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The Main Research Characteristics of the Development of the Concept of the Circular Economy Concept: A Global Analysis and the Future Agenda

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In recent years, the concept of the Circular Economy has acquired greater traction, both in the research community and in wider society, as an instrument that provides innumerable methodologies with which to face the environmental, social, and environmental challenges caused by the linear production model. This study focuses on analyzing the degree of advancement of the Circular Economy in the scientific field through a bibliometric analysis (or scientometrics) of 5,007 research articles available in Scopus database and published during the period 2005–2007. The main research characteristics are presented, and the Paris Climate Conference (COP21), held on December 12, 2015, is highlighted as a key driver of this particular line of research. The analysis revealed the main authors, journals, subject area, countries and current and future lines of research, finding that the Circular Economy is a paradigm with environmental, economic and social implications, both for the productive system and for consumers.

Keywords: circular economy, environmental sustainability, economic sustainability, social sustainability, bibliometrics

INTRODUCTION

The traditional linear economy model of "take, make and throw away" is unsustainable (Frosch and Gallopoulos, 1989; Ness, 2008), which establishes the need to transition to more sustainable sociotechnical systems (Seiffert and Loch, 2005; Markard et al., 2012). The externalities of the linear production model are threatening the economic and environmental sustainability of our planet, and the natural ecosystems thereon (EMF, 2012; Geng et al., 2012; Stiehl and Hirth, 2012; Su et al., 2013; European Commission 2014a; European Commission, 2014b; Park and Chertow, 2014). Similarly, society faces high unemployment rates and poor working conditions, causing social vulnerability, which is conceptualized through poverty and increasing inequalities (Sen, 2001; Banerjee et al., 2011). Sustainability requires the development of a balanced production system that takes into consideration economic, social, environmental, and technological aspects (Ren et al., 2013). To this end, the Circular Economy (CE) is a new paradigm that contributes to the positive reconciliation of all these elements (EMF, 2012; Birat, 2015).

The concept of the Circular Economy has gradually gained prominence in political agendas (Brennan et al., 2015), for example, in the European Commission, through the comprehensive package of the European Circular Economy (European Commission, 2015) and, in China, through the Law for the Promotion of the Circular Economy (Lieder and Rashid, 2016). From a scientific point of view, the Circular Economy (CE) is also gaining increasing attention, which has led to the publication of a large number of case studies, reviews, scientific reports, and research articles, etc., aimed at developing the concept of the Circular Economy (CE) (Yap, 2005; Andersen, 2007; Charonis, 2012; EMF, 2012; Lett, 2014; Naustdalslid, 2014; Prendeville et al., 2014; Club of Rome, 2015; Argudo-Garcia et al., 2017; Molina-Moreno et al., 2019).

The concept of the Circular Economy arises as a set of ideas drawn from different economic and environmental paradigms whose main objective is to improve the efficiency of resources in order to balance the relationship between the economy, the environment, and society (Ghisellini et al., 2016; Murray et al., 2017; Giampietro, 2019). Stahel and Reday (1976) introduced the concept of industrial economics, and Stahel (1982) introduced the need for a shift from property to use thinking. New features have been incorporated into the concept in recent years, such as the cradle-to-cradle theoretical concept (McDonough and Braungart, 2010), ecology (Commoner, 2020), loop economy and performance (Stahel, 2010), regenerative design (Lyle, 1996), biomimicry (Benyus, 1997), and the blue economy (Pauli, 2010).

According to Korhonen et al. (2018), the origin of the Circular Economy is in the ecological economy, while for Andersen (2007) and Su et al. (2013), it was adopted for the first time in 1989 by Pearce and Turner when they explored how natural resources provide the inputs for production and consumption, and eventually become waste, in their investigation of the characteristics of traditional economic systems (Pearce and Turner, 1990).

However, at present, the most recognized definition is that provided by the Ellen MacArthur Foundation, which defines the Circular Economy as “an industrial economy that is restorative or regenerative by intention and design” (Fundación Ellen MacArthur EMF, 2013). In this way, companies need to develop production models based on the 10r philosophy (reduce, reuse, reject, rethink, redistribute, repair, restore, reuse, recycle, and recover) (Bag et al., 2021). Under this philosophy, the concept of redesign is based on the ability of companies to use products and services more intensively and develop awareness in interested parties, focusing on the minimum use of natural resources (Gupta et al., 2019; Jabbour et al., 2020). This encourages the reuse of products that still have operational functionalities, favoring the development of repair systems (Goyal et al., 2018). At the same time, companies must take into account remanufacturing and repair, lengthening the useful life of products, both for the same use and to develop different functionalities (Gurita et al., 2018). Similarly, a more efficient use of recycling, considering circular principles, makes it possible to recover energy and materials, in order to either incorporate them back into the cycle or promote their natural absorption (Fischer and Pascucci, 2017; Bag et al., 2021).

The tension between the excessive use of natural resources and the limits of circular flows is a reality (Sehnem et al., 2019); the Circular Economy presents a new paradigm: “waste is food”, which assumes that all materials and products are a temporary deposit of materials or nutrients that will become new inputs and will be incorporated back into the production chain, thus extending their useful life (Tukker, 2015). Therefore, the concept of waste is eliminated, so that the nutrients flow permanently (Smol et al., 2015), thus maintaining the status of waste as a productive resource (Braungart, 2007).

The Circular Economy not only has important implications from an environmental point of view. From an economic point of view, the European Commission considers the Circular Economy to be able to generate transactions that produce annual profits in Europe worth € 600,000 for the manufacturing sector (Fundación Ellen MacArthur EMF, 2013; European Commission, 2014a). According to the Finland’s Independence Celebration Fund, the Circular Economy would generate annual profits of 2,500 million euros, and the world economy would generate profits of 1,000 million dollars annually. However, there is a certain relationship between the transition towards the Circular Economy model and the level of development of the territories. According to Singh and Ordoñez (2016), the principles of circularity appear more intensively in developed countries than less developed ones.

Nevertheless, for Korhonen et al. (2018), the circular economy has been developed and led mainly by experts, while the empirical content remains largely unexplored. This limited theoretical development leads to unclear practical implications for sustainability (Giampietro, 2019), resulting in some ambiguity regarding the circular economy. Other authors question the suitability of the concept in terms of social inclusion and climate change (Sehnem et al., 2019). Therefore, this paper attempts to analyze the level of theoretical and scientific development of the circular economy concept and fill the gap about its implications and theoretical benefits on social, economic, and environmental sustainability.

As far as we know, some theoretical reviews have been presented on the concept of circular economy, but we have not identified any bibliometric analysis, which is an appropriate method to uncover key attributes and research themes (Donthu et al., 2021; Kumar et al., 2021). The main objective of this study was to analyze the degree of the scientific or theoretical development of the concept of Circular Economy, based on the productivity of research articles, authors, journals, institutions, and countries considering their international cooperation networks, in order to establish current and future lines of research.

To this end, this research demonstrates a mapping of the circular economy concept through the bibliometric methodology, in which current knowledge and future research trends occupy a central place. Therefore, the following research questions are explored in this review paper:

Q1. What is the trend of CE publications?
Q2. What are the main topic areas in CE?
Q3. Who are the most prolific contributors (authors, journals, countries, and institutions)?
Q4. What are the main international collaborative networks (authors, countries, and institutions)?
Q5. What are the main research topics in CE?

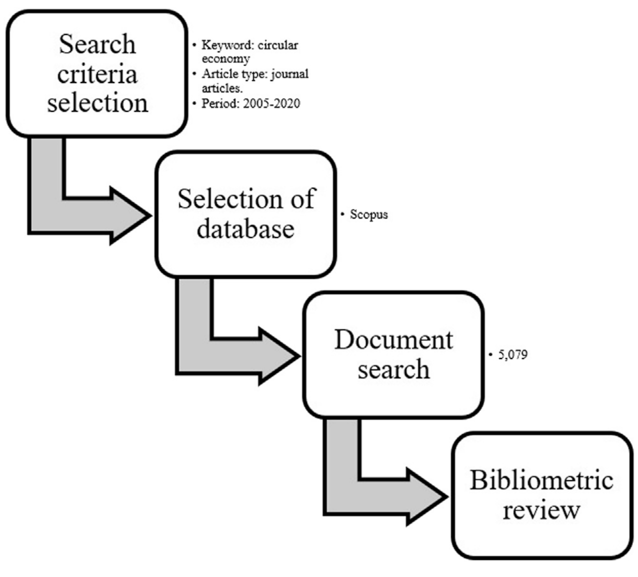

FIGURE 1 | Applied methodology.

MATERIALS AND METHODS

The search for these studies took place in February 2021, and the study was carried out in four phases (**Figure 1** shows the logical sequence applied to obtain the data to be studied). The methodology of this research is based on bibliometric analysis or scientometry, which is a technique applied to publications and allows the extraction of metadata to examine the evolution of an area of knowledge in a certain period of time (Lievrouw, 1989; Cronin, 2001; Zhu and Guan, 2013).

First, the search criteria were selected: (a) keywords: Circular Economy (CE); (b) article type: journal articles. For Paul et al. (2021) bibliometric review should be performed on journal articles because 1) they are evaluated on the basis of novelty and 2) they undergo rigorous peer review, which indicates higher quality; (c) period: the previous 16 years were covered, i.e., the period of time between 2005 and 2020, as is done in other research studies related to bibliometrics (Veer and Khiste -Ganajan, 2017; Liao et al., 2018).

Second, the database was selected. The main databases closely related to the field were consulted, such as Web Of Science, Scopus, PubMed, and Google Scholar (Harzing and Alakangas, 2016; Mongeon and Paul-Hus, 2016). Finally, the research articles from Scopus were selected, as it is the scientific database that has a high number of articles, authors, and journals that meet the scientific quality requirements of peer review (Ackerson and Chapman, 2003; Mingers and Lipitakis, 2010). In addition, this repository provides the largest volume of information in terms of authors, institutions, and countries (Zhang and Eichmann-Kalwara, 2019). Indeed, Scopus is a recognized database to conduct bibliometric reviews (Donthu et al., 2021), as it is recognized as a high-quality repository (Baas et al., 2020), and the correlation with its measurements with those available, for example, in the Web of Science are extremely high (Archambault et al., 2009), although the coverage of the latter is lower (Paul et al., 2021), making it a complete database and high quality for your review.

Finally, we exported the database, carried out the analysis, and established the main conclusions. The sample consisted of 5,007 articles that met the search requirements. This methodology allowed us to analyze the year of publication, the journal, the subject area, the author and co-authors, the institution, the country, the keywords that were included in the research work, and the citations count, the H index, and the Scimago Journal Rank (SJR) impact factor of the main works (Durieux and Gevenois, 2010), establishing the degree of interest in the subject investigated.

We used the VOSwiever tool (Sedighi, 2016; Gálvez-Sánchez et al., 2021; Meseguer-Sánchez et al., 2021) to generate network maps for each of the variables used, allowing us to group and process words.

RESULTS

Evolution of Scientific Literature (Q1)

This section shows the results related to the main characteristics of the scientific literature. The 2005–2020 time horizon was divided into four quadrennia to facilitate comparative analysis and understanding.

Table 1 presents the main results obtained concerning the evaluation of the number of articles published, the authors, the countries, the total and average number of citations, and the number of journals in which the research articles on Circular Economy had been published.

It is clear to see how the scientific literature of each period is at least double that of the previous 4-year period. While in the first quadrennium (2005–2008), 69 articles were published, in the 2017–2020 period, 4,436 were published, representing an increase of 6,429%. The number of publications in the last quadrennium is especially relevant, since it represents 88.6% of the total production of scientific articles on Circular Economy during the 2005–2020 period.

As can be seen in **Figure 2**, although the growth in articles was constant during each period, from the 2013–2016 quadrennium, this growth was exponential. This could have been driven by the Paris Climate Conference (COP21) on December 12, 2015, which was the first universal and legally binding agreement adopted by the European Union and its member states on climate change (COP21, 2015). Although the objective of this work was not to present the agreements dealt with at COP21, its importance should be noted, as it was ratified by the 55 countries that represented at least 55% of world emissions and is considered the first major Summit on environmental protection.

Paris Climate Conference (COP21) seems to have had an important impact, not only at the institutional level, but also in the research community, since the number of authors who delved into this line of research increased considerably throughout the period, especially in the 2017–2020 quadrennium. For example, during the 2005–2008 period, 162 researchers published on the concept, instruments, and methodologies of the Circular

TABLE 1 | Characteristics of the scientific literature on Circular Economy.

Year	Articles	Authors	Countries	Citations	TC/A	Journals
2005–2008	69	162	10	0	0.00	39
2009–2012	117	294	17	159	1.36	62
2013–2016	385	1,080	47	1,309	3.40	189
2017–2020	4,436	13,469	135	28,009	8.02	1,028

(TC/A): average number of citations per article.

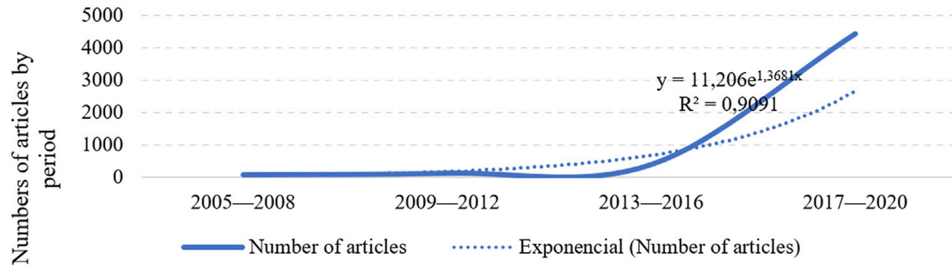

FIGURE 2 | Evolution of the number of articles published on Circular Economy.

Economy, and in the quadrennium 2017–2020, 13,469 did so, which represents an increase of 8,314%. It is especially relevant that the number of authors in this last quadrennium represent 90% of all authors. This clearly shows the increasing interest from the scientific community in the development of the Circular Economy as a new paradigm that provides valid solutions to the issues addressed at COP21. Obviously, this growth in the number of authors, which was comparatively greater than the number of articles published, led to an increase in the average number of authors per research article, which went from 2.3 in 2005–2008 to 3 in 2017–2020.

Moreover, the international magnitude of the development of the Circular Economy is clearly observed in the number of countries participating in the research field. For example, in 2005–2008, only 10 countries paid attention to the development of the research line, and in the 2017–2020 quadrennium, a total of 135 did so, which represents an increase of 1,250%.

Regarding the number of citations, the growth was also exponential. In the first period analyzed (2005–2008), no citations were made to other Circular Economy articles in the 69 articles published; however, in the other analyzed periods, a total of 29,477 citations were obtained, of which the last analyzed period (2017–2020) accounted for 28,009, representing 95% of the total citations in the research area. Thus, the average number of citations per article reached 6.31. Together, these two indicators show the degree of interest and development in the Circular Economy in the research community.

Finally, in the 2005–2008 period, 39 journals published research articles on the Circular Economy; in 2017–2020, 1,028 did so, with a total of 1,318 journals interested in this line of investigation. As with all of the indicators discussed above, there was a very significant increase here, further demonstrating the strength of the current trend in this line of research.

Distribution of Publications by Subject Area (Q2)

This section shows the results of the main subject areas in which research articles on the Circular Economy were published.

For the 2005–2020 period, 27 thematic areas of knowledge related to scientific literature on the Circular Economy were identified in the Scopus database, focusing on articles that could be classified into more than one thematic area (Meseguer-Sánchez et al., 2020). **Figure 3** shows the five subject areas with the highest volume of published research articles.

It is observed how Environmental Science is the thematic area with the highest volume of research articles during the entire 2005–2020 period, with a total of 2,979, which represents 26.33% of the total scientific literature. In volume, this is followed by Energy (n = 1,513, 13.37%), Engineering (n = 1,409, 12.45%), Social Sciences (n = 1,048, 9.26%), and Business, Management, and Accounting (n = 980, 8.66%). The other thematic areas individually represent less than 5%. This diversity of thematic areas shows the transversal nature of the Circular Economy as a paradigm that not only encompasses environmental needs, but also social and economic ones.

Journals and Authors Productivity (Q3 and Q4)

This section shows the results related to the productivity of authors and their main characteristics, such as international cooperation networks, and the most productive journals in this line of research.

Table 2 lists the 20 most productive journals on the Circular Economy, and their main characteristics in the 2005–2020 period. Firstly, it is clear to see that 45% are positioned in the first quartile (Q1), while the remaining 40% are in the second quartile (Q2).

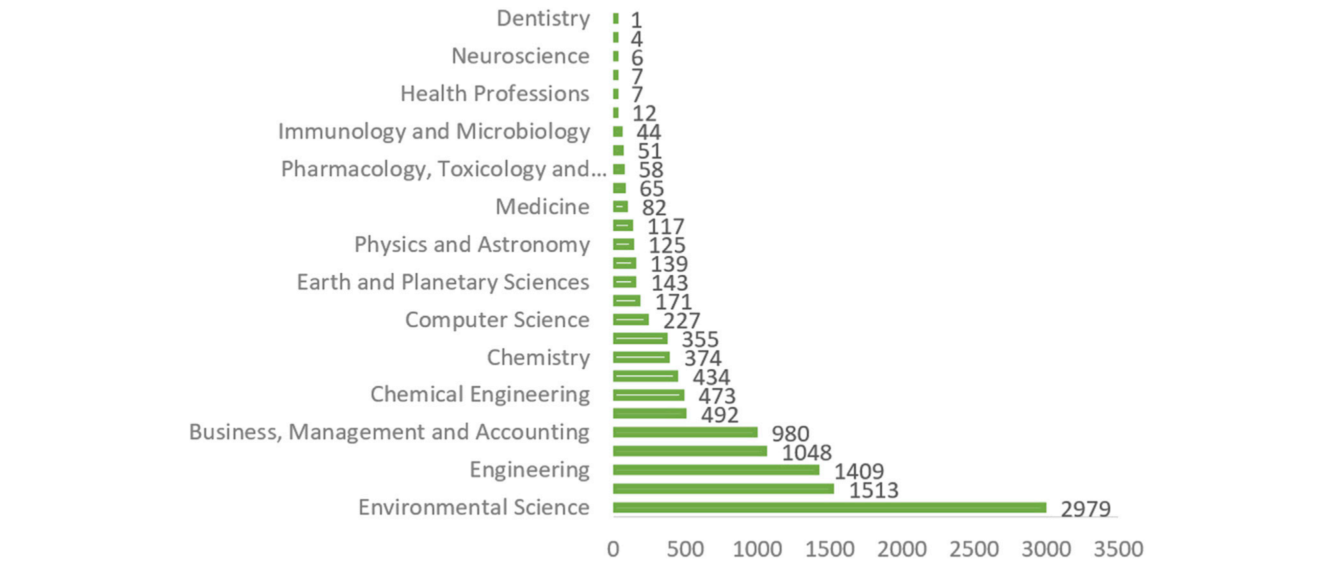

FIGURE 3 | Evolution of the number of articles published on the Circular Economy according to subject area.

This indicates that this line of research, despite being relatively immature, is having a very high impact on the international scientific community.

These journals received 2,124 research articles, representing 42% of all articles published on the Circular Economy. The analysis of the origin of the journals shows that 80% were European, while the remaining 20% were of American origin.

The Journal Of Cleaner Production was the journal with the highest volume of articles, with a total of 559 research articles published in the 2005–2020 period, followed by Sustainability Switzerland (422) and Resources Conservation And Recycling (249). The Journal Of Cleaner Production was the first journal to publish research articles on the Circular Economy, with the first publication in 2006, followed by Resources Conservation And Recycling and Journal Of Industrial Ecology, both with their first publications in 2017. These were the only three journals that published research articles on the Circular Economy throughout the entire period analyzed (2005–2020). Moreover, Applied Sciences Switzerland, Detritus, and the International Journal Of Production Research were the latest to publish in this line of research.

The Journal Of Cleaner Production was also the journal with the highest total number of citations, with 13,932 throughout the period, followed by Resources Conservation And Recycling, with 5,551. However, the publication of a significantly lower volume of articles by the Journal Of Industrial Ecology (80), with a high total number of citations (3,266), makes it the journal with the highest average number of citations per article, with 40; i.e., 83 citations were received for each published article. This was followed by the Journal Of Cleaner Production, with 24.92.

The H index of the articles (the number of articles that have at least the same number of citations as that many articles the journal has published in that line of research) shows that, again, the Journal Of Cleaner Production and Sustainability Switzerland demonstrated the best results (144 and 119, respectively). However, the journal's H index was higher in Science Of The Total Environment (224). As for the Scimago Journal Rank (SJR), the journal with the greatest influence was Resources Conservation And Recycling (2,215; Q1), followed by the Journal Of Cleaner Production (1886; Q1).

Table 3 shows the 10 most productive authors in terms of Circular Economy publications in the 2005–2020 period and their main characteristics. Firstly, it is clear to see that 60% of the authors were European, followed by 20% who were American and 20% who were Asian.

Geng, Y., from Tongji University, China, was the most productive author, with a total of 25 research articles on the Circular Economy published in the 2005–2020 period, followed by Lundström, from Aalto University, Finland, with 20 published articles, who also had the highest H index in the field.

Moreover, Sarkis, J. was the earliest author, first publishing in 2008, followed by Geng, Y. in 2009: these are the only two authors, among the most productive, who began to develop the concept of the Circular Economy in the first decade of the 20th century. For this reason, they are the authors with the highest total numbers of citations and the highest average numbers of citations: Geng, Y. had 2,128 citations, with an average of 85.12 citations per article, which is more than Sarkis, J. with 774 citations and a 59.54 average number of citations per article. However, Geng, Y. did not publish in 2020, and so is the only author from the most productive list to interrupt their scientific literature on the Circular Economy this year.

Figure 4 shows the international cooperation networks between the main authors on the Circular Economy based on

TABLE 2 | Ranking of the 20 most productive journals on the Circular Economy.

Journal	A	TC	TC/a	H index articles	H index journal	SJR	C	First article	Last article	A			
										2005–2008	2009–2012	2013–2016	2017–2020
Journal of cleaner production	559	13,932	24.92	144	173	1,886 (Q1)	Netherlands	2006	2020	2	6	53	498
Sustainability Switzerland	422	3,456	8.19	119	68	0.581 (Q2)	Switzerland	2013	2020	0	0	20	402
Resources conservation and recycling	249	5,551	22.29	74	119	2,215 (Q1)	Netherlands	2007	2020	2	3	15	229
Waste management	125	1751	14.01	39	145	1,634 (Q1)	United Kingdom	2009	2020	0	1	11	113
Science of the total environment	97	1,057	10.90	37	224	1,661 (Q1)	Netherlands	2015	2020	0	0	3	94
Journal of industrial ecology	80	3,266	40.83	21	95	1,808 (Q1)	United States	2007	2020	1	7	4	68
ACS sustainable chemistry and engineering	56	311	5.55	2.3	85	1,766 (Q1)	United States	2016	2020	0	0	2	54
Energies	55	355	6.45	17	78	0.635 (Q2)	Switzerland	2015	2020	0	0	2	53
Environmental science and pollution research	53	338	6.38	14	98	0.788 (Q2)	Germany	2015	2020	0	0	3	50
Journal of environmental management	53	951	17.94	14	161	1,321 (Q1)	United States	2010	2020	0	1	2	50
Procedia environmental science engineering and management	49	66	1.35	10	5	0.164 (Q3)	Romania	2014	2019	0	0	4	45
Business strategy and the environment	43	745	17.33	11	94	1,828 (Q1)	United States	2017	2020	0	0	0	43
Waste and biomass valorization	42	241	5.74	14	35	0.569 (Q2)	Netherlands	2015	2020	0	0	3	39
Resources	41	438	10.68	14	24	0.722 (Q2)	Switzerland	2014	2020	0	0	6	35
Applied sciences Switzerland	40	114	2.85	8	35	0.418 (Q2)	Switzerland	2018	2020	0	0	0	40
Materials	39	207	5.31	12	98	0.647 (Q2)	Switzerland	2016	2020	0	0	1	38
Chemical engineering transactions	31	92	2.97	14	32	0.316 (Q3)	Italy	2015	2020	0	0	3	28
Detritus	30	43	1.43	10	-	-	Italy	2018	2020	0	0	0	30
International journal of production research	30	490	16.33	6	125	1,176 (Q1)	United Kingdom	2018	2020	0	0	0	30
Waste management and research	30	148	4.93	10	73	0.650 (Q2)	United Kingdom	2015	2020	0	0	6	24

(J): journals (A): number of articles; (TC): number of citations (TC/A): an average number of citations per article; (SJR); Scimago Journal Rank (quartile); (C): country.

TABLE 3 | Ranking of the 10 most productive authors in terms of Circular Economy publications.

Author	A	TC	TC/a	Institution	C	1st A	Last A	H index
Geng, Y.	25	2,128	85.12	Tongji university	China	2009	2019	7
Lundström, M.	20	205	10.25	Aalto university	Finland	2017	2020	8
Hou, H.	15	46	3.07	Kunming university of science and technology	China	2017	2020	3
Torretta, V.	14	110	7.86	Università degli studi dell'Insubria	Italy	2018	2020	4
Liu, X.	13	3.4	2.62	Kunming university of science and technology	China	2018	2020	3
Sarkis, J.	13	774	59.54	Worcester polytechnic institute	United States	2008	2020	3
Smol, M.	13	148	11.38	Mineral and energy economy research institute of the polish academy of sciences	Poland	2016	2020	3
Azapagic, A.	12	271	22.58	The university of manchester	United Kingdom	2017	2020	4
Bocken, N.	12	425	35.42	The international institute for industrial environmental economics	Sweden	2017	2020	5
Dewulf, J.	12	292	24.33	ETH zürich	Switzerland	2017	2020	2

(A): number of articles; (TC) number of citations; (C): country; (TC/A): an average number of citations per article; (First A): first article published; (Last A): last article publicated; (H-index): Hirsch index in this research area.

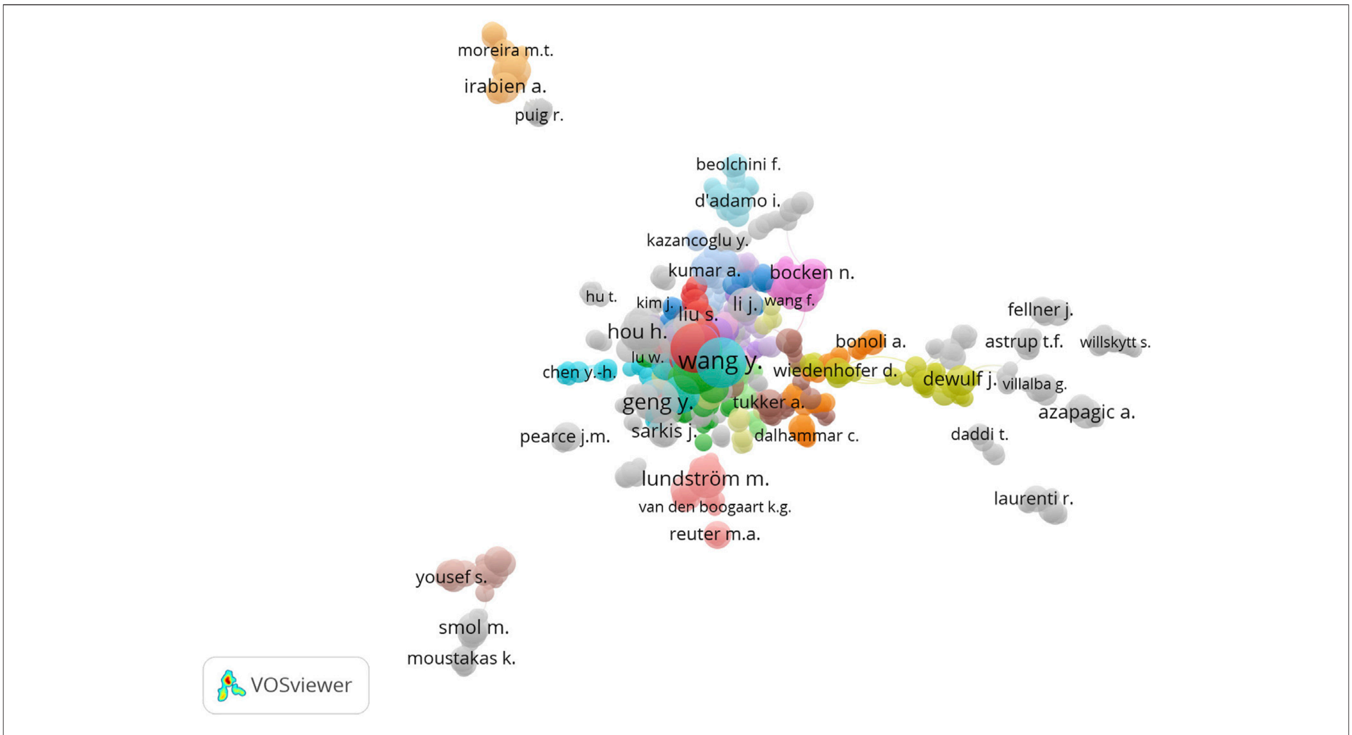

FIGURE 4 | Authors' international cooperation networks based on co-authorship.

the analysis of co-authorship. The analysis of cooperation networks allows us to understand the relationships between researchers and the dissemination of knowledge (Chen, 2006). Collaborations can contribute to the exchange of ideas that generate new research, with synergies increasing opportunities for publication in quality journals (Acedo et al., 2006). The colors show the working groups, and the sizes of the circles shows the volumes of the scientific literature developed.

Selecting an interaction of at least three co-authored published research papers, a total of 36 clusters were obtained, representing 709 authors. Thus, with the exception of Torretta, V. from Italy, all the authors within the 10 most productive belonged to different international cooperation clusters. This shows, on the one hand, that there is strong international cooperation in scientific literature on the Circular Economy and, on the other, that these international cooperation networks have very strong and productive ties.

Productivity of Institutions and Countries (Q3 and Q4)

Here, we show the results of the main characteristics of the most productive institutions and countries in terms of the Circular Economy production, their cooperation rates, and their international cooperation networks over the 2005–2020 period.

Table 4 shows the 10 most productive institutions in the field of the Circular Economy, in which 80% were European and the remaining 20% were Asian.

TABLE 4 | Ranking of the 10 most productive institutions in the field of Circular Economy.

Institution	C	A	TC	TC/a	H index	CI (%)	TC/a	
							IC	NIC
Delft university of technology	Netherlands	112	3,368	30.07	26	36.6	38.93	24.96
Aalto university	Finland	73	853	11.68	29	42.5	11.10	12.12
Chinese academy of sciences	China	68	2,282	33.56	16	51.5	53.29	12.64
Consiglio nazionale delle ricerche	Italy	59	289	4.90	2.3	40.7	6.08	4.09
Lunds universitet	Sweden	57	1,236	21.68	21	63.2	22.22	20.76
Tsinghua university	China	54	1,008	18.67	17	27.8	26.60	15.62
Danmarks tekniske universitet	Denmark	52	811	15.60	19	50.0	10.92	20.27
Politecnico di Milano	Italy	51	870	17.06	18	41.2	20.90	14.37
CNRS center national de la recherche scientifique	France	49	313	6.39	15	59.2	7.52	4.75
Alma mater studiorum university of bologna	Italy	49	1,667	34.02	6	44.9	69.73	4.93

(C): country (A): number of articles; (TC) number of citations (TC/A): an average number of citations per article; (H-index): Hirsch index in this research area (CI%): percentage of articles produced with international collaboration; (IC): number of citations per article made with international collaboration; (NIC): number of citations per article made without international collaboration.

TABLE 5 | Ranking of the 10 most productive countries in terms of Circular Economy publications.

Country	A	TC	TC/a	H index	A			
					2005–2008	2009–2012	2013–2016	2017–2020
Italy	721	7,983	11.07	171	0	3	39	679
China	683	10,182	14.91	135	59	101	121	402
United Kingdom	582	11,680	20.07	127	4	1	46	531
Spain	556	4,727	8.50	156	0	0	20	536
United States	321	5,487	17.09	68	3	7	19	292
Germany	314	4,135	13.17	76	0	1	33	280
Netherlands	311	6,936	22.30	73	0	1	33	277
Sweden	249	5,772	23.18	52	1	1	28	219
France	225	2,622	11.65	65	0	1	18	206
Finland	208	3,317	15.95	54	0	1	12	195

(A): number of articles; (R): position rank by number of articles in the 4-year period; (TC): number of citations; (TC/A): number of citations per article; (H-index): Hirsch index on the research topic.

Delft University of Technology was the most productive institution, with a total of 112 research articles on Circular Economy published, followed by Aalto University and Chinese Academy of Sciences, with 73 and 68 articles published, respectively. Regarding the total number of citations received, Delft University of Technology had the highest volume, with a total of 3,368, followed by the Chinese Academy of Sciences with 2,282, the latter also having the second highest average number of citations per published article, with 33.56, behind the Alma Mater Studiorum Università di Bologna, with an average of 34.02.

Despite the fact that Aalto University and Delft University of Technology were the two institutions from the most productive list with a higher H index in the research area (with 29 and 26, respectively), they were among the institutions that presented the worst results in the index international cooperation (with 42.5 and 36.6%, respectively).

In this sense, Lunds Universitet was the institution with the highest rate of international cooperation (with 63.2% of published articles), followed by CNRS Center National de la Recherche Scientifique, with 59.2% of articles published on the Circular Economy. Together with the Chinese Academy of Sciences and Danmarks Tekniske Universitet, they were the four institutions that published most articles with international co-authorship as opposed to domestic authors.

However, despite these data, 80% of the most productive institutions received a higher average number of citations per article when their articles were published with international co-authors. Alma Mater Studiorum Università di Bologna had the highest average number of citations in terms of international cooperation, with 69.73 citations for each published article. It is noteworthy that Alma Mater Studiorum Università di Bologna only received an average of 4.93 citations for articles published with only domestic authors. On the contrary, Danmarks Tekniske Universitet, which published 50% of its articles with international cooperation, received half the average number of citations as compared to articles in which only local authors contributed.

Table 5 shows the main characteristics of the countries that contributed to the development of the Circular Economy concept in the 2005–2020 period.

Italy had the highest volume of research articles on the Circular Economy published, with a total of 721, followed by China, with 683. Moreover, they were the two countries with the highest H index in this line of research (with 171 and 135, respectively). However, the United Kingdom was the country

TABLE 6 | International cooperation networks of the 10 most productive countries in terms of Circular Economy publications.

Country	NC	Main collaborators	CI (%)	TC/a	
				IC	NIC
Italy	59	Spain, United Kingdom, Netherlands, Germany, Sweden	37.2	16.35	7.95
China	57	United States, United Kingdom, Netherlands, Italy, Australia	34.0	27.55	8.41
United Kingdom	67	China, United States, Italy, Netherlands, Spain	52.9	21.31	18.68
Spain	47	Italy, United Kingdom, Portugal, United States, Germany	39.4	10.90	6.94
United States	54	China, United Kingdom, France, Finland, Germany	62.0	18.93	14.10
Germany	60	Italy, United Kingdom, Netherlands, Finland, United States	52.2	17.83	8.07
Netherlands	47	United Kingdom, Italy, China, Germany, Belgium	56.9	27.27	15.75
Sweden	45	Italy, Finland, United Kingdom, Netherlands, United States	54.6	26.92	18.68
France	61	United Kingdom, United States, Italy, Netherlands, Canada	62.2	13.99	7.81
Finland	37	Sweden, United States, Germany, Netherlands, China	48.6	22.67	9.60

(NC): number of collaborative countries; (CI): percentage of countries in collaborative papers; (TC/A): number of citations per article; (IC): international cooperation; (NIC): no international cooperation.

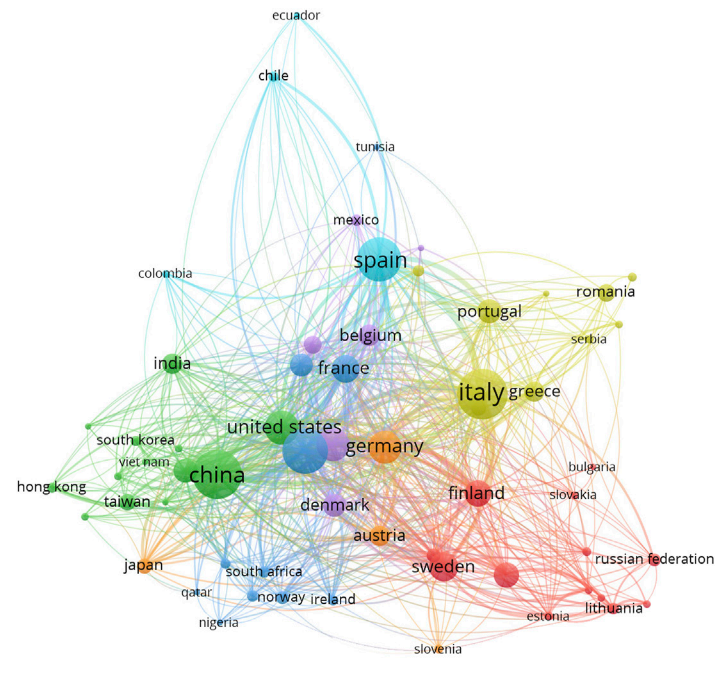

FIGURE 5 | Network of cooperation between countries based on the co-authorship of articles published on the Circular Economy.

with the highest number of total citations, with 11,680 for its 582 published articles; while China had a total of 10,182 citations. Despite this, Sweden and the Netherlands received the highest average number of citations per article, with 23.18 and 22.30 for each published article, respectively.

Finally, it should be noted that China, the United Kingdom, the United States, and Sweden were the only countries that published articles on the Circular Economy throughout the 16 years analyzed. In fact, if it were not for the strong growth in publications in the final 4 years in Italy, China would have been the most productive country, since it was in first position in all the periods analyzed, except for the final one.

Table 6 shows the results of the analysis of the international cooperation networks of the most productive countries. We see that United Kingdom had the highest number of international collaborators, with a total of 67, followed by France and Germany, with 61 and 60, respectively.

France and the United States were the countries with the highest rates of cooperation, with 62.2 and 62% of their articles published with international co-authors, respectively. Only Italy, China, Spain, and Finland published more articles with domestic authors as opposed to international co-authors. However, all countries received a higher average number of citations per published article when they published through international cooperation networks, with China, Sweden, and the

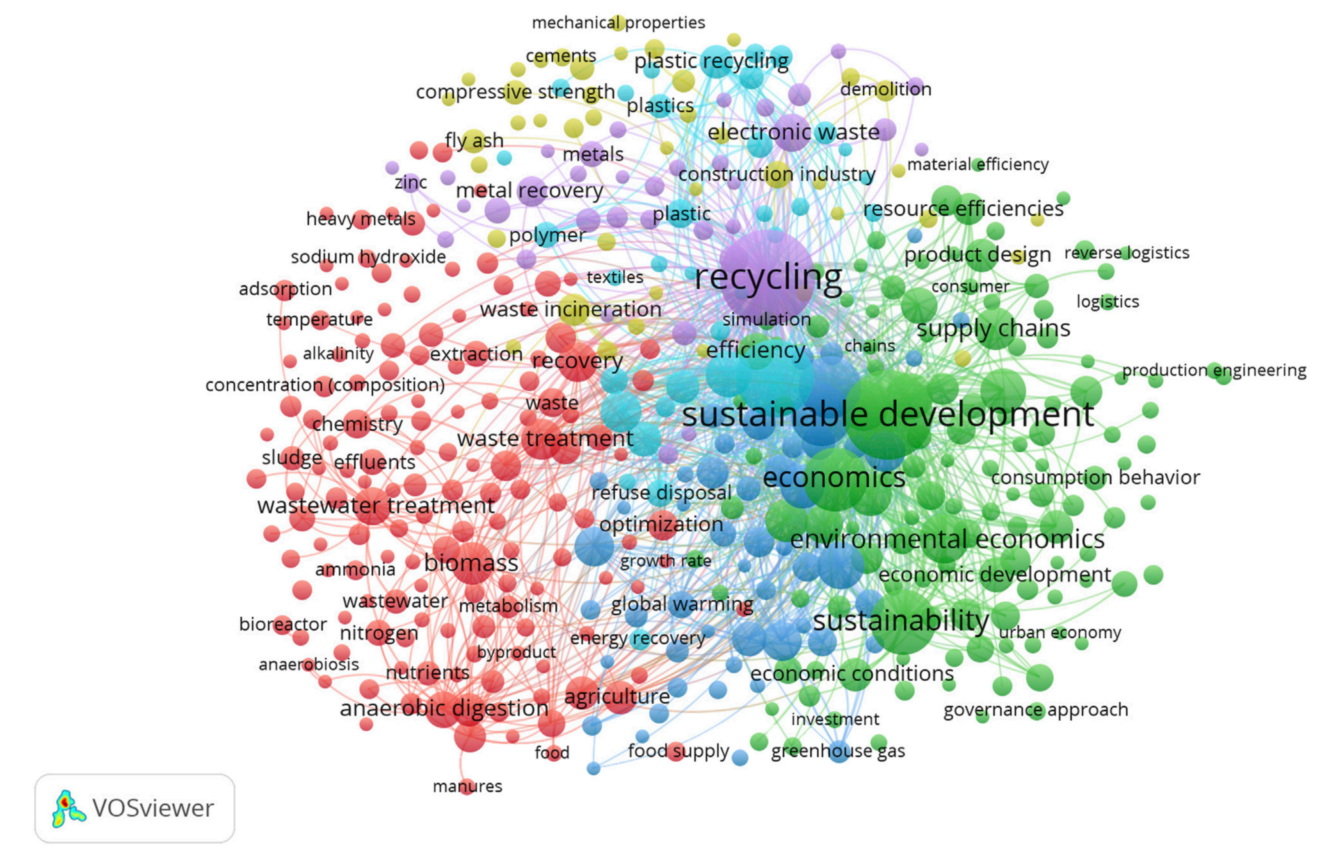

FIGURE 6 | Keywords in Circular Economy publications based on co-occurrence.

Netherlands demonstrating the highest average numbers of citations in the publication of articles through international cooperation (with 27, 55, 27.27, and 26.92, respectively).

Finally, **Figure 5** shows the collaboration map between the main countries based on the co-authorship of published research articles on the Circular Economy. The colors show the networks and the size of the circles indicates the productivity of the networks. Given the high number of articles published in this field, it was established that there was an interaction of at least 10 studies that were published with international co-authorship.

The results show an international cooperation network made up of 61 countries, grouped into seven international cooperation networks. The first cluster, red in color, brings together the largest number of countries, with a total of 13, led by Sweden and Finland. With the exception of Egypt, all its members are European.

The green international cooperation network is also made up of 13 countries, led by China and the United States, and is mainly made up of countries in Asia. On the other hand, the dark blue cluster, formed by 11 countries, and led by the United Kingdom, has a greater continental diversity, with African, European, American, and Asian countries.

Italy leads the yellow cluster, which forms an international network of 10 countries, which, excepting *Argentina*, are all European. The purple cluster, led by Netherlands, made up of six European, American, and African countries, is of a very similar composition to the dark blue cluster.

Finally, the light blue cluster, led by Spain and made up of only four countries, shows a strong cultural link, as it is mainly made up of South American countries. The orange cluster shows the same trend, also being made up of four countries led by Germany, and demonstrating a strong relationship with the Asian continent through the presence of Japan.

KEYWORD ANALYSIS

This section provides the results of the analysis of keywords used by the authors with a relevant link to this field, the network map of these keywords based on co-occurrence, and their evolution during the period of time analyzed (2005–2020). The premise is that keywords are representative of the content of the article (Comerio and Strozzi, 2019). The co-occurrence of keywords helps to create an understanding of a research field (Ding et al., 2001). From a total of 5,007 research articles, 170,048 keywords were obtained.

On the basis of the co-occurrence method, **Figure 6** shows the main keywords used over the 16 year period, selecting those with at least 20 interactions. The analysis of the co-occurrence of these keywords is a very effective method to

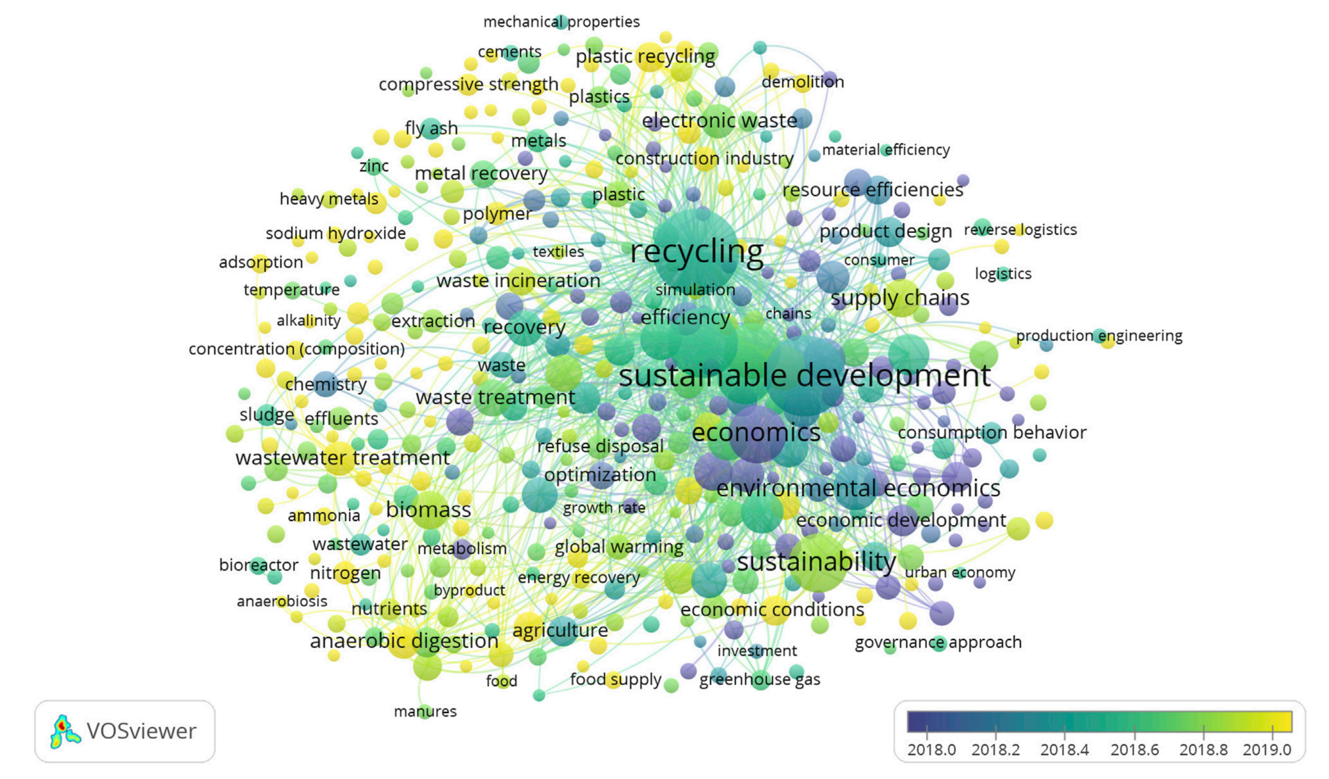

FIGURE 7 | Evolution of keywords in Circular Economy publications based on co-occurrence.

explore the main research topics and new research trends (Fang et al., 2018). In this way, Voswiever extracts the keywords from the documents, calculates the frequency, and finally acquires the matrix of keywords (Park and Nagy, 2018).

Excluding the concept of the Circular Economy to avoid erroneous conclusions, 438 keywords were obtained that were grouped around six clusters. The color of the circles shows the keyword groupings, and the size refers to the number of times it was used.

The first cluster, in red, which brings together the greatest number of keywords (147), refers to recuperative technologies, the main objective of which is to reduce the use of energy in the production process through reuse, thus reducing the amount of gases emitted. Numerous studies address the development of recuperative technology in mineral resources, such as natural gas (Nikpey et al., 2014; Abdul-Qyyum et al., 2018), biogas (Cobbledick et al., 2016; Yang et al., 2017), coal (Kuchonthara et al., 2005), and oil (Kansha et al., 2012), among others.

On the other hand, the second cluster, in green, is made up of 127 keywords and defines the Circular Economy as a transversal paradigm that provides solutions aimed at sustainable development in all its dimensions, such as the social and the social economy. In this way, the Triple Bottom concept argues that companies adopting environmentally responsible behavior will also obtain significant economic and social benefits (Alhaddi, 2015; Gimenez et al., 2012; McWilliams et al., 2016, among others). This has given rise to new businesses that favor the labor inclusion of vulnerable groups (Martínez-Medina et al., 2021).

The third cluster, in dark blue, is composed of 52 keywords and focuses on the paradigm shift to the Circular Economy, i.e., transitioning from the linear economy model to a waste management system in response to the need for urban spaces to effectively and efficiently manage local waste (Sharholy et al., 2008; Guerrero et al., 2013).

The yellow cluster is composed of 42 keywords focused on industry 4.0 and materials, and the main objective of integrating information and communication technologies (ICT) into manufacturing systems to promote industrial business performance. It is considered that industry 4.0 could represent a new industrial era (Lasi et al., 2014; Parlanti, 2017; Reischauer, 2018).

The purple cluster, composed of 36 keywords on critical raw materials, refers to understanding that mineral resources, whose reserves are limited and distribution is uneven, are extremely necessary for the development of certain functions in technology and production (Hofmann et al., 2018), thus establishing important economic, social, environmental, and political challenges.

Finally, the light blue cluster is made up of 34 by-products and waste items, and its main objective is the development of techniques for waste management, recovery, reprocessing, and commercialization, thus reducing environmental impact by increasing the shelf life of original products.

Figure 7 shows the degree of maturity of the Circular Economy keywords.

The legend in the figure shows a time horizon of 2 years, which demonstrates that practically all keywords recently acquired importance, indicating a strong degree of evolution in the Circular Economy field. The development of recuperative technologies, the management of the supply chain, and the economic aspects derived from the Circular Economy and industry 4.0 are particularly relevant today for the research community.

CONCLUSION AND DISCUSSIONS

This study aimed to analyze the degree of development of the concept of the Circular Economy from a scientific or theoretical perspective in the 2005–2020 period, using a bibliometric analysis (or the scientometry methodology) of 5,007 research articles located in the Scopus database. Although for some authors the scientific basis of the Circular Economy dates from the 18th and 19th centuries (Desrochers, 2002; Desrochers, 2004), the first research article available in Scopus that includes the term "Circular Economy" in the title of the article, abstract, or keywords is from 2004 (Dajian, 2004; Lei, and Yi, 2004; Strebel and Posch, 2004; Xu et al., 2004).

From reading the most relevant research articles in CE and analyzing the co-occurrence of the keywords, we extract a theoretical understanding and the proposed lines of research in this trend of research.

The theoretical concept of circular economy is derived from the combination of ideas from previous currents of thought whose main objective was to reduce the consumption of natural capital, cleaner production, or reuse of inputs (e.g., industrial ecology, cradle to cradle theory, performance economics, natural capitalism and in recent years new trends such as the concept of zero net emissions, among others). The original principles of the circular economy were reduction, reuse, and recycling (Feng and Yan, 2007; Lett, 2014). **Figure 6** shows a high number of keywords associated with these principles, highlighting that currently "recycling" appears in 20.9% of published research articles on the circular economy. This principle is very attractive from an environmental point of view, as it requires less use of natural resources, less energy and less labor (Castellani et al., 2015), while the principles of reuse and recycling aim to extend the life cycle of the product and reintroduce it into the production cycle at the end.

Internationally, the circular economy is considered an essential strategy for cleaner production (Bilitewski, 2012), as it introduces more environmentally friendly products and processes that reduce the flow of non-renewable and harmful inputs (Van Berkel et al., 1997; Van Berkel, 2007). The new research trends presented in **Figure 7** demonstrate that recuperative technologies, supply chain management, and Industry 4.0 will contribute to the development of environmental benefits in the coming years. Therefore, we propose the following research question for future research:

Q1. Is CE the paradigm that will help achieve net zero emissions by 2050?

With the theoretical development of the circular economy, its principles have been gradually expanded and currently, there are 10 (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) (Bag et al., 2021). This has led to a larger dimension that includes important economic and social implications.

Redistribution represents a rethinking of the economy by giving a greater role to use than to ownership. This undoubtedly allows for a strengthening of the social base and creates a "safer and more equitable space for society" (Raworth, 2017). Along with the redesign, companies can offer products and services with high social and environmental implications to their customers, generating shared value (Dyllick and Muff, 2015). Indeed, Belmonte-Ureña et al. (2021) find that the circular economy contributes to the fulfillment of Sustainable Development Goals with high social implications, such as SDGs 1, 2, 3, 4, 5, 8, and 10. However, in practical application, this requires governments to value the benefits in resource efficiency, greenhouse gas emissions reduction, economic growth, and job creation (Wijkman and Skånberg, 2015; Genovese et al., 2017).

One of the major global challenges of our time is the inclusion of vulnerable groups. In this way, we propose the following research question:

Q2. Is CE a new paradigm that creates opportunities for social and professional inclusion for vulnerable groups?

There are five main conclusions of the bibliometric review:

a) Since 2004 there has been a significant and exponential increase in the number of research papers on the Circular Economy, especially in the 2017–2020 period. This was a consequence of the celebration of COP21 in Paris in 2015, in which the governments of 24 countries and the European Commission released 4.6 billion dollars annually for research into clean energies (Gates, 2021) (Q1).
b) The analysis of the subject areas showed that Environmental Science is the subject area with the highest volume of research articles; however, the five main subject areas also include Energy, Engineering, Social Sciences, Business, Management, and Accounting, which indicates both the high degree of transversality in the field and its multidisciplinary nature (Q2).
c) The authors' analysis shows an 8.314% increase in publications in just 16 years, with the Chinese Geng, Y. being the most prolific author in the field with 25 published research articles. the Journal Of Cleaner Production and Sustainability Switzerland were the two most productive journals in the period of time analyzed, with 559 and 422 published research articles, respectively. Delft University of Technology and Aalto University were the most productive, with 112 and 73 research articles published. With regard to countries, Italy and China were the most productive, with 721 and 683 articles published (Q3). Althoug China is the first nation with specific Circular Economy legislation (Beaulieu, 2015), in all of the indicators analyzed, the clear predominance of Europe is observed, probably motivated by the fact that a significant number of the countries participating in the COP21 in Paris were European, which, together with the consideration that more developed countries have a greater degree of implementation of the Circular Economy (Singh

and Ordoñez, 2016; Kirkman and Voulvoulis, 2017), shows the European Union to be the engine driving the transition to a productive model based on circularity. This study aimed at providing an accurate image of the evolution of the concept of the Circular Economy, showing the references within the research line and the main trends today.

d) There is a strong international collaborative network in EC. On the one hand, 706 authors in this line of research are grouped in 36 clusters with at least 3 co-authorship publications. On the other hand, as many as 61 countries are grouped in 7 clusters with at least 10 collaborations in publications. The United Kingdom and France are the countries with the highest number of international collaborators (67 and 61 respectively, while Alma Mater Studiorum Università di Bologna and the Chinese Academy of Sciences had the highest rates of international collaborations.

e) The analysis of the keywords shows six main lines of research within the Circular Economy field, such as recuperative technologies, sustainability in a transversal orientation, waste management, industry 4.0, critical raw materials, and the treatment of by-products and waste. The temporal analysis shows how all the keywords are relatively recent, which is why new concepts, techniques, tools, and methodologies are emerging that are rapidly attracting the attention of the research community. The hottest lines of research at present are as follows: the development of recuperative technologies, the management of the supply chain, the economic aspects derived from the Circular Economy, and Industry 4.0. (Q5).

Finally, this work has certain research limitations that could form the basis of future research. For instance, the methodology used is quantitative in nature, and does not consider qualitative aspects of the question, but further research could use systematic literature reviews to delve deeper in the areas for aggregation of the knowledge here outlined. Finally, the use of other keywords, a different study period, research materials other than the articles considered or performance of the search in other databases could all influence the results obtained.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

VM-S and FJG-S: conceptualization and investigation. VM-S, FJG-S, VM-M, and GW-F-B: methodology and writing—original draft preparation. VM-S and FJG-S: software and data curation. VM-S, FJG-S, VM-M, and GW-F-B: validation. VM-S, FJG-S, and VM-M: formal analysis. VM-S and GW-F-B: resources. VM-S and FJG-S: writing—review and editing. VM-S, FJG-S, VM-M and GW-F-B: supervision and project administration. All authors have read and agreed to the published version of the manuscript.

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