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Technology development as a tool towards circularity: a research agenda

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ABSTRACT

New technological development enables to implement circular economy (CE) practices. This phenomenon is taking particular interest for the Academy. The aim of this study is to analyse the cognitive and intellectual structure of the relationship between CE and technology. The proposed research questions seek to answer how the evolution of the number of publications per year, the main authors, journals, institutions and countries in this field, and the most relevant topics and papers in the research area are. It is used a bibliometric approach of co-word analysis of 996 articles published on Web of Science. In addition, it is proposed a research agenda after reviewing the most cited articles and points the research trend topics. There is a need to include topics associated with the social sphere, since most of the research is focused on environmental aspects and economic effects. In recent years, research has been polarised towards the blockchain, Big Data and biorefinery technologies. Although these technologies are in demand, it should not ignore other emerging technologies that could be key to circularity, such as those related to product redesign or changes in production infrastructures.

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1. Introduction

Circular Economy (CE) has brought a revolution at the productive, economic and social levels to advancing on the route to sustainability. Circularity principles delink economic growth from overconsumption of resources (Pearce & Turner, 1990). The promotion of sustainable development from a circular perspective places higher demands on recycling and production (Hasheminasab et al., 2022). CE implies a break with previous organisational boundaries by including new raw materials, new waste and/or new energy sources, incorporating new actors into the network of relationships. In a complementary way, a reduction in the consumption of materials and energy is sought. The transition from a linear to a circular model requires

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transformations in the value chain activities of organisations, which requires a new framework for action (Hasheminasab et al., 2022).

In this context, CE needs innovative technologies for its correct implementation (Smol et al., 2017) that can facilitate the incorporation of new raw materials, managing waste rationally, optimising production systems, and favouring communications and relations between the different stakeholders (Ajwani-Ramchandani et al., 2021). The use of technologies in circular processes can also improve aspects beyond production, for example by ensuring the protection and confidentiality of the data of the actors involved (Upadhyay et al., 2021). 'Technology advancements such as blockchains, artificial intelligence, Internet of Things, big data, robotics, among others, might help to close the loop and enable a move away from the current linear to a truly CE' (Ajwani-Ramchandani et al., 2021, p. 2). Therefore, the study of technology in the implementation of the principles of circularity has attracted a significant interest of researchers in different sectors, for instance, batteries in the automotive industry for electric vehicles (Baars et al., 2021) or photovoltaic technologies (Heath et al., 2020) or improving patient confidentiality and wellbeing in the health sector (Upadhyay et al., 2021). Accordingly, technological development for the implementation of the principles of circularity has been applied in various sectors but in two types of utilities fundamentally. Those related to (1) production and distribution and (2) those related to the improvement of relations, communication and guarantee of rights among stakeholders.

The first utility of advanced technology achieves more energy-efficient processes with less or no environmental impact at all *stages or activities of production or distribution* in CE—circular procurement, circular design, recycling and remanufacturing—(Khan et al., 2021). Closed-loop systems for achieving circular practices needs of technological development for product treatment, improving industry management and upgrading equipment (Yuan et al., 2008). Specific applications in the circular production of a good or service range from the use of new energies changes in the design or operation of production or waste management—using various technologies or a combination of them. Two main aspects are focusing on the implementation of technologies in the CE: (1) waste management and its new applications and (2) the potential of Industry 4.0 throughout the lifetime of the product or service.

On the first aspect, research is being carried out on the design of new technological routes for waste management to obtain bioenergy, like the anaerobic digestion waste management technology (Ferreira et al., 2021). On the second aspect, Industry 4.0 is promoting sustainable growth and waste minimisation (Kanojia & Visvanathan, 2021). Although the influence of Industry 4.0 on the CE has been verified, there is a prevalence in the application of certain technologies 4.0 (Rosa et al., 2020). In this regard, blockchain technology, essential in the advancement of Industry 4.0, facilitates practices related to circular purchasing, circular design and recycling, improving traceability throughout the product life cycle (Khan et al., 2021) optimising the infrastructure (Pham et al., 2019).

A second utility of technology in developing the principles of circularity relates to improving the conditions under which stakeholder relationships and communications take place. For this purpose, three types of technologies stand out: (1) blockchain technology, (2) geographic information systems and (3) artificial intelligence and big data. Firstly, blockchain technology enables lower transaction costs and improves performance and communication throughout the supply chain (Upadhyay et al., 2021). Secondly, geographic information system assesses the environmental and economic potential of different direct recycling strategies (Senán-Salinas et al., 2021). Thirdly, artificial intelligence through big data analytics can collect information from diverse sources and stakeholders (Modgil et al., 2022) that favour circular capabilities moderating organisational flexibility and industry dynamism (Bag et al., 2021b).

However, there is still not much systematic analysis of this high scientific production. This rapid evolution of research activity requires an evaluation of the literature to summarise the relevant literature that explain the role of recent technologies in the CE. Knowing the status of research on circular technologies will enable researchers to make smarter decisions on the topics of future studies. To this end, the following research questions are established:

(RQ1) Which is the historical evolution of the number of papers?
(RQ2) Which are top authors, countries, institutions, and journals in this field of research?
(RQ3) Which are the main topics and papers in the research field?
(RQ4) Which is the future research agenda related to the main research topics?

This paper is divided up as follows. After the introduction, in section 2 the methodology used is described. Section 3 presents results and the suggested research agenda. Finally, section 4 includes the conclusions.

1.1. Previous bibliometric studies on CE and technology

There are 49 papers related with CE and bibliometric in the database WoS, from them, 24 connects include the keywords CE and technology. However, in most of the articles the concept of technology plays a tangential or secondary role. Table 1 shows the four bibliometric articles that up to 2021 have analysed the relationship between CE and technology, considering this as the main focus of the study.

Bibliometric articles that link technology and the CE are scarce. All of them have studied this relationship by considering specific technologies within the general framework of technology. Our study performs a bibliometric and content review of the most cited papers considering technology in the CE in a broad sense. It is essential to know the main technologies researched and their application. Achieving a holistic perspective of the analysed phenomenon will allow us to design a future research agenda in the most complete and integrated way for both researchers and companies.

2. Methodology

This study uses bibliometrics methods to analyse the thematic structure of CE and technology though citation bibliometric indicators. Bibliometrics analysis is the quantitative study of bibliographic data (Sánchez-Pérez et al., 2021) that enable scholars to

Table 1. Previous bibliometric analysis related to CE and technology.

References	Journal	Purpose	Technology implied
Nobre and Tavares (2017)	*Scientometrics*	A bibliometric literature review of CE and big data/IoT application, between 2006-2015, using 'R' statistical tool	Big data, IoT
Cavalieri et al. (2021)	*Sustainability*	Internet of Things applied to CE focus on manufacturing sector's case studies (2018-2020) by VOSviewer.	IoT: metallurgical-IoT, IoT-enabled decision support system
Boloy et al. (2021)	*Water, Air & Soil Pollution*	CE bibliometric analysis and systematic literature review about waste-to-energy technologies (1945-2020) by VOSviewer.	Waste energy: anaerobic digestion, biogas plants.
Armenise et al. (2021)	*Journal of Analytical and Applied Pyrolysis*	Plastic pyrolysis technologies bibliometric survey towards circularity (2001-2020) by VOSviewer.	Pyrolysis for plastic waste recycling

Source: Web of Sciences database.

organise, understand and synthesise a particular research field (Vogel & Güttel, 2012). This type of analysis allows researchers to visualise by science mapping techniques, the evolution of the cognitive structure of a specific area (Wang et al., 2020). Bibliometric is widely used in academic disciplines linked to social science among others (Ellegaard & Wallin, 2015).

The process carried out in this paper consists in three phases (Figure 1). In the first phase are identified the most relevant articles, selecting documents that study circularity and technology using the WoS database. The database includes journal articles, and the data range is up to December 2021. The search terms were 'circular economy' and 'technology'. Documents were searched by full record and cited references in WoS, filtered by Web of Science Core Collection, selecting Science and Social Citation Index, and excluding conference proceedings and book citations. As it can be seen in Figure 1, the number of papers drawn were 1258; then, it is filtered by only articles and finally, obtained 996 results. All the papers were double-checked to eliminate incoherencies.

In the second phase—bibliometric analysis—it is selected keyword frequency and citations by VOSviewer software (Van Eck & Waltman, 2010). The relationship between two units of analysis was established by co-occurrence analysis. Moreover, it is examined the most representative authors and journals.

In the third phase, it is analysed the most cited papers both in the whole period and in the last years (2020 and 2021) to draw the main research trend topics according to the technologies involved.

3. Results

3.1. Publication measures

Figure 2 shows the evolution in the number of articles published considering the period between January 2006 and December 2021. There has been an increase of publications since 2015, highlighting the period from 2017 to 2021. This number of studies shows that interest in the subject continues, which is why it is useful to know

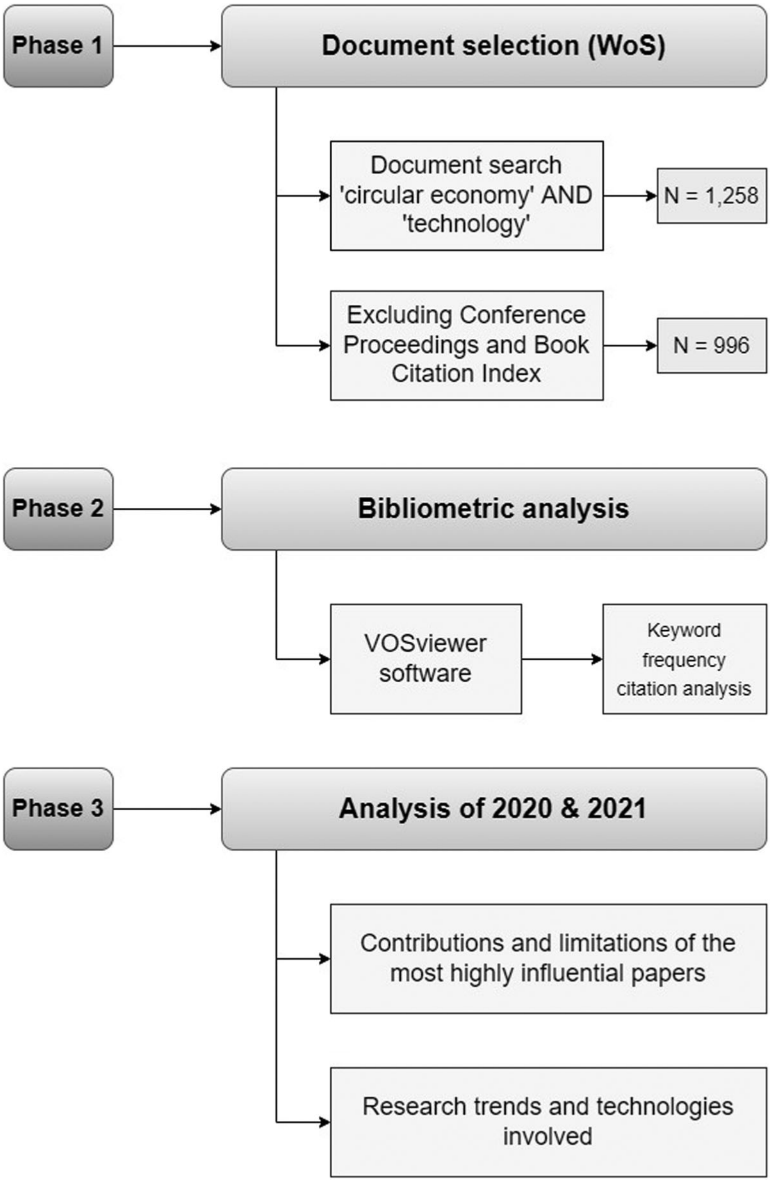

Figure 1. Research and analysis methodology.
SSource: own elaboration.

more about this research in detail and to guide future steps in this area. This phase coincides with the promotion of environmental policies in certain regions, e.g., the European Commission and the implementation of its CE program to ensure sustainable consumption and production (Hasheminasab et al., 2022), which has given a boost to research in this area. The United Nations General Assembly approved the 2030 Agenda for Sustainable Development in 2015 (United Nations, 2015). Technologies—such as waste-to-energy technologies (AlQattan et al., 2018)—can help accelerate the achievement of the 17 United Nations Sustainable Development Goals

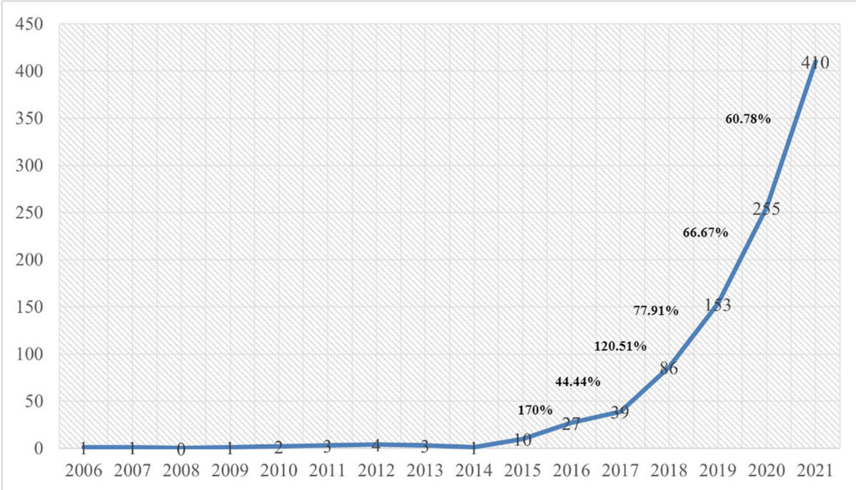

Figure 2. Historical evolution of WoS publications about CE and technology.
Source: own elaboration.

(SDGs) set out in the 2030 Agenda by making businesses and societies more inclusive, sustainable and resilient. It highlights the increase of articles during the years 2020 and 2021 with an increase of 155 articles (+60.78) and 102 articles (+66.67) in 2020. This growth shows that it is still on an upward trend. Therefore, an analysis of where research is being focused will also allow to find gaps that need to be filled.

Table 2 shows the ranking of the top 10 countries, institutions and journals using the information collecting in WoS and including the percentage of the total sample (N = 996). The top 10 countries or regions highly represented are China, Spain and United Kingdom. China is a pioneer in sustainable and circular strategies, notably the CE law implemented in 2009 (Lieder & Rashid, 2016).

The most prolific institution and journal are Delf University of Technology and Journal of Cleaner Production, respectively. As it can be seen, there are different research areas such as environmental science ecology, engineering and science technology.

The 996 articles were written by 4050 authors. Table 3 present the most prolific authors in CE and technology. Highlighting that several of these authors have published papers in co-authorship with each other.

3.2. Thematic organisation

3.2.1. Co-word analysis

Co-word analysis is a technique of content analysis that mapping the strength of association between information items in data collection (Callon et al., 1991). It is a methodology for describing and discovering different interactions in scientific research in specific fields (Muñoz-Leiva et al., 2012). From 996 articles examined with 5404 keywords, with a minimum of 15 occurrences, 69 met the threshold carried out by VOSviewer software.

Table 2. Distribution of articles by most influential countries, institutions and journals.

	Countries			Institutions			Journals			Research areas		
R		N	%		N	%		N	%		N	%
1	China	154	15.46%	Delft University of Technology	24	2.41%	Journal of Cleaner Production	135	13.55%	Environmental Sciences Ecology	547	54.92%
2	Spain	121	12.15%	Lund Univers	15	1.51%	Sustainability	102	10.24%	Engineering	455	45.68%
3	United Kingdom	113	11.34%	Aalto University	13	1.31%	Resources, Conservation and Recycling	51	5.12%	Science Technology	347	34.84%
4	Italy	105	10.54%	Technical University of Denmark	13	1.31%	Waste Management	26	2.61%	Energy Fuels	101	10.14%
5	United States	102	10.24%	Worcester Polytechnic Institute	13	1.31%	Science of the Total Environment	25	2.51%	Chemistry	88	8.83%
6	Germany	84	8.43%	Chinese Academy of Science	12	1.20%	Energies	23	2.31%	Materials Science	69	6.93%
7	Finland	54	5.42%	Kaunas University of Technology	12	1.20%	Applied Sciences	22	2.21%	Business Economics	69	6.93%
8	Netherlands	53	5.32%	Shanghai Jiao Tong University	11	1.10%	Journal of Environmental Management	18	1.81%	Water Resources	40	4.02%
9	Australia	47	4.72%	University of Cantabria	11	1.10%	ACS Sustainable Chemistry Engineering	16	1.61%	Physics	35	3.51%
10	India	45	4.52%	University of Johannesburg	11	1.10%	Journal of Industrial Ecology	14	1.41%	Biotechnology Applied Microbiology	30	3.01%

Abbreviations: R = rank, N = total number of documents; % = percentage from the total sample (N = 996).
Source: Web of Sciences database.

Table 3. Most prolific authors in CE and technology.

Rank	Author	Country of author	University/organisation	Publications
1	Sarkis, J.	United States	Worcester Polytechnic Institute	15
2	Yousef, S.	United Arab. Emirates	Khalifa University of Science and Technology	9
3	Cortina, J.L.	Spain	Polytechnic University of Catalonia	7
4	Tatariants, M.	Lithuania	Kaunas University of Technology	7
5	Geng, Y.	China	Shanghai Jiao Tong University	6
6	Gibert, O.	Spain	Polytechnic University of Catalonia	6
7	Irabien, A	Spain	University of Cantabria	6
8	Kazancoglu, Y.	Turkey	Yasar University	6
9	Bag, S.	South Africa	University of Johannesburg	5
10	García-Calvo, E.	Spain	University of Alcalá	5

Source: Web of Sciences database.

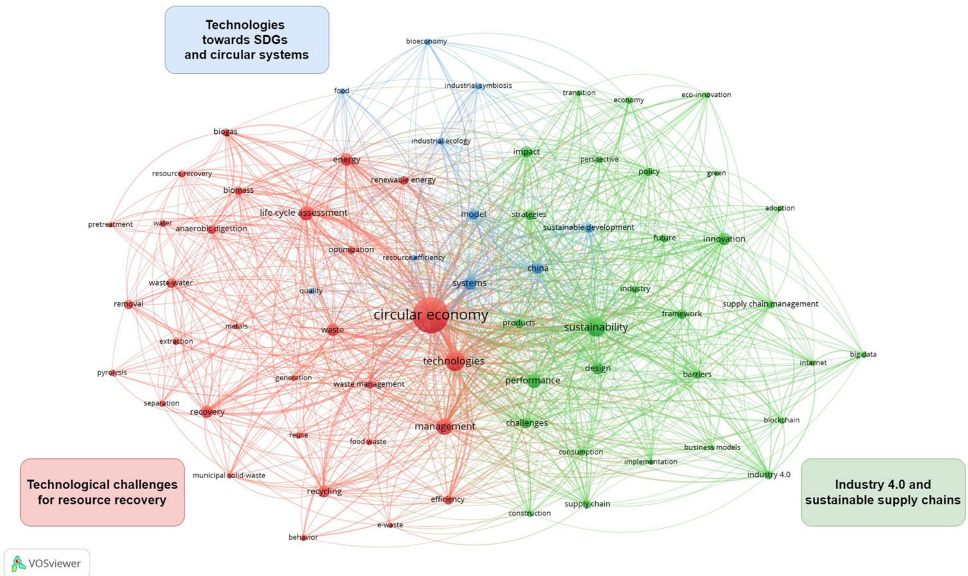

Figure 3. Co-word analysis VOSviewer.
Source: own elaboration.

As it can be seen in Figure 3, in the red cluster the main words are linked with 'circular economy' practices: 'resource recovery', 'recycling', 'separation', 'removal' and 'energy optimisation'. Regarding the last one, this can be enhanced by new technologies development in processes related to energy recovery. For instance, the adoption of 'anaerobic digestion' in 'waste management' using recycled 'biogas' as bioenergy in the transition towards a cleaner production (Ferreira et al., 2021). The application of new energy recycling as an alternative to fossil fuels—by waste-to-fuel—is crucial and the effective and sustainable 'municipal solid waste' management play a key role in the proceeding (Hoxha et al., 2019).

'Food waste' biotechnological process in valorisation is widely used in the industry to prevent the surplus food generation (Mokrejs et al., 2021). Moreover, thanks to 'resource recovery technologies' is possible the transformation of 'wastewater' into feedstock (Udugama et al., 2020). Thus, this cluster is named 'technological challenges for resource recovery' according to the previous processes involved and the technological challenge required to address them.

The green node, titled 'Industry 4.0 and sustainable supply chains' associates the technological innovations of Industry 4.0 such as 'blockchain' in the transition to achieve circularity and sustainability in 'supply chains' (Mukherjee et al., 2022). The evaluation and selection of a more sustainable supply network can be improved thanks to smart transportation and logistics by means of tokenisation—blockchain—contributing to sustainability (Esmaeilian et al., 2020). In addition, the establishment of effective treatments in product recovery for the implementation of circular closed-loop supply chains can be achieved thanks to Internet of Things (IoT), and the data obtained (Delpla et al., 2022).

The blue cluster named 'technologies towards SDGs and circular systems' is closely related to theoretical framework focus on CE technologies. Gómez et al. (2018) point that technology for information and knowledge 'models' can support the implementation of circularity in manufacturing 'systems'. The node contains terms related to 'sustainable development' and their goals formulated by United Nations in 2015 that could be reached thanks to future and new renewable biotechnologies, following 'bioeconomy' principles by means of enabling technologies' (Laibach et al., 2019).

'Industrial symbiosis' that implies a 'resource efficiency' system and valorisation of waste with the endeavour of organisations from different industries (Trokanas et al., 2014). Considering, that most of the papers that connect these topics and new technologies, such as Artificial Intelligence (AI), are based on 'China' case studies (Manaf et al., 2021).

3.2.2. Most influential articles

It is conducted a more in-depth review of the most cited papers, differentiating between the most cited articles in the last 15 years—the full time of this research—and in 2020 and 2021.

Table 4 shows the most cited articles ordered by the highest number of citations (TC). Half of the articles are theoretical, or literature reviews and the other half are empirical or case studies.

Emphasising that the bulk of the articles are regarding to China's CE development. Peters et al. (2007) analyse how the CE and technological development can avoid emissions related to production and consumption in China. Regarding with China's CE implementation, Park et al. (2010) discuss by means of three case studies the opportunities and the challenges occasioned by the balance between economic and environmental issues to implement CE policies in organisations. About China's construction and demolition waste and the adoption of CE for this industry, Huang et al. (2018) propose a designing effective CE model thank to innovative technologies such as precast construction technologies. Furthermore, Ranta et al. (2018) examined a comparison between CE institutional actions in China, US and Europe.

Highlighting Nascimento et al. (2019) and Rajput and Singh (2019) focused on how to enable CE practices with technologies from Industry 4.0.

To complement the above analysis, the content of the most cited articles in 2020 and 2021 is analysed to gain a better understanding of the research trend. Thus,

Table 4. The most cited articles in the field of CE and technology in the last 15 years.

R	Title	Reference	Journal	TC
1	China's growing CO_2 emissions—A race between increasing consumption and efficiency gains	Peters et al. (2007)	Environmental Science and Technology	444
2	Green, circular, bioeconomy: A comparative analysis of sustainability avenues	D'Amato et al. (2017)	Journal of Cleaner Production	349
3	The Relevance of CE Practices to the Sustainable Development Goals	Schroeder et al. (2019)	Journal of Industrial Ecology	327
4	Construction and demolition waste management in China through the 3 R principle	Huang et al. (2018)	Resources, Conservation and Recycling	292
5	Exploring Industry 4.0 technologies to enable CE practices in a manufacturing context A business model proposal	Nascimento et al. (2019)	Journal of Manufacturing Technology Management	231
6	Creating integrated business and environmental value within the context of China's CE and ecological modernisation	Park et al. (2010)	Journal of Cleaner Production	185
7	Exploring institutional drivers and barriers of the circular economy: A cross-regional comparison of China, the US, and Europe	Ranta et al. (2018)	Resources Conservation and Recycling	173
8	Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda	Jabbour et al. (2019)	Technological Forecasting and Social Change	165
9	Ecological utilisation of leather tannery waste with CE model	Hu et al. (2011)	Journal of Cleaner Production	154
10	Connecting circular economy and industry 4.0	Rajput and Singh (2019)	International Journal of Information Management	152

Abbreviations: R = rank, TC = total citations in WoS.
Source: Web of Sciences database.

Table 5 summarises the most influential papers with an analysis in depth in terms of their main contributions and limitations.

Some articles are related with the manufacturing industry focused on developing countries such as South Africa (Bag et al., 2021a) and India (Gupta et al., 2020). Highlighting that researchers have not paid enough attention to social factors, and it is required for more research into social development through circular technology (Zhang et al., 2020).

The main technologies involved are part of the Industry 4.0: (1) blockchain, focus on smart logistics and tokenisation (Esmaeilian et al., 2020), (2) Big Data implementation as a priority towards a circular and sustainable supply chain (Jabbour et al., 2020) and (3) Artificial Intelligence in the automotive industry to address the transition to circular supply chains (Bag et al., 2021b). Other technologies are related to bioenergy such as anaerobic digestion and biorefinery technologies (Awasthi et al., 2020). In addition, clean energies play a key role for recycling and recovery actions toward CE principles.

Table 6 shows the recent research trends according to the most influential articles during years 2020 and 2021 highlighting the main technologies involved, the related articles and countries where they are applied.

Table 5. Highly influential papers in CE and technology during 2020 and 2021.

R	Reference	Journal	Article category	TC	Contributions	Limitations
1	Esmaeilian et al. (2020)	*Resources, Conservation & Recycling*	Literature review Case studies	112	Identification of blockchain capabilities towards sustainable supply chains by means of smart business models, transportation and smart logistics and tokenisation.	Lack of successful case studies. Consider economic and social issues.
2	Nandi et al. (2020)	*Industrial Management & Data Systems*	Qualitative research	105	Analysing the positive and direct relationship between localisation-agility-digitisation skills and blockchain-circular economy systems.	Expand the sample is required.
3	Bag et al. (2021b)	*Technological Forecasting and Social Change*	Literature review Empirical	91	An overview about Big Data and Artificial Intelligence to address circular supply chains in manufacturing practices (automotive). In this regard institutional pressures playing a key role.	Extend the analysis to other geographical areas.
4	Pham et al. (2020)	*Journal of Environmental Management*	Literature review Empirical	81	Findings show the European countries requirement of minimising carbon towards renewable energies following the 'Environmental Kuznets Curve'.	Extend the analysis to other geographical areas.
5	Zhang et al. (2020)	*Resources, Conservation & Recycling*	Methodological tool	81	Evaluating a new framework of LCA data integrating emerging technologies such as blockchain, Internet of Things and Big Data that improves supply chain sustainability in remanufacturing organisations.	New methods focused on social development are required. Further studies about Artificial Intelligence.
6	Awasthi et al. (2020)	*Renewable & Sustainable Energy Reviews*	Review analysis	77	How biomass waste is used in biorefinery technologies, by composting, anaerobic digestion and its implementation in developing countries.	Incorporate assessment tools according to sustainability and circular bioeconomy.
7	Chen et al. (2020)	*Science of the Total Environment*	Literature review	76	Reviewing green chemistry principles practices throughout strategies towards circularity: collaboration, integrated management system, cleaner production, new business models and education programs.	Implementation of the green chemistry principles considering a new technological approach (big data, IoT).
8	Baars et al. (2021)	*Nature Sustainability*	Literature review Empirical	75	Scenarios with different strategies towards circular supply chains in the automotive sector by means of technologies for cobalt substitution and reduction with electric vehicles batteries.	Further analysis about different batteries is required.

(*continued*)

Table 5. Continued.

R	Reference	Journal	Article category	TC	Contributions	Limitations
9	Häußler et al. (2021)	*Nature*	Empirical	73	Showing a fully polyethylene-like materials for a closed-loop chemical recycling approach.	Lack of long-chain monomers availability.
10	Velenturf and Purnell (2021)	*Sustainable Production and Consumption*	Literature review Framework developed	69	Reflexions of sustainable development and CE relationships, providing a framework about implementation, designing and evaluation.	Actualise the actions with future policies.
11	Bag et al. (2021a)	*Journal of Cleaner Production*	Empirical	66	Providing a theoretical model of Industry 4.0 applied on manufacturing. Highlighting the positive effect that Industry 4.0 has with sustainable production and this with CE.	Low response rate.
12	Julianelli et al. (2020)	*Resources, Conservation & Recycling*	Literature review Empirical	66	Developing a taxonomy for critical success factors (CSF) according to industrial sustainability, planning and management, ICT, promoters and relationships of the reverse logistics to apply CE in supply chains.	Amplifying the sample to other databases and extend the scope with other components of the supply chains.
13	Upadhyay et al. (2021)	*Journal of Cleaner Production*	Literature review	64	Exploring how blockchain impacts and contributes to CE, social responsibility and sustainability: facilitating communication across the supply chain, security, reducing carbon footprint and transaction costs.	Future quantitative analysis is required.
14	Cainelli et al. (2020)	*Research Policy*	Empirical	64	Analysing CE adoption by means of clean technologies and innovations showing that environmental policies play a key role.	More in-depth specific information of eco-innovation types.
15	Coderoni and Perito (2020)	*Journal of Cleaner Production*	Empirical	61	Evaluating purchase waste-to-value (WTV) food intentions applying circular practices through technology development to reducing environmental impact throughout a questionnaire to Italian consumers.	Use a representative sample. Extending the questionnaire to other geographical areas.
16	Panagopoulos and Haralambous (2020)	*Journal of Environmental Chemical Engineering*	Case study	60	Findings show that zero liquid and minimal liquid discharges technologies are circular strategies in resource recovery and wastewater reuse.	Renewable energy source coupling is required with those technologies.

(*continued*)

Table 5. Continued.

R	Reference	Journal	Article category	TC	Contributions	Limitations
17	Nguyen et al. (2021)	*Nature*	Empirical	58	Providing degradable batteries made by sustainable materials as an alternative to lithium and cobalt.	Continue working on the battery lifespan.
18	Gupta et al. (2020)	*Resources, Conservation & Recycling*	Literature review Empirical	56	Identification of sustainable supply chains boundaries and innovative strategies, such as investment in the latest technologies, regarding the manufacturing sector.	Consider social barriers and extend the analysis to other organisations or industries.
19	Heath et al. (2020)	*Nature Energy*	Literature review	56	Evaluation of photovoltaic module recycling infrastructures for the recovery of materials according to circular economy principles.	Update the study based on photovoltaic technology progresses.
20	Jabbour et al. (2020)	*Science of the Total Environment*	Literature review	55	Studying challenges in big data analytics implications—as a fundamental capability for firms—for sustainable supply chains.	Extend the analysis to other databases and Industry 4.0 technologies.

Abbreviations: R = rank, TC = total citations in WoS, considering more than 20 cites.
Source: Web of Sciences database.

Table 6. Recent research trend topics.

	Research trends	Technologies involved	References	Countries
Supply chains	Circular and sustainable supply chains	Big Data Analytics	Jabbour et al. (2020)	N/A
		Blockchain, IoT and Big Data	Zhang et al. (2020)	N/A
		Big Data; AI	Bag et al. (2021b)	South Africa
	Supply chain communication	Blockchain	Upadhyay et al. (2021)	N/A
Production	Sustainable production	Industry 4.0	Bag et al. (2021a)	South Africa
Logistics	Smart transportation; logistics, tokenisation	Blockchain	Esmaeilian et al. (2020)	N/A
			Nandi et al. (2020)	
	L-A-D capabilities			
	Reverse logistics	ICT	Julianelli et al. (2020)	N/A
CE principles	Anaerobic digestion	Biorefinery technology	Awasthi et al. (2020)	Developing countries
	Wastewater reuse	Zero liquid discharge	Panagopoulos and Haralambous (2020)	N/A
	Recycling and recovery	Clean energy technologies: photovoltaic technology and batteries	Heath et al. (2020)	US, Europe
			Baars et al. (2021)	EU

Source: Web of Sciences database.

3.3. Research agenda

Based on the previous results—the most cited articles and clusterisation—the following points have set out as a research agenda to fill the gaps that the papers have highlighted. Also included topics that the current state-of-the-art has ignored or insufficiently studied.

1. *Expand the technologies under study or its applications*. Industry 4.0 tools play a key role. A further step must now be taken, seeking new applications for these tools, and extending the tools studied (Ghobakhloo, 2020). Some of these new applications must be accompanied by new regulatory and legal frameworks, which will require a multidisciplinary perspective for their development.
2. *Study of the social aspects of the impacts of circular technologies.* Although some articles have made a theoretical approach to the social aspects (Upadhyay et al., 2021), there is a significant lack of research in this regard. In addition, the study of the Sustainable Development Goals (SDG) related to social aspect is required if the 2030 Agenda is to be met.
3. Related to the previous point, there is a need for studies that explore the application of different types of technologies to analyse production utilities and stakeholder relations. Both utilities are deeply interrelated. To illustrate, big data tools that interpret the data from the different stakeholders must accompany the development or adaptation of technologies that enable the design of products that facilitate their subsequent recovery.
4. *New geographical areas in the field of study.* Faced with China as the main country in the research, researchers must incorporate new countries to consider their idiosyncrasies (Pham et al., 2020). It is worth mentioning the inclusion of developing countries, where the implementation of the CE is especially useful to achieve a sustainable framework in their industry and services (Halog & Anieke, 2021).
5. *Increase the number of empirical investigations*. Most of the works analysed are theoretical. There is a need for a practical perspective that provides results that facilitate making decisions and the implementation of technologies in the CE (Hossain et al., 2020).
6. *Adapting to a post-pandemic period.* Focus on the year 2020 and considering the necessary review period of the articles before publication, there is not yet an effect of Covid 19 on research. A study is required of the effect of the management of the Covid-19 health crisis on technological development in the circular field to enable its implementation, considering the social, cultural and organisational changes that are affecting the production and services sector in its adaptation to change.

4. Conclusions

As opposed to traditional consumption models, based on mass product consumption and significant environmental and social impact, the CE proposes a more sustainable approach with corresponding changes in production methods and consumption patterns (Modgil et al., 2022). In the design of closed loops that involves betting on the utility of products and services rather than mere possession, technologies play a key role. This study presents the cognitive structure of CE with technology, providing information about the state of academic contributions and linkages between both topics.

The interest in this topic continues growing year after year, to implement the best technology in firms with the purpose of make a transition towards CE. A strongly high interest on the topic studied runs into the last 6 years (2015–2021) highlighting years 2020 and 2021 (RQ1). Findings reveal that China, Spain and United Kingdom are the most representative regions in number of articles, and scholars from these regions are also the most cited. Stressing Journal of Cleaner Production as the most productive source in this research topic (RQ2). The main topics are related to the Industry 4.0 implementation towards sustainable and circular supply chains, sustainable production, smart transportation and logistics, and the recycling and recovery by using clean energy technologies (RQ3). To answer RQ4, a research agenda has been set that has important theoretical and practical implications for the use of technological tools in the field of the CE.

In terms of theoretical or academic implications, this study represents a contribution by providing a general theoretical framework for a subject of great interest to researchers that is still only partially analysed. This may be because of the complexity of the subject analysed due to the large number of technological tools and their applications or possibilities. However, a reflection on the theoretical development of the current research will allow for a better orientation of the following research proposals. Furthermore, the research highlights the need for a greater number of empirical studies. Once a solid theoretical basis has been built, it needs to be tested with data. Research has focused mainly on the productive sector, so there is a need for a greater theoretical contribution in services. In addition, given the large amount of research on environmental and economic issues, new work needs to look more deeply into the social question. In parallel, more empirical studies are needed as a sound theoretical basis is built up, which must be tested with data.

After shedding light on the academic contributions and linkages, highlighting the importance of technology development to redesign business models towards CE practices in firms. In terms of practical implications, the study provides to review treatment technology and circular management to reduce costs. Industry 4.0 tools, such as cloud computing, artificial intelligence, data-driven analysis and Internet of Things (IoT), among others, accelerate CE transition. However, the undisputed potential of Industry 4.0 and of blockchain technology has meant that both concepts have become 'trendy' in the field of research. There is a risk of over-focusing on this topic and a broader perspective is required, considering new applications for these tools and the incorporation of new technological tools. The application of widely used methods such as LCA involves the consideration of their different dimensions and their adaptation to different sectors. Finally, the present research is of interest beyond the business sphere. Worldwide policymakers are considering this sustainable necessity to implement circular practices.

The results and maps help in the understanding and the visualising of the current 'state-of-the-art' and could be useful to offer insights to the academia and to public, private organisations, and worldwide policymakers. Nevertheless, our study has several limitations. The main limitation is that some relevant papers in the field may not be included on WoS, the database used in this research. A few documents did not include keywords which suppose a limitation for the co-ocurrence analysis of words. Moreover, the articles reviewed are written in English, excluding other languages and consequently a part of published papers. And, unavoidably, the interpretation of the co-word analysis maps visualised by VOSviewer is subjective with the results obtained.

This paper brings clarity to CE and technology literature to understand the evolution of this research topic. It would be interesting to analyse again in the future the evolution of the scientific production if attention to this phenomenon continues growing up with the years. A complementary analysis of specific technologies in the circular field would be of interest, such as, emerging digital technologies (de Souza et al., 2021). A deeper understanding of the main typologies of technologies provides insight into the specific applications in use. Finally, future papers with other bibliometric methodologies, such as bibliographic coupling or strategic diagrams, and the use of others software like Histcite or Scimat, can provide and complement the results of this study.

Disclosure statement

The authors report there are no competing interests to declare.

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