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The evolution of Resources Conservation and Recycling over the past 30 years: A bibliometric overview

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ABSTRACT

The aim of this study is to investigate the publication characteristics and development of Resources Conservation and Recycling (RCR) during its past 30 years. Through bibliometric analysis, this paper identified the most prolific authors/institutions/countries and the most cited articles, and tracked the dynamic evolution of hot topics. Besides, VOS viewer software was applied to visualize the collaboration network, journal co-citation network, and keywords co-occurrence network. The study revealed a positive trend in literature production of RCR. The most productive institution, is University of Utrecht in Netherlands, in terms of both total publication and total citations. Keywords frequency and keywords co-occurrence network analysis showed that the most prolific themes are corresponded to the basic aims and scope of the journal. The mainstream research in RCR focuses on recycling, waste management, sustainability, and environmental impact. Life cycle assessment, material flow analysis, and substance flow analysis are popular methods in recent years. Moreover, the emerging hot topics may attract great interest in future, including “food waste”, “carbon footprint”, “resource efficiency”, “circular economy”, “waste of electric and electronic”, “packaging waste”, and “China”. Knowing the objective bibliometric characteristics and the research topic evolution can serve as a useful reference for future studies, which may be of interest to the general audience.

1. Introduction

The Resources, Conservation and Recycling is a monthly, leading international peer-reviewed scientific journal in the field of environmental sciences and engineering environmental. As the result of the merger of two journals, Resources and Conservation (founded in 1975) and Conservation & Recycling (found in 1976), RCR was born as a brand-new international publication in 1988, and is published by Elsevier and included in the Journal Citation Reports of the Web of Science Core Collection, which only indexes those journals that are recognized with the highest quality. The current Editor-in-Chief is Associate Professor Ming Xu from the University of Michigan. Seven professors and scholars from the USA, Denmark, Brazil, France, and China are serving as associate editors. Consistent with its mission, RCR has published a great number of researches on sustainable management and conservation of resources. To celebrate its 30th anniversary, it is desired to evaluate the performance of RCR, explore the evolution trend of its hot topics, and provide guidance references for relative researchers through a scientific and visual way.

Bibliometric is widely recognized as a well-established research method in the information science particularly for evaluating the research performance of academics and universities. It adopts quantitative analysis and statistical methods to analyze the bibliometric characteristics of a given field, evaluate the performance of authors/institutions/countries, discover the hot topics, and reveal the research tendency in future. Many studies have considered specific topics under a bibliometric framework, such as low carbon development (Wang et al., 2017), waste management (Chen et al., 2015), transportation (Najmi et al., 2017), and ecological environment (Zhi and Ji, 2012). There are also several bibliometric studies analyzing only one journal to provide a broad picture of the leading trends in that journal. For example, Chan et al. (2009) provided the retrospective evaluation of European Financial Management from 1995 to 2008. Cobo et al. (2015) analyzed the first 25 years of the Journal of Knowledge-Based Systems. Zeleznik et al. (2017) studied the evolution of the Journal of Advanced Nursing over 40 years. Laengle et al. (2017) analyzed the first 40 years of the European Journal of Operational Research. Calma and Davies (2017) studied the Journal of Higher Education from 1972 to 2014. Through such bibliometric perspective, readers can gain a quick overview on the types and themes of publications, the most productive

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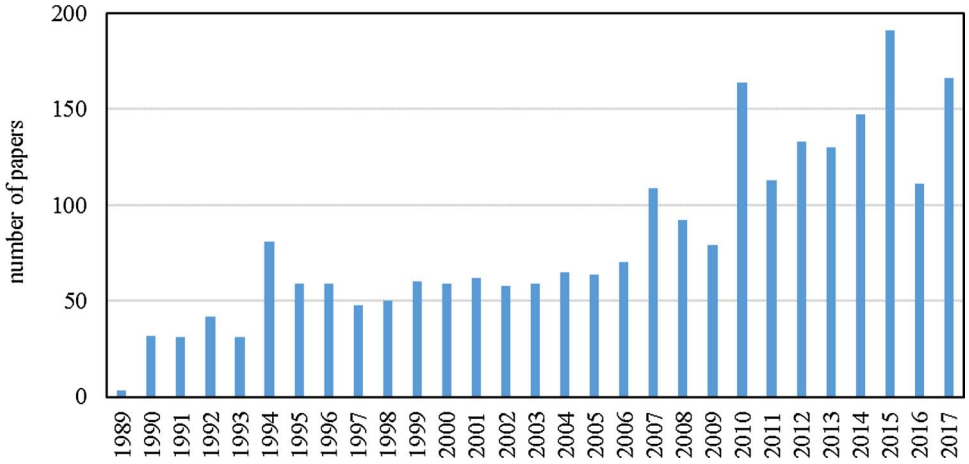

Fig. 1. Annual number of articles published in RCR.

Table 1
The most productive countries/areas in RCR (Top 20).

Rank	Country/Area	TP	TC	TC/TP	h-index	≥100	≥50
1	USA	401	6059	15.11	34	5	18
2	China	274	4017	14.66	34	3	18
3	UK	261	6239	23.90	42	7	30
4	Sweden	129	2952	22.88	32	2	17
5	Netherlands	119	2009	16.88	27	2	6
6	Spain	116	2346	20.22	29	1	9
7	Italy	101	1652	16.36	24	0	5
8	Japan	93	1357	14.59	20	1	5
9	India	90	2147	23.86	25	3	11
10	Australia	80	1821	22.76	24	2	9
11	Canada	73	1368	18.74	18	3	7
12	Brazil	72	936	13	17	0	0
13	Germany	71	1197	16.86	21	0	5
14	France	70	1219	17.41	18	0	7
15	Taiwan	69	1508	21.86	21	2	5
16	Denmark	53	1158	21.85	18	2	6
17	Turkey	51	933	18.29	19	0	4
18	Belgium	51	817	16.02	17	1	3
19	Austria	46	971	21.11	15	1	2
20	Greece	44	777	17.66	17	0	2

TP: total publications; TC: total citations; TC/TP: the citations per publication; ≥: the number of publications whose citations larger than the threshold (50 or 100). Articles originating from Taiwan region were not included under China heading for analysis; Articles originating from England, Scotland, Ireland, and Wales were grouped under the UK heading.

authors/affiliations/areas, and even the trend of hot topics. Such analysis and information present an added value for the journal. To the best of our knowledge, bibliometric analysis has not yet been applied to analyze the development and evolution of RCR.

Therefore, an expansion of the previous studies, the main purpose of this study is to provide a general overview of RCR journal over the past 30 years through bibliometric analysis in honor of its 30th anniversary. Based on various statistic indicators and bibliometric mapping, this study tries to 1) identify the key contributing countries/institutions/authors; 2) discover the collaboration relationship in RCR; 3) reveal how RCR links to other journals; 4) identify the research focuses and hotspot evolution in RCR.

This paper is structured as follows: Section 2 briefly describes the bibliometric methods and data sources used in the analysis. Section 3 presents the major bibliometric characteristics of RCR journal. Section 4 maps collaboration relationship, journal co-citation analysis, and keywords co-occurrence by using the VOS viewer software. Section 5 summarizes the main findings and conclusions of the paper.

2. Data and methodology

Bibliometric analysis is a popular tool to quantitatively analyze literatures published in a specific area (Zhi and Ji, 2012). Using a wide range of indicators and methods, it can discover the distributed architecture characteristics and patterns of the underlying science and technology, but also can assess the development trends or future research (Li et al., 2009; Zhang et al., 2017). For example, the number of publications indicates the productivity of an author, and the number of citations correlates with authors' influence in the scientific field. The h-index proposed by Hirsch (2010) also can be used to assess the total effective output of a researcher with strengths of simplicity and immediate intuitive meaning. The number of authors above a citation threshold permits to identify the authors with a certain level of influence. Keywords analysis can be used to monitor and identify the development of science (Garfield, 1990). Through these bibliometric indicators, a general informative overview of the bibliographic material can be presented.

Network analysis based on graph theory can be adopted to map the relationships between various nodes and detective the network structure. In bibliometric mapping, the nodes in the network can be authors, institutions, countries, literatures, references, journals, and even keywords related to a specific research field. The links can represent the collaboration, co-occurrence, citation, and co-citation relationships between them. Characteristic analysis and cluster analysis of network can help to discover the underlying structure of complex network, which is crucial to reveal the research hotpots and identify the communities/groups/modules (Du et al., 2013; Wang et al., 2016). Besides, in order to show the complex network more intuitively and directly, VOS Viewer (Van Eck and Waltman, 2010), a popular and free software, is used to present a graphical visualization of the bibliometric material published in RCR.

In spite of other internationally known databases (e.g., Scopus, Google Scholar, and Econ Lit), the Web of Science (WoS) database, currently owned by Thomson & Reuters, is usually recognized with the highest quality and extensively used for scientific research retrieval (Merigó et al., 2016). This study focuses on RCR publications from 1988 to 2017 using the WoS database. "Resources Conservation and Recycling" were used as the publication name to search for all years. The research resulted in a total of 2594 documents published in RCR until August 2017, consisted of 8 document types, i.e. articles (2368), reviews (161), proceedings papers (158), editorial materials (37), notes (14), corrections (11), reprints (2) and item about an individual (1). Only articles, 91.29% of the total documents, were analyzed in the following study. Downloaded document information for analysis included author(s), title, source (journal title), language, document type, author keywords, addresses, cited reference count, times cited,

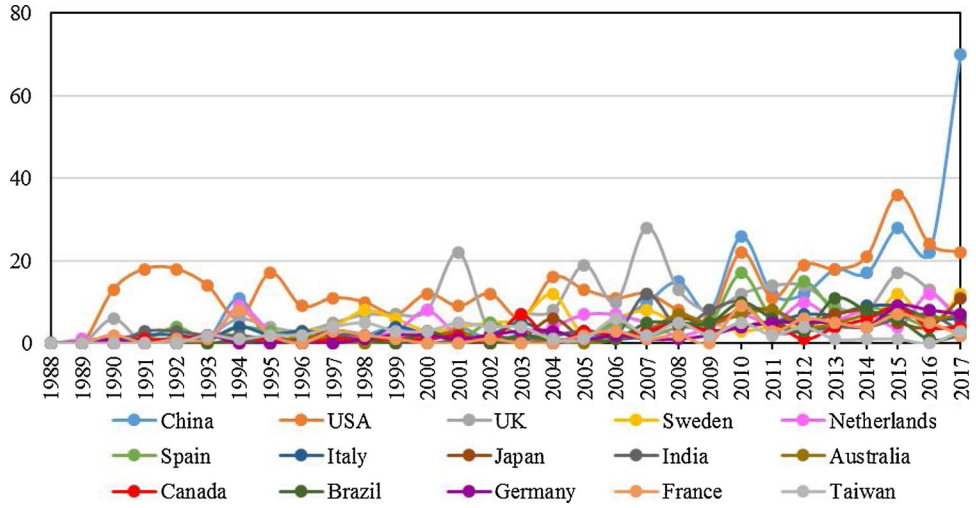

Fig. 2. The growth trends of the 15 most productive countries.

Table 2
The most productive institutions in RCR (TP ≥ 15).

Rank	Institution, Country	TP	TC	TC/TP	Single-institute			Inter-institutional collaborated		
					SI (%)	TC	TC/SI	CI (%)	TC	TC/SI
1	University of Utrecht, Netherlands	43	901	20.95	46.51%	333	16.65	53.49%	568	24.70
2	Tsinghua University, China	40	300	7.50	47.50%	174	9.16	52.50%	126	6.00
3	Chinese Academy of Sciences, China	32	476	14.88	28.13%	155	17.22	71.88%	321	13.96
4	Asian Institute of Technology, Thailand	28	275	9.82	96.43%	268	9.93	3.57%	7	7.00
5	University Tokyo, Japan	28	405	14.46	35.71%	179	17.90	64.29%	226	12.56
6	Yale University, USA	27	520	19.26	44.44%	210	17.50	55.56%	310	20.67
7	Lulea University of Technology, Sweden	25	599	23.96	64.00%	544	34.00	36.00%	55	6.11
8	University Ghent, Belgium	25	330	13.20	24.00%	119	19.83	76.00%	211	11.11
9	Hong Kong Poly tech University, China	24	675	28.13	50.00%	432	36.00	50.00%	243	20.25
10	University Coll Northampton, UK	23	685	29.78	43.48%	257	25.70	56.52%	428	32.92
11	Swedish University of Agricultural Science, Sweden	21	372	17.71	57.14%	261	21.75	42.86%	111	12.33
12	Indian Institute Technology, Indian	19	569	29.95	63.16%	437	36.42	36.84%	132	18.86
13	Beijing Normal University, China	16	204	12.75	0	0	0	100%	204	12.75
14	National Institute for Environmental Studies, Japan	16	341	21.31	18.75%	80	26.67	81.25%	261	20.08
15	Northeastern University, USA	15	213	14.20	73.33%	146	13.27	26.67%	67	16.75
16	Technical University Denmark, Denmark	15	287	19.13	46.67%	200	28.57	53.33%	87	10.88
17	University Southampton, UK	15	374	24.93	60.00%	162	18.00	40.00%	212	35.33
18	Vienna University of Technology, Austria	15	207	13.80	46.67%	148	21.14	53.33%	59	7.38

TP: total number of publications; TC: citation frequency based on the full WoS count at the time the data was download; TC/TP: citations per article; SI: single-institution articles; CI: inter-institutional collaborated articles; SI(%) + CI(%) = 1.

Table 3
Most productive authors in RCR (TP ≥ 10).

Name	Affiliation	Country	TP	TC	TC/TP	h-index
Phillips PS	University of Northampton	UK	33	775	23.48	15
Worrell E	University of Utrecht	Netherlands	29	745	25.69	15
Read AD	Kingston University	UK	23	709	30.82	14
Dewulf J	Ghent University	Belgium	20	297	14.85	8
Graedel TE	Yale University	USA	16	377	23.56	11
Rechberger H	Vienna University of Technology	Austria	14	297	21.21	8
Huang GH	University of Regina	Canada	13	301	23.15	8
Poon CS	Hong Kong Polytechnic University	China	12	378	31.50	8
Patel MK	University of Geneva	Switzerland	12	358	29.83	8
Govindan K	University of Southern Denmark	Denmark	11	463	42.09	8
Imteaz MA	Swinburne University of Technology	Australia	11	239	21.73	7
Gabarrell X	Autonomous University of Barcelona	Spain	10	255	25.50	8
Li YP	Beijing Normal University	China	10	229	22.90	7
Allwood JM	University of Cambridge	UK	10	293	29.30	6

TP: the number of published articles in RCR; TC: the number of citations; TC/TP: the cites per article; Affiliation: where the author is working at the moment of publication.

Table 4
The most cited articles in RCR according to WoS (Top 15).

Rank	Title	Author (s)	Country	PY	TC	C/Y
1	The possibility of in-situ heavy-mental decontamination of polluted soils using crops of metal-accumulating plants	Baker AJM, McGrath SP, Sidoli CMD, Reeves RD	UK	1994	417	18.13
2	Production of levulinic acid and use as a platform chemical for derived products	Bozell JJ, Moens L, Elliott DC, Wang Y et al.	USA	2000	379	22.29
3	Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations	Cherubini F, Bird ND, Cowie A, Jungmeier G et al.	Austria	2009	354	44.25
4	Sorption of acid dyes from effluents using activated carbon	Choy KKH, McKay G, Porter JF	China	1999	238	13.22
5	High performance cementing materials from industrial slags – a review	Shi CJ, Qian JS	India	2000	214	12.59
6	An overview of utilization of slag and sludge from steel industries	Das B, Prakash S, Reddy PSR, Misra VN	Canada	2007	211	21.10
7	Electronic waste recycling: A review of US infrastructure and technology options	Kang HY, Schoenung JM	USA	2005	202	16.83
8	A kinetic study of dye sorption by biosorbent waste product pith	Ho YS, McKay G	China	1999	198	11.00
9	An analysis of the drivers affecting the implementation of green supply chain management	Diabat A, Govindan K	United Arab Emirates	2011	171	28.50
10	Material efficiency: A white paper	Allwood JM, Ashby MF, Gutowski TG, Worrell E	UK	2011	170	28.33
11	Use of aggregates from recycled construction and demolition waste in concrete	Rao et al. (2007)Rao A, Jha KN, Misra S	India	2007	159	15.90
12	Power station fly ash – a review of value-added utilization outside of the construction industry	Lyer RS, Scott JA	Australia	2001	158	9.88
13	Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio	Lehtomaki A, Huttunen S, Rintala JA	Finland	2007	156	15.60
14	Methodological aspects of life cycle assessment of integrated solid waste management systems	Finnveden G	UK	1999	149	8.28
15	A review of the use of recycled solid waste materials in asphalt pavements	Huang Y, Bird RN, Heidrich O	Sweden	2007	148	14.80

Country: the country where the first institution of the corresponding author is located in; PY: publication year; TC: total citation; C/Y: citations per year

publisher information, page count, ISSN, and subject category, among other source data.

3. Basic bibliometric analysis

3.1. General statistics

Since the first publication in 1989, the amount of total articles published in RCR is 2368. Fig. 1 presents the annual publications of this journal. The overall upward trend of publication amounts can be divided into three periods. In the first period, the initial five years (1989–1993), the annual publications were less than 50. During the second period, from 1994 to 2009, the average annual publication was 67, more than 50 but still less than 100. After the peak in 2010, the average annual publication was 144, more than 100. With more worldwide concern on environmental and ecological issues, the publications in RCR will increase continuously in future.

3.2. Country/area statistics

During the past 30 years, there are total 83 countries/areas that make a great contribution research publications in RCR. Table 1 presents the 20 most productive countries in RCR with respect to a number of indices, such as total publication, total citation, average citation, as well as the h-index. The countries/areas are ranked by total productivity. The number of articles from the USA was 401, accounted for 15.87% of total publications, far more than those of any other countries. Following the USA, China and UK rank the 2nd and 3rd in the number of publications, respectively. However, UK has the highest average citations per publication (23.90), the highest h-index (42), and the most high-cited papers, where 7 papers are cited more than 100 times and 30 papers more than 50 times. This indicates that UK has published most of leading articles in RCR and has great influence. Among the top 20 productive countries, only three are developing countries, i.e. China, India, and Brazil.

Fig. 2 shows the annual publications from the 15 most productive countries in RCR. In general, the USA has always stayed ahead in the article production and kept steady growth in publication in RCR. It should be noticed that China has experienced a dramatic growth since 2007, and even surpassed the USA to rank first in 2017. The remaining countries experienced a similar trend of slow growth in the number of publications. This also indicates that the growth of publications in RCR is mainly driven by China and the USA, and that China has a great potential to be the most productive country in future.

3.3. Institution statistics

A total of 1842 institutions have published their research in RCR by August 2017. Table 2 presents the most productive institutions with total publications more than 15. Among them, four institutions are from China, two from the USA, UK, Sweden, and Japan. Meantime, except the Chinese Academy of Sciences, Asian Institute of Technology, Indian Institute Technology, and National Institute Environmental Studies, the others are all universities. University of Utrecht ranked first in terms of the total publications (43), followed by Tsinghua University (40) and Chinese Academy of Sciences (32). Indian Institute Technology ranked the 12th in terms of total publications, but ranked the 1 st with respect to the citations per articles (29.95), which implies the research published by Indian Institute Technology has great influence. Almost all institutions possess a favorable cooperative relationship with other institutions. However, most articles (96.43%) of Asian Institute of Technology published in RCR are single-institute, and few involved inter-institutional collaborated. By contrast, the articles from Beijing Normal University published in RCR are all inter-institutional collaborated, which indicates it possesses a favorable international cooperation.

Table 5
Main keywords used in the RCR (frequency more than 30).

Author keywords	FR (%)	1995–2001		2002–2009		2010–2017	
		FR (%)	R	FR (%)	R	FR (%)	R
Recycling	349 (3.13)	73 (3.78)	1	123 (3.80)	1	152 (2.57)	1
Life cycle assessment	216 (1.94)	22 (1.14)	3	49 (1.51)	2	145 (2.45)	2
Waste management	128 (1.15)	17 (0.88)	4	49 (1.51)	2	62 (1.05)	4
Material flow analysis	101 (0.91)	6 (0.31)	21	28 (0.86)	4	67 (1.13)	3
Municipal solid waste	85 (0.76)	23 (1.19)	2	22 (0.68)	6	40 (0.68)	6
China	59 (0.53)	3 (0.16)	52	10 (0.31)	17	46 (0.78)	5
Sustainability	57 (0.51)	4 (0.21)	36	14 (0.43)	8	39 (0.66)	7
Reuse	53 (0.48)	9 (0.47)	11	25 (0.77)	5	19 (0.32)	13
Environmental impact	39 (0.35)	8 (0.41)	13	11 (0. 34)	13	20 (0.34)	10
Solid waste management	37 (0.33)	11 (0.57)	8	13 (0. 40)	11	13 (0.22)	29
Waste	37 (0.33)	12 (0.62)	6	11 (0. 34)	13	14 (0.24)	25
Landfill	35 (0.31)	15 (0.78)	5	9 (0. 28)	20	11 (0.19)	36
Composting	34 (0.30)	8 (0.41)	13	9 (0. 28)	20	16 (0.27)	21
Substance flow analysis	31 (0.28)	–	–	8 (0.25)	23	23 (0.39)	9
Waste of electric and electronic equipment	30 (0.27)	–	–	6 (0.19)	43	24 (0.41)	8
Wastewater	30 (0.27)	12 (0.62)	6	10 (0.31)	17	8 (0.14)	67

FR (%): Frequency of occurrences and it's percentage; R: rank in different periods.

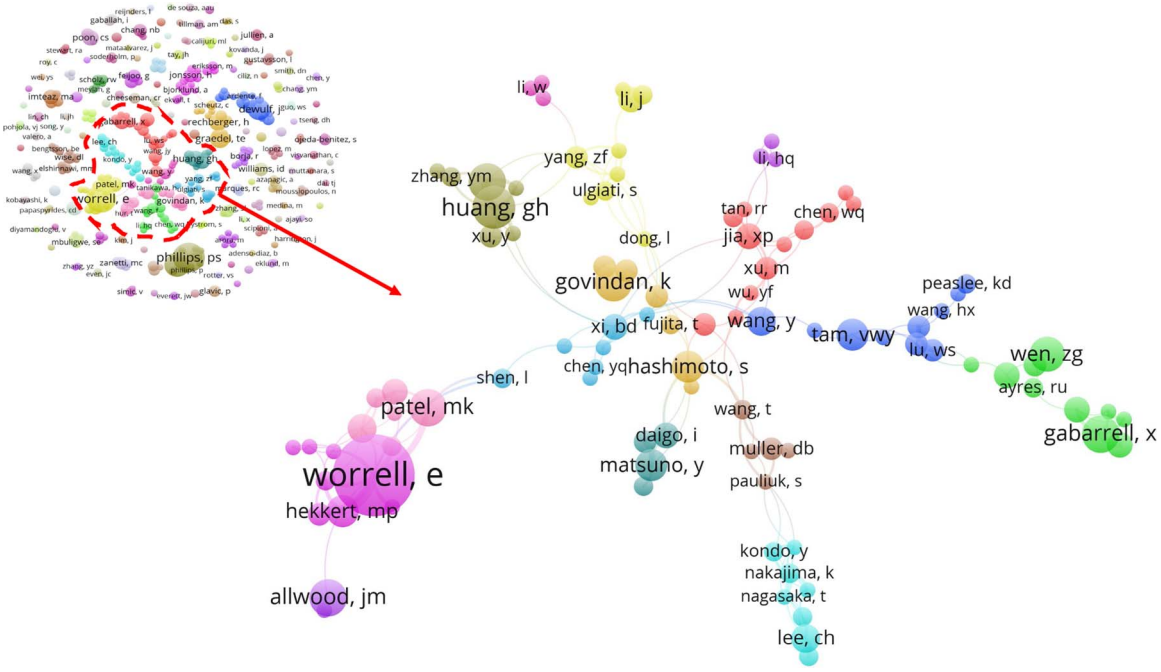

Fig. 3. Co-authorship network of RCR with the threshold of minimum 3 publication.

Table 6
Characteristic of the largest subnetwork of author collaboration in RCR.

Characteristic	Value
Nodes	101
Edges	187
Node degree (avg.)	3.70
Network diameter	7
Path length (avg.)	3.00
Density	0.04

3.4. Author statistics

In total, 6082 authors were acknowledged for making their contributions to this journal. Although most of them have published one or two articles, there are some authors who have made substantial contributions to the journal. Table 3 presents these most productive authors in RCR with a minimum publication level of 10 papers. More than half of these most productive authors are from European countries. The most productive author is Phillips PS from the UK with 33 publications, followed by Worrell E from Netherlands and Read AD from the UK (each with 29 and 23 papers). The research papers of these authors focus on waste management, material efficiency and recycling. For example, Phillips PS devotes to the research on waste management and recycling (Tonglet et al., 2004a; Tonglet et al., 2004b; Phillips et al., 2011). Worrell E contributes a lot in the field of material efficiency and management, and resource conservation (Hekkert et al., 2002; Manda et al., 2015; Bousios and Worrell, 2017). Read AD focuses on landfill, solid waste management, and recycling (Read, 2003; Phillips et al., 2004; Manga et al., 2008). They also have high h-index, which indicates they receive the high influence based on their papers published in the journal. Moreover, it should be noticed that Govindan K ranking ninth in terms of total publication receives the most citations per publication with 42.09, since one of his publications "an analysis of

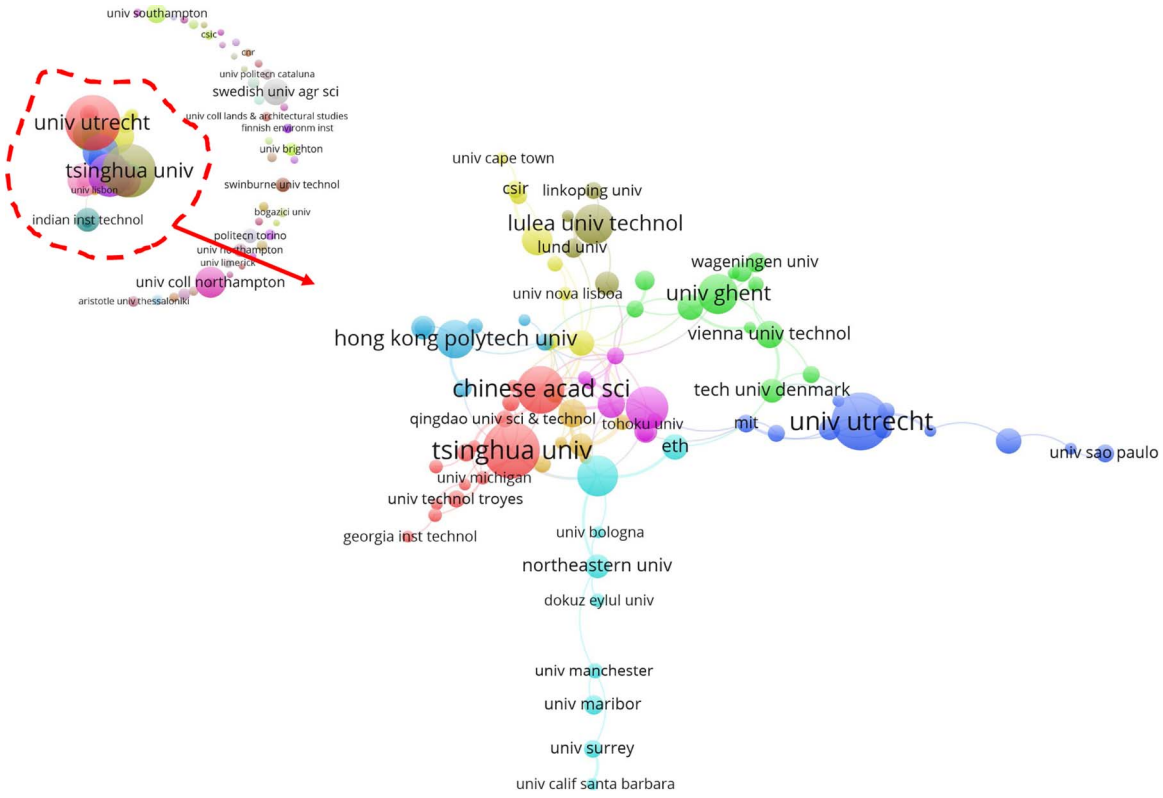

Fig. 4. Co-authorship of institutions publishing in RCR with the threshold of minimum 5 publications.

Table 7
Characteristic of the largest subnetwork of institution collaboration in RCR.

Characteristic	Value
Nodes	83
Edges	150
Node degree (avg.)	3.61
Network diameter	4
Path length (avg.)	1.90
Density	0.04

the divers affecting the implementation of green supply chain management" has very high citations (186 times) so far.

3.5. Article citation

According to WoS, RCR has received 41,899 citations during these 30 years. The citation frequency of publication reflects its academic influence. Table 4 lists the top 15 frequently cited articles in RCR. Among the top 15 frequently cited articles, 3 are from the UK, 2 from the USA and China. Article entitled with "The possibility of in-situ heavy-mental decontamination of polluted soils using crops of metal-accumulating plants", published by Baker et al. (1994) from the UK in 1994, has received the most citations, 417 times. While article "Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations", published by Cherubini et al. in 2009, has the highest citations per year (44.25), which indicates it has great influence. Most highly cited articles listed in Table 4 are published in the 2000s, four published in the nineties, and none in the eighties, which indicates the influence of publications in RCR has improved greatly in recent years. The main highly cited articles focus on waste management, material efficiency, and recycling, but many other topics are also involved in the list, including chemicals, bioenergy, green supply chain management, dyes, and cementing materials.

3.6. Keywords frequency

Author keywords, deliberated by authors, can highlight the core content and theme of article. Thus keywords frequency analysis can be used to reveal the research trends and changes. There were total 6254 keywords listed by authors in RCR. After merging synonymous keywords and congeneric phrases, 5669 keywords were identified ultimately. Among them, 4398 (77.58%) keywords were used only once, 575 (10.14%) keywords were used twice, and 227 (4%) keywords were used three times. A large number of once-only author keywords probably indicate a lack of continuity in research and a wide disparity in research focuses. The main keywords with frequency more than 30 times in RCR are listed in Table 5 to show the mainstream research in RCR. The most frequently used author keyword is "recycling" (349; 3.13%), which is the main topic of RCR journal. "Life cycle assessment" (216; 1.94%) and "waste management" (128; 1.15%) are the second and third most frequently used author keywords.

Since most articles in RCR did not provide author keywords before 1995, the keywords frequency change to identify the major tendency of these studies is analyzed from 1995 to 2017; which is divided into three periods. The frequency of these top 3 keywords remained at a high level during the whole period. It is noticeable that the frequency of some keywords changes greatly. For example; "material flow analysis" and "substance flow analysis" are the key research methods to quantify the resources utilization and environmental impact; and have become popular. Sustainability; recognized as a common global consensus; has also gained greater attention. As one of the fast growing developing countries; China faces serious resources and environmental issues. Thus; specific China problems have been discussed and studied a lot. Besides; with the fast technical innovation; the "waste of electric and electronic equipment" has also been raised up and become a hot topic. By contrast; the rank of keywords "solid waste management"; "waste"; "landfill" and "wastewater" has declined.

In general, recycling, reuse, sustainability, and environmental impact are the hot topics. In the study of waste management, municipal

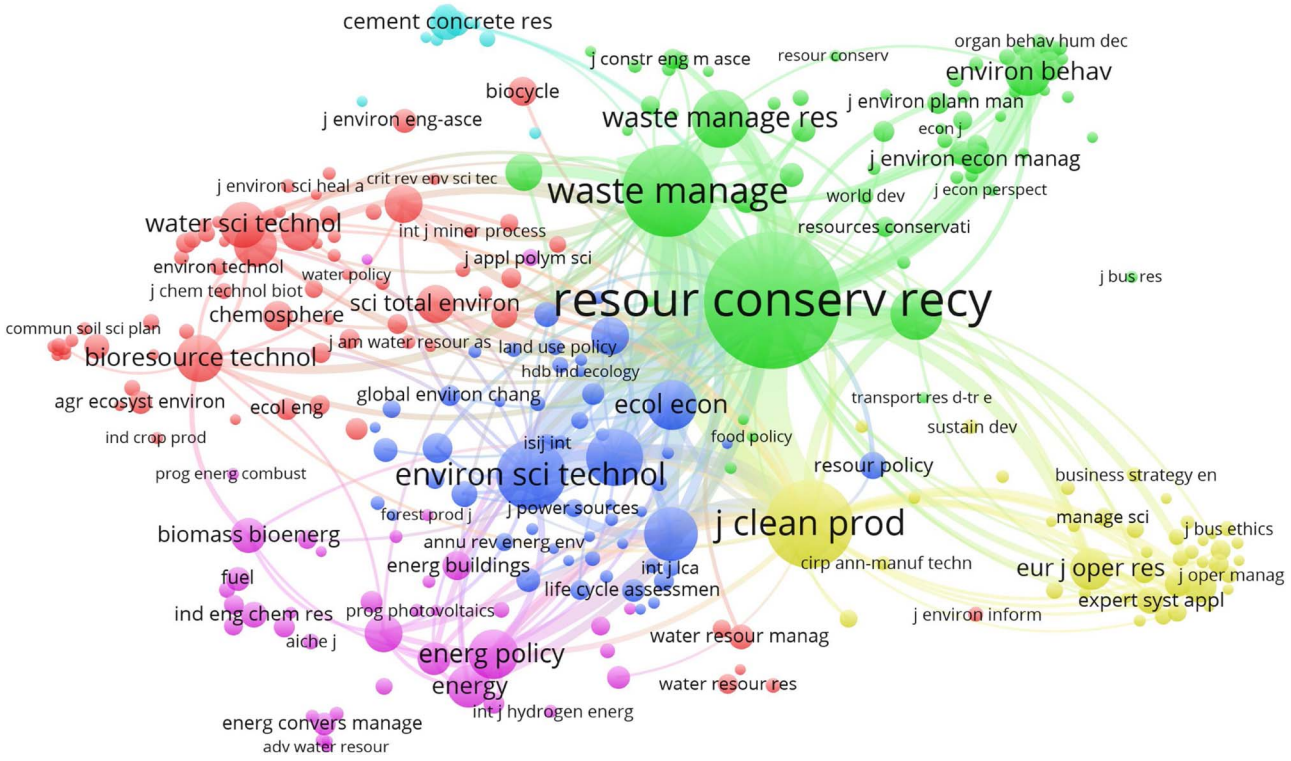

Fig. 5. Journals bibliographic coupling with a threshold of 20 citations and considering the 200 most influential connections.

Table 8
Number of articles from journals citing documents published in RCR (Top 20).

Rank	Source	Citations	Total link strength	IF	Categories
1	Resources, Conservation and Recycling	4290	74383	3.313	Engineering, Environmental; Environmental Sciences
2	Waste Management	1862	36601	4.030	Engineering, Environmental; Environmental Sciences
3	Journal of Cleaner Production	1693	38687	5.715	Green & Sustainable Science & Technology; Engineering, Environmental; Environmental Sciences
4	Environmental Science & Technology	1050	22122	6.198	Engineering, Environmental; Environmental Sciences
5	Waste Management & Research	687	12949	1.803	Engineering, Environmental; Environmental Sciences
6	Journal of Industrial Ecology	663	14586	4.123	Green & Sustainable Science & Technology; Engineering, Environmental; Environmental Sciences
7	International Journal of Life Cycle Assessment	591	11975	3.173	Engineering, Environmental; Environmental Sciences
8	Journal of Environmental Management	550	13794	4.010	Environmental Sciences
9	Energy Policy	514	11089	4.140	Energy & Fuels; Environmental Sciences
10	Ecological Economics	512	9925	2.965	Ecology; Environmental Sciences
11	Bioresource Technology	437	9003	5.651	Agricultural Engineering; Biotechnology & Applied Microbiology; Energy & Fuels
12	Water Science and Technology	429	7986	1.197	Engineering; Environmental; Environmental Sciences; Water Resources
13	Environment and Behavior	418	9745	3.378	Environmental Studies; Psychology; Multidisciplinary
14	Energy	371	8443	4.520	Thermodynamics; Energy & Fuels
15	Water research	365	7471	6.942	Engineering, Environmental; Environmental Sciences; Water Resources
16	European Journal of Operational Research	356	8982	3.297	Operations Research & Management Science
17	Journal of Hazardous Materials	293	6988	6.065	Engineering; Environmental; Engineering, civil; Environmental Sciences
18	Renewable & Sustainable Energy Reviews	291	7617	8.050	Green & Sustainable Science & Technology; Energy & Fuels
19	Science of the Total Environment	285	6633	4.900	Environmental Sciences
20	Desalination	281	5529	5.527	Engineering; Chemical; Water Resources

*IF: the journal impact factor which obtained from Journal Citation Reports (JCR) Science Edition 2016.

solid waste, landfill, waste of electric and electronic equipment, and wastewater are attracting increasing attention in recent years. Besides, from the methodology perspective, life cycle assessment and material flow analysis are popular and frequently utilized.

4. Network analysis

4.1. Collaboration network analysis

The left upper part of Fig. 3 illustrates the collaboration network of the key authors with at least 3 publications in RCR journal. Each node represents an individual author, and the link implies the collaboration relationship. The size of the node demonstrates the author's publications, and the thickness of link indicates the intensity of cooperation. Since the whole collaboration network is decentralized and sparsely connected, in this study, we only focus on the largest subnetwork with 101 nodes to identify the major research communities and academic relations. The main characteristic of this subnetwork is shown in Table 6. Through VOS Viewer software, 15 research communities in the largest subnetwork were identified and differentiated by different

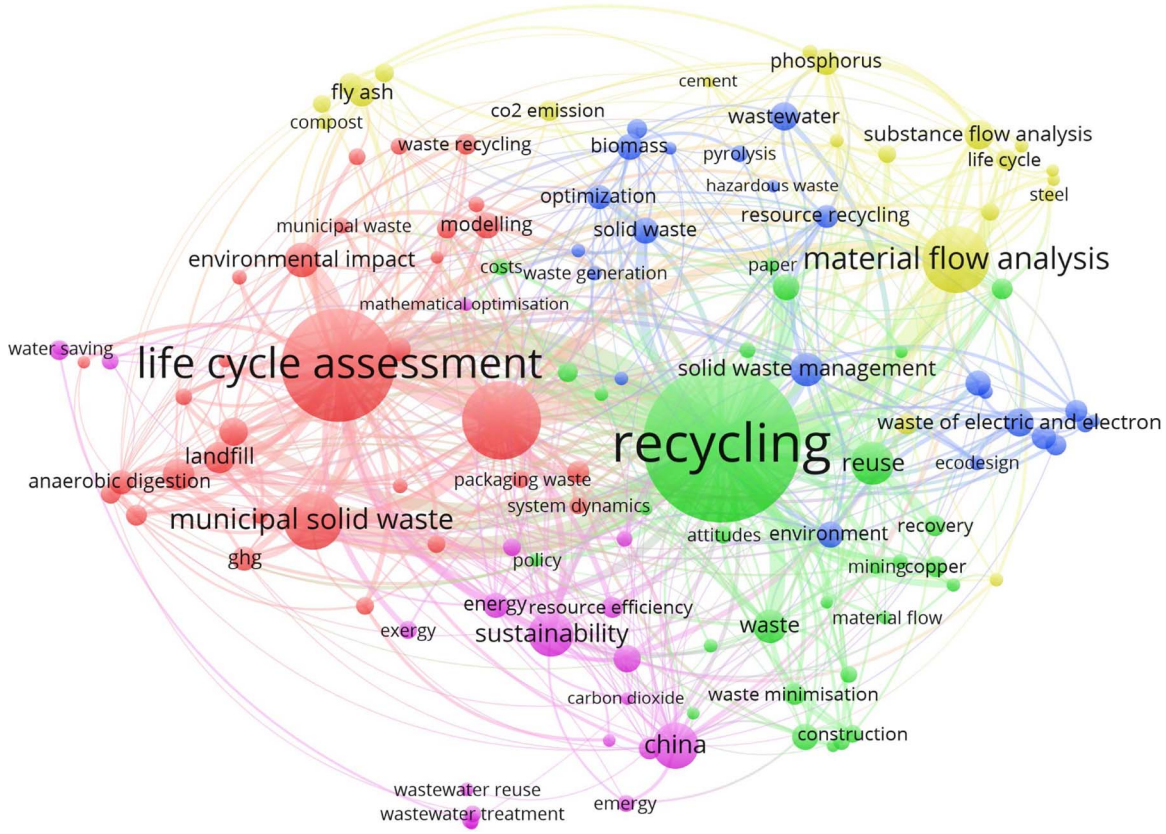

Fig. 6. Keywords co-occurrence network in RCR with a threshold of 10 times and considering the 500 most influential connections.

Table 9
Research topic clusters of RCR journal based on author keywords.

Cluster #	No. of node	Research topic
1	32	life cycle assessment, waste management, environmental impact, landfill, composting, incineration, modeling, GHG
2	29	Recycling, reuse, waste, plastic, sustainable development, waste minimization
3	23	solid waste management, wastewater, waste of electric and electronic equipment, solid waste, Biomass, electronic waste, optimization, resource recycling, reverse logistics
4	21	material flow analysis, substance flow analysis, fly ash, phosphorus, heavy metals, material efficiency
5	20	China, sustainability, energy, resource efficiency, exergy, wastewater

colors. The largest node in the subnetwork is Worrell E from University of Utrecht, Netherlands. His community mainly focuses on sustainability, material flow analysis, environmental impact assessment, and resource recycle (Bousios and Worrell, 2017; Shen et al., 2011; Shen and Qian, 2011; Patel et al., 1998). The second largest node is Huang GH from University of Regina, whose community mainly focuses on optimal decision support for water resources, waste management, and environmental system under uncertainty (Huang et al., 2017; Liu et al., 2014; Sun et al., 2010). The largest cluster in red belongs to Jia XP from Qingdao University of Science & Technology, China, who has active collaborative relationship with other researchers from different institutions.

The left upper part of Fig. 4 illustrates the cooperative relationships of institutions with the threshold of minimum 5 publications. The whole network is consisted of 138 nodes, most of which are scattered. Therefore, we only focus the largest subnetwork with 83 nodes and 150 links, whose main characteristic is presented in Table 7. It can be seen that the largest cluster in red includes 14 nodes, mainly consisted of universities in China and the USA. University of Southern Denmark with 16 links has the most collaborators around the world. The most productive node, University of Utrecht (with node degree 41), has collaborative relationships with MIT, University of Cambridge, University of California, Berkeley, University of Leeds, and University of Geneva. The second productive node, Tsinghua University (with node degree 40), has 8 collaboration partners from the USA and China, including Lawrence Berkeley National Laboratory, Arizona State University, University of Michigan, Yale University, University of Chinese Academy of Science, Chinese Academic of Science, Qingdao University of Science and Technology, and Hong Kong University of Science and Technology.

4.2. Journal co-citation network analysis

If two items are cited together by the third one, there is co-citation relationship between them. Through co-citation analysis, the correlation between the references/journals can be directly identified (Small, 1973). In this study, journal co-citation analysis is used to investigate how other journals connect to RCR. The references cited in RCR are from 30,357 journals. Fig. 5 illustrates the journal co-citation network of RCR considering a minimum threshold of 20 times citations and showing 200 most influential connections. Table 8 lists the top 20 largest nodes, which also represent the most influential journals. It is not surprising that the most cited references from RCR journal itself. Except this, Waste Management (IF = 4.030), Journal of Cleaner

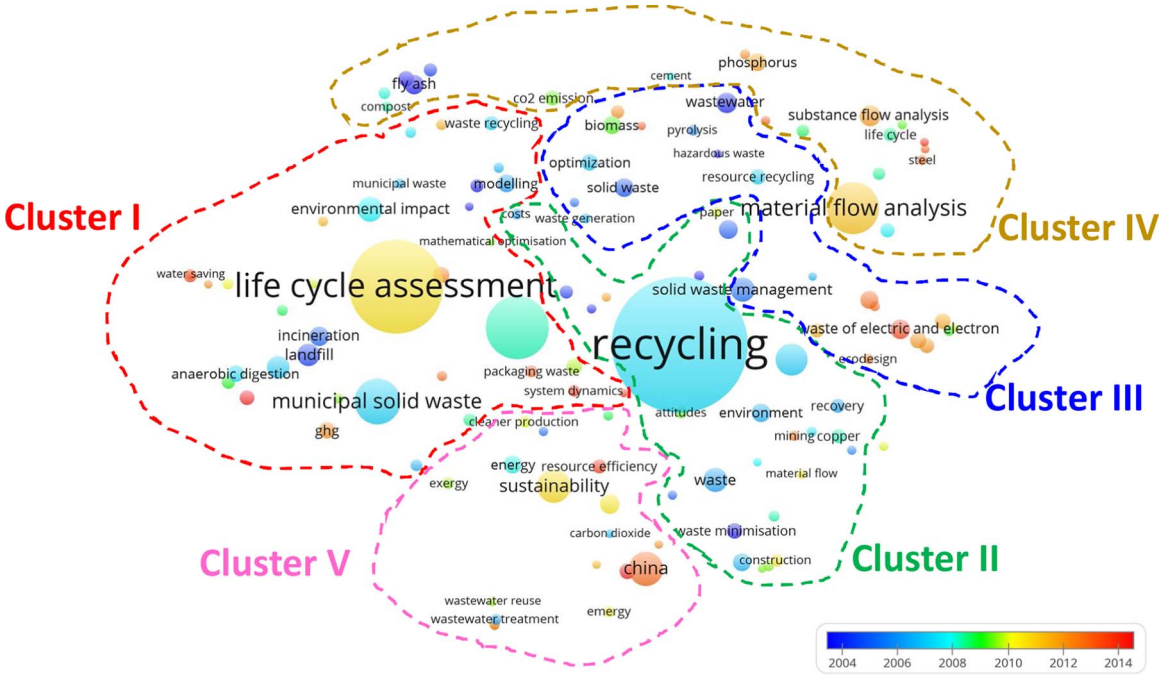

Fig. 7. Main clusters of keywords co-occurrence network with timeline.

Production (IF = 5.715), and Environmental Science & Technology (IF = 6.198) are cited a lot and have great influence on the publication in RCR. Other journals that play an important role include Waste Management & Research, Journal of Industrial Ecology, Ecological Economics, The International Journal of Life Cycle Assessment, Energy Policy, and Journal of Environmental Management. In general, RCR has strong connections with other leading journals in the categories of Environmental Sciences, but also cites journals from other fields, such as Bioresource Technology, Environment and Behavior, Energy, European Journal of Operational Research, and Desalination. This implies that the content in RCR is broad and interdisciplinary.

4.3. Keywords co-occurrence network analysis

Keywords co-occurrence is one of the content analysis methods. In this study, the nodes in the co-occurrence network are author keywords, and the links represent the times of author keywords appeared in a paper simultaneously. It can help to capture co-occurrence relationships of keywords, identify research topic cluster and detect the theme structure change. Co-occurrence network illustrated by visualization tools can provide a clear and direct understanding of the network relationship among different keywords. Since it is difficult and inefficient to analyze the huge co-occurrence network structure of 5669 author keywords. We identify 124 keywords using the threshold of the minimal 10 times appeared in the articles. Fig. 6 depicts the keywords co-occurrence network and clusters. There are five clusters with different colors. Table 9 shows more detailed cluster labels to identify research focuses of each cluster. Cluster I mainly pay more attention on evaluating environmental impact and GHG using life cycle assessment methods. Cluster II and III focus on the study of solid waste, wastewater, waste of electric and electronic equipment. Cluster IV places more emphasis on physical flow analysis methods, where “material flow analysis” and “substance flow analysis” are most frequently keywords. Cluster V mainly studies the sustainability issues, which involve energy, exergy, resource efficiency, and water. Besides, the specific environmental and resource problems in China have been studied a lot.

In addition, to show the topic evolution during the past years, Fig. 7 illustrates the keywords co-occurrence network with the timeline, where the node color represents the average publication year. It can be found that the research topic of Cluster II can be dated back to around 2008. While the other clusters have emerged new topics in recent years. For example, “food waste”, “packaging waste”, and “carbon footprint” in Cluster I, “waste of electric and electronic” in Cluster III, “dynamic material flow analysis”, “in-use stock”, “agriculture” and “steel” in Cluster IV, and “resource efficiency”, “circular economy”, “rainwater harvesting”, “China” in Cluster V are the emerging hot topics in RCR. It is obvious that the size of these red nodes representing recent emerging topics is still small, which indicates that the relative studies in RCR are few, but it has the great potential to grow in future.

5. Conclusion

In this paper, a retrospective evaluation of the RCR journal from a bibliometric perspective was presented for its first 30-year. The bibliometric analysis and network mapping were performed by using information on the authors, afflictions, institutions, citation statistics, and references of total 2368 published articles in RCR. Through this, we identified the most influential authors/institutions/countries, gained insights on the collaboration network, and visualized the evolution of keywords co-occurrence network. In general, this study led to the following detail conclusions:

- RCR has attracted more interest of researchers in worldwide, which is observed the great growth of publications.
- During past 30 years, the USA and China have made great contribution to the growth of publications in RCR. USA has always been the most productive country in RCR. However, China has shown a great potential and growth since 2007 and even surpassed the USA to rank first in 2017.
- University of Utrecht took the leading position of institutions in total articles and total citations. Indian Institute Technology also has great influence with highest citations per article. University of Southern Denmark played a key role in intimate collaboration with other institutions around the world. At the current time, institution collaboration, which may bring research closer to the real world, has become the main trend. Many different opportunities could be clearly available in future.
- Top 5 key authors that play a prominent role in RCR are Phillips PS

from the UK, Worrell E from Netherlands, Read AD from the UK, Dewulf J from Belgium, and Graedel TE from the USA.

- From the author collaboration network analysis, we can find some high productive authors have stable and long-term cooperative relationship, such as Worrell E and Patel MK, Huang GH and Li YP.
- RCR has close relationship and shares common research base with other excellent journals in the field of engineering environmental and environmental sciences, where top 3 are Water Management, Journal of Cleaner Production, and Environmental Science & Technology. Meanwhile, RCR also cited journals in many other fields, indicating its research scope is broad and interdisciplinary.
- The mainstream research of RCR mainly focuses on recycling, waste management, sustainability, and environmental impact. Life cycle assessment, material flow analysis, and substance flow analysis are popular methods used to analyze the environmental impact, GHG emission, and resource efficiency. In addition, “food waste”, “carbon footprint”, “resource efficiency”, “circular economy”, “waste of electric and electronic”, “packaging waste”, and “China” are the emerging hot topics in RCR, with as yet a short history, but with a clear tendency to attract great interest in future.

This study can be seen as a snapshot of the RCR journal, which would help researchers to ascertain general patterns quickly. The readers can gain their interested information from abundant bibliometric data. It may influence the researchers’ selection of future studies since we have presented the main topics of RCR journal for publishing. It would be useful for researchers who chose to publish their studies in it.

There are still some limitations in this study. The data about RCR journal solely from WoS database, which may exclude other citation information. Besides, an interesting avenue for future work would be to conduct a more detailed analysis and bring a more in-depth discussion of the results. For example, the theoretical gaps of the research themes in RCR journal should be further explored. The differences of research themes between RCR and other related journals (e.g. Waste Management, Journal of Cleaner Production, and Environmental Science & Technology) should be studied and compared in future.

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