DIGITAL TRANSFORMATION FOR A CIRCULAR ECONOMY: INSIGHTS FROM CO-WORD ANALYSIS

Abstract

This work aims to analyze the relationship between Digitalization and the Circular Economy, identify the key terms and concepts used in the scientific literature, and examine their relationship to each other to produce a set of guidelines that show the application of digital technologies in different Circular Economy implementation practices. For this purpose, the bibliometric technique of co-words (or matching of words) was used. Specifically, a total of 199 documents from the Web of Science database published up to December 2022, were analyzed using Biblioshiny software. The strategy map showing the evolution of the relationship between them is presented. The results show which authors, articles, and journals have the greatest influence on the subject. By analyzing co-words, a map of the most important themes was created, showing how digital transformation has evolved to establish the transition of companies to the Circular Economy. Different thematic approaches such as sustainability and the use of digital technologies to promote different Circular Economy practices are proposed. This study provides an analysis of the use of digital technologies in implementing the Circular Economy. It highlights successful initiatives and the challenges companies and governments face in this process and examines the changes in business models and industrial practices. Recommendations for future research are proposed to simultaneously promote Digitalization and the Circular Economy and contribute to the achievement of long-term sustainability goals.

Keywords: Circular Economy, Digitalization, Bibliometric Analysis, Co-words Analysis.

JEL Classification: Q01, 030, M15, M21

1 Introduction

The Circular Economy (CE) is linked to the idea that waste, once treated most appropriately, can be turned back into resources by creating a closed loop in the production and consumption chain. The idea is to implement a system that promotes a new production and consumption model to replace the linear model of use, consumption, and discard. In this paradigm shift, digital technologies play an important role insofar as they lead to a specialization of the value chain and connectivity between different actors (Wiesmüller, 2014).

The fourth industrial revolution, called Industry 4.0, was driven by the introduction of digital technology in the industry (Wiesmüller, 2014). The digital transformation in industrial and service companies leads to new ways of competing to serve more demanding customers. The process of digitalization in the manufacturing sector which, by renewing the value chain, changes the way of working. The continuous exchange of data in real-time makes it possible to be more flexible and faster, which has a direct impact on profitability and productivity. Industry 4.0 anticipates greater operational effectiveness and the development of new products, services, and business models associated with the use of digital technology (Kagermann, 2014; Lasi et al., 2014; Oesterreich & Teuteberg 2016). Digitalization promotes new opportunities to minimize resource use (Nascimento et al., 2019) and achieves cleaner production (Kazancoglu et al., 2018).

In this regard, CE and Industry 4.0 have received increasing attention over the past decade, largely through separate and independent research in both areas. Most research has focused on the ability of digitalization to achieve sustainable and green supply chains (Giovanni and Cariola, 2021). Industry 4.0 is widely recognized as an enabler of CE (Lopes de Sousa et al., 2018), and in particular, the adoption of digital technologies and connected objects has great potential to facilitate the creation of circular systems (Bocken et al., 2016). The application of these technologies is changing the way companies produce, market, and distribute their goods and services, and facilitating the innovation of business models that leverage the entrepreneurial opportunities created by the CE (Zhang et al., 2023). Despite the existence of previous studies that have created various frameworks for the intersection of CE and digital technologies, there remains a significant gap in the development of a comprehensive guiding framework that explains the practical application of digital technologies at different stages of CE implementation.

Thus, this paper aims to analyze the relationship between digitalization and the CE, identifying the key terms and concepts used in the scientific literature and how they relate to each other, to provide a set of guidelines that reveal the application of digital technologies in different CE implementation practices. The following research questions have been addressed in this study:

RQ1. *What are the current research trends in the field of EC and Digitalization?*

RQ2. *What kind of digital technologies can be applied in each practice of EC implementation?*?

RQ3. *What can be the future lines of research in the field of CE and Digitalization?*

The use of bibliometrics is suitable to objectively and systematically examine the current state of a research area, so a bibliometric analysis of the scientific literature was carried out to present the conceptual structure of this research field and to answer the research questions posed.

By answering these research questions, our paper makes an important contribution to the literature by identifying key research trends in CE and Digital Transformation. The insights derived from our bibliometric analysis not only provide valuable guidance for future academic research but also serve policymakers by informing and supporting the development of effective public policies. Our findings can serve as a valuable resource for policymakers in their efforts to promote digital transformation in disadvantaged sectors, ultimately facilitating sustainable development and the achievement of Sustainable Development Goals.

The analysis is structured as follows: firstly, a bibliometric methodology is presented to identify the most relevant topics that allow newcomers to enter this research field. Secondly, it highlights the evolution of the CE in companies with the introduction of different digital technologies.

2 Background

The concept of the CE has its origins in the European Union's Action Programmes, and its scientific foundations and solutions have been extensively elaborated. A central element of the CE theory is the transformation of business processes into sustainable resource systems, rather than perpetuating cycles of energy and material flows. Therefore, the application of digital tools within the CE is central to the elimination of waste and the mitigation of adverse environmental impacts.

Specifically, Digitalization plays a crucial role as an enabler of the CE by providing visibility and intelligence to assets and products by collecting and analyzing asset-related data, which improves decision making and optimizes processes in the circular economy by generating greater flows of data and digital information (Antikainen et al., 2018; Chen et al., 2023). CE encompasses practices rooted in the 3R principle of reducing, reusing, and recycling resources, to minimize environmental impact, maximize economic benefits, safeguard the environment, and promote sustainable resource consumption (Gharfalkar et al., 2018). Driven by advances in technologies such as artificial intelligence (AI) and data analytics, on the one that hand, Digitalization improves the efficient use of resources, thus favoring one of the fundamental CE practices, such as reduction, in the sense that Digitalization provides the tools to collect, analyze and use data-driven insights to optimize resource use (Audretsch et al., 2023; García-Muiña et al., 2019). On the other hand, it enables the analysis of a wealth of data on resource consumption, waste generation, and product performance, making it easier for companies to identify opportunities to reduce and reuse resources (Bressanelli et al., 2022). Similarly, the Internet of Things (IoT) allows product information to be shared globally, creating connections between suppliers, and disassembling part selectors and recyclers. This networked system improves the efficiency of recycling processes (Chauhan et al., 2022).

By leveraging several Industry 4.0 technologies, such as data analytics, data mining, Internet of Things (IoT), and cyber-physical systems, significant opportunities arise to achieve sustainable industrial value and advance CE (Antikainen et al., 2018; Rüßmann et al., 2015). In addition, digital technologies such as blockchain and artificial intelligence improve transparency and traceability throughout a product's lifecycle, facilitating greater accessibility and enhancing opportunities for remanufacturing, refurbishment, and recycling (Fogarassy and Finger, 2020). The implementation of Industry 4.0 has shown that its use in production opens new pathways for industrial development and therefore has great potential to create sustainable industrial value in social, economic, and environmental dimensions by improving resource efficiency (Khan et al., 2021). Circular solutions are essential to address the challenges posed by growing environmental problems and resource depletion.

In the literature, different review papers analyze research topics focusing on CE and Digitalization or the introduction of different digital technologies. However, these are works that do not use bibliometric techniques but are based on Systematic Literature Reviews (Cagno et al., 2021; Okorie et al., 2018; Agrawal et al., 2022; Da Silva & Sehnem, 2022; Liu et al., 2022; among others).

Specifically, Okorie et al. (2018) focus the systematic literature review on the empirical literature related to digital technologies, Industry 4.0, and circular approaches, from the point of view of the 9 R's. Potting et al. (2017) expanded the classical 3R's model by considering 9 circular strategies: Refuse, Reduce, Resell/Reuse, Repair, Refurbish, Remanufacture, Reuse, Recycle, Recover Energy, and Remove. The results of this review highlight that research on CE-enabled digital technologies remains a relatively untouched area of research in the nine (9) circular approaches. Pavlovilc et al. (2021) review attempts to analyze digital tools that can be used to monitor and measure (through the proposal of various indicators) the circular level of a business organization. Cagno et al. (2021) in their systematic literature review identify that an integrated and holistic analysis of the relationships between Digital Technologies and the transition to the CE is needed. Da Silva & Sehnem (2022) present different pathways and challenges in the relationship between CE and I4.0: applying those technologies to clean production, using blockchain and big data in the circular supply chain, increasing the impact of additive manufacturing on CE, seeking a better understanding on how I4.0 technologies can adequately support CE in the stakeholders' vision and discerning the factors to implement those theoretical fields in supply chains. Liu et al. (2022), on the other hand, conducted a systematic literature review to identify what are the main functions of digital technology for the CE and how these digital functions can be used to implement CE strategies. With this review, the authors identify 13 critical functions of digital technology that are most relevant for CE strategies.

Unlike previous works, Agrawal et al. (2022) use a systematic literature review methodology and bibliometric techniques to present the review in the field of CE and Sustainable Business Performance in the age of digitalization. This study reveals that digitalization could be of great help in the development of sustainable circular products.

2.1 Dynamics of Scientific Knowledge

To identify patterns of knowledge in the scientific literature, bibliometric methods synthesize and quantify bibliographic data extracted from research papers (Theeraworawit et al., 2022; Zupic and Cater, 2015). Co-word analysis is a specific method of bibliometric analysis that is based on the idea of co-occurrence, or the simultaneous occurrence of words in the same document (Callon et al., 1983), which allows literature content to be associated in a network of knowledge entities through networks of co-words (Wang et al. 2015). It is accepted that authors provide several keywords to represent the main research topic of their article. By using these keywords, the conceptual structure can be identified through the construction of a thematic map and the development of a research field (Pinillos et al., 2022). In our case, we analyzed the research topics and found the connections between EC and EC using co-word analysis.

Co-word analysis is based on co-occurrence analysis that identifies objects that tend to occur together. The units of analysis can be keywords, authors, or references, which provide insight into the state of the art. By measuring co-occurrences of terms in publications we can quantify the strength of their links (Bailón-Moreno et al., 2006), thus revealing the structure of the science (Chavalarias & Cointet, 2009).

Co-word analysis takes as the unit of analysis the authors' keywords that appear together in the abstract, keywords or title of the same article (Xu et al., 2018) forming networks in which they act as nodes and their appearance within an article denotes an edge in the network so that their subsequent co-appearances in articles of keyword pairs increase the weight of the respective edge (Choudhury & Uddin, 2016). The size of each node is proportional to the occurrence of the item and the size of the line edges is proportional to their co-occurrence. As a result of this analysis, a set of clusters is obtained that represent groups of textual information that can be understood as semantic or conceptual groups of different topics addressed in the research field (Cobo et al., 2011).

The analysis of the research topics is completed with the map or strategic diagram that represents the study topics characterized according to their centrality and density, where centrality measures the intensity of the connections with other clusters for a given cluster and density establishes the strength of the links that unite the words that make up the cluster (Callon et al., 1991, Cobo et al., 2011). The higher the centrality the more the cluster represents a set of research considered crucial and reflects the importance of the topic within the research field (Ribeiro et al., 2022). Therefore, the location of a cluster on the map reveals its strategic position within a scientific field according to its internal development and its importance in the considered field (Lascialfari et al., 2022).

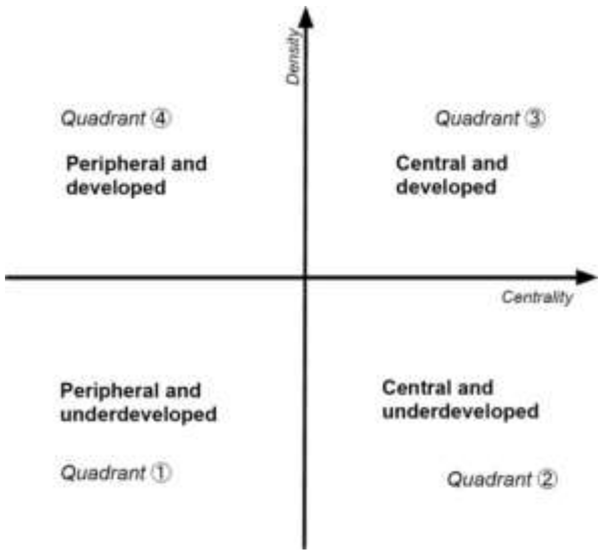

Fig. 1: Strategic diagram and characterization of clusters. Source: Lascialfari et al. (2022) adapted from Callon et al. (1991)

Taking these variables into account, the themes can be classified in a two-dimensional space according to the quadrant in which they are positioned as shown in Fig. 1 (Callon et al., 1991; Lascialfari et al., 2022):

- Quadrant 1: Peripheral and underdeveloped: represents those unstructured, weakly developed, and marginal issues that are of little interest to the field of study under consideration.
- Quadrant 2: Core and underdeveloped: deals with topics that are underdeveloped but have the potential to become core and promising lines of research.
- Quadrant 3: Core and developed: represents the driving themes of the field, which are well developed and important for the structure of the field of study.
- Quadrant 4: Peripheral and Developed: represents themes that are well developed but of decreasing importance as they are highly specialized topics.

Following the work of Lascialfari et al. (2022), the topics found in the lower quadrants (1 and 2) constitute niche topics as they have low density, while the upper quadrants (3 and 4) represent main or relevant topics as they show a high density. In this way a niche group can move up to a main group, i.e., novel research topics can become main groups, remain as niches, or disappear over time depending on whether or not they reach higher degrees of density and centrality.

Bearing in mind that the temporal evolution of a scientific field will be determined by the existence of variations in centrality and density, the life cycle of research topics in any field can be inferred. Lascialfari et al. (2022) extend the strategy map by including the dynamic aspects of research topics. The authors explain the life cycle in terms of three movements: scaling-out, scaling up, and scaling-down. Scaling-out refers to the increase in centrality and occurs when the words or terms of a research topic are increasingly adopted by scientists and connected to other topics; it refers to the initial stage when the research acquires external connectivity and is more widely adopted by scientists. Scaling-up occurs when a research topic acquires complexity and becomes more internally structured. This is reflected in an increase in the density or number of connections between words or terms within the topic cluster. As a result, the topic moves from being a niche topic to a main topic. Finally, scaling-down indicates a decrease in centrality while maintaining a high density as the terms that are part of the cluster are adopted less and less. In this way, the life cycle of research topics can be represented in a dynamic strategy map (Fig. 2). On the other hand, if a promising cluster increases its internal structure, the mainstream expands in quadrant 3 characterized by driving themes, while the latter may move into quadrant 4 reflecting the decline of the theme in question. In short, the dynamic strategy map provides a picture of the structure of a field in terms of temporal evolution by establishing how niche themes can become mainstream themes.

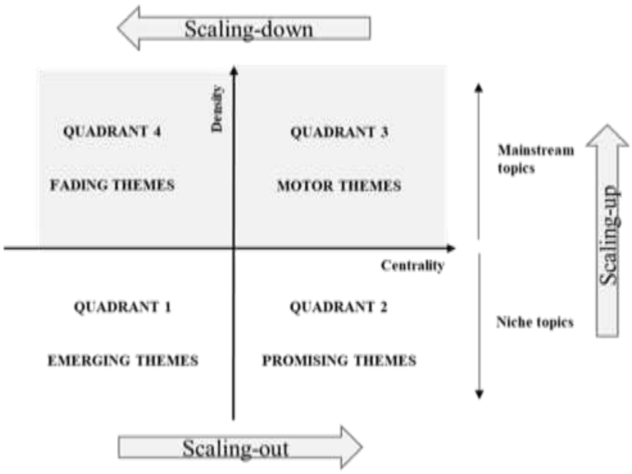

Fig. 2: Dynamic strategy diagram. Source*:* Lascialfari et al. (2022)

Examining a single strategy map may not be sufficient to provide insight into research, as a static view does not reveal the underlying dynamics as research evolves. This is because it may not show the full picture of how clusters of research themes move from one quadrant to another over time. An analysis of different strategy maps at different points in time should be carried out to analyze the position of clusters on the strategy map. Scientific fields that rapidly develop niche clusters towards major clusters reflect a higher cumulative development, while those fields that do not achieve such dynamics receive less attention and remain as specialized clusters with lower development.

3 Methodology

Following Moher et al. (2009), we used the PRISMA methodology to select the articles under analysis. This methodology provides a step-by-step process that helps to synthesize the literature in a rigorous, explicit, and transparent way (Bressanelli et al., 2022; Alhawari et al., 2021). Specifically, the selection process is carried out in 4 stages (identification, selection, eligibility, and inclusion) as shown in Figure 3. Using this method, keywords were identified, and articles were selected for inclusion in the analysis. The choice of the WoS database is justified by the fact that it collects the certified knowledge contained in published scientific articles and conference proceedings. The existing databases cover different scientific disciplines in different ways and have both advantages and limitations (Bakhmat et al., 2022; Bar-Ilan, 2010; Martínez et al., 2015). In addition, the integration of data from different databases can lead to inconsistencies in the analysis, making it advisable to consider the outcome of the unification process in the case of large samples of articles (Kumpulainen & Seppänen, 2022). WoS is one of the world's most recognized databases for retrieving academic social science literature in terms of the number of publications, citations, impact indices and other metadata needed to develop a bibliometric analysis (Gil-Gomez et al., 2023; Martínez et al., 2015; Zhang and Liu, 2023) and is widely used by researchers in different fields of knowledge (e.g. Albahari et al., 2022; Ren et al., 2023; Zhang and Liu, 2023), so its use provides sufficient guarantee to develop a rigorous analysis of the thematic evolution of the field under study over time (Martínez et al., 2015; Yu et al., 2022).

In the identification stage, and to obtain the final sample of articles to be analyzed, the most frequently used keywords in both research constructs or topics (CE and Digitalization) were examined to enable the most accurate possible search for the topics of study to be carried out. For this purpose, a plain text file was extracted from WoS for each construct and the keywords used were extracted, obtaining a total of 4,918 and 7,393 keywords for CE and Digitalization respectively. The most frequently used words were used. Thus, based on the work of Liu et al., (2022) the final sample of articles was made using the following keywords, Boolean operators, and advanced search options: TS= ("circular economy*" OR "CE principle*" OR "bioeconomy" OR "circular design*" OR "circular business*" or CE) and TS= (digit* or IoT or "internet of things" or "big data" or "artificial intelligence" or AI or "industry 4.0"). As there are many derivations in both fields, the asterisk was used to capture all possible derivations.

As a result, a sample of 251 articles was obtained, published between 2017 and 2022, which included the search terms in their title, keywords, and abstracts. For the citing sample, articles published in the areas of *Business, Business Finance, and Management* were considered.

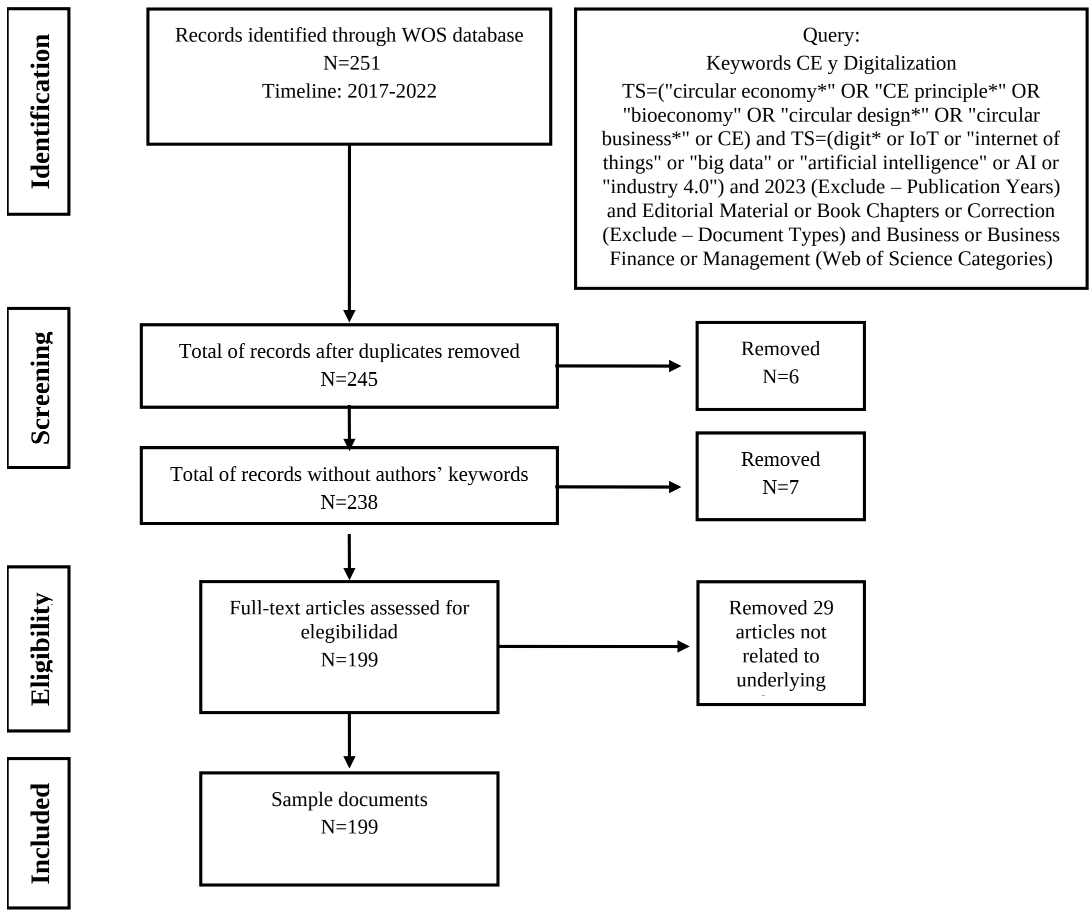

Fig. 3: Methodology for article collection following PRIMA guidelines. Source: own elaboration.

Subsequently, the database obtained was standardized. Duplicate articles, those that did not deal with the field of study, and those that did not present author keywords were reviewed and eliminated, leaving the database comprising a total of 199 articles.

The bibliometric study was carried out with the Bibliometrix software (Aria and Cuccurullo, 2017) based on the R language, which provides a simple graphical environment through Biblioshiny that allows the files to be downloaded in Excel format for processing. With Biblioshiny we obtained a file with keywords and proceeded to standardize and normalize them. As the program itself allows the use of synonyms and the elimination of words that are not useful, both Excel sheets were created in .csv format for use in the analysis.

The steps set out by Choudhury and Uddin (2016) and Xu et al. (2018) were used to create a synonym file, normalizing plurals (e.g., technologies as technology), abbreviations (e.g., CE as a Circular Economy), derivations (e.g., industry 4, or I4 as industry 4.0) and words with similar meanings. A synonym file was obtained for 42 keywords, with a total of 102 words that were considered synonyms. Similarly, a file was obtained of words to be eliminated, either because they did not make sense (e.g. q56 or ahp) or because they did not have a complete meaning (e.g. cluster or consumer).

The characteristics of the sample are given in Table 1. The first papers were published in 2017, which meant an annual growth of 16.5% with an average age per paper of 1.66 years, highlighting the interest in the study of digitalization to achieve CE in companies. The 199 papers used 72 different sources, 182 articles, and 17 proceedings, which used a total of 12,311 references and received an average of 25.2 citations per paper. Concerning the number of authors, only 15 papers were written by a single author, bringing the total number of authors to 590, which means an average of 3.7 authors per paper.

Table 1: Descriptive analysis of the sample

Description	Results
Timespan	2017:2023[1]
Sources (Journals, Proceedings)	72
Documents	199
Annual Growth Rate %	16,5
Document Average Age	1,66
Average citations per doc	25,2
References	12.511
DOCUMENT CONTENTS	
Keywords Plus (ID)	467
Author's Keywords (DE)	622
AUTHORS	
Authors	590
Authors of single-authored docs	15
AUTHORS COLLABORATION	
Single-authored docs	15
Co-Authors per Doc	3,7
International co-authorships %	54,27
DOCUMENT TYPES	
Article	132

[1] The year 2023 appears in the descriptive table because among the documents obtained, there are early Access documents without a date because they were published in the year 2023 but were entered in the database earlier.

Article; early access	25
Proceedings Paper	17
Review	23
Review; early access	2

Source: own elaboration.

About the analysis of the strategy map obtained, a static analysis has been carried out that shows the current situation of the research considering the entire period included in the sample (2017-2023). In addition, their respective strategic maps have been analyzed for three time periods (2017-2019, 2020-2021 and 2022-2023). As this is an incipient area of study, it has been decided to divide the period by years rather than by the number of publications, since most of them are in the last two years.

4 Results analysis

4.1. Descriptive Analysis

Before the discussion of the results, we present a descriptive analysis of the results, first presenting those corresponding to the citing sample and then to the cited sample. Concerning the evolution of the literature, an exponential increase in publications can be observed in Fig. 4, with substantial growth in the last two years, with a total of 40 articles in 2021 (20.10%) reaching 116 articles published in 2022, which represents 58.29% of the total number of articles published on the subject of study. The decrease in the year 2023 is because only the early accesses that appear in the search performed are included.

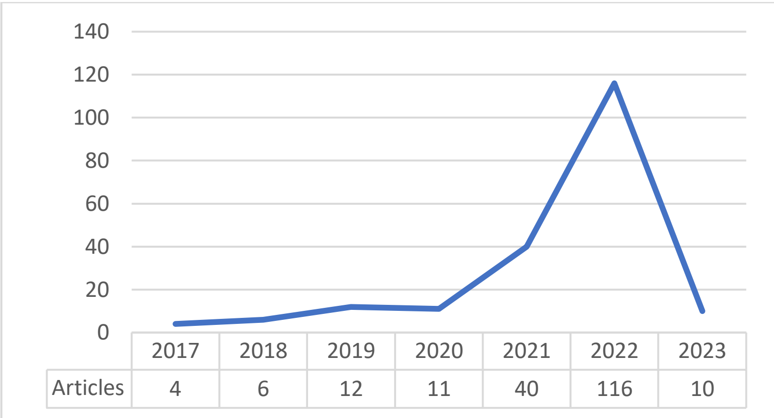

Fig. 4: Evolution of scientific production. Source*:* Authors

The journals in which they have been published, "Business Strategy and The Environment" (26), "Technological Forecasting and Social Change" (23), "Journal of Enterprise Information Management" (16), and "Operations Management Research" (11) have published 38% of the papers, while 47 publications have only one paper related to the topic. In addition, the H Index of the journals was obtained to evaluate the impact and quality of the research. Table 2 shows the importance of the publications and their impact. The first two have an H Index of 17, with 937 and 1081 citations respectively, showing the relevance with the citations received in only 3 years since the publication of the published work.

Table 2: Most relevant sources

Source	H_index	TC	NumberPapers	Year
BUSINESS STRATEGY AND THE ENVIRONMENT	17	937	26	2019
TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE	17	1081	23	2019
JOURNAL OF ENTERPRISE INFORMATION	8	212	16	2021

MANAGEMENT				
JOURNAL OF BUSINESS RESEARCH	6	378	8	2020
OPERATIONS MANAGEMENT RESEARCH	6	119	11	2022
INTERNATIONAL JOURNAL OF LOGISTICS-RESEARCH AND APPLICATIONS	5	186	9	2022
INTERNATIONAL JOURNAL OF PRODUCTIVITY AND PERFORMANCE MANAGEMENT	5	146	7	2022
BENCHMARKING-AN INTERNATIONAL JOURNAL	4	183	5	2021
INDUSTRIAL MARKETING MANAGEMENT	4	147	4	2017
JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	4	383	4	2019

Source: own elaboration

This aspect is shown in Fig. 5, which reflects the distribution of the literature in the relevant sources following Bradfor's Law (Bradford, 1934), a law that establishes that publications on a field of study can be organized into three zones according to relevance and divides three zones, Zone 1 represents the journals that publish most frequently and are important in the subject of study both in terms of the number of publications and citations received, zone 2 includes those publications that have an average number of publications and citations, and zone 3 comprises the tail of journals that rarely publish on the subject and are of marginal importance. As can be seen in the figure the four cited journals appear in zone 1 (76 papers), reflecting the impact of these publications in the study of CE and Digitalization. In zone 2 12 journals are contributing 58 papers (29.1%) and finally zone 3 with 65 published articles (32.6%).

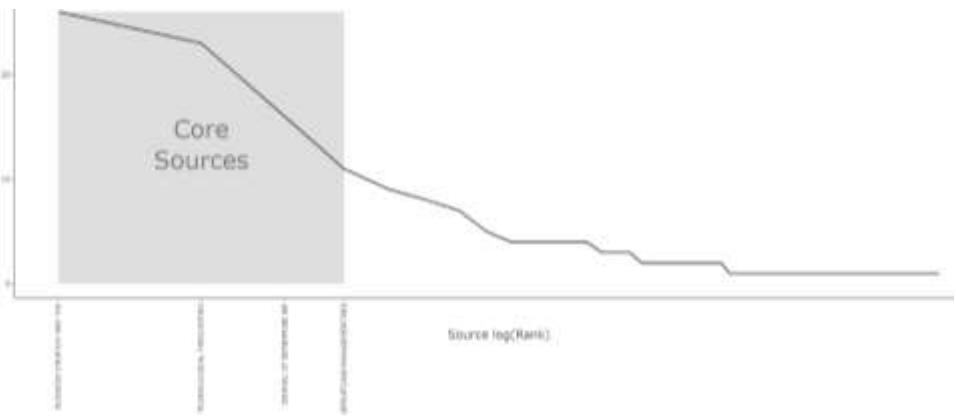

Fig. 5: Core Source by Bradford's Law. Source: Biblioshiny (2023)

The scientific production by authors is also analyzed in terms of publications and citations received as shown in Table 3. Regarding the number of authors 87% have published a single paper, 8% have published 2 papers and 4.6% of the authors have published more than 3 papers. The authors with the most published papers on CE and Digitalization are Kumar, Kazancoglu & Yu with 9, 8, and 8 respectively. The sample has received a total of 1905 citations of which the first 20 authors have received 742 citations (39%) indicating the relevance of these authors in the development of this line of research. Among them Garza-Reyes, Gupta, Bag, Jabbour C. & Jabbour A. ~~Caiado~~ stand out, having been cited ~~186~~ 224 times.

Table 3: Most productive and relevant authors.

Authors	Articles	Citations	H Index
KUMAR A	9	8	7
KAZANCOGLU Y	8	9	7
YU Z	8	17	7

KHAN SAR	7	18	7
BAG S	6	44	6
JABBOUR CJC	6	41	6
GARZA-REYES JA	6	51	5
JABBOUR ABLD	6	41	5
SINGH RK	6	7	4
LUTHRA S	5	2	4
AGRAWAL R	4	7	3
BELHADI A	4	4	3
GOZACAN-CHASE N	4	6	3
GUPTA S	4	47	4
KAYIKCI Y	4	6	3
MANGLA SK	4	5	4
UMAR M	4	5	4
DEL VECCHIO P	3	14	3
GUNASEKARAN A	3	9	3
KRISTOFFERSEN E	3	32	

Source*:* own elaboration

Finally, it is considered that the authors cite those works that they consider relevant to their research and that support their hypotheses or approaches, so it is relevant to highlight those works most cited by the sample as they are those that have contributed most to the literature. To show the most relevant aspects, the number of citations received (Citations BC) and the number of global citations (Global citations) were considered. These measures show the impact and influence of the documents within the scientific community. Table 4 shows the most cited articles of the sample have received a total of 321 citations by the articles of the sample and were published between 2018 and 2022, reflecting the novelty and youth of the research.

Table 4: Most relevant articles in research on Digitalization and the CE.

Document	Year	Citations DB	Global Citations
NASCIMENTO DLM, 2019, J MANUF TECHNOL MANA	2019	43	329
JABBOUR CJC, 2019, TECHNOL FORECAST SOC	2019	33	217
KRISTOFFERSEN E, 2020, J BUS RES	2020	31	167
GUPTA S, 2019, TECHNOL FORECAST SOC	2019	29	162
AWAN U, 2021, BUS STRATEG ENVIRON	2021	22	138
BAG S, 2022, INT J ORGAN ANAL	2022	19	123
BAG S, 2021, TECHNOL FORECAST SOC	2021	15	159
CENTOBELLI P, 2020, BUS STRATEG ENVIRON	2020	14	180
CHAUHAN C, 2021, BENCHMARKING	2021	14	59
DEL GIUDICE M, 2021, INT J LOGIST MANAG	2021	14	101
RAJPUT S, 2021, BENCHMARKING	2021	14	88
MASSARO M, 2021, BUS STRATEG ENVIRON	2021	12	67
SPRING M, 2017, IND MARKET MANAG	2017	11	104
CEZARINO LO, 2021, MANAGE DECIS	2021	11	66
PATWA N, 2021, J BUS RES	2021	9	122
RAJALA R, 2018, CALIF MANAGE REV	2018	8	45

KHAN SAR, 2022, INT J LOGIST-RES APP	2022	8	98
CHIDEPATIL A, 2020, ADM SCI	2020	7	47
SHARMA R, 2021, J ENTERP INF MANAG	2021	7	81

Source: own elaboration

Looking at the citations in databases, we can see that the papers Nascimiento et al., (2019) and Jabbour et al., (2019) have the highest number of citations, with 43 and 33 respectively. This indicates that these papers have generated substantial interest and have been recognized within the scientific community. The number of citations received outside the sample highlights the importance of the topic.

Both papers analyze business models oriented to the CE. In the first paper, Nascimento et al. (2019) explore how Industry 4.0 technologies can be integrated into business models that favor the development of CE practices such as recycling and reuse. Specifically, they suggest that reusing materials in the development of new products minimizes resource consumption and negative impact on the environment by developing business models that contemplate the integration of web technologies, reverse logistics, and additive manufacturing. However, the work of Jabbour et al. (2019) propose that the business models proposed by the ReSOLVE model will only be viable if the stakeholders' perspective is incorporated, for which the characteristics of Big Data (volume, variety, velocity, and veracity of the data) play a fundamental role and must be adapted to each of the business models.

The papers in the sample have referenced 12,497 papers that have been cited 18,174 times. Table 5 shows the papers most cited by the sample and which constitute the theoretical basis. The top 10 papers have received a total of 248 citations while 12,203 have received less than 5 citations and are review papers. The papers by Geissdoerfer et al. (2017), Ghisellini et al. (2016), and Kirchherr et al. (2017) are reviews of the CE literature and represent the seminal papers of the research line. The rest of the papers present reviews on the relationship between CE and Industry 4.0 that allow the development of integrated models for the study of both phenomena.

Table 5: Most relevant references.

Cited References	Citations
JABBOUR ABLD, 2018, ANN OPER RES, V270, P273, DOI 10.1007/S10479-018-2772-8	64
GEISSDOERFER M, 2017, J CLEAN PROD, V143, P757, DOI 10. 1016/J.JCLEPRO.2016.12.048	61
GHISELLINI P, 2016, J CLEAN PROD, V114, P11, DOI 10.1016/J.JCLEPRO.2015.09.007	50
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Source: own elaboration

A prominent role in the scientific literature is played by the keywords used by the authors to describe their work. The results show that a total of 565 keywords have been used 1129 times, of which only 53 have been used more than 2 times, so most of them (456) have been used only once. The most relevant keywords are "circular economy" and "industry 4.0", 132 and 56 times respectively, which is logical for the search used. The first 20 keywords were used 426 times, which represents 37.8% of the total number of keywords.

To identify the specific research topics, Circular Economy and Industry 4.0 were eliminated as they distorted the representativeness of the other words. As a result, "sustainability" and "sustainable development goals" were the most used keywords, which were used 44 and 20 times respectively, followed by "supply chain", "digital technology" and "literature review". Fig. 6 shows the keyword cloud according to the number of times used, which makes the most relevant keywords appear larger. Sustainability achieving Sustainable Development Goals focuses its analysis on the incorporation of the three principles of sustainability - environmental, economic, and social - from a broader perspective than the CE. The rest of the top 10 keywords include the importance of the production function in the implementation of the CE (supply chain, sustainable operation, or sustainable supply chain) and the main technologies that favor the development of CE practices (digital technology, artificial intelligence, blockchain or additive manufacturing).

Fig. 6: Keywords. Source: Biblioshiny report

4.2. Trends in research

The research topics are obtained through the analysis of co-words that facilitate the identification and interpretation of these, to answer the first research question posed. The co-word network is presented in Fig. 7 and reflects the co-occurrences between keywords, where the nodes represent a word and the relationship between words is reflected in the size of the lines joining each node. The size of each node reflects the occurrence of each word, and the size of the line is proportional to the co-occurrence. The results show the existence of 7 clusters: sustainable supply chain, fuzzy logic, additive manufacturing, sustainability, business model, sustainable development goals, and manufacturing firms.

The sustainability cluster represented in purple stands out because the term sustainability has a high centrality (259) indicating its importance in the cluster, suggesting that sustainability is a key theme in the relationship between CE and digitalization. Its relationship with the words "supply chain" and "blockchain" highlights the importance of the use of blockchain technology in the supply chain in that it allows tracking and verification of supply chain transactions and material flows, which can contribute to the achievement of sustainability goals.

The second most relevant cluster, represented in brown, relates the words "sustainable development goals", "sustainable operations" and "smart manufacturing". The improvement of production and the development of smart manufacturing favor the implementation of a more sustainable production that favors the achievement of sustainable development goals.

The cluster represented in red relates to the keywords "digital technology", "artificial intelligence", "circular business model" and "sustainable supply chain". This group of words includes research focused on the use of artificial intelligence and digitalization to achieve sustainable supply chains with which to create circular business models.

The rest of the clusters represented relate few keywords, although they can distinguish different lines of research such as additive manufacturing, product-service system, or fuzzy logic.

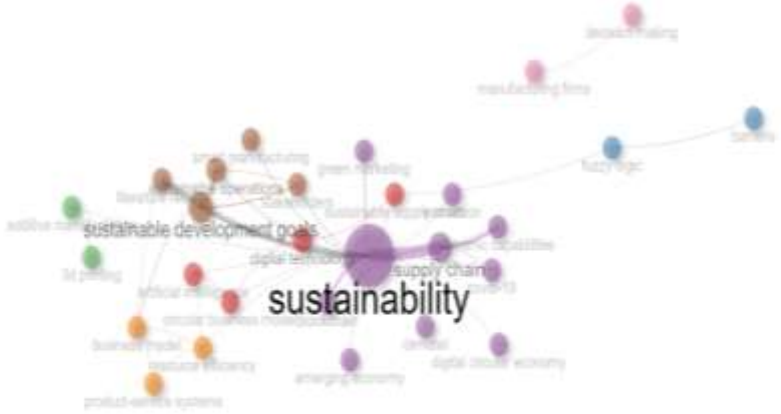

Fig. 7: Co-occurrence Network. Source: Biblioshiny report

The analysis of the research topics has been completed with the strategic diagram that represents the importance of the topics according to their density and centrality, which allows for the placement of the topics in different quadrants. As can be seen in Fig. 8, 15 research themes are identified and distributed in 8 niche themes presented in the lower quadrants, while another 7 are listed as main streams in the upper quadrants.

The first quadrant includes those unstructured or marginal topics with little development. The results show in this quadrant the research focused on Technological innovation includes the works of Yu et al. (2022) and Borge et al. (2022) which highlight the importance of emerging technologies and the networks that enable such technologies to be developed. For Yu et al. (2022) emerging technologies such as blockchain and business analytics techniques play a relevant role in implementing CE practices such as remanufacturing and recycling which provide firms with analytics techniques, smart contract facilities, transparency, and visibility in the information flow of SC processes.

Quadrant 2 lists those topics that have the potential to become major themes. Consistent with the results obtained in the co-word network, the most prominent topics are those related to achieving Sustainable Development Goals, the circular supply chain, and sustainability, with those related to barriers, digital innovation, *SMEs,* and *decision-making* being less relevant.

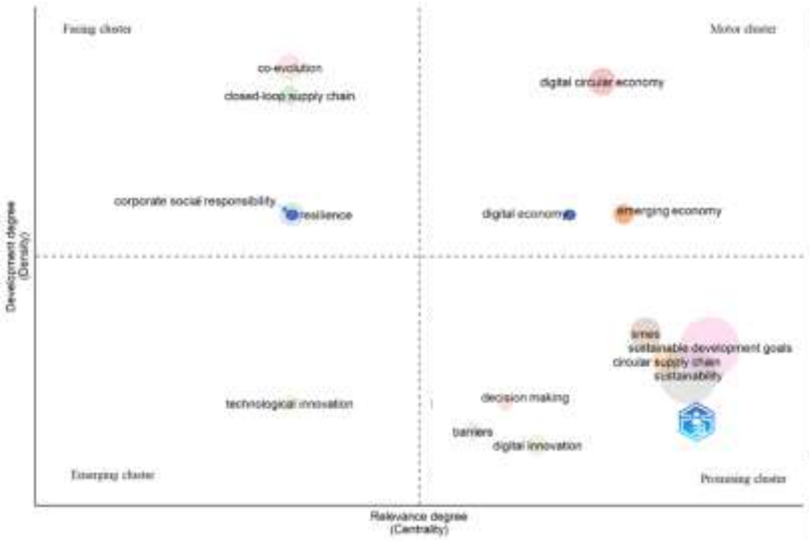

Fig. 8: Research trends: Static Strategic Diagram Source: Biblioshiny report

The cluster that groups the highest number of words is the available development objectives cluster that groups keywords such as sustainable development objectives (20), digital technology (14), sustainable operations (13), artificial intelligence (11), stakeholders (11) or business model (10) among others. The research line of the cluster focuses on the achievement of sustainable development objectives through the implementation of CE practices and the application of digital technology in production. The most relevant works in this cluster highlight Kayikci, Kazancoglu, Gozacan-Chase & Lafci (2022); Gupta, Chen, Hazen, Kaur & Gonzalez (2019), Sonar, Ghosh, Singh, Khanzode, Akarte & Ghag (2022) and Jabbour et al. (2019). These works have their foundation in stakeholder theory to achieve the SDGs. The achievement of SDGs can be facilitated through a smart supply chain (Kayikci et al., 2022), additive manufacturing (Sonar et al., 2022), and long large-scale data (Jabbour et al., 2019).

Related to the previous one, the cluster called sustainability includes the words sustainability (44), supply chain (17), or blockchain (11). In this cluster the research tries to achieve social, environmental and economic sustainability principles through the use of technological capabilities applied to supply chain and circular business models (Belhadi, Kamble, Gunasekaran & Mani, 2022), the use of blockchain to improve traceability and transparency between different actors (Ayan, Guner & Son-Turan, 2022) that favors the extension of product shelf life and the reverse supply chain (Liu, Trevisan, Yang & Mascarenhas, 2022).

In the third quadrant appear the consolidated themes that are constituted as drivers of research between CE and Digitalization: digital circular economy, digital economy, and emerging economy. These clusters have common in that they deal with the circularity of companies from a technological perspective in which IoT, Business Analytics, or Big data facilitate the implementation of Smart circular strategies that allow taking advantage of digital technologies to carry out specific and effective circular strategies ranging from their application to corporate strategy to operational strategies (Kristoffersen et al., 2020; Rennings et al., 2023).

Finally, the fourth quadrant includes specialized topics or those that are in the process of disappearing, such as corporate social responsibility, resilience, co-evolution, and a closed-loop supply chain. Within these groups, co-evolution and close-loop stand out with the highest number of papers. The topic related to the word co-evolution considers the analysis of the product life cycle and introduces servitization as a way to develop the CE, digitalization can convert the product offer into a service offer, and develop new business opportunities (Salminen et al., 2017) or find new ways to innovate taking into account the product life cycle (Ruohomaa et al. 2017). The research focuses on the closed-loop supply chain cluster treats the supply chain as a closed loop in which goods and materials can be integrated with circular processes, in which IoT and big data facilitate resource management and consideration of the participating stakeholders (Kayikci et al., 2022).

The thematic evolution between the years 2017 and 2020 and their relationships are shown in the Sankey Diagram (Fig. 9). The themes existing between the years 2017 and 2019 are shown on the left side, and in the center, the themes between the years 2020 and 2021 and on the left side are the themes corresponding to the year 2022 and the beginning of 2023. It can be seen that the business model has been maintained in the three periods and sustainability in two of the three periods, both reflecting the central role they occupy in the interests of researchers. The years 2020 and 2021 are expanded to 10 topics appearing issues related to digital technology, artificial intelligence, barriers, innovation, and environmental sustainability and decision making, while sustainability derives from topics such as additive manufacturing and stakeholder engagement. The theme for the 2022-2023 period boils down to three major topics: SDGs, sustainability, and sustainability of operations, which reflect the importance of Industry 4.0 technologies as a tool to develop sustainability.

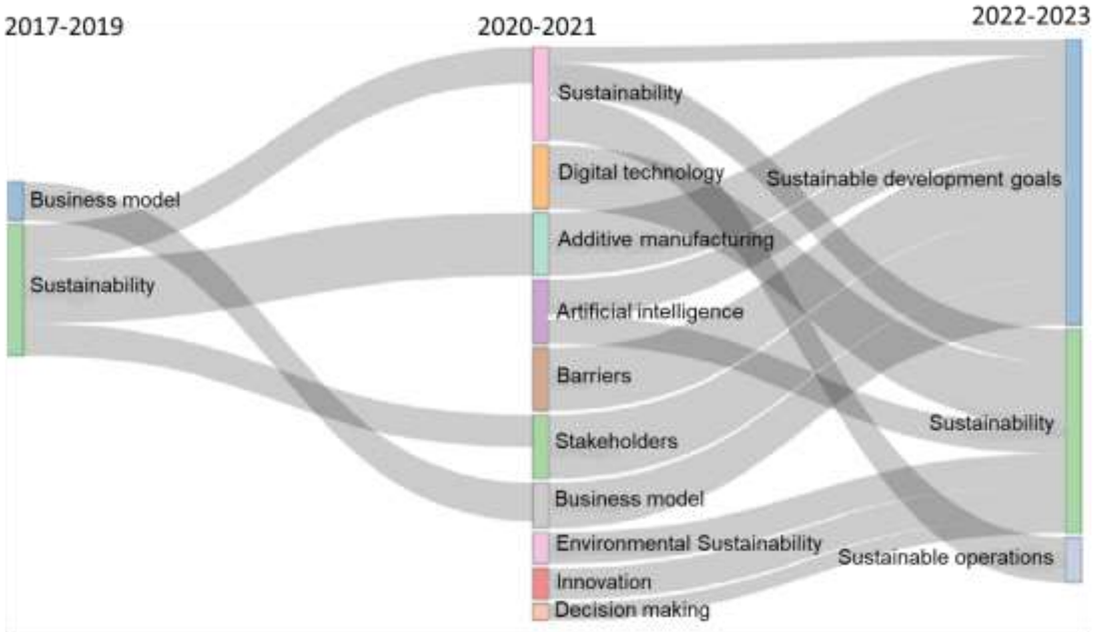

Fig. 9: Thematic Evolution. Source: Biblioshiny report

The dynamic thematic map (Fig. 10) can be used to observe the evolution of themes and the consolidation or non-consolidation of study themes. The years 2017-2019 show the existence of four thematic clusters: business model, circular clothing, sustainability, and co-evolution. Business model and circular clothing are placed in quadrant 1 reflecting topics that have marginal relevance in the field, while sustainability and co-evolution represent major themes. Sustainability being in quadrant 3 represents themes that are consolidated by having internal and external consistency with other thematic areas, while co-evolution represents specialized themes that may disappear.

In the following period, the strategic diagram has 11 clusters, 5 in the niche quadrants (large group decision-making, innovation, stakeholders, digital technology, and sustainability) and 6 in the quadrants representing mainstream (artificial intelligence, remanufacturing, business model, environmental sustainability, decision making and digital circular economy). Observing the evolution concerning the previous period, the topic related to business models has been consolidated in this period, going from being an emerging topic to becoming a driving theme. On the contrary, the sustainability theme that was in quadrant 3 in the period 2017- 2019 moves to quadrant 2, indicating that it remains an internally consolidated theme, although it has lost relevance in the field of study as a whole. During this period, the themes of innovation and decision-making appear in quadrant 1, while in quadrant 2 the theme of digital technology emerges, with stakeholders between quadrants 1 and 2. It is worth noting the emergence of the themes of artificial intelligence and remanufacturing as driving themes and environmental sustainability, decision making, and digital circular economy as specialized themes.

In the 2022-2023 period, sustainable operations appear as an emerging theme in the first quadrant. In the second quadrant, digital innovation, emerging technologies, and SMEs are promising themes. The sustainability cluster increases both its density and its centrality, moving into the third quadrant as a main theme closely related to the sustainable development goals cluster, which appears together with a circular supply chain. Close-loop supply chain and Smart manufacturing appear between the second and third quadrants and are likely to become driving themes in the future. Finally, competitiveness appears in the fourth quadrant as a specialized topic and sustainable performance appears between the first and fourth.

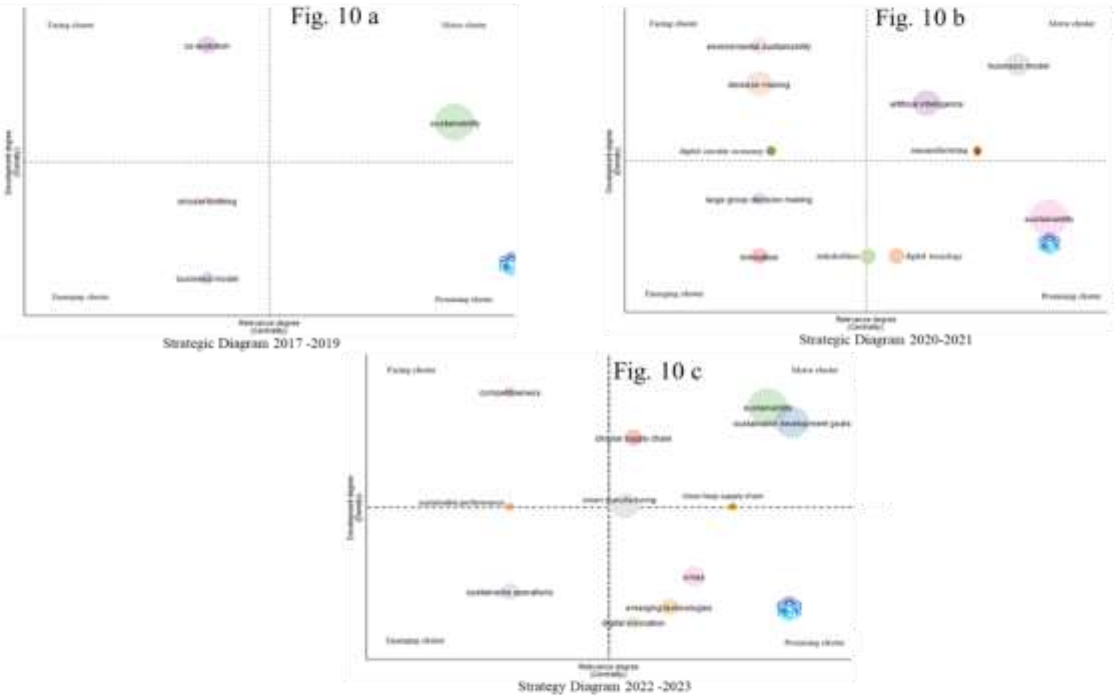

Fig. 10a: Dynamic strategic diagram 2017-2019. **Fig. 10b**: Dynamic strategic diagram 2020-2021. **Fig. 10c**: Dynamic strategic diagram 2022-2023. Source: Biblioshiny report

5 Discussion

The results of the bibliometric analysis, in combination with the in-depth analysis of the selected papers, have allowed us to answer the research questions initially posed in this paper.

Concerning the first Research Question, *What are the current research trends in the field of CE and Digitalization?* Bibliometric analysis has allowed us to analyze the key terms and concepts used in scientific literature and how they relate to each other and to identify not only the main research trends in this field of study but also the most promising topics. On the one hand, we used the strategy map (Figure 8) to identify the most relevant topics and their classification according to their relevance from a static point of view. The results shown in Figures 9 and 10 provide a dynamic view that allows us to observe the current trend of the topics.

The static analysis of the research trends highlights the need to deepen topics such as sustainability, SDG, circular supply chain, and digital innovation, as they appear as promising topics. From the dynamic analysis, the temporal evolution of the first three shows that they have become driving topics to explain the relationship between EC and digitalization, following the direction suggested by the life cycle proposed by Lascialfari et al. (2022).

A crucial research trend has turned out to be related to **Sustainability and Sustainable Development Goals (SDG)**, whereby the CE and Digital technologies play an important role in achieving several of the SDGs (Nascimento et al., 2019; Jabbour et al., 2019; Gupta et al., 2019; Bag et al., 2021). On the one hand, digital technologies help create more sustainable and efficient industrial processes and develop new sustainable products and services (SDG 9). CE principles help reduce waste and promote more sustainable consumption and production patterns (SDG 12). The CE and digitalization technologies can help reduce greenhouse gas emissions and mitigate climate change (SDG 13). CE principles can help reduce marine and land-based pollution and promote biodiversity conservation (SDG 14). On the other hand, digitalization applied to circular practices has a positive impact on sustainability by enabling the reuse and recycling of wasted materials. Moreover, digital technologies have significant potential to achieve sustainable value creation in social, economic, and environmental dimensions, improve resource efficiency, create sustainable business models, and prepare the path for environmentally sustainable manufacturing practices.

The application of these concepts (Sustainability and SDGs) to the functional area of operations involves referring to **Sustainable operations**, as shown in the Sankey diagram, and is another of the research trends that have been identified (De Souza et al., 2021; Hettiarachchi et al., 2022; Jabbour et al., 2019; Patyal et al., 2022; Sharma et al., 2021). Sustainable operations are focused on managing and improving business processes to minimize negative environmental impacts and maximize long-term economic and social benefits. This entails adopting practices and approaches that promote resource efficiency, waste reduction, carbon footprint minimization, and social equity. Involves working closely with suppliers and ensuring responsible practices throughout the supply chain. This may include assessing the environmental and social impacts of suppliers, promoting fair and ethical practices, and selecting suppliers who share the company's sustainability values and goals.

An additional research trend that has been identified following the bibliometric analysis concerns the **Circular Supply Chain and Digital innovation.** Circular Supply Chain considers the three dimensions of sustainability (i.e. economic, environmental, and social) and aims to improve the firm’s performance (Awan et al., 2021; Bag & Rahman, 2023; Sandvik & Stubbs, 2019). Digitalization and the CE promote supply chain sustainability by improving resource efficiency, increasing transparency and traceability, fostering collaboration and reuse, and stimulating sustainable design innovation. These practices contribute to reducing environmental impact, minimizing waste, and encouraging a more responsible and ethical approach to supply chain management. Digital technology plays an important role in enabling a sustainable supply chain, in particular, the use of digital technologies improves sorting and recycling activities, creating transparency, traceability, and automation in supply chain management.

Concerning the second Research Question: *RQ2 What kind of digital technologies can be applied in each practice of CE implementation?* The results of the bibliometric analysis carried out from the point of view of keywords are inconclusive in the sense that it has not been possible to identify types of digital technologies on a separate basis, but rather they have been grouped under the term 'digital technology' (except “Artificial Intelligence”). This has meant that to answer this question, it has been necessary to analyze in depth the content of the papers that constitute the study sample; since under the term "digital technology" we find different digital technologies that can enable the implementation of different CE practices, some of which stand out: Blockchain, Data Analytics, Big Data, Artificial Intelligence, IoT and Smart Technology, among others.

Digital technologies, such as Blockchain have a key role in the implementation of **remanufacturing** and **recycling** practices (Rehman Khan, et al., 2022; Rusch et al., 2023; Yu et al., 2022). Blockchain technology allows secure and immutable recording of transactions, therefore can be leveraged to enhance transparency, traceability, and accountability in remanufacturing and recycling processes. For example, to create a transparent and tamper-proof record of the entire lifecycle of a product, including its origin, composition, and previous usage. This enables efficient tracking and verification of products and materials, ensuring their proper handling and facilitating reverse logistics. Furthermore, the application of blockchain technology significantly contributes to CE practices, promoting circular procurement,

supporting circular design principles, and facilitating the critical process of **rethinking** resource usage (Khan et al., 2021; Kayikci et al., 2022). This technology enables efficient collaboration, information sharing, and feedback loops among designers, manufacturers, and consumers and promotes the integration of circular design principles from the early stages, emphasizing factors such as durability, reparability, modularity, and recyclability.

Similarly, Business analytics techniques, including data analytics, predictive modeling, and optimization algorithms, provide valuable insights and support decision-making processes in the implementation of **remanufacturing** and **recycling** practices (Awan et al., 2021; Kristoffersen et al., 2020; Yu et al., 2022). By analyzing historical data and patterns, predictive analytics can forecast demand, identify potential maintenance or quality issues, and optimize resource allocation. This helps improve planning and resource utilization, reducing waste and increasing efficiency in remanufacturing processes, providing real-time data and insights for decision-making at various stages of the remanufacturing and recycling processes.

The utilization of Big data technology can promote circularity by addressing diverse linear economy problems as it integrates various aspects of the CE through physical, cyber, and stakeholder interactions (Barbosa et al., 2022; Chauhand et al., 2022; Jabbour et al., 2019; Modgil et al., 2021; Rusch et al., 2023) since this technology enables organizations to gather and analyze data throughout the entire product lifecycle. This technology is widely recognized as an important driver for the transition to a CE since it also contributes to the reuse, waste reduction, and recycling of products (Kazancoglu et al., 2021; Pinheiro et al., 2022). Companies identify opportunities for **repair, remanufacturing, and recycling b**y tracking product usage, maintenance, and end-of-life processes This comprehensive understanding that big data plays an important role in the product lifecycle since allows for better resource allocation, waste reduction, and **circular product design.**

Smart Manufacturing leads to an increase in process efficiency, lower operational costs, an increase in the quality of the product, and enhanced safety and sustainability (Tiwari et al., 2022; Sharma et al., 2021). This technology plays a critical role in advancing **Circular Economy principles** (Kerin & Pham, 2020; Jabbour et al., 2019). Smart manufacturing enables the efficient customization and personalization of products based on consumer preferences. By leveraging technologies and data analytics with which to produce products on-demand, reducing overproduction and waste. These practices align with the circular economy principles of minimizing resource consumption and maximizing product value.

The Internet of Things is being increasingly utilized for the development of feedback-rich systems and loops throughout the entire product life cycle. By adopting the IoT and collecting data during product utilization, companies can replace the end-of-life concept with product life extension and circular loops (Alcayaga et al., 2017; Awan et al., 2021; Cui et al., 2021; Rajput and Singh, 2019). The adoption of the IoT brings about a new set of opportunities like **maintenance, reuse, repair, remanufacturing, and recycling loops** (Chauhan et al., 2022; Kristoffersen et al., 2020; Rusch et al., 2023). IoT technologies enable the connection of devices, sensors, and systems, allowing for the seamless exchange of data and the creation of smart ecosystems. Through this technology, businesses can maximize the value and lifespan of products, minimize waste generation, and foster a more sustainable and resource-efficient economy.

Artificial Intelligence techniques are helpful in each step of the **circular design** and optimization process, because provide various benefits such as cutting costs, identifying hidden patterns, improving quality, and enhancing responsiveness (Pinheiro et al., 2022; Rajput and Singh, 2019). Implementing AI enhances productivity via improved optimization, real-time data analysis, and enhanced design, which all help to enable circularity (Chauhan et al., 2022). AI techniques enable advanced data analysis and pattern recognition, allowing designers to gain valuable insights from large and complex datasets, processing and analyzing data related to product lifecycle, resource usage, and environmental impact.

Finally, concerning the third research question *RQ3. What could be the future research directions in the field of CE and Digitalization?* The analysis of the papers that constitute the study sample, in conjunction with the results of the bibliometric analyses that have been carried out, has allowed us to identify several ideas that can serve as a basis for the development of future research.

Firstly, analyzing the role of Product Service Systems (PSS) as a business model innovation for achieving Digitalization enabled CE (Chauchan et al., 2022). PSS allows companies to extend product lifetimes, maximize product utilization, and create value beyond the physical product. Future research can explore the potential benefits, challenges, and implications for achieving a digitally enabled CE, to determine effective strategies and best practices, to accelerate the transition towards a more sustainable and circular future.

Secondly, it would be interesting to examine the practices of CE and Digital Transformation in specific sectors. In the literature, some sectors, such as the automotive and textile sectors, have been extensively studied, while other sectors such as energy, construction, agriculture, and transport, have hardly been addressed. It could be interesting to analyze the challenges and opportunities of digital transformation in these sectors and identify best practices and strategies to implement circular economy principles. In addition, examining the socioeconomic and cultural factors that influence the adoption and adaptation of digital technologies in different sectors and contexts would provide insights into strategies for successful technology transfer and implementation.

Along the same lines, the mechanisms and challenges associated with transferring digital technologies to promote the CE could be explored. It would be interesting to explore how knowledge, expertise, and technological solutions developed in advanced digital economies can be effectively transferred to less developed regions or industries to promote the CE, exploring the role of knowledge-sharing networks, public-private collaborations, and policies in facilitating technology transfer for circular economy initiatives. Understanding the barriers, enablers, and best practices in technology transfer related to Digitalization and the CE can help design effective policies and interventions that promote sustainable development and CE on a global scale.

Some studies have focused on analyzing not only the impact of digitalization on the development of circularity strategies in companies but also on the performance of companies. However, it would be necessary to develop new metrics and performance indicators to assess the environmental, economic, and social impact of the digital circular initiatives carried out by companies.

Finally, it could be interesting to examine the role of digital platforms in facilitating circular supply chains. In particular, to investigate the design, implementation, and governance of digital platforms that connect various stakeholders (e.g., manufacturers, suppliers, consumers) to enable resource sharing, traceability, and collaboration in circular value chains.

6 Conclusions

In conclusion, this study provides valuable findings on the current state and evolving trends in research related to the circular economy and digital transformation. Therefore, it is necessary to consider the thematic evolution to identify the actual trends that are manifested in Sankey's model highlighting sustainability, SDG, and sustainable operations. It highlights the importance of staying up to date with emerging issues in the field and the need for continued research to address circular economy challenges. Digitalization serves as a fundamental enabler of the Circular Economy, this facilitates more sustainable decision-making, ultimately driving the progress of circular practices.

However, this work is not without limitations. In this regard, it should be noted that a limitation of the study could be associated with the fact that only articles published in WoS-indexed journals were analyzed and some important papers on the topics of the circular economy and digitalization may be missing due to language barriers or not being indexed. However, WoS is a database that indexes the most influential journals and provides metadata with fewer errors than others (Ren et al., 2023), providing a sufficient guarantee to develop a rigorous bibliometric analysis of the conceptual structure under study (Martínez et al., 2015; Yu et al., 2022). Future research could enrich the analysis with papers also written in other languages, not only in English, using other databases (for example, SCOPUS) or other methodologies, such as a systematic review of literature, which could lead to different conclusions and interpretations. On the other hand, the criteria used in the search protocol followed and the debugging of keywords are not exempt from a certain subjectivity, a common limitation in this type of study. However, the work is meticulously documented in the decisions made, making it replicable.

Despite these limitations, the work makes important contributions from both a theoretical and practical point of view. This study contributes to the body of knowledge through the analysis of the evolution of Digitalization in the CE, to understand the role of digitalization in favoring the CE. In particular, our findings support the theory of sustainable innovation (Boons and McMeekin, 2019; Tello and Yoon, 2008). This theory is based on the idea that technological innovation can be driven by sustainability goals and can play a key role in the transition to more sustainable economic practices, such as the circular economy. It examines how companies and organizations can adopt new technologies and business models that not only generate economic benefits but also reduce environmental impacts and promote social responsibility. Specifically, this research can help academics and practitioners understand the factors that should be considered before adopting a type of digital technology to achieve not only circularity of operations but also sustainability.

The analysis provides a basis for further research in this direction. Thus, based on the research findings, various research gaps in this area are proposed in the form of research questions that provide recommendations for future research (Table 6).

Table 6: Proposal for future research

Theme	Research gap – Research question
Digitalization, CE, Product Service Systems (PSS)	- How can PSS be effectively leveraged as a business model innovation to promote a Digitalization-enabled Circular Economy (CE)? - What strategies and best practices can be identified to accelerate the adoption of PSS for achieving a more sustainable and circular future?
Sectorial Research in CE and Digitalization	- How do digital transformation and CE practices vary across specific sectors, such as energy, construction, agriculture, and transport? - What are the sector-specific challenges and opportunities associated with digital transformation in the context of CE?
Technology Transfer and CE	- What mechanisms and challenges are involved in the transfer of digital technologies to advance Circular Economy (CE) objectives? - How can knowledge-sharing networks, public-private collaborations, and policy frameworks facilitate effective technology transfer for CE initiatives? - What are the barriers, enablers, and best practices in technology transfer related to Digitalization and CE, and how can these inform the design of global-scale policies and interventions?
Metrics and Indicators	- How can new metrics and performance indicators be developed to comprehensively assess the environmental, economic, and social impact of digital circular initiatives undertaken by companies? - What is the holistic impact of digitalization on circularity strategies and company performance, including broader societal and environmental effects?
Digital Platforms and CE	- How do digital platforms facilitate circular supply chains, and what is the impact of their design, implementation, and governance? - What are the key benefits and challenges associated with digital platforms connecting stakeholders (e.g., manufacturers, suppliers, consumers) to enable resource sharing, traceability, and collaboration within circular value chains?

	- How can digital platforms revolutionize supply chain sustainability and circularity, and what strategies can enhance their effectiveness in this regard?

Source: own elaboration

Finally, the results of the analysis have the potential to be useful to policymakers by providing insights that enable the design and implementation of effective policies and interventions that promote digitalization, sustainable development, and CE, ultimately driving positive environmental, economic, and social outcomes.

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