Circular Economy and Sustainability (2025) 5:441–459
https://doi.org/10.1007/s43615-024-00420-3

ORIGINAL PAPER

Evolution of Waste and Circular Economy: Pre- and Post-Covid-19

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Received: 21 March 2024 / Accepted: 2 August 2024 / Published online: 7 October 2024
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Abstract
Waste generation is a serious problem in both developed and developing countries, exacerbated by Covid-19. In recent years, circular economy is a promising solution to sustainable waste management. Therefore, this study aims to present the evolution of waste and circular economy research before, during and after Covid-19. A bibliometric analysis of 1,149 scientific articles from the Scopus database in July 2023 was conducted, using Microsoft Excel, Vosviewer and biblioshiny. The results were obtained using standard bibliometric indicators such as publication and citation trends, influential countries, institutions, authors and sources, and keyword analysis. The results show that the number of publications and citations in this field has increased tremendously over the years, indicating the importance of knowledge for both developed and developing countries. The main actors in this field are both developed (European) and developing countries/institutions. Many sources of the publications are from reputable journals. Keyword analysis shows that waste management is the main topic before and after Covid-19, with plastic and agricultural waste being more prominent after Covid-19. The findings provide some direction for future research and underline the importance of using appropriate tools to undertake a thorough bibliometric study.

Keywords Bibliometric · Waste · Circular economy · Covid-19

Introduction

Waste production is a by-product of economic and population growth. There is a positive correlation between income and waste generation, with high-income countries producing more waste compared to low-income countries [1]. High-income countries produce a third (34%) of the world's waste, despite accounting for only 16% of the world's population [2, 3]. The problem is even greater in low-income countries, as they become a dumping ground for high-income countries [4]. Moreover, due to their inadequate treatment facilities, more than 90% of their waste is openly dumped or incinerated, leading to serious safety, health

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and environmental problems [5, 6]. As a result, waste is piling up faster in these countries because they are unable to manage it. By 2030, annual global waste generation is expected to reach 2.59 billion tonnes [1] and it is estimated that waste generation will increase by 73% from 2020 levels to 3.88 billion tonnes in 2050 [6].

Different types of waste pose different risks and therefore require special attention. Industrial waste, for example, accounts for about 50% of the total global waste generated [7]. It is almost 18 times larger than municipal waste [3], although many studies (10,603 documents found in Scopus) focus on municipal waste, neglecting the serious environmental impact of industrial waste (6,330 documents). Plastic waste is also considered the biggest threat to the environment as it can pollute waterways and the ecosystem for hundreds or thousands of years [2], as plastic is not biodegradable [8]. Although it accounts for 12% of all waste, our ability to deal with this waste is already overwhelmed as most of it ends up in landfill and only 9% of the 9 billion tonnes of plastic produced has been recycled [8]. Plastic can also enter the human body through food and water consumption or through respiration [9]. Indeed, microplastics have been found in human blood [10]. If current production trends continue, plastic waste is estimated to triple by 2060 [11].

In terms of quantity, annual production of waste electrical and electronic equipment (e-waste) is smaller in volume (53.6 million tonnes) than plastic waste (300 million tonnes), but it is the fastest growing waste stream in the world, with annual growth of 3– 5% compared to 2% for plastic [12]. If nothing changes, e-waste is expected to double [13]. E-waste makes up 70% of toxic waste in landfill [14]. Yet e-waste contains valuable minerals such as copper, silver and gold. The value of these minerals is approximately $62.5 billion globally, which is higher than the annual GDP of most countries [15]. However, the recycling rate is low [14] and is around 17% [12, 16]. It is not easy to extend their life because the technologies used to extract the mineral are costly and inefficient [14]. Moreover, they are designed for a specific useful life and are not meant to be repaired or reused, thus enabling the sale of new products [16].

In addition to the above waste, the problem of food waste is much more serious than we thought, with more than one-third of the food produced globally wasted or lost each year [17, 18]. Not only does food waste contribute to more than 1.3 billion tonnes of waste per year [19, 20], the rotting food also causes 3.3 billion tonnes of greenhouse gases and costs us scarce water and land resources [19, 21]. If the trend of food waste could be reversed, the food could feed 2 billion people in the world [22], which is more than enough to feed all the hungry people in the world [23]. Food loss and waste are not only associated with social and environmental problems, but also represent a significant economic loss [20, 24], costing the world $936 billion per year [25].

The presence of Covid-19 has given additional load to the existing problem and impaired progress towards achieving the sustainable goals promoted by the United Nations [26]. Covid-19 has led to an increase in healthcare/medical waste, such as used syringes, vaccine bottles, test kits and face masks [27]. Plastic waste is also getting worse [28] as stay-at-home policies increase the use of disposable packaging of purchased produce and takeaway food [29]. Mountains of local produce such as onions, eggs and milk are wasted due to labour restrictions, transport restrictions and restaurant closures [28]. Import restrictions have led to export producers producing products too large for the local market to absorb, leading to a significant increase in organic waste [29]. Worse, communities have stopped recycling, making local waste obvious [30]. In the post-Covid19 era, the trend towards online shopping continues [31] and therefore requires proper waste management to address the problem.

The circular economy has been introduced as one of the possible solutions to reduce the current waste problem. It is gaining popularity in many countries, especially in Europe and China [32], due to its promising environmental, economic and social impacts. Therefore, the aim of this study is generally to analyse the various studies that have been carried out in the context of the circular economy and waste management by means of a bibliometric analysis.

Literature Review

The circular economy is a regenerative system in which resources are minimised either as inputs to production or as waste from consumption through life extension, repair, maintenance, reuse, recovery, refurbishment and recycling [33]. In other words, it focuses on closing the loop of material and energy flows while emitting as little waste as possible into the environment [34] by preserving parts or products for as long as possible so that they retain their maximum value and quality [35–38]. To achieve this goal, the products designed need to be high quality, durable and long-lasting so that they can reduce consumption [39]. At the end of a product's life cycle, the circular economy emphasises the 4Rs approach: reduce, reuse, recycle and recover [36, 40].

Research on circular economy, its concept and applications for waste reduction has increased enormously. In recent years, many studies have conducted a bibliometric analysis on waste and the circular economy. However, many of the studies [32, 41–46] used a small number of articles, which is less than 500, which does not justify the use of the bibliometric method [47], or/and overlooked on the data cleaning, a critical step in bibliometric analysis [48] as it is time and resource consuming [49]. When the dataset is too small, bibliometric analysis does not make sense [50] and it is difficult to form a reasonable research topic or to identify the emerging trends of a topic. Moreover, the accuracy of the results depends on the accuracy of the data, so impure data can lead to inaccurate results [51].

In addition, some studies have looked at the circular economy literature from a narrow perspective, focusing specifically on a particular country. For example, Cui and Zhang [52] examined policy development in China, Martinho and Mourão [43] focused on the European Union, while Mhlanga et al. [42] examined studies from Africa. According to Donthu et al. [47], bibliometric analysis should be used if the scope of the review is broad and not too specific. There are also studies that are exempt from the problems mentioned above, but their coverage only extends to 2022. In particular, Goyal et al. [53] conducted a bibliometric analysis on the general concept of circular economy. However, many researchers such as Razmjooei et al. [54], Theeraworawit et al. [55], Morales and Belmonte-Ureña [56] and Schöggl et al. [57] were interested in looking at the circular economy from a sustainability perspective, as the circular economy was introduced to achieve sustainability in the management of scarce resources. Similarly, Ruiz-Real et al. [58] examined the circular economy and the environment, as the intensive use of resources affects environmental quality.

Therefore, this study aims to analyse waste and circular economy in a general form with a large sample size, focusing on the pre- and post-COVID-19 period. In particular, five research questions were developed to guide the research process:

i. What are the research trends of waste and circular economy?
ii. What are the most productive countries and their collaboration network, and the most prolific institution in waste and circular economy research?
iii. What are the most influential articles, authors and sources?
iv. What are the most common keywords and keywords co-occurrence, and how have they evolved in the pre-and post-Covid-19?

The present study differs from previous bibliometric studies in many ways. First, a proper data cleaning process was carried out using both Microsoft Excel and OpenRefine to ensure the quality of the datasets. Second, it examines the impact of Covid-19 and describes how the research themes have evolved. Despite its impact on sustainability and the implementation of the circular economy, Covid1-9 is not covered, with the exception of one study [55], although it was briefly addressed. Finally, future directions for the waste and circular economy are identified, particularly following the damage caused by Covid-19. This paper is structured as follows. Section 2 explains the methods used to review the previous studies. Section 3 presents the results and discussion to answer the five research questions. Section 4 concludes the paper with some recommendations for the future.

Methods

Bibliometric analysis is a quantitative study that analyses large amounts of scientific data. Two main methods used were performance analysis and science mapping. Performance analysis, a descriptive study, evaluates the contributions of different research constituents (e.g.: authors, institutions, countries, etc.) in a particular field of study [47]. This analysis applies citation- and publication-related metrics such as total number of publications, total number of citations, average number of citations, and so on. Meanwhile, scientific mapping was used to analyse the relationships among different research constituents. The method of co-word analysis was utilised to determine the content of the publication by examining the keywords used by the authors. Science mapping was further supported by network analysis to deepen the discussion and provide more clarity through the use of visualisation approaches.

Data Collection The online database Scopus was used because of its advantages over other databases such as Web of Science (WOS), Google Scholar (GS) and PubMed. Scopus is the largest abstract and citation database in the world [59]. Compared to the other three databases, Scopus has a large number of publications that are useful for both bibliographic analysis and keyword searches [60]. In terms of citation analysis, Scopus has twenty per cent higher coverage compared to WOS [61]. GS has relatively low-quality data that is unsuitable for bibliometric analysis in terms of quality control and retrieval [62]. PubMed, on the other hand, is widely used for scientific studies [60]. The article selection included all forms of publications such as journals, books and conference papers. This study is divided into two periods: the pre-Covid19 era (before to 2019) and the post-Covid19 era (starting from 2020).

Search Strategy Two keywords "circular economy" and "waste" were used to search the titles of the publications. The keywords and search strings were found as follows: TITLE ("circular economy" AND "waste"). A total of 1,149 research documents between 2007 and 2024 were found, which included the author's name, document title, year, source title, affiliation, correspondence address, author keywords, index keywords and references. Figure 1 shows the search query flow in the Scopus database.

Data Cleaning and Harmonisation In the cleaning process, the author's name, affiliation, keywords and index keywords must be standardised and harmonised. Some authors use different names with different abbreviations in their publications [63]. Some have multiple ID numbers and are treated as different people by the bibliometric tools. Some databases only provide the authors' first and last names, and many authors may use similar information [51]. They are then considered to be the same person, even though they are not, which

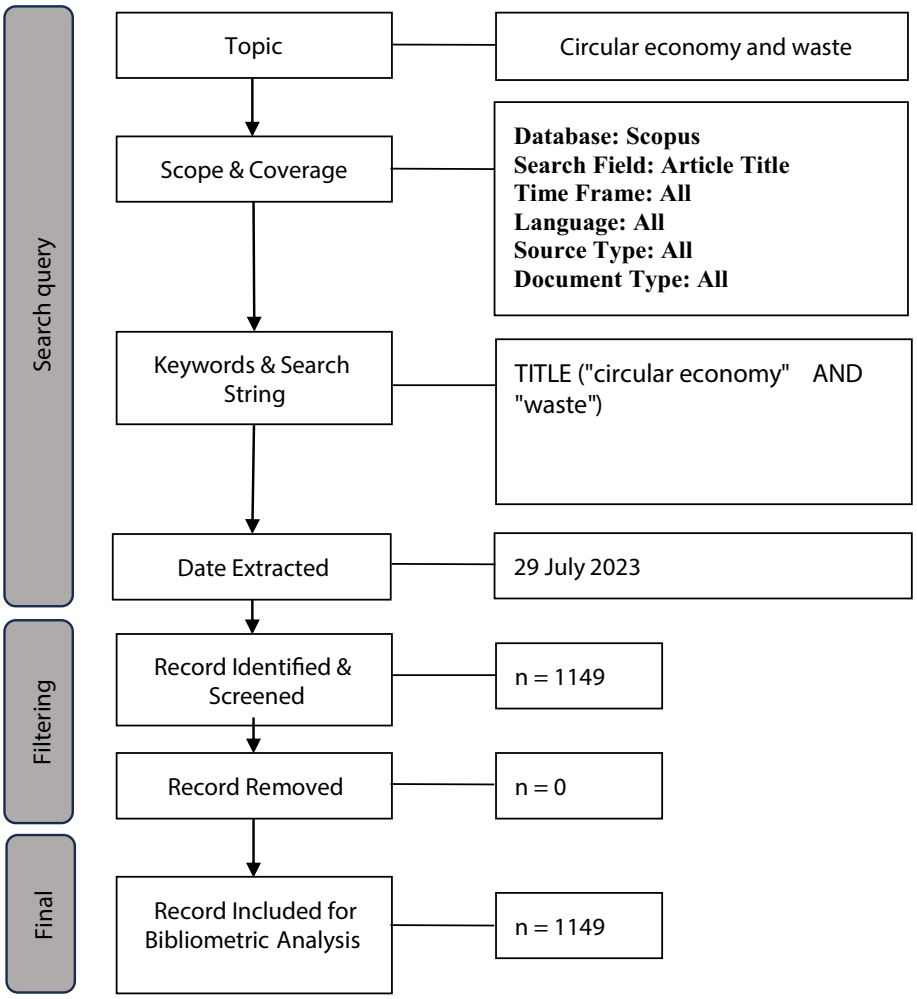

Fig. 1 Flow diagram of search query process

requires data cleaning. The situation is similar with affiliations. Since they are given by the authors, they can write the name of the affiliation as they wish. For example, the name of the university can be written in their own language or translated into English, or an abbreviation is used. They are then seen as different institutions, although they are actually the same. Some also write the name of their department or faculty instead of the name of their university [51].

There are also frequent spelling mistakes made by the authors when they wrote their affiliation. It is therefore necessary to harmonise the affiliation before carrying out the analysis. Harmonisation should also be done for authors and indexed keywords as some authors use British or American English, soma singular or plural, while some use abbreviations. The data was cleaned using both Microsoft Excel and OpenRefine software. With a large data set, the tendency to miss errors is high, so software is needed to reduce the problems. "Facet", an OpenRefine cleaning tool that is sorted alphabetically, was used to edit and harmonise the data. In addition, "cluster" is another tool that was used to automatically clean and harmonise the data using different "keying functions" (fingerprint, n-gramme fingerprint, meta-phone3, cologne phonetic, daitch-mokotoff and both-morse) and methods (key collision and nearest neighbour).

Tools and Data Analysis Microsoft Excel was used to analyse the research trend, the most productive countries, institutions, articles and authors. This study also uses VOSviewer to visualise the country collaboration network, applying the overlay visualisation to show the evolution of country collaboration. The overlay visualisation is also used to illustrate the evolution of keyword co-occurrence. In addition, biblioshiny is utilised to present the most relevant sources in the field, the most frequently used keywords by authors and the thematic map for pre-and-post Covid-19.

Results and Discussion

Research Trends

The research trend (measured by the number of publications and citations) shows whether the topic is gaining popularity among scholars or is no longer important, which may be an indication for others to study in this area or not. Figure 2 shows the development of publications and citations on the topic of circular economy in relation to the waste problem for the period from 2007 to 2024. It shows that the total number of publications has increased exponentially over the year, indicating the importance and relevance of the topic to the current situation. The highest number of citations was in 2020 and the lowest between 2007 and 2009. The year 2023 shows a lower number of publications as this study was conducted on 29 July 2023.

In the early years (2007 – 2015), there were few studies in this area and only a few publications per year. Although China passed the Circular Economy Promotion Law in 2009, the concept only focused on improving resource productivity, especially energy, as Chinese industries are largely dependent on energy [64]. Therefore, the narrow scope of

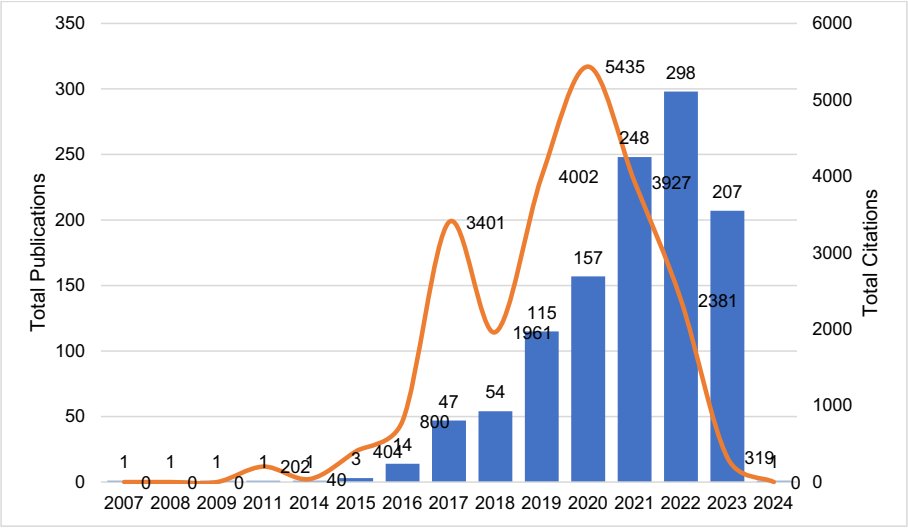

Fig. 2 Trend of publication and citation

the circular economy may not be attractive to many academic communities. In 2012, the most important report on the circular economy, cited in 796 articles, was published by the Ellen MacArthur Foundation [65]. However, it has not yet been adopted by policymakers or industry, as the toolkit "Delivering the Circular Economy: A Toolkit for Policymakers" [66], which aims to support the transition to a circular economy, was published later in 2015.

From 2016 to 2018, the interest of the academic community increased after the European Union adopted a Circular Economy Action Plan in 2015 [67], which led to a significant increase in scientific production in the following 6 years [32]. In addition, China has revised its Circular Economy Promotion Law (2017) to the circularity of industrial system, which is of greater importance to many countries around the world. In addition, China has included the importance of the circular economy as a national policy in its 13th Five–Year Plan (2016—2020) [64].

As of 2019, the topic of circular economy has gained importance in research, especially in Europe, in order to achieve the Sustainable Development Goals (SDGs) introduced by the United Nations in 2015 [68]. In particular, Goal 12, which aims to ensure sustainable consumption and production, focuses on waste management, such as reducing food waste and losses along production and supply chains, including post-harvest losses (Goal 12.3), managing chemicals and all wastes throughout their life cycle to minimise their negative impacts on human health and the environment (Goal 12.4), and reducing waste generation through prevention, reduction, recycling and reuse (Goal 12.5). The adoption of the SDGs as part of the 2030 Agenda, which prioritises the use of the circular economy as a tool to achieve the SDGs [55], is one of the drivers of the increase in overall publications.

According to scientists at NASA, 2020 was the second warmest year on record in which the annual target temperature was higher than the 1981–2010 average [69], making the fight against pollution and its impact on climate change increasingly important. In conjunction

with the UN SDGs on climate change (Goal 13), action in the form of plans, strategies and policies led to more publications on waste-related issues [41]. A greater number of publications was observed in 2020 [32] and after Covid-19, when large amounts of health and plastic waste were generated, which promoted the development of efficient strategies for a sustainable waste management system [41].

Most Productive Countries and their Collaboration Network and most Prolific Institutions

The most productive countries/institutions reflect countries or institutions that promote sustainability or are more concerned with environmental issues, especially with regard to waste. Table 1 shows the most productive countries in publishing articles on waste and circular economy. Among the top ten countries, India is the most prolific with 216 articles accounting for 18.8% of the total publications, followed by Italy (16.3%), the United Kingdom (13.4%) and China (11.8%). The number of publications and total number of citations is expected to be high in India, China and European countries, as governments have committed to include the circular economy in their policies [64, 67].

In addition, China (30%), followed by the United States (15%), the European Union (9%) and India (7%) are the largest greenhouse gases emitters in the world [70]. Therefore, their interest in the circular economy is justified. It can also be observed that besides China and India, developing countries such as Brazil and Malaysia are also showing great interest in this area. The reason for this could be that these countries produce many industrial products and therefore produce more waste, so they need to reduce the environmental impact with a more sustainable method.

Moreover, Fig. 3 shows that India, China, United Kingdom (UK) and Italy collaborated with many countries. The UK works closely with European countries as well as with Australia and China, while India and China tend to cooperate with developing countries. The figure shows that countries like the United States, Sweden, Argentina, etc. are among the pioneers in this field (shown in purple colour). Later, Italy, UK, China and Spain also focused on the circular economy (represented in dark green). In recent years, developing

Table 1 Most productive countries

Country	TP	TC	NCP	C/P	C/CP	h-index
India	216	4449	156	20.60	28.52	33
Italy	187	4590	161	24.55	28.51	37
United Kingdom	154	4830	121	31.36	39.92	33
China	136	5075	121	37.32	41.94	42
Spain	132	3237	116	24.52	27.91	31
Brazil	121	1453	87	12.01	16.70	21
Poland	95	1361	73	14.33	18.64	19
Australia	79	2037	65	25.78	31.34	24
United States	71	2525	53	35.56	47.64	23
Malaysia	69	969	53	14.04	18.28	19

TP total publications, *TC* total citations, *NCP* no of cited publications, *C/P* average citations per publication, *C/CP* average citations per cited publication

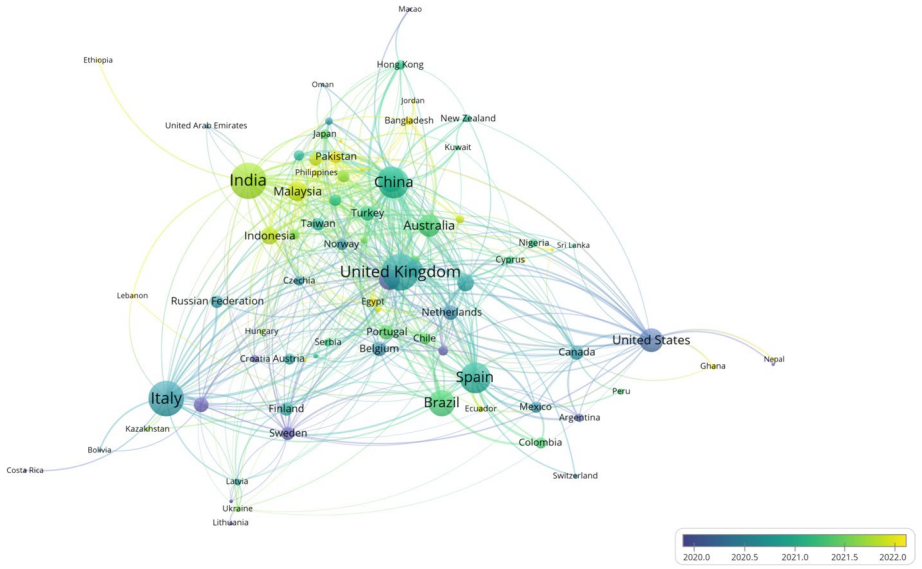

Fig. 3 VOSviewer visualization of country collaboration network

countries like India, Malaysia, Indonesia, the Philippines, Pakistan, Bangladesh and Egypt have ventured into the circular economy. The possible reason for this is that these countries have inadequate waste management facilities, most of which end up in landfills [71]. Therefore, they are looking for a sustainable solution [6].

Table 2 lists the ten most active institutions for the 114 articles published, representing 10% of the total documents related to waste and circular economy research. As expected, half of the most productive institutions are dominated by European countries, such as the Silesian University of Technology (Poland), the Politecnico di Milano and the University of Trento (Italy), the National Technical University of Athens and the Aristotle University

Table 2 Most prolific institutions

Institution	TP	TC	NCP	C/P	C/CP	h-index
Universiti Teknologi Malaysia	15	398	14	26.53	28.43	10
Silesian University of Technology	15	83	12	5.53	6.92	5
Politecnico di Milano	12	377	12	31.42	31.42	8
University of Leeds	12	526	12	43.83	43.83	8
National University of Singapore	11	552	11	50.18	50.18	9
National Technical University of Athens	11	98	8	8.91	12.25	3
Federal University of Santa Catarina	10	54	9	5.40	6.00	3
The University of Queensland	10	399	8	39.90	49.88	7
University of Trento	9	329	8	36.56	41.13	5
Aristotle University of Thessaloniki	9	234	9	26.00	26.00	5

TP total publications, *TC* total citations, *NCP* no of cited publications, *C/P* average citations per publication, *C/CP* average citations per cited publication

of Thessaloniki (Greece). However, it is a surprise that Universiti Teknologi Malaysia comes first in terms of total number of publications and total number of citations. This could probably because the Malaysian government is promoting the circular economy by including it in its national policy (12th Malaysia Plan), leading to more publications in this field due to the availability of research grants.

Most Influential Articles, Authors and Sources

The information on the most influential articles and authors shows the main sources referred to by many scholars, reflecting the high quality and usefulness of the content of the articles. The most popular sources are beneficial for those who want to publish their articles in the field. Table 3 shows the most influential articles, with the most cited article coming from Rostkowski et al. (2017), followed by Huang et al. (2015), Pant et al. (2016) and so on. The first two top papers addressed how waste can be converted into energy in developed and developing countries, which is beneficial to many countries around the world. In addition, many of these articles have been published in prestigious journals such as Journal of Cleaner Production, Bioresource Technology and Resources, Conservation and Recycling.

The most influential authors in terms of i) total number of publications and ii) total number of citations are listed in Table 4. The highest number of publications are by Rada E C. and Zorpas A A. (8 papers), followed by Othman, M H D., Dubey, B K., Kurniawan, T A., Goh, H H., and Hao, J L. (7 papers). The most cited authors are fifteen authors who wrote an article entitled "Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe" with 501 citations.

Figure 4 shows the top ten journals publishing in the field of circular economy related to waste issues. Journal of Cleaner Production has the highest number of publications, 101 documents, followed by Sustainability (83), Science of the total environment (34), etc. Most of these journals are higher ranked journals (Q1), with the exception of the IOP Conference Series and the Handbook of Solid Waste Management.

Most Trending Keywords, Themes and their Evolution in the Pre-and Post-Covid-19

Keywords reveal the current and emerging topic in the field [54] and help identify future research trends and directions [72, 73]. In general, the most common keywords used by authors in the period before and after Covid19 are waste management, recycling and circular economy (Table 5). The order of the keywords is slightly different in both periods, depending on the need of the research at that time. For example, plastic waste jumps to third place because the consumption of single-use products [32] through online shopping [31] increased the amount of packaging waste after the Covid19 pandemic. Nevertheless, concerns about the issues are the same in both periods, with the exception of agriculture, as import restrictions during Covid-19 led to an increase in agricultural, environmental and food waste [29]. It is therefore to be expected that more research will be conducted in this area in the post-Covid era.

The results of the VOSviewer show that the keywords that occur most frequently together are circular economy, waste management and recycling (Fig. 5). It was found that in the early studies on circular economy, keywords such as material flow analysis, life cycle assessment, industrial ecology, sorting, incineration and biorefinery were among the most frequently occurring keywords (highlighted in purple). The introduction of the basic

Table 3 Most influential articles

Author(s)	Title	Source Title	TC	C/Y
Rostkowski P., Thorne R., Krzyżyńska R., Al-Mansour F., López I., Colón J., Ponsá S., Vlasopoulos A., Anguilano L., Czajczyńska D., Jouhara H., Katsou E., Malinauskaite J., Stanchev P., Spencer N. (2017)	Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe	Energy	501	71.57
Huang I., Liu I., Chiang P., Pan S., Chang E., Du M.A. (2015)	Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review	Journal of Cleaner Production	389	43.22
Pant D., Khan M., Syamsiro M., Ismail I., Miandad R., Nizami A., Rehan M., Shahzad K., Waqas M., Ouda O., Naqvi M. (2017)	Waste biorefineries: Enabling circular economies in developing countries	Bioresource Technology	327	46.71
Rutqvist J., Lacy P. (2016)	Waste to wealth: The circular economy advantage	Waste to Wealth: The Circular Economy Advantage	277	34.63
Ordoñez I., Singh J. (2016)	Resource recovery from post-consumer waste: important lessons for the upcoming circular economy	Journal of Cleaner Production	269	33.63
Duan Y., Liu T., Zhang Z., Awasthi M.K., Awasthi S.K., Sarsaiya S., Chen H., Kumar A., Kumar S., Singh E., Ravindran B., Wainaina S., Taherzadeh M.J. (2020)	Resource recovery and circular economy from organic solid waste using aerobic and anaerobic digestion technologies	Bioresource Technology	264	66.00
Dewulf J., Huysman S., Ragaert K., De Meester S., De Schaepmeester J. (2017)	Performance indicators for a circular economy: A case study on post-industrial plastic waste	Resources, Conservation and Recycling	242	34.57
Govindan K., Murniningsih R., Setiawan A., Fatimah Y.A. (2020)	Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia	Journal of Cleaner Production	218	54.50
Akkerman R., Bramer E., Brem G., Dierkes W., Naqvi S.R., Prabhakara H.M. (2018)	A critical review on recycling of end-of-life carbon fibre/glass fibre reinforced composites waste using pyrolysis towards a circular economy	Resources, Conservation and Recycling	216	36.00
Mahpour A. (2018)	Prioritizing barriers to adopt circular economy in construction and demolition waste management	Resources, Conservation and Recycling	210	35.00

TC Total citation, *C/Y* citation per year

Table 4 Most influential authors

i) By no. of publications (TP)								
Author's Name	TP	NCP	TC	C/P	C/CP	h-index	g-index	m-index
Rada, E C	**8**	7	323	40.38	46.14	5	1	0.714
Zorpas, A A	**8**	8	216	27	27	6	1	1.2
Othman, M H D	**7**	7	294	42	42	7	0	2.333
Dubey, B K	**7**	7	222	31.71	31.71	5	0	0.833
Kurniawan, T A	**7**	7	294	42	42	7	0	2.333
Goh, H H	**7**	7	294	42	42	7	0	2.333
Hao, J L	**7**	6	176	25.14	29.33	5	1	1
Velis, C A	**6**	6	407	67.83	67.83	4	1	0.5
Ramakrishna, S	**6**	6	349	58.17	58.17	5	0	1
Kazançoğlu, Y	**5**	5	57	11.4	11.4	4	0	1.333
ii) By no. of citation (TC)								
Author's Name	TC	TP	NCP	C/P	C/CP	h-index	g-index	m-index
Czajczyńska, D	**501**	1	1	501	501	1	0	0.143
Spencer, N	**501**	1	1	501	501	1	0	0.143
Malinauskaite, J	**501**	1	1	501	501	1	0	0.143
Al-Mansour, F	**501**	1	1	501	501	1	0	0.143
Anguilano, L	**501**	1	1	501	501	1	0	0.143
López, I.C	**501**	1	1	501	501	1	0	0.143
Jouhara, H	**501**	1	1	501	501	1	0	0.143
Colón, J	**501**	1	1	501	501	1	0	0.143
Stanchev, P	**501**	1	1	501	501	1	0	0.143
Ponsá, S	**501**	1	1	501	501	1	0	0.143
Vlasopoulos, A	**501**	1	1	501	501	1	0	0.143
Katsou, E	**501**	1	1	501	501	1	0	0.143
Rostkowski, P	**501**	1	1	501	501	1	0	0.143
Thorne, R.J	**501**	1	1	501	501	1	0	0.143
Krzyżyńska, R	**501**	1	1	501	501	1	0	0.143

TP total publications, *NCP* no of cited publications, *TC* total citations, *C/P* average citations per publication *C/CP* average citations per cited publication

concepts of the circular economy was frequently discussed during this period, as the circular economy was newly introduced due to its promising impact on the environment. Incineration and biorefinery, which are alternatives to landfill, were also discussed as they can reduce the amount of waste and convert it into energy with little environmental impact [44].

The research focus was then shifted to organic waste, agriculture, food waste, packaging, recycling, valorisation, biogas and biowaste. Stay-at-home policies, use of disposable products, panic buying and import restrictions led to an increase in different types of waste, so more focus was given to recycling plastic packaging and waste through valorisation, biogas and bio-waste. However, in the post-Covid-19 era, keywords such as Covid-19, medical waste, environmental impact, clean production, barriers, strategy and management became the emerging terms (highlighted in yellow). Scholars actively discussed these issues as Covid-19 produced large amounts of waste and affected environmental quality

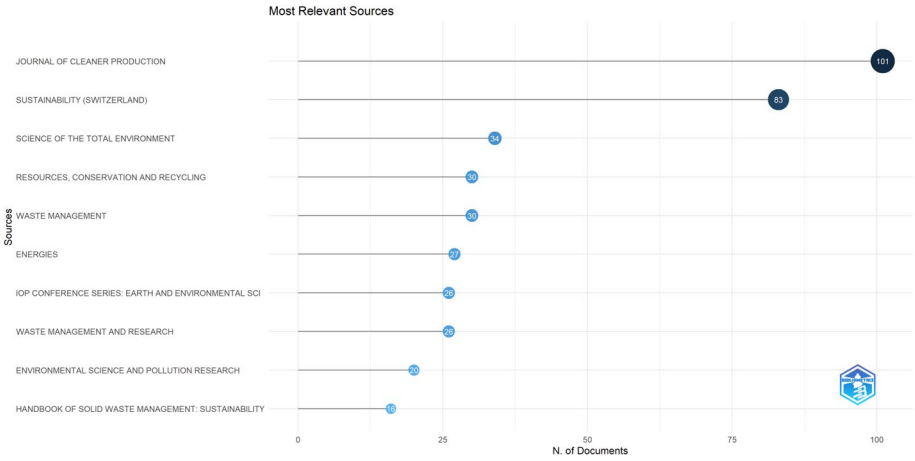

Fig. 4 Most relevant sources

[29]. Many barriers and challenges to integrating the circular economy into production were identified, hence the need for proper management and strategies.

Limitations

Like any other research publication, this study has some limitations. First, this study relies primarily on the Scopus database and therefore may not cover all relevant publications in the field. To solve this problem, future studies could use several databases to obtain a comprehensive result. Furthermore, the bibliometric study only provides quantitative findings and does not cover the qualitative aspects needed for a detailed understanding of the topic. Therefore, future research could complement the bibliometric study with other research methods, such as a systematic literature review.

Table 5 Most trending keywords

Pre-Covid19		Post-Covid19	
Words	Freq	Words	Freq
Waste management	131	Waste management	495
Recycling	114	Circular economy	379
Circular economy	103	Recycling	365
Energy	54	Plastics	209
Solid Waste	49	Energy	191
Waste	48	Sustainable development	187
Municipal solid waste	42	Solid Waste	175
Plastics	37	Agriculture	166
Sustainable development	37	Municipal solid waste	151
Waste treatment	29	Waste	145

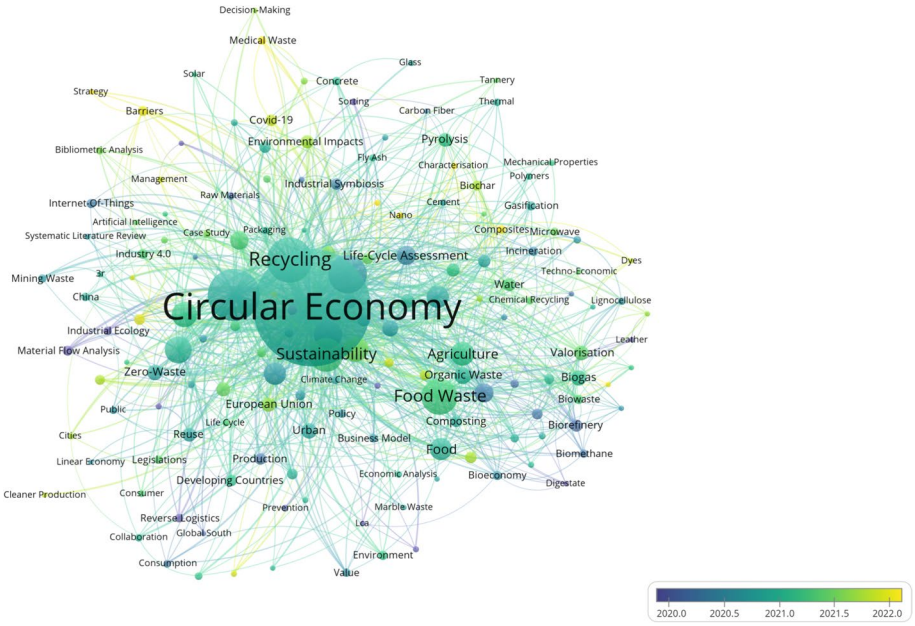

Fig. 5 VOSviewer visualization of keywords co-occurance

Conclusion & Recommendations

The present study has some knowledge implications. By analysing research trends and identifying the most influential countries, institutions, articles, keywords and topics, this study provides a synthesis of existing research on waste and circular economy. Firstly, the research trends show that the circular economy is of great interest to many parties such as government, industries and households, as evidenced by the exponential increase in annual publications. Many countries are embracing and implementing the circular economy in managing waste in response to the United Nations SDGs. More research is expected to be conducted in this area as the problem of waste generation from various sources such as industrial waste, e-waste, food waste, municipal waste, etc. is increasing especially in the post Covid-19 era and therefore a sustainable solution via circular economy is required to address the problem.

Secondly, the most productive countries show that about one third of the countries are developing countries (China, India and Malaysia), and many other developing countries such as Indonesia, Pakistan, Bangladesh, etc. are showing interest in the circular economy; therefore, it is expected that more research will come from these countries. Also, about 70% of the most productive countries include circular economy in their national policies, which encourages researchers to write more articles in this area to reflect the concern emphasised by their government. Additionally, collaboration between countries is increasing, indicating the importance and relevance of the circular economy and waste generation in these countries. Moreover, Russia is one of the largest emitters of greenhouse gases after India [70], but the number of publications on this topic is extremely low (about 1.6 articles/year). Therefore, Russia should be more proactive in promoting the circular economy to its citizens to ensure sustainable practises. In countries such as Africa and

North America, the number of publications is also lower, suggesting that there is still room for more studies. The high cost of waste treatment technologies is not only a problem for low-income countries such as Africa, but also in North America [44]. Future research on government intervention/incentives or possible cooperation in the form of financial support from external parties such as NGOs could be conducted.

Third, the most popular institutions show that European universities are actively involved in research on the circular economy, responding to policies initiated by their governments. Therefore, many areas of study such as technological innovation, policy initiatives or business models could be explored to achieve their 2030 agenda. It means that government support, e.g. in the form of research funding, motivates researchers to focus their research on a specific area. For example, the result shows that although Malaysia is new in this research area, the government's involvement and support helps the university to produce the highest number of total productions and total citations. Moreover, most of the widely cited articles are from 2015 – 2020, although research on the circular economy started in 2007. This suggests that the potential applications of the concept to generate something useful like energy/wealth prompted many researchers to undertake the study. This result can therefore serve as a guide for future studies that focus on the circular economy's ability to create value from waste.

Also, most of the influential articles are published in prestigious journals. This shows that the articles are not only of high quality, but are also useful for many parties such as academics, government organisations and private companies. Additionally, most of the keywords used by the authors from before and after Covid-19 reflect their concern about the environmental aspects. Previous studies [58] argued that the fundamental aspects of circular economy such as economic and social impacts are always neglected. However, this paper found that many recent studies have included economic (production, business model, economic analysis, value, strategy, management, techno-economic aspects) and social aspects (extended producer responsibility, public, cities, consumers) in their analysis, which is reflected in the author's keywords. It shows that these two areas have been newly opened up and still offer much room for future studies. Moreover, medical waste is one of the emerging issues in the post-Covid 19 era, so future research needs to be conducted on innovative solutions to create circularity within the medical industrial supply chain. Ranjbari et al. [74] suggested three research areas to support circular economy in this industry: (i) technological and methodological advances for the recycling process, (ii) the use of more reusable products instead of disposable products in the development of medical products, (iii) policy incentives to support this industry, especially in developing countries.

In conclusion, the application of the circular economy in the post-Covid-19 is urgently needed due to the increasing waste from the food industry, plastics and packaging and should therefore be reflected in policy. To accelerate the implementation of circular economy policies, the use of digitalisation in a variety of business models is a must [75]. Financial support, especially for developing and emerging countries, must also be provided, probably through crowdfunding or the help of other non-governmental organisations, as they have financial constraints and yet produce a large amount of waste that could be useful for the application of the circular economy. The introduction of sharing platforms [76] to increase utilisation rates through collaboration between waste producers and industries that benefit from the inputs could accelerate the implementation of the circular economy. Engage the private and public sectors in public–private collaborations to realise circular economy initiatives [77].

In short, this study reviews the existing literature and provides a guide for future studies focusing on the research gaps. Moreover, this study emphasises the proper process of conducting a bibliometric study, as the quality of results depends on the accuracy of data collection. While there are a few studies on bibliometric analysis of circular economy and related issues, many of the studies suffered from unclean data and/or the use of a small number of documents. Therefore, the future bibliometric study should address these problems and use appropriate tools. Furthermore, the issue of waste and circular economy is not only important for developed countries, but also for developing and poor countries, where the waste problem is still unsolved. Moreover, there is currently no bibliometric study that focuses on all types of waste, such as municipal waste, industrial waste, plastic waste, e-waste, food waste and so on, even though they have an alarming impact on the environment. Many studies focus on a particular type of waste or a particular country. This study draws attention to the fact that different types of waste pose different risks to human safety and health and therefore require the same attention from scholars as well as from the relevant authorities.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43615-024-00420-3.

Funding This work was supported by the Ministry of Higher Education Malaysia (RACER19-034–0034).

Data Availability Available upon request.

Declarations

Ethical Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests No competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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