Sustainability Switzerland" have more than 10 documents, their SJR factor and average citation per document are quite low.

Table 4

Sources with the highest number of articles

Source	SJR	TP	TC	C/D
IFIP Advances in Information and Communication Technology	0.18	20	14	0.7
Journal Of Cleaner Production	1.47	17	446	26.2
Sustainability Switzerland	0.54	13	42	3.2
IOP Conference Series Materials Science and Engineering	0.2	9	0	0.0
Advanced Materials Research	0.12	6	2	0.3
ACM International Conference Proceeding Series	0.16	5	6	1.2
International Journal of Production Research	1.43	5	53	10.6
Procedia CIRP	0.67	5	27	5.4
Applied Mechanics and Materials	0.12	4	0	0.0
Ceur Workshop Proceedings	0.17	4	0	0.0
Lecture Notes in Computer Science	0.29	4	2	0.5
Procedia Manufacturing	0.2	4	11	2.8
Smart Innovation Systems and Technologies	0.17	4	2	0.5
Supply Chain Management	1.99	4	97	24.3

Explanation. SJR= Scimago Journal Rank in 2017; TP= Total papers; TC= Total citations; C/D= average citation per document.

As pointed out by Amirbagheri et al. (2018) and Jelvehgaran Esfahani et al. (2019), a valuable point of view is obtained by data on authors, universities and countries of papers citing the topic under study. This analysis provides essential information about sustainability and digitalization in the supply chain literature. Table 5 shows the top 10 authors, universities and countries by the number of documents; while Table 6 shows the top 10 by total citations (TC).

Table 5

Top 10 number of documents: authors, institutions and countries

R	Author	TP	TC	Institution	TP	TC	Country	TP	TC
1	Lv, X.	4	0	Xi'an Jiaotong University	7	2	United States	84	1782
2	Sayogo, D.S.	4	16	Shanghai Jiao Tong University	6	13	United Kingdom	62	325
3	Weng, Y.	4	0	Ministry of Education China	5	0	China	54	72
4	Zhang, J.	4	16	Delft University of Technology	5	112	Italy	32	251
5	Andersen, D.F.	3	14	Cardiff University	5	12	Netherlands	21	451
6	Bechtsis, D.	3	29	Huazhong University of Science and Technology	5	1	Germany	20	88
7	Bo, Z.	3	0	University of Cambridge	5	50	India	17	114
8	Goudarzi, N.	3	3	University of Manchester	4	45	Australia	16	64
9	Kumaraswamy, M.M.	3	26	Zhejiang University	4	0	Canada	12	197
10	La Scalia, G.	3	24	Dalian University of Technology	4	10	Spain	12	34

Explanation. TP= Total papers; TC= Total citations

Table 6

Top 10 citations: authors, institutions and countries

R	Author	TP	TC	Institution	TP	TC	Country	TP	TC
1	Sarkis j.	3	129	University of Alabama	1	868	United States	84	1782
2	Bechtsis D.	3	29	Georgia State university	1	868	Netherlands	21	451
3	Tsolakis N.	3	29	UCLA	2	197	United Kingdom	62	325
4	Kumaraswamy M.M.	3	26	Sustainable operations solutions	1	196	Italy	32	251
5	La Scalia G.	3	24	University of Massachusetts	1	196	Canada	12	197
6	Micale R.	3	24	Rockwell automation	1	196	Switzerland	7	170
7	Sayogo D.S.	4	16	University of Texas	1	196	India	17	114
8	Zhang J.	4	16	University of Groningen	1	168	Germany	20	88
9	Andersen D.F.	3	14	Elon university	1	151	Portugal	8	85
10	Luna-Reyes L.F.	3	14	Ouroboros holdings, llc.	1	151	Finland	6	83

Explanation. TP= Total papers; TC= Total citations

Upon further examination of the number of citations, the distribution changes. That is, considering authors, institutions and countries with the largest number of documents do not necessarily have the highest number of citations. For example, the largest number of articles on sustainability and digitalization in the supply chain was published by the Xi'an Jiaotong University. Unfortunately,

despite being the leading publisher of articles in the quantitative aspect (number of articles), this center has been poorly cited (i.e., it only has 2 citations). In contrast, University of Alabama has only 1 document but 868 citations. However, it is important to note that the United States appear in first place in both tables (configurations). This result is in accordance with the Bibliographic coupling of countries using VOSviewer software (see Fig. 1).
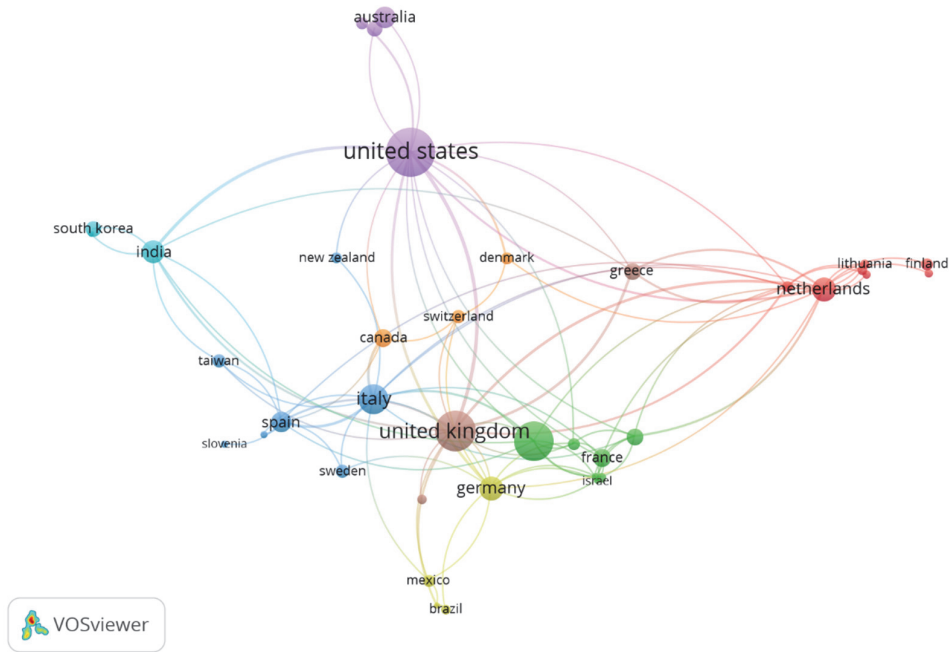

Fig. 1. Bibliographic coupling of countries

3.3. Keywords mapping

Finally, we used the analysis of keywords provided by the authors' publications. The previous part has focused the analysis on general results concerning leading authors, institutions and countries in the field of sustainability and digitalization in the supply chain. However, it is also useful to examine such outputs as co-occurrence of keywords.
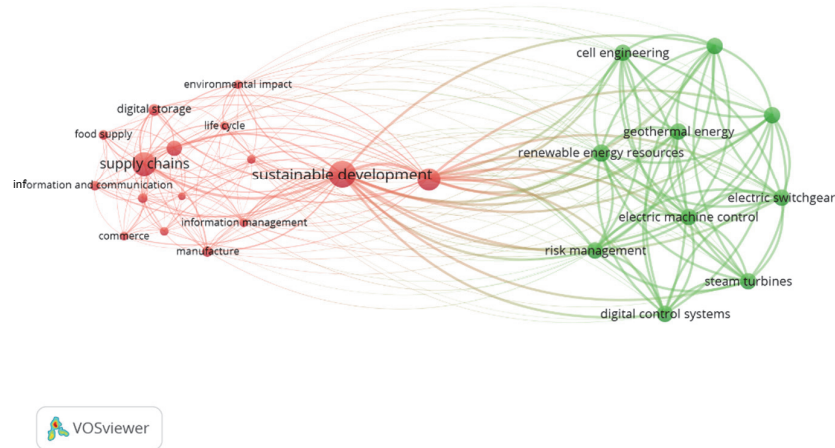

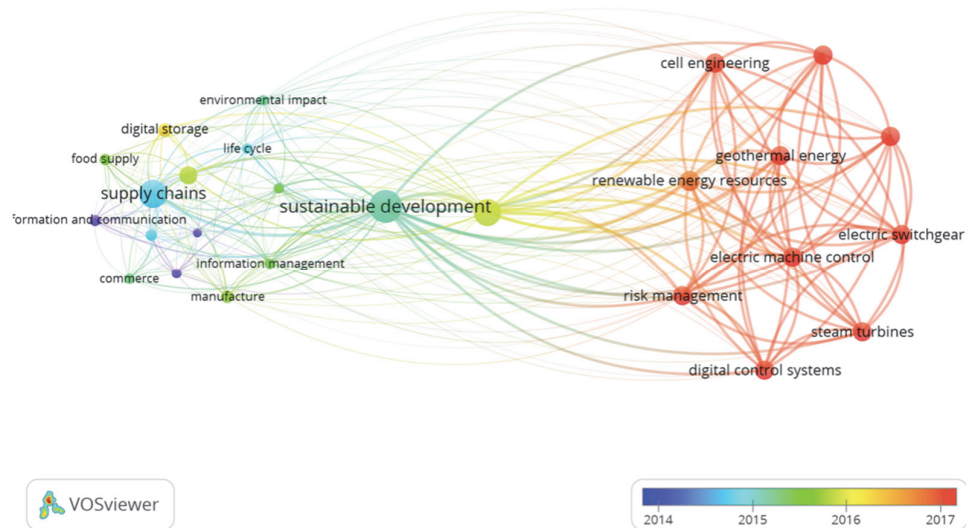**Fig. 2.** Co-occurrence of author keywords of evaluated documents

Fig. 3. Timeline visualization of co-occurrence of author keywords of evaluated documents

To this end, this study uses VOSviewer software (Van Eck and Waltman 2010). In the special set, 4049 different keywords were identified. Fig. 2 shows the 26 most frequent keywords that have been repeated at least 20 times. As it can be seen, the two different clusters are separated by distinct colors (i.e., red and green). Therefore, it can be stated that the topic under the study is structured around 2 clusters (1) Supply chain management and sustainability, concepts and practices (e.g., life cycle analysis, manufacturing, environmental impact, etc.) and (2) energy related technologies (e.g., renewable energy sources, steam turbines, cell engineering, etc.). Moreover, and to gain a deeper insight into the results presented in Fig. 2, Fig. 3 shows the timeline visualization of co-occurrence of author keywords of evaluated documents. That is an evolution of keywords usage along the years (2002-2018). Regarding this evolution, it can be stated that first approaches about sustainability and digitalization in the supply chain correspond to 'formation and communication', 'competition' and 'innovation'. Nowadays, keywords have evolved to the energy related technologies (i.e. green cluster).

4. Conclusions and future research

This article presents a bibliometric analysis with the aim of investigating the contributions and interrelations between sustainability and digitalization in the supply chain management. This analysis is based on a sample with 484 papers. The dynamics of research on this topic, in chronological terms, are growing. It must be stressed that it has been an important number of publications in the 2017. The leading scientific areas are Engineering, Energy, Computer Science and Business, Management and Accounting. Engineering proved to be an essential area of study. "The Journal of Cleaner Production" should be considered as the most focused journal on these topics. The most important institution contributing to the field by the number of documents is Xi'an Jiaotong University. In terms of total citations, the leading institution is University of Alabama. In geographical terms, the most prolific region is United States (by number of documents and by total citations). Finally, our research identified contributions and gaps in this body of knowledge; where the USA is the most influential country; and the topic is structured around 2 clusters (1) Supply chain management, concepts and practices and (2) energy related technologies. It is worth to emphasize the originality of the research carried out. To the best of our knowledge, there are no bibliometric analyses focusing strictly on scientific research on sustainability and digitalization in supply chains. Moreover, for the first time, we have presented a broad spectrum of trends or concentrations in terms of dynamics in time, scientific areas, research centers, journals, countries or thematic areas. Our results may facilitate the planning, designing, running and publishing of future research on this topic

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