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The Influence of the Circular Economy: Exploring the Knowledge Base

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Abstract: The objective of this study is to analyze the main factors influencing research on the concept of 'circular economy' (CE) by focusing on authors, institutions, and countries and emphasizing the documents that deal both with CE and SMEs. The Web of Science (WoS) includes 1711 documents related to CE, with the first publication dated 2006. The graphical analyses use the WoS Core Collection database and visualization of similarities (VOS) viewer software. We also employ several bibliometric techniques including co-citation and bibliographic coupling. The results of the analysis indicate that the field of CE research has broad readership and includes internationally authored papers although China seems to be the leader in this research area.

Keywords: bibliometrics; web of science; Vos viewer; circular economy; co-citation; bibliographic coupling

1. Introduction

Circular economy (CE) is receiving more and more attention worldwide as a way to overcome the current production and consumption (based on continuous growth) model. CE is intended to increase the use efficiency of resources, with special attention to urban and industrial waste, to achieve a better balance between the economy, environment, and society by promoting certain adoption production patterns within the economic system [1].

CE implementation worldwide is still in its early stages and is focused more on recycling than reuse. Some significant results have been achieved in areas such as waste management, for example. CE implies the adoption of cleaner production patterns at the firm level, increased responsibility and awareness among producers and consumers, use of renewable technologies and materials (wherever possible), and the adoption of appropriate policies and stable tools [1].

The number of publications on CE has been growing exponentially in recent years and identify the most productive and influential researchers in the field, the major journals publishing on CE, and the universities leading developments in this discipline. Bibliometrics is a popular analytical method and has contributed much to the state of the art of the research in this field. Bibliometrics is used for quantitative analyses in management [2], entrepreneurship [3], innovation [4], and psychology [5] among other fields. It is an appropriate method for in-depth analysis of single journals to obtain a broad picture of leading trends. Bibliometrics has been applied to several journals, including *Technovation* [6,7], *Journal of Knowledge Management* [8], and *Accounting Review* [9]. It has been used also for in-depth analyses of regions [10], countries [11], institutions, and authors [12] favored by a particular publication.

Bibliometrics is a research method which analyzes bibliographic material using quantitative and statistical methods [13,14]. It has been employed for quantitative analysis of the bibliographic material in a particular field. In this research, it is applied to work (articles, reviews, letters, notes) included in the WoS database. The main bibliometric indicators are the number of publications, the number of citations, and h-index [12].

Some common bibliometric methods include mapping techniques [15,16]. In the present study, we analyze authors, institutions, countries, and keywords related to CE research using WoS data and VOS viewer software [17,18].

The aim is to examine the main factors influencing CE research by focusing on authors, institutions, and countries. The WoS includes 1711 documents related to CE. The concept was proposed by Chinese academics in 1998 [19] and was adopted formally by the Chinese government in 2002. It was seen as reducing the contradiction between rapid economic growth and shortage of raw materials and energy [20]. The first publications in ISCI indexed journals were recorded in 2006.

The present article is structured as follows. Section 2 provides a brief review of the CE literature. Section 3 describes the methodology, Section 4 presents the results of the bibliometric analysis based on leading authors, institutions, and countries, and provides a graphical analysis highlighting co-citations and bibliographic couplings. The paper concludes in Section 5 with a discussion.

2. Literature Review

The origins of CE are mainly the economy and the environmental sector. The notion of CE emerged from different types of thinking. Environmental economists, Pearce and Turner [21], proposed the concept of a circular ecological system drawing on the work of the ecological economist Boulding [22]. According to some authors [23,24], CE emerged from the idea of an ecological industry and analysis of the operation of industrial systems (industrial metabolism) and optimization, and extended them to the entire economic system to propose a new model of economic development, production, distribution, and product recovery.

There is no finite definition of CE but at its core is the idea of production process loops which reduce inputs and reuse or recycle products and waste to increase the quality of life through greater resources efficiency. In practice, this includes the creation of optimized resources flow networks among companies, eco-industrial parks, and the regional infrastructure. CE is considered a new business model which is expected to lead to more sustainable and greater social development [25–28].

The complexity involved in the idea of sustainable development means that most of the time, its implementation needs to be supported by innovation designers that provide services to achieve appropriate radical change to policy and decision-making processes [29,30]. CE could become the solution to the need to reduce the environmental impact of current economic systems.

In China, CE is promoted as a top-down national policy, while in other areas and countries such as the European Union, Japan, and the United States it is considered a tool for designing environmental and waste management policies from the bottom up. The ultimate goal of CE is to ease the pressure on the environment from economic growth [1].

One example of a CE implementation is rechargeable batteries, which have led to the emergence of electric cars and renewable energy. To minimize the environmental impact associated with the new reusable products, we need to integrate sustainable materials into rechargeable batteries, choosing chemical products with minimum environmental impacts which are easily recyclable or are integrated within a complete CE cycle. require to significantly Increasing battery life requires the solution to sustainability and cost-related problems and continuous monitoring of battery status during operation to minimize their degradation [31].

CE requires greater implementation of green technologies, and broader and more complete design of alternative solutions throughout the life cycle of processes, combined with how these processes interact with their environment and the relevant economy. Regeneration involves not just material or energy recovery but also an improved economic model compared to the current economic model [29,30].

3. Method

Bibliometrics can be employed in various ways. Some bibliometric studies focus on author or university productivity based on the number of publications [32]. Bibliometrics can be used for citation analysis which is a useful way to evaluate research based on measuring the influence of sets of articles, by institutions or authors [33–35]. The h-index identifies the number of studies X which received Y or more citations [36–38]. Thus, the h-index is based on a combination of articles and citations: If a group of publications (by an author, institution, etc.) has an h-index of 10 this means that the articles included in this group of publications have received at least 10 citations [39]. This study focuses on academic research on the CE, which is an evolving field of study that is attracting increased interest from academia. The bibliometric analysis uses WoS data.

Table 1 presents publications and citations structure related to work on the CE between 2006 and 2018. We consider several citation thresholds based on the number of articles receiving a specific minimum number of citations: 200, 100, 50, 25, 10, 5 and 1.

Table 1. Annual citation structure.

Y	TP	TC	>200	>100	>50	>25	>10	>5	>/=1
2006	4	23	0	0	0	0	1	1	3
2007	15	741	1	2	6	7	7	9	12
2008	6	235	0	1	2	3	3	5	6
2009	13	526	1	1	4	5	9	9	11
2010	12	687	0	1	7	9	9	11	12
2011	18	796	0	2	7	9	15	16	16
2012	19	629	0	2	3	8	12	13	15
2013	23	600	0	1	4	6	12	16	22
2014	43	969	0	2	3	13	23	31	40
2015	87	1685	1	3	8	17	44	57	79
2016	218	2884	1	2	7	30	82	133	187
2017	444	3232	1	3	7	23	83	164	359
2018	809	1294	0	0	0	2	22	83	405

* Number of publication is >/=.

The first work on the CE was published in 2006 which makes it a modern concept. The first papers were published in *Chinese Geographical Science*, *Journal of Central South University of Technology and Journal of Cleaner Production* and discuss ecological and sustainable development. Since 2016, the number of papers has increased hugely from 87 in 2015 to 809 in 2018, while the number of citations has increased from less than a hundred in 2014 to 3232 in 2017. The seeming smaller number of citations in 2018 is because there has not been sufficient time for the most recent papers to be cited.

4. Results

This section presents the results of the study. We focus first on authors, followed by institutions and then countries.

Table 2 presents the 50 most frequently cited documents on CE and shows that five papers received more than 200 citations. The paper that has received the highest number of citations (340) is "China's growing CO(2) emissions—A race between increasing consumption and efficiency gains" which was published in 2007 in *Environmental Science & Technology* and was authored by Peters, Weber, Guan and Hubacek (2007) [40]. This research discusses the opportunities in the context of China's rapid development for the implementation of CE and other policies. Adopting a CE approach should help China to avoid the high levels of emissions typical of contemporary developed countries.

Table 2. The 50 most cited documents.

R	TC	Title	Author/s	Year	C/Y
1	340	China's growing CO(2) emissions—A race between increasing consumption and efficiency gains	Peters, G.; Weber, C.; Guan, D.; Hubacek, K.	2007	26.15
2	286	A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems	Ghisellini, P.; Cialani, C.; Ulgiati, S.	2016	71.5
3	263	Product services for a resource-efficient and circular economy—A review	Tukker, A.	2015	52.6
4	249	Recycling of waste printed circuit boards: A review of current technologies and treatment status in China	Huang, K.; Guo, J.; Xu, Z.	2009	22.64
5	217	Sustainability and in situ monitoring in battery development	Grey, C.; Tarascon, J.M.	2017	72.33
6	187	Current options for the valorization of food manufacturing waste: A review	Mirabella, N.; Castellani, V.; Sala, S.	2014	31.17
7	166	A review of the circular economy in China: Moving from rhetoric to implementation	Su, B.; Heshmati, A.; Geng, Y.; Yu, X.	2013	23.71
8	159	Developing country experience with eco-industrial parks: A case study of the Tianjin Economic-Technological Development Area in China	Shi, H.; Chertow, M.; Song, Y.	2010	15.9
9	155	The Circular Economy A new sustainability paradigm?	Geissdoerfer, M.; Savaget, P.; Bocken, N.; Hultink, E.	2017	51.67
10	153	Towards circular economy implementation: A comprehensive review in context of manufacturing industry	Lieder, M.; Rashid, A.	2016	38.25
11	151	Towards a national circular economy indicator system in China: An evaluation and critical analysis	Geng, Y.; Fu, J.; Sarkis, J.; Xue, B.	2012	18.88
12	137	Organizing Self-Organizing Systems	Chertow, M.; Ehrenfeld, J.	2012	17.13
13	136	Recycling of WEEEs: An economic assessment of present and future e-waste streams	Cucchiella, F.; D'Adamo, I.; Koh, L.; Rosa, P.	2015	27.2
14	135	Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'	Geng, Y.; Doberstein, B.	2008	11.25
15	120	The E factor 25 years on: The rise of green chemistry and sustainability	Sheldon, R.	2017	40
16	112	Progress Toward a Circular Economy in China The Drivers (and Inhibitors) of Eco-industrial Initiative	Mathews, J.; Tan, H.	2011	12.44
17	109	An introductory note on the environmental economics of the circular economy	Andersen, M.	2007	8.38
18	108	How Circular is the Global Economy? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005	Haas, W.; Krausmann, F.; Wiedenhofer, D.; Heinz, M.	2015	21.6
19	108	Products that go round: Exploring product life extension through design	Bakker, C.; Wang, F.; Huisman, J.; Den Hollander, M.	2014	18
20	103	The dynamics of industrial symbiosis: A proposal for a conceptual framework based upon a comprehensive literature review	Boons, F.; Spekkink, W.; Mouzakitis, Y.	2011	11.44

Table 2. *Cont.*

R	TC	Title	Author/s	Year	C/Y
21	98	Implementing China's circular economy concept at the regional level: A review of progress in Dalian, China	Geng, Y.; Zhu, Q.; Doberstein, B.; Fujita, T.	2009	8.91
22	96	Enhanced Landfill Mining in view of multiple resource recovery: A critical review	Jones, P.; Geysen, D.; Tielemans, Y.; Van Passel, S.; Pontikes, Y.; Blanpain, B.; Quaghebeur, M.; Hoekstra, N.	2013	13.71
23	94	Product design and business model strategies for a circular economy	Bocken, N.; De Pauw, I.; Bakker, C.; Van der Grinten, B.	2016	23.5
24	93	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	Mohan, S.; Nikhil, G.N.; Chiranjeevi, P.; Reddy, C.; Rohit, M.V.; Kumar, A.; Sarkar, O.	2016	23.25
25	91	The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context	Murray, A.; Skene, K.; Haynes, K.	2017	30.33
26	88	Creating integrated business and environmental value within the context of China's circular economy and ecological modernization	Park, J.; Sarkis, J.; Wu, Z.	2010	8.8
27	87	Development pattern and enhancing system of automotive components remanufacturing industry in China	Zhang, T.; Chu, J.; Wang, X.; Liu, X.; Cui, P.	2011	9.67
28	83	Evaluating green supply chain management among Chinese manufacturers from the ecological modernization perspective	Zhu, Q.; Geng, Y.; Sarkis, J.; Lai, K.	2011	9.22
29	83	Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications	Zhu, Q.; Geng, Y.; Lai, K.	2010	8.3
30	82	Recovery and recycling of lithium: A review	Swain, B.	2017	27.33
31	82	Eco-industrial parks: National pilot practices in China	Zhang, L.; Yuan, Z.; Bi, J.; Zhang, B.; Liu, B.	2010	8.2
32	81	Conceptualizing the circular economy: An analysis of 114 definitions	Kirchherr, J.; Reike, D.; Hekkert, M.	2017	27
33	80	Ecological utilization of leather tannery waste with circular economy model	Hu, J.; Xiao, Z.; Zhou, R.; Deng, W.; Wang, M.; Ma, S.	2011	8.89
34	74	Designing the Business Models for Circular Economy-Towards the Conceptual Framework	Lewandowski, M.	2016	18.5
35	74	Moving Toward the Circular Economy: The Role of Stocks in the Chinese Steel Cycle	Pauliuk, S.; Wang, T.; Muller, D.	2012	9.25
36	74	Emergy analysis of an industrial park: The case of Dalian, China	Geng, Y.; Zhang, P.; Ulgiati, S.; Sarkis, J.	2010	7.4
37	71	Contributing to local policy making on GHG emission reduction through inventorying and attribution: A case study of Shenyang, China	Xi, F.; Geng, Y.; Chen, X.; Zhang, Y.; Wang, X.; Xue, B.; Dong, H.; Liu, Z.; Ren, W.; Fujita, T.; Zhu, Q.	2011	7.89
38	71	Resource consumption of new urban construction in China	Fernandez, J.	2007	5.46
39	69	Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications	Genovese, A.; Acquaye, A.; Figueroa, A.; Koh, L.	2017	23
40	66	Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models	Witjes, S.; Lozano, R.	2016	16.5

Table 2. *Cont.*

R	TC	Title	Author/s	Year	C/Y
41	66	The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy	Smol, M.; Kulczycka, J.; Henclik, A.; Gorazda, K.; Wzorek, Z.	2015	13.2
42	66	Bio-derived materials as a green route for precious & critical metal recovery and re-use	Dodson, J.; Parker, H.; Garcia, A.; Hicken, A.; Asemave, K.; Farmer, T.; He, H.; Clark, J.; Hunt, A.	2015	13.2
43	63	Interrogating the circular economy: The moral economy of resource recovery in the EU	Gregson, N.; Crang, M.; Fuller, S.; Holmes, H.	2015	12.6
44	63	Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan	Dong, L.; Zhang, H.; Fujita, T.; Ohnishi, S.; Li, H.; Fujii, M.; Dong, H.	2013	9
45	62	Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: A review	Pan, S.; Du, M.; Huang, I.; Liu, I.; Chang, E.; Chiang, P.	2015	12.4
46	62	Effectiveness of the policy of circular economy in China: A DEA-based analysis for the period of 11th five-year-plan	Wu, H.; Shi, Y.; Xia, Q.; Zhu, W.	2014	10.33
47	62	Fatty acids production from hydrogen and carbon dioxide by mixed culture in the membrane biofilm reactor	Zhang, F.; Ding, J.; Zhang, Y.; Chen, M.; Ding, Z.; Van Loosdrecht, M.; Zeng, R.	2013	8.86
48	59	Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research	Sauve, S.; Bernard, S.; Sloan, P.	2016	14.75
49	59	Energy conservation and circular economy in China's process industries	Li, H.; Bao, W.; Xiu, C.; Zhang, Y.; Xu, H.	2010	5.9
50	58	Putting a circular economy into practice in China	Feng, Z.; Yan, N.	2007	4.46

The second most cited paper is "A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems", authored by Ghisellini et al. and published in 2016 [1] in the *Journal of Cleaner Production*. It has received 286 citations. This paper provides a review of the literature on CE up to 2016. The authors consider that the implementation of CE is in its early stages and is focused mainly on recycling rather than reuse. However, some sectors have made important changes in the area of waste management, with high waste recycling rates being achieved in some selected developed countries. CE implies adoption of cleaner production patterns at the firm level, use of renewable technologies and materials, increased responsibility of producers and consumers, and adoption of appropriate, clear, and balanced policies and tools. This paper has received fewer citations but was published only in 2016. Therefore, in relative terms, it is the most frequently cited paper having been cited over 71 times in a year compared to 26 times for the paper that was published in *Environmental Science & Technology*.

The third most cited paper in our list is "Product services for a resource-efficient and CE—A review" authored by Tukker and published in 2015 [41,42] in *Journal of Cleaner Production*. It reviews the published work on product service systems and compares it to the review published in 2006 in the same journal.

Among the top 50 publications, 16 are focused on China or a Chinese region. China has adopted CE as an economic rather than just an environmental strategy. China's government is promoting development of its economy and society together with sustainable environmental protection.

Moreover, according to the WoS, there are just 26 documents that merge the CE research with SMEs. The most cited one (88 citations) is "Evaluating green supply chain management among Chinese manufacturers from the ecological modernization perspective" by Zhu, Geng, Sarkis and Lai in 2011 in *Transportation Research Part E-Logistics and Transportation Review*. This paper deals with whether Chinese manufacturer clusters (form by SMEs) varying in their extent of implementing green supply chain management. The second most cited document is entitled "Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers" (2016), published in *Sustainability* and it deals with the barriers and enablers experienced by SMEs when implementing circular economy business models. The third most cited document is "Circular Economy in Spanish SMEs: Challenges and opportunities", published in *Journal of Cleaner Production*. This research focuses on exploring the potential for implementation of the CE in SMEs and their barriers and opportunities.

It is necessary to evaluate more than one indicator to estimate the global contribution of an author or institution. Table 2 presents total publications (TP), total citations (TC), h-index, and relative number of TC/TP. Table 3 presents the 50 leading authors in CE research based on number of publications and impact.

Table 3 shows that Yong Geng from Shanghai Jiao Tong University is the leading author with 42 publications. Yong Geng's work also received the highest number of citations (1483) followed by Qinghua Zhu (Shanghai Jiao Tong University—515 citations), Joseph Sarkis (Worcester Polytechnic Institute—497 citations), and Tsuyoshi Fujita (National Institute for Environmental Studies—472 citations). In relative terms, Bing Xue (Chinese Academy of Sciences), Joseph Sarkis (Worcester Polytechnic Institute), and Conny Bakker (Delft University of Technology) have the most citations per publication (almost 50 citations to each of their published papers).

Table 3 also shows that China is the country with the strongest focus on CE research with 18 among the top 50 authors located in China. This is in line with the results in Table 2 for publications from China and Chinese regions.

According to Cole and Cole [43], there are four categories of academics based on productivity and the number of citations received. The prolific category includes authors with high numbers of papers and citations, mass producer includes authors with a high number of publications but a lower number of citations, perfectionist includes highly cited authors with only a few published papers, and the silent category includes the least productive and least cited authors. Yong Geng from Shanghai Jiao Tong University is ranked top with more than 40 publications and 1483 citations, so it is categorized as prolific.

Table 3. Top 50 leading authors.

R	Authors	University	Country	TP	TC	H	TC/TP
1	Yong Geng	Shanghai Jiao Tong U	China	42	1483	20	35.31
2	Hong Wang	Chinese Academy of Social Sciences	China	11	2	1	0.18
3	Wenjun Li	Chinese Academy of Social Sciences	China	11	2	1	0.18
4	Qinghua Zhu	Shanghai Jiao Tong U	China	13	515	10	39.62
5	Tsuyoshi Fujita	National Institute for Environmental Studies	Japan	12	472	11	39.33
6	Jingxing Zhao	Chinese Academy of Social Sciences	China	12	24	1	2.00
7	Zhe Liu	Dalhousie University	Canada	9	89	6	9.89
8	Xushu Peng	Chinese Academy of Social Sciences	China	11	2	1	0.18
9	Jianguo Qi	Chinese Academy of Social Sciences	China	11	2	1	0.18
10	Bin Wu	Chinese Academy of Social Sciences	China	11	2	1	0.18
11	Robert C. Brears	Mitidaption, Canterbury	New Zealand	10	2	1	0.20
12	Joseph Sarkis	Worcester Polytechnic Institute	USA	10	497	9	49.70
13	Sergio Ulgiati	Beijing Normal U	China	10	385	4	38.50
14	Liang Dong	Leiden U	Netherlands	9	201	7	22.33
15	Angel Irabien	U of Cantabria	Spain	9	20	2	2.22
16	Gintaras Denafas	Kaunas U of Technology	Lithuania	8	15	2	1.88
17	Phil Purnell	U of Leeds	England	8	77	5	9.63
18	Bing Xue	Chinese Academy of Sciences	China	8	393	8	49.13
19	Zhifang Zhou	Central South U	China	8	42	3	5.25
20	Xiaohong Chen	Central South U	China	7	57	4	8.14
21	Pen-Chi Chiang	National Taiwan U	Taiwan	7	83	4	11.86
22	Joanna Kulczycka	AGH U of Science & Technology	Poland	7	112	5	16.00
23	Mari Lundstrom	Aalto U	Finland	7	11	2	1.57
24	Shu-Yuan Pan	National Taiwan U	Taiwan	7	83	4	11.86
25	Jingzheng Ren	Hong Kong Polytechnic U	China	7	88	6	12.57
26	Jhuma Sadhukhan	U of Surrey	England	7	43	4	6.14
27	Lei Shi	Tsinghua U	China	7	47	3	6.71
28	Marzena Smol	Polish Academy of Sciences	Poland	7	112	5	16.00
29	Zongguo Wen	Tsinghua U	China	7	141	4	20.14
30	Anastasia Zabaniotou	Aristotle U of Thessaloniki	Greece	7	70	5	10.00
31	Ruben Aldaco	U of Cantabria	Spain	6	14	2	2.33
32	Fiona Charnley	Cranfield U	England	6	61	3	10.17
33	Eleni Iacovidou	U of Leeds	England	6	54	4	9.00
34	Carmen Jaca	U of Navarra	Spain	6	28	3	4.67

Table 3. *Cont.*

R	Authors	University	Country	TP	TC	H	TC/TP
35	Jinhui Li	Tsinghua U	China	6	81	4	13.50
36	Maria Margallo	U of Cantabria	Spain	6	14	2	2.33
37	Marta Ormazabal	U of Navarra	Spain	6	28	3	4.67
38	Serenella Sala	European Commission Joint Research Centre	Italy	6	218	3	36.33
39	Marianne Thomsen	Aarhus U	Denmark	6	78	5	13.00
40	Xu Xiao	Central South U	China	5	35	3	7.00
41	Conny Bakker	Delft U of Technology	Netherlands	5	240	3	48.00
42	Nancy M. P. Bocken	Delft U of Technology	Netherlands	5	266	3	53.20
43	Lucian Ionel Cioca	Lucian Blaga U of Sibiu	Romania	5	29	3	5.80
44	Olli Dahl	Aalto U	Finland	5	5	1	1.00
45	Zhipeng Dai	Kunming U Sci & Technol	China	5	6	2	1.20
46	Mark Esposito	Harvard U	USA	5	19	2	3.80
47	Johann Fellner	Vienna U of Technology	Austria	5	23	2	4.60
48	Moises Frias	Spanish National Research Council (CSIC)	Spain	5	14	2	2.80
49	Minoru Fujii	National Institute for Environmental Studies	Japan	5	186	5	37.20
50	Petteri Halli	Aalto U	Finland	5	8	2	1.60

Martyn (1964, p. 236) defines bibliographic coupling as "two papers that share one reference contain one unit of coupling, and the value of a relationship between two papers having one or more references in common is stated as being of strength one, two, etc., depending on the number of shared references" [44].

Information on bibliographic coupling is derived from the similarities between two documents, authors, institutions, or countries based on citations. Thus, bibliographic coupling highlights documents, authors, institutions, or countries which simultaneously cite a third document, author, institution, and country in their reference lists. On this basis, we can create clusters of authors, institutions, and countries involved in similar research.

Bibliographic coupling of authors (Figure 1) occurs when two authors reference the same third author in their publications. The strength of the bibliographic coupling is determined by the total number of references or citations to the same other third documents. There is a large bibliographic coupling cluster on the CE around Yong Geng (leading author for the number of publications—see Table 3). This author is coupled to Angel Irabien (number 15 Table 3), Phil Purnell (number 17 Table 3), and Joanna Kulczycka (number 22 Table 3).

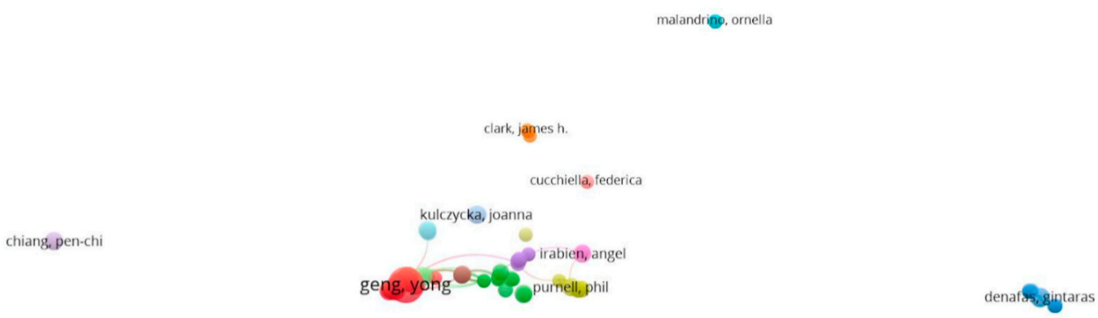

Figure 1. Bibliographic coupling of authors publishing on circular economy (CE): Minimum publication threshold of four documents and 75 links.

The leading authors are from China. China has become one of the world's fastest-growing economies with an annual growth rate of 9.7% GDP. This economic success has affected the quality of life of its population. It is predicted that China will become the largest CO_2 emitter in the world [40], and China's rapid economic growth is creating serious global and local environmental problems. Knowing how to recognize the key factors that drive energy consumption and CO_2 emissions in China is essential for the development of global climate policies, these factors also provide information on how other emerging economies can develop and also keep emissions at low levels. China has improved its energy efficiency, which is reducing its CO_2 emissions. The Chinese government is supporting structural improvements to production systems as part of a CE political policy.

Table 4 presents the 50 most productive and influential institutions publishing work on CE, ranked according to the number of publications. Delft University of Technology leads with 49 publications, and the Chinese Academy of Sciences (48 publications) has the highest number of citations (1484) and the highest h-index (23). Note that the total number of publications and the total number of citations are absolute values, while h-index and the citations to publications ratio considers both the number of publications and the number of citations. The citations to publications ratio favors institutions with fewer publications, but more citations, and the h-index is advantageous for institutions with high numbers of publications but fewer citations to them.

Table 4. The most productive and influential institutions.

R	Organization	Country	TP	TC	H	TC/TP	ARWU	QS
1	Delft U of Technology	Netherlands	49	1004	16	20.49	151–200	54
2	Chinese Academy of Sciences	China	48	1484	23	30.92	/	/
3	Tsinghua U	China	34	385	12	11.32	45	25
4	Aalto U	Finland	32	152	7	4.75	301–400	137
5	Shanghai Jiao Tong U	China	28	591	13	21.11	101–150	62
6	National Institute for Environmental Studies Japan	Japan	26	812	16	31.23	/	/
7	Shenyang Institute of Applied Ecology Cas	China	26	1183	17	45.50	/	/
8	Technical U of Denmark	Denmark	24	84	6	3.50	151–200	116
9	Lund U	Sweden	23	128	6	5.57	101–150	78
10	U of Cambridge	United Kingdom	23	584	7	25.39	3	5
11	Cranfield U	United Kingdom	21	108	4	5.14	/	/
12	Helmholtz Association	Germany	21	170	7	8.10	/	/
13	Royal Institute of Technology	Sweden	20	307	7	15.35	201–300	98
14	U of Leeds	United Kingdom	19	516	7	27.16	101–150	101
15	Wageningen U Research	Netherlands	19	139	7	7.32	101–150	124
16	Dalian U of Technology	China	18	729	12	40.50	201–300	551–600
17	Bucharest Academy of Economic Studies	Romania	17	8	2	0.47	/	/
18	U of Bologna	Italy	17	321	4	18.88	201–300	188
19	Chalmers U of Technology	Sweden	16	110	6	6.88	201–300	133
20	Ku Leuven	Belgium	16	155	6	9.69	86	71
21	Polytechnic U of Milan	Italy	16	222	6	13.88	201–300	170
22	U of Chinese Academy of Sciences Cas	China	16	281	8	17.56	/	/
23	U of Manchester	United Kingdom	16	77	6	4.81	34	34
24	U of Surrey	United Kingdom	16	84	6	5.25	301–400	264
25	Central South U	China	15	69	4	4.60	201–300	801–1000
26	Spanish National Research Council (CSIC)	Spain	15	63	4	4.20	/	/
27	Imperial College London	United Kingdom	15	100	6	6.67	24	8
28	Shandong U	China	14	139	7	9.93	301–400	551–600
29	Leiden U	Netherlands	13	353	6	27.15	74	109
30	National Taiwan U	Taiwan	13	109	5	8.38	151–200	76
31	Utrecht U	Netherlands	13	224	5	17.23	51	109
32	Finnish Environment Institute	Finland	12	184	7	15.33	/	/
33	Ghent U	Belgium	12	84	5	7.00	61	125
34	Parthenope U Naples	Italy	12	389	4	32.42	/	/

Table 4. *Cont.*

R	Organization	Country	TP	TC	H	TC/TP	ARWU	QS
35	Polytechnic U of Madrid	Spain	12	39	4	3.25	501–600	491–500
36	U of Cantabria	Spain	12	25	3	2.08	801–900	/
37	U of Aveiro	Portugal	12	41	3	3.42	401–500	501–550
38	U of Oxford	United Kingdom	12	138	7	11.50	7	6
39	U of Queensland	Australia	12	106	6	8.83	55	47
40	Aarhus U	Denmark	11	203	6	18.45	65	119
41	Chinese Academy of Social Sciences	China	11	2	1	0.18	/	/
42	Norwegian U of Science Technology Ntnu	Norway	11	746	5	67.82	101–150	259
43	Romanian Academy of Sciences	Romania	11	36	3	3.27	/	/
44	U College London	United Kingdom	11	64	4	5.82	17	7
45	U of Granada	Spain	11	56	5	5.09	201–300	501–550
46	U of Southern Denmark	Denmark	11	111	6	10.09	301–400	384
47	Vienna U of Technology	Austria	11	93	5	8.45	301–400	182
48	Yale U	USA	11	461	8	41.91	12	16
49	Aalborg U	Denmark	10	56	5	5.60	201–300	379
50	Autonomous U of Barcelona	Spain	10	49	3	4.90	301–400	195

Overall, this ranking is dominated by China (9) and the United Kingdom (8), followed by Spanish (5), Netherlands (4) and Danish (4) institutions.

Bibliographic coupling of institutions occurs when the publications of two institutions reference the same third institution. Figure 2 shows that five institutions dominate: Delft University of Technology, Chinese Academy of Sciences, Tsinghua University, Shanghai Jiao Tong University, and Technical University of Denmark. All are in the top 10 most influential institutions for CE research. According to this bibliographic coupling analysis, these five institutions have similar numbers of citations, although they belong to four different clusters.

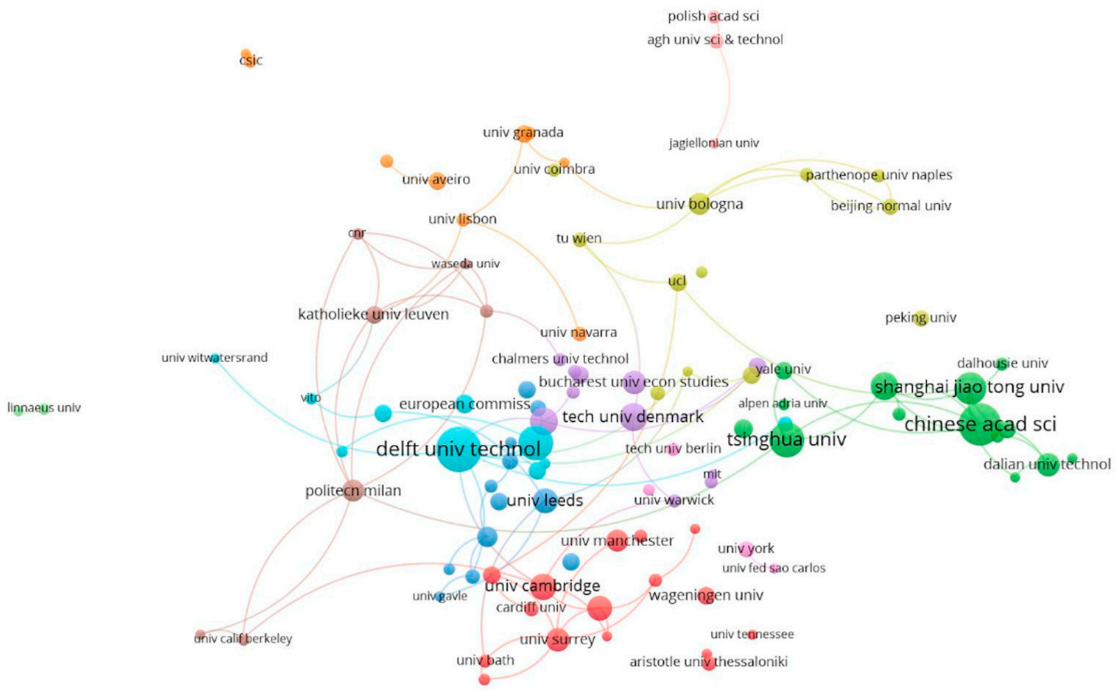

Figure 2. Bibliographic coupling of institutions publishing on CE: minimum publication threshold of five documents and 100 links.

A large number of studies reference implementation of CE in China. This country seems strongly committed and attracted to CE due to the enormous environmental, human health, and social problems posed by its rapid and continued economic development pattern [45–47]. As China's speedy development continues, there will be opportunities to implement and extend policies such as CE which could help China avoid the high levels of emissions in the developed countries [40].

Table 5 presents the most productive and influential countries in the field of CE research based on the indicators used above but including the national population to provide a productivity per million inhabitants number.

Again, China leads the ranking for both total publications and total citations, followed by the United Kingdom, Italy, Spain, and the Netherlands. However, in relative numbers (total citations per total publications) Norway is ranked first with more than 45 citations per publication while Spain which is in the top five has less than five citations per publication. Thus, the leading countries for total citations per total population are Norway (45.95), Japan (23.37), South Korea (22.14), South Africa (21.09), USA (17.73), and the Netherlands (17.66).

In terms of total publications per population, Finland (13.97), Denmark (11.09), and Sweden (10.03) are the leaders. For total citations per population, Norway (165.27), Netherlands (147.44), Sweden (120.19), and Denmark (103.65) are the most influential countries.

Table 5. The most productive and influential countries.

R	Country	TP	TC	H	TC/TP	Population	TP/POP	TC/POP
1	China	305	4860	36	15.93	1,386,000,000	0.22	3.51
2	United Kingdom	273	3251	27	11.91	66,022,273	4.13	49.24
3	Italy	193	1921	19	9.95	60,551,416	3.19	31.73
4	Spain	152	720	13	4.74	46,572,028	3.26	15.46
5	Netherlands	143	2526	26	17.66	17,132,854	8.35	147.44
6	USA	120	2128	20	17.73	325,719,178	0.37	6.53
7	Germany	118	908	17	7.69	82,695,000	1.43	10.98
8	Sweden	101	1210	16	11.98	10,067,744	10.03	120.19
9	Finland	77	472	10	6.13	5,511,303	13.97	85.64
10	Australia	66	697	13	10.56	24,598,933	2.68	28.33
11	Denmark	64	598	13	9.34	5,769,603	11.09	103.65
12	France	64	611	12	9.55	67,118,648	0.95	9.10
13	Belgium	58	482	12	8.31	11,372,068	5.10	42.38
14	Romania	52	87	5	1.67	19,586,539	2.65	4.44
15	Austria	50	438	8	8.76	8,809,212	5.68	49.72
16	Poland	47	354	9	7.53	37,975,841	1.24	9.32
17	Portugal	46	193	8	4.20	10,293,718	4.47	18.75
18	Japan	43	1005	17	23.37	126,785,797	0.34	7.93
19	Brazil	41	152	7	3.71	209,288,278	0.20	0.73
20	Canada	39	544	10	13.95	36,708,083	1.06	14.82
21	Greece	35	330	8	9.43	10,760,421	3.25	30.67
22	Taiwan	29	228	6	7.86	23,571,000	1.23	9.67
23	Switzerland	26	145	6	5.58	8,466,017	3.07	17.13
24	South Korea	21	465	8	22.14	51,466,201	0.41	9.04
25	India	20	183	4	9.15	1,339,000,000	0.01	0.14
26	Norway	19	873	9	45.95	5,282,223	3.60	165.27
27	New Zealand	15	3	1	0.20	4,793,900	3.13	0.63
28	Lithuania	14	36	3	2.57	2,827,721	4.95	12.73
29	Mexico	13	49	4	3.77	129,163,276	0.10	0.38
30	Russia	12	36	4	3.00	144,495,044	0.08	0.25
31	Chile	11	140	7	12.73	18,054,726	0.61	7.75
32	South Africa	11	232	4	21.09	56,717,156	0.19	4.09
33	Czech Republic	10	17	2	1.70	10,591,323	0.94	1.61
34	Ireland	10	53	4	5.30	4,813,608	2.08	11.01
35	Croatia	9	15	2	1.67	4,125,700	2.18	3.64
36	Singapore	9	66	5	7.33	5,612,253	1.60	11.76
37	Turkey	9	24	3	2.67	80,745,020	0.11	0.30
38	Hungary	8	17	3	2.13	9,781,127	0.82	1.74
39	Malaysia	8	28	3	3.50	31,624,264	0.25	0.89
40	Slovenia	8	31	2	3.88	2,066,748	3.87	15.00
41	Colombia	7	71	4	10.14	49,065,615	0.14	1.45
42	Estonia	7	31	2	4.43	1,315,480	5.32	23.57
43	Thailand	7	32	3	4.57	69,037,513	0.10	0.46
44	Ukraine	7	30	3	4.29	44,831,159	0.16	0.67
45	Cyprus	6	56	3	9.33	1,179,551	5.09	47.48
46	Egypt	6	16	3	2.67	97,553,151	0.06	0.16
47	Ecuador	5	17	2	3.40	16,624,858	0.30	1.02
48	Serbia	5	25	2	5.00	7,022,268	0.71	3.56
49	Bangladesh	4	28	3	7.00	164,669,751	0.02	0.17
50	Indonesia	4	45	1	11.25	263,991,379	0.02	0.17

Table 6 shows that Europe is the region with the highest number of publications and citations in the field of CE while Northern Europe (Norway, Sweden, Denmark, etc.) is the region with the most publications and the most citations.

Table 6. Productivity by supranational regions.

	TP	TC	TC/TP	Population	TP/POP	TC/POP
1 Europe	1608	15410	9.58	705,857,086	2.28	21.83
Eastern Europe	136	541	3.98	267,261,033	0.51	2.02
Northern Europe	565	6524	11.55	101,609,955	5.56	64.21
Southern Europe	448	3235	7.22	141,392,29	3.17	22.88
Western Europe	459	5110	11.13	195,593,799	2.35	26.13
2 Asia	465	7020	15.10	3,543,682,729	0.13	1.98
Eastern Asia	369	6330	17.15	1,564,251,998	0.24	4.05
South Eastern Asia	28	171	6.11	370,265,409	0.08	0.46
Southern Asia	53	439	8.28	1,527,240,751	0.03	0.29
Western Asia	15	80	5.33	81,924,571	0.18	0.98
3 North America	159	2672	16.81	362,427,261	0.44	7.37
4 Oceania	81	700	8.64	29,392,833	2.76	23.82
5 Latin America	64	380	5.94	293,033,477	0.22	1.30
6 Africa	17	248	14.59	154,270,307	0.11	1.61
7 Central America	13	49	3.77	129,163,276	0.10	0.38

The most influential journal on CE field of research is *Journal of Cleaner Production* with 267 publications and 4735 citations (Table 7). This journal also has the highest impact factor (IF: 5.651). The next ranked are *Sustainability* and *Resources Conservation and Recycling*. Although *Sustainability* accounts for a higher number of publications (123 vs. 105). *Resources Conservation and Recycling* has more citations (1172 vs. 476). That is, *Resources Conservation and Recycling* has published fewer papers on the circular economy, but these publications have been highly cited, and thus, are more influential. Similarly. *Environmental Science Technology* has 13 publications but 499 citations—a relative number of total citations per total publications of 38.38, the *Journal of Industrial Ecology* has 42 publications and 98 citations (TC/TP: 23.76), and *Renewable Sustainable Energy Reviews* has 17 publications and 343 citations (TC/TP: 20.18). So, in relative terms, the journal ranking is led by: *Journal of Cleaner Production*, *Journal of Industrial Ecology*, *Bioresource Technology, Renewable Sustainable Energy Reviews, Environmental Science Technology, Green Chemistry*.

Table 7. Journals publishing in the field of 'circular economy'.

Name	TP	TC	TC/TP	TC 13–18	IF	IF 5 y	T50	H
Journal of Cleaner Production	267	4735	17.73	3861	5.651	6.352	17	32
Sustainability	123	476	3.87	476	2.075	2.177	1	11
Resources Conservation and Recycling	105	1172	11.16	921	5.12	5.228	4	18
Waste Management	59	375	6.36	274	4.723	5.262	1	10
Journal of Industrial Ecology	42	998	23.76	523	4.356	5.068	4	16
Science of the Total Environment	25	190	7.60	114	4.61	4.984	1	6
Waste Management Research	21	69	3.29	69	1.631	1.955	0	5
Bioresource Technology	20	349	17.45	349	5.807	5.978	1	10
Journal of Environmental Management	20	195	9.75	110	4.005	4.449	1	6
Resources Basel	19	70	3.68	70	/	/	0	5
Acs Sustainable Chemistry Engineering	17	77	4.53	77	6.14	6.415	0	4
Environmental Engineering and Management Journal	17	31	1.82	31	1.334	1.021	0	4
Renewable Sustainable Energy Reviews	17	343	20.18	263	9.184	10.093	0	8
Waste and Biomass Valorization	15	50	3.33	50	1.874	1.787	0	5
Amfiteatru Economic	14	8	0.57	8	0.664	0.566	0	2
Environmental Science and Pollution Research	14	97	6.93	97	2.8	2.989	0	4
Design Journal	13	8	0.62	8	/	/	0	2
Environmental Science Technology	13	499	38.38	81	6.653	7.25	2	7
Journal of Material Cycles and Waste Management	13	219	16.85	50	1.693	1.832	0	6
Research Series on the Chinese Dream and Chinas Development Path	12	3	0.25	3	/	/	0	1
Development of Circular Economy in China	11	2	0.18	2	/	/	0	1
Current Opinion in Green and Sustainable Chemistry	10	37	3.70	37	/	/	0	4
Energies	10	39	3.90	39	2.676	3.045	0	4
Green Chemistry	10	298	29.80	298	8.586	8.717	2	5
Production Planning Control	10	7	0.70	7	2.33	2.933	0	1
Business Strategy and the Environment	9	67	7.44	67	5.355	6.426	0	3
Natural Resource Management and the Circular Economy	9	1	0.11	1	/	/	0	1
Palgrave Studies in Natural Resource Management	9	1	0.11	1	/	/	0	1
Proceedings of the Institution of Civil Engineers Waste and Resource Management	9	22	2.44	22	/	/	0	3
Thunderbird International Business Review	9	21	2.33	21	/	/	0	2

Co-citation is defined as two documents which are cited by the same third document [48]. Figure 3 presents the co-citation mapping of journals publishing in CE. There are three clusters: One led by the *Journal of Cleaner Production*. a top journal in cleaner production, environmental, and sustainability research with an impact factor of 5.651, one led by *Resources Conservation and Recycling*, also a top journal with an impact factor of 5.12, and one led by *Journal of Environmental Management* (IF: 4.005), *Environmental Science Technology* (IF: 6.653), and *Energy Policy* (IF: 5.45).

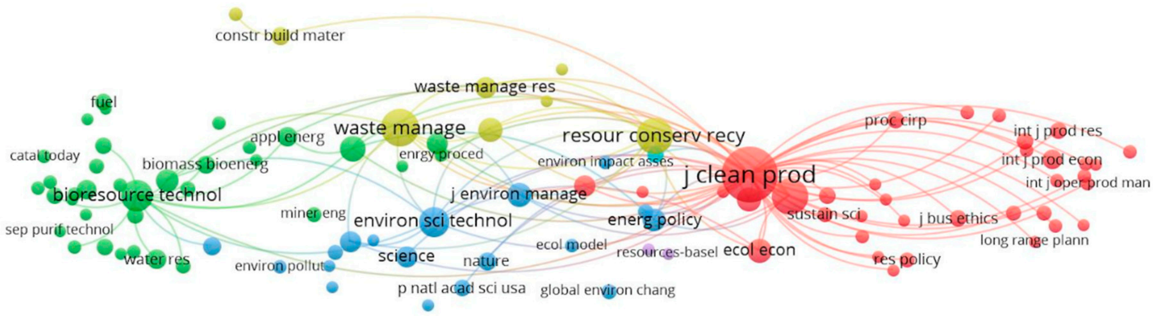

Figure 3. Co-citation of journals in circular economy: Minimum citation threshold of 90 and 100 links.

5. Discussion and Conclusions

This paper provides a bibliometric overview of the leading trends in the field of CE. We examined authors, institutions, and countries relying on bibliographic information from the WoS Core Collection database. We provide a mix of descriptive results and graphical analyses.

CE offers good prospects for a gradual improvement of current production and consumption models, which are no longer adequate due to the environmental reality and current social inequality. CE is a clear indicator of inefficiency in the use of resources [1].

Among the most cited publications and most influential countries based on the top 50 publications, 16 are focused on China or a Chinese region. At the macro level, CE developments at the eco-city, eco-municipality, and eco-province levels are among the most prominent environmental movements in China. The Chinese government is encouraging Chinese companies to design more environmentally-friendly products and to adopt cleaner technology in their manufacturing processes [20] to develop eco-industry clusters which simultaneously promote economic growth and environmental health. It is focusing on circular economy strategies to improve resources productivity and eco-efficiency, reform environmental management, and achieve sustainable development [20].

The most productive and influential authors are linked to Chinese institutions. The leading author, Yong Geng is from the Shanghai Jiao Tong University and has the highest numbers of publications and citations (more than 40 publications and 1483 citations).

The most influential journal, *Journal of Cleaner Production* has an impact factor of 5.651. It considers the concept of cleaner production as contributing to reducing the production of waste while making more efficient use of energy, water, resources, and human capital. The circular economy is one of its main fields of interest.

Regarding the future lines of research proposed by the latest manuscripts on CE, Grey and Tarascon [49] state that future research is plenty of opportunities, related to ambitious multidisciplinary research. For example, a new analytical method for optimization of battery chemistries is needed, in order to bring new technologies to the market and social demands. Geissdoerfer et al. [50] think that there are two main critical areas where the research on CE must focus: (1) The relation between companies and policy makers, "the linkage between Circular Economy and emerging concepts such as the Performance Economy Sharing Economy, and new business forms such as benefit corporations could be investigated" and (2) the relation between circular economy, sustainability and performance (of supply chains, business models, and innovation systems). Sheldon [51] also states two main future research areas. "First, the change from a fossil-based to a renewable bio-based manufacture of existing commodity chemicals and new materials which are biocompatible and biodegradable. Second, the transition from an unsustainable linear economy to a circular one which designs products and processes with conservation of resources and elimination of waste in mind, a truly green economy."

Focusing on the future research in the field of CE within SMEs, Ormazabal et al. [52] state that there are opportunities in the research of Industrial Associations (IA) and the implementation of CE, because most of the SMEs belong, according to this authors, to a IA. Moreover, another recommendation is to study the opportunities that the implementation of CE can provide when SMEs Inco pore it in their corporate strategy [53–56].

We have provided a general overview of the leading authors, institutions, and countries publishing CE research. This approach provides a snapshot of the main drivers of this field of research and has some limitations. First, we use WoS Core Collection data, therefore, the limitations that apply to these data also apply to our study. For example, WoS uses full counts giving one unit to each co-author of a paper. This benefits articles with several co-authors. To account for this, we use fractional counting in the mapping process with VOS viewer, so each paper has one unit which is fractioned according to the number of co-authors. Therefore, we present our findings for both full and fractional counting and show that there are no significant deviations between these two methods. Another limitation is that the number of papers published over the last five years has increased so authors, institutions, and countries that have performed better during these years, are higher ranked in the tables.

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