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Article

Waste from Electric Vehicle: A Bibliometric Analysis from 1995 to 2023

Arief Nurdini [1,2], Rahmat Nurcahyo [1,*] and Anton Satria Prabuwono [3]

[1] Industrial Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia; arief.nurdini11@ui.ac.id
[2] Industrial Engineering Department, Faculty of Industrial Technology, Gunadarma University, Depok 16424, Indonesia
[3] Faculty of Computing and Information Technology in Rabigh, King Abdulaziz University, Rabigh 21911, Saudi Arabia; aprabuwono@kau.edu.sa
* Correspondence: rahmat@eng.ui.ac.id

Abstract: The introduction of electric vehicles (EVs) represents a promising solution for addressing urban air pollution, particularly CO_2 emissions in the transportation sector. Numerous countries are actively promoting EV adoption and the electrification of transportation systems, leading to a surge in research on EV-related topics. This study employs bibliometrics as a valuable tool to investigate the research landscape in electric vehicle waste management. Drawing from a dataset of 593 documents retrieved from SCOPUS from 1995 to 20 September 2023, this research employs descriptive analysis and bibliometric mapping techniques. Notably, China stands out as the leading contributor to publications, with Tsinghua University being a prominent research institution in this field. An examination of keyword trends reveals dynamic shifts in research focus. In 2023, the most frequently occurring topic is "closed loop". "Recycling" is the dominant keyword, appearing 681 times. Additionally, TreeMaps and VOSviewer results indicate that the most commonly used keywords are "electronic waste" and "recycling". Projections suggest that "recycling materials" will gain prominence in mid-2023, further highlighting the evolving nature of this research field. Researchers in recycling materials disciplines can leverage these insights to explore new research avenues and contribute to sustainable waste management practices in the context of electric vehicles.

Keywords: electric vehicle; electronic waste; e-waste; bibliometric; R tools; VOSviewer

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1. Introduction

Over the last few decades, there has been a steady increase in the amount of carbon dioxide (CO_2) released into the atmosphere, and people's use of fossil fuels is directly related to global warming [1]. Based on the Environmental Protection Agency (EPA) report, CO_2 is the main gas content in global greenhouse gas emissions and is produced by fossil fuels in industrial activities, which account for up to 65% of the total global greenhouse gases [2]. In addition, the transportation sector contributed 22% of total CO_2 emissions in 2020 [3].

Introducing electric vehicles has been seen as an excellent opportunity to reduce urban air pollution, especially CO_2, from the transportation sector. Promoting electric vehicles to quickly replace internal combustion engine (ICE) vehicles is an essential strategy for countries worldwide [4]. Therefore, many countries are actively promoting the electrification of the transportation sector and encouraging the use of electric vehicles [5]. In addition to the desire to reduce CO_2 emissions, psychological factors also play a role in influencing people to use electric vehicles [6]. Based on data from the International Energy Agency (IEA) contained in the Global E.V. Outlook 2022, more than 16.5 million electric vehicles were sold in 2021, an increase of 6.6 million units from the previous year. However, the

largest electric car market in the world is still dominated by China, followed by Europe and America.

Sales of electric vehicles will rise along with the number of waste parts from these vehicles that will be recycled, including car bodywork, tires, plastics, traction batteries, electric motors, power electronics, electronic components, etc. [7,8]. Furthermore, electric car electrical component waste is also dangerous but highly valuable [9].

Review papers and bibliometric research analysis are two ways to summarize research publications [10]. Bibliometric analysis has gained immense popularity in business research in recent years. Its popularity can be attributed to the development, accessibility, and availability of bibliometric tools like Gephi, Leximancer, and VOSviewer, as well as to the scientific databases Scopus and Web of Science. The cross-disciplinary pollination of the bibliometric methodology from information science to business research. More importantly, the popularity of bibliometric analysis in business research is not a fad but rather a reflection of its utility for (1) handling large volumes of scientific data and (2) producing high research impact [11]. By rigorously interpreting vast amounts of unstructured data, bibliometric analysis aids in deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of established areas. Therefore, bibliometric studies promote innovation and create a strong foundation for meaningfully advancing research. Researchers can use bibliometric analysis to their advantage by having a single point of access to information, looking into knowledge gaps, coming up with creative research ideas, and positioning their intended contributions to the field [10]. The method used is based on keywords in the Scopus database, which will be further analyzed using R-Tools and VOSviewer. This study aimed to explore the following key questions:

1. Which publications, institutions, countries, and authors have made the most significant contributions to research on electric vehicles and the waste they produce?
2. How are the authors, organizations, and nations related to one another and work together in academic research?
3. What are the current prominent research topics in this field, how are they evolving, and what will capture attention in the future?

2. Materials and Methods

2.1. Data Collection

SCOPUS, a database of content from the esteemed journal, was used in this study. Since it contains more articles than other databases, such as Web of Science [12], the Scopus database was chosen for this study's bibliometric analysis. This study did not assess Google Scholar because there were no reliable results [13]. Five hundred ninety-three documents related to electric vehicles and electronic waste were published between 1995 and September 2023. The papers will be used for further data analysis.

2.2. Bibliometric: VOSviewer and R Tools

A study method known as "bibliometrics" uses the library and information science to provide data and analysis in various formats, including statistical and quantitative methods [14]. An essential research area is bibliometrics since it offers detailed historical data that can be used to predict future research trends [15]. In addition, a range of crucial indicators, including h-index, impact factors, citations, and current status, can be used by universities, instructors, researchers, and professors to evaluate the quality of a study. There are many bibliometric tools, like VOSviewer and R Tools. VOSviewer is a free program for creating and displaying bibliometric networks, which can be based on citations, bibliographic coupling, co-citations, or author relationships. These networks can contain journals, researchers, or individual publications. The entire bibliographic dataset was acquired in .csv format from the Scopus database. Initially, we installed and loaded the Bibliometrix R package using R Studio. We then initiated the Biblioshiny application by typing "Biblioshiny()" in the R console. Biblioshiny serves as a web-based tool that offers non-programmers access to the Bibliometrix package within R [16]. Numerous tools

provided by Bibliometrix enable scholars to undertake in-depth bibliometric analyses [17]. In this paper, the tools of bibliometric VOSviewer 1.6.18 developed by Nees Jan van Eck and Ludo Waltman at Leiden University and R-Tool version 4.2.2 are combined to get a better result.

2.3. Literature Search

A comprehensive scientific literature search on the SCOPUS database. The search was further modified to include other terms, such as "electric vehicle" OR "electric vehicles" OR "EV" AND "electronic waste" OR "e-waste". The established period covered data from 2015 to 2023, and to improve the efficiency of the search process, the search was limited to specific terms. On 20 September 2023, the last web page visit occurred. The methodology flowchart is depicted in Figure 1.

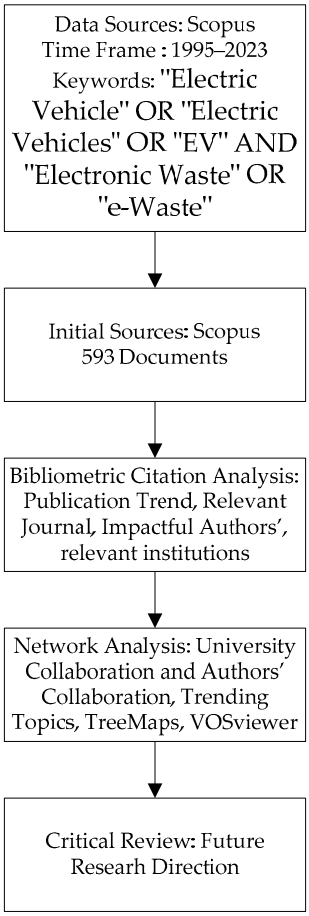

Figure 1. Methodological Flowchart for Bibliometric.

3. Results

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

3.1. Data Analysis

The documents are from 1995 to 20 September 2023, and have 234 sources. A brief description can be seen in Table 1. A total of 593 documents were discovered, of which 363 are articles. During the time of the study, a total of 1944 authors contributed to the topic. The average age of the documents is 2.89, with the average number of citations per doc being 32.86. And then, 20,626 references are found in 593 documents. KeyWords Plus reached 4191, compared to the author's 1351 keywords. Only 17 documents with a single

author's name were found. We found one book, 14 book chapters, 116 conference papers, three conference reviews, 1 note, and 95 reviews.

Table 1. Main Information about the Data.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1995:2023
Sources (Journals, Books, etc.)	234
Documents	593
Annual Growth Rate %	17.71
Document Average Age	2.89
Average citations per doc	32.86
References	20,626
DOCUMENT CONTENTS	
Keywords Plus (ID)	4191
Author's Keywords (DE)	1351
AUTHORS	
Authors	1944
Authors of single-authored docs	15
AUTHORS COLLABORATION	
Single-authored docs	17
Co-Authors per Doc	4.67
International co-authorships %	23.95
DOCUMENT TYPES	
Article	363
Book	1
book chapter	14
conference paper	116
conference review	3
Note	1
Review	95

3.2. Annual Publications

The fundamental details about the publications are extracted using the Bibliometrix sub-tool Biblioshiny. We could see a significant annual growth rate of 17.71 percent in the number of publications. Only one document was published in 1995. The article describes the energy and environmental impacts of electric vehicle battery production and recycling. Based on Scopus, there are 11 citations in this paper. The topic of electronic waste increased from 2010 to 2015, then decreased in 2016. Then, there was a significant increase from 2017, with 27 articles, until 2021 and 2022, with 117 and 118 articles. For more details, see Figure 2.

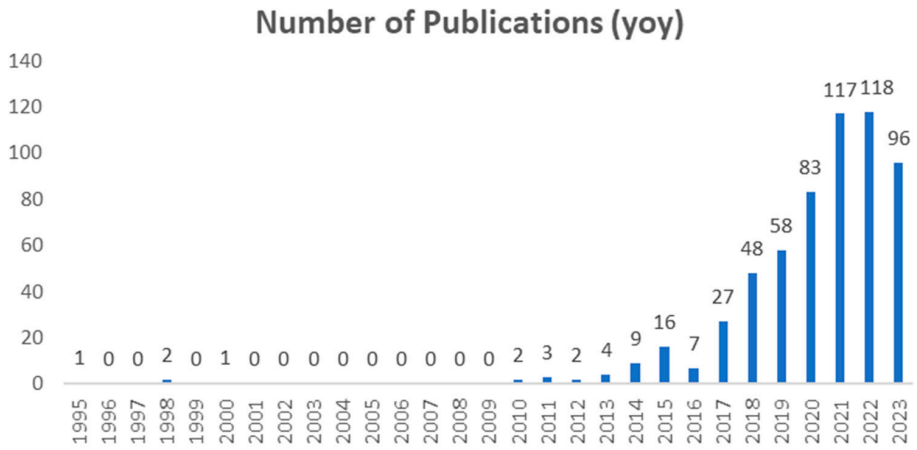

Figure 2. Number of Publications.

3.3. Annual Citations

The number of articles' citations increased as more research was conducted. Based on Figure 3, there are 11 citations for publication in 1995. Moreover, there are no citations from 1996 and 1997, 1999, and 2001 to 2009 because researchers carried out no publications. The average per doc, the citation from 1995 to 20 September 2023, is 32.86. The citations increased from 2017 with 871 citations, 2018 with 3030 citations, 2019 with 3546 citations, and 2020 with 4166 citations. We can observe that, from 1995 through early 2023, there has been a wide variety of citations per year, increasing in some and declining in others.

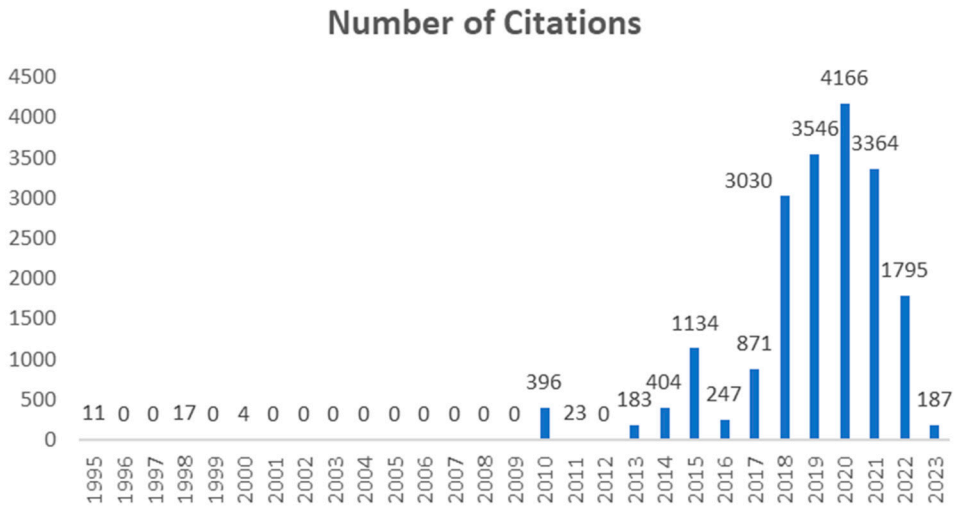

Figure 3. Number of Citations.

3.4. Highly Cited Papers

We found the most cited paper in "Lithium-ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals" article by [18]. The paper was published in the Journal Joule with Cell Press Publisher. The top 30 highly cited papers can be found in Table 2.

Table 2. Top 30 Highly Cited papers.

No.	Document Title	Journal	Publisher	Year	Citation	Authors
1	Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals	Joule	Cell Press	2017	782	[18]
2	Sustainable Recycling Technology for Li-Ion Batteries and Beyond: Challenges and Future Prospects	Chemical Reviews	American Chemical Society	2020	718	[19]
3	State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations	IEEE Access	Institute of Electrical and Electronics Engineers Inc.	2018	493	[20]
4	Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries	Joule	Cell Press	2019	431	[21]
5	A Mini-Review on Metal Recycling from Spent Lithium-Ion Batteries	Engineering	Elsevier Ltd.	2018	408	[22]
6	Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles-Critical issues	Journal of Cleaner Production	Elsevier Ltd.	2010	393	[23]

Table 2. *Cont.*

No.	Document Title	Journal	Publisher	Year	Citation	Authors
7	Recycling of spent lithium-ion batteries in view of lithium recovery: A critical review	Journal of Cleaner Production	Elsevier Ltd.	2019	392	[24]
8	Current li-ion battery technologies in electric vehicles and opportunities for advancements	Energies	MDPI AG	2019	388	[25]
9	Novel approach to recover cobalt and lithium from spent lithium-ion battery using oxalic acid	Journal of Hazardous Materials	Elsevier	2015	368	[26]
10	Examining different recycling processes for lithium-ion batteries	Nature Sustainability	Nature Publishing Group	2019	360	[27]
11	Lithium-ion batteries—Current state of the art and anticipated developments	Journal of Power Sources	Elsevier B.V.	2020	322	[28]
12	A review on the growing concern and potential management strategies of waste lithium-ion batteries	Resources, Conservation and Recycling	Elsevier B.V.	2018	287	[29]
13	A future perspective on lithium-ion battery waste flows from electric vehicles	Resources, Conservation and Recycling		2014	285	[30]
14	Pyrometallurgical options for recycling spent lithium-ion batteries: A comprehensive review	Journal of Power Sources	Elsevier B.V.	2021	254	[31]
15	Solving spent lithium-ion battery problems in China: Opportunities and challenges	Renewable and Sustainable Energy Reviews	Elsevier Ltd.	2015	247	[32]
16	Future material demand for automotive lithium-based batteries	Communications Materials	Springer Nature	2020	246	[33]
17	A critical review of lithium-ion battery recycling processes from a circular economy perspective	Batteries	MDPI	2019	227	[34]
18	Circular economy strategies for electric vehicle batteries reduce reliance on raw materials	Nature Sustainability	Nature Research	2021	180	[35]
19	Biotechnological strategies for the recovery of valuable and critical raw materials from waste electrical and electronic equipment (WEEE)—A review	Journal of Hazardous Materials	Elsevier B.V.	2019	174	[36]
20	Recent progress on the recycling technology of Li-ion batteries	Journal of Energy Chemistry	Elsevier B.V.	2020	166	[37]
21	Metallurgical and mechanical methods for recycling of lithium-ion battery pack for electric vehicles	Resources, Conservation and Recycling	Elsevier B.V.	2018	162	[38]
22	Energy and environmental assessment of a traction lithium-ion battery pack for plug-in hybrid electric vehicles	Journal of Cleaner Production	Elsevier Ltd.	2019	158	[39]
23	The Recycling of Spent Lithium-Ion Batteries: a Review of Current Processes and Technologies	Electrochemical Energy Reviews		2018	156	[40]
24	An overview of recycling and treatment of spent LiFePO4 batteries in China	Resources, Conservation and Recycling	Elsevier B.V.	2017	147	[41]
25	Progress and status of hydrometallurgical and direct recycling of Li-Ion batteries and beyond	Materials	MDPI	2020	146	[42]

Table 2. *Cont.*

No.	Document Title	Journal	Publisher	Year	Citation	Authors
26	Comparative environmental life cycle assessment of conventional vehicles with different fuel options, plug-in hybrid and electric vehicles for a sustainable transportation system in Brazil	Journal of Cleaner Production	Elsevier Ltd.	2018	146	[43]
27	Recycling and environmental issues of lithium-ion batteries: Advances, challenges and opportunities	Energy Storage Materials	Elsevier	2021	143	[44]
28	The importance of design in lithium-ion battery recycling-a critical review	Green Chemistry	Royal Society of Chemistry	2020	124	[45]
29	Eco-Efficiency Analysis of a Lithium-Ion Battery Waste Hierarchy Inspired by Circular Economy	Journal of Industrial Ecology	Blackwell Publishing	2017	137	[46]
30	Graphite Recycling from Spent Lithium-Ion Batteries	ChemSusChem	Wiley-VCH Verlag	2016	136	[47]

3.5. Most Relevant Sources

Resources are identified to determine the performance of the sources used. Based on Table 3, Resources, Conversation, and Recycling from the Netherlands are at the top, with 45 documents and an impact factor of 13.716. The Journal of Cleaner Production is a second, with a total of 30 documents and an impact factor of 11.072, and the third is the Journal of Energy Storage, with 23 documents and an impact factor of 8.907. The three prominent journals are from the Netherlands. For more details regarding the most relevant resources, see Figure 4.

Table 3. Most Relevant Sources with Impact Factor.

No.	Name of Journal	Number of Publications	Impact Factor	Rate (%)
1	Resources Conservation and Recycling	45	13.716	7.63%
2	Journal of Cleaner Production	30	11.072	5.08%
3	Journal of Energy Storage	23	8.907	3.90%
4	Energies	17	3.2	2.88%
5	Procedia CIRP	16	2.17	2.71%
6	Waste Management	14	8.816	2.37%
7	SAE Technical Papers	13	0.638	2.20%
8	ACS Sustainable Chemistry and Engineering	12	9.224	2.03%
9	Others	420		71.19%

3.6. Corresponding Author's Countries

Corresponding authors are divided into two categories: multi-country publication (MCP), which includes authors from several nations and such publications show cross-national or international collaboration; and single-country publication (SCP), where all writers are from the same country and the publication is an example of intra-national cooperation. Based on Figure 5, China has the most corresponding author documents, with 39 MCP documents and 147 SCP documents. The second country, the United States, has five MCP documents and 49 SCP documents. The third country is Germany, with eight MCP documents and 57 SCP documents.

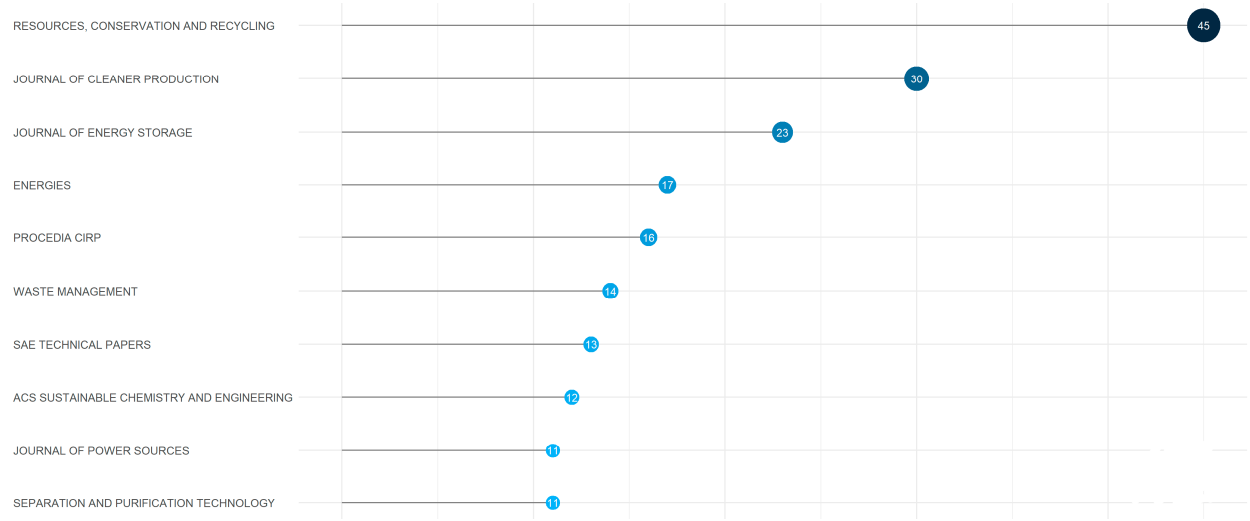

Figure 4. Most Relevant Sources.

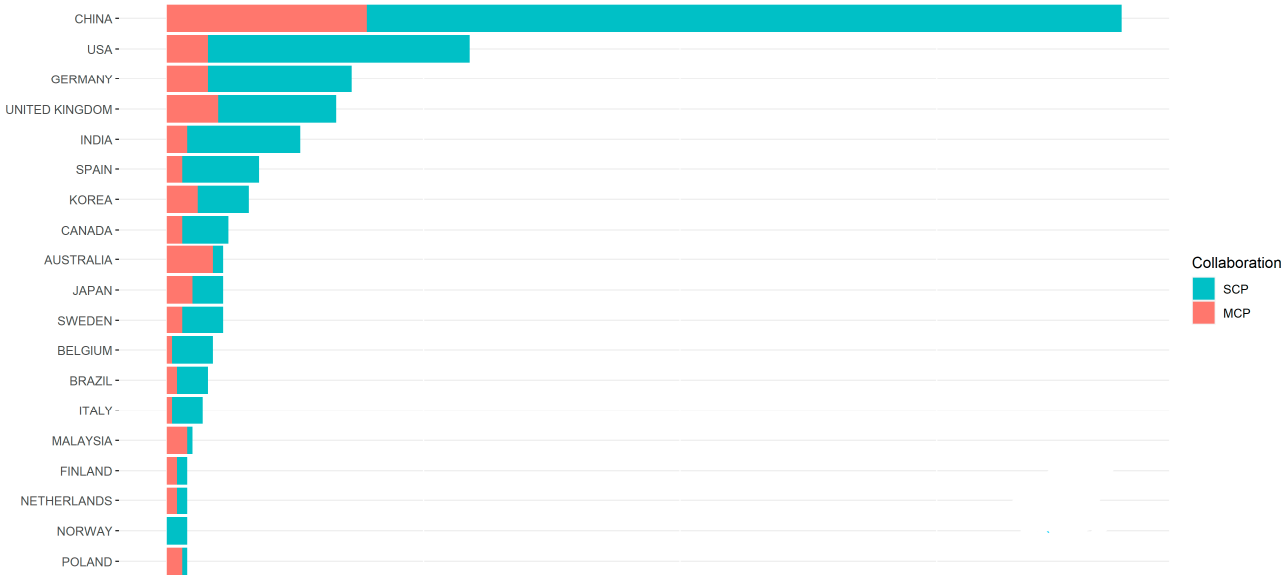

Figure 5. Corresponding Author's Countries.

3.7. Most Relevant Affiliations

The most relevant affiliations were identified to determine which university has produced the most publications on electric vehicles and electronic waste. Tsinghua University and Central South University in China are first and second, with 79 and 51 articles, respectively. The third place is Chalmers University of Technology, with 37 articles. For more details regarding the most relevant affiliations, refer to Figure 6.

3.8. Subject Categories

Subject areas are examined to determine which topics are most popular with researchers. For example, according to Figure 7, we can see that the top three research areas are engineering 22%, environmental science 19%, and energy 18%.

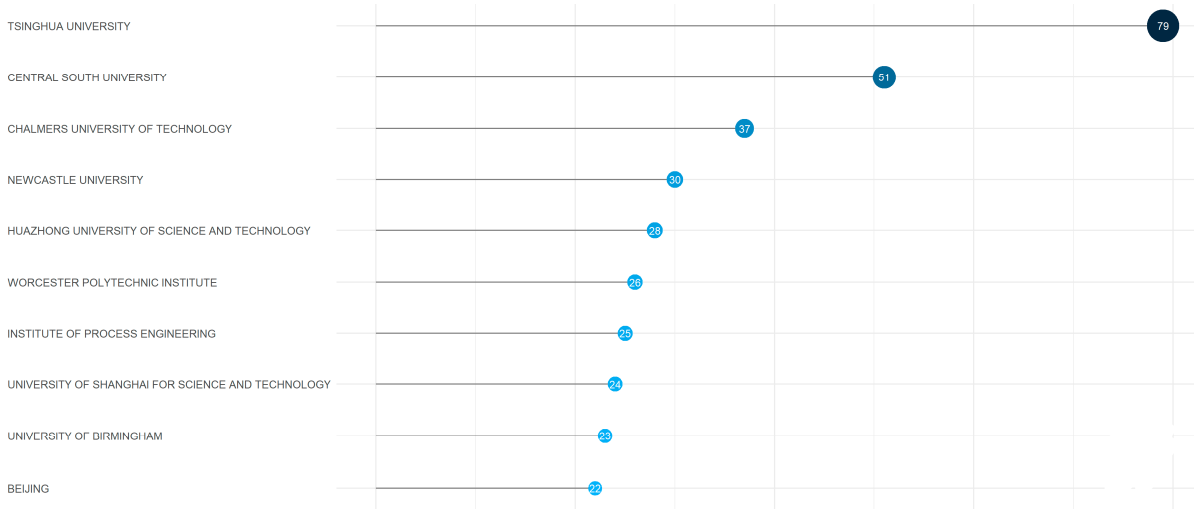

Figure 6. Most Relevant Affiliations.

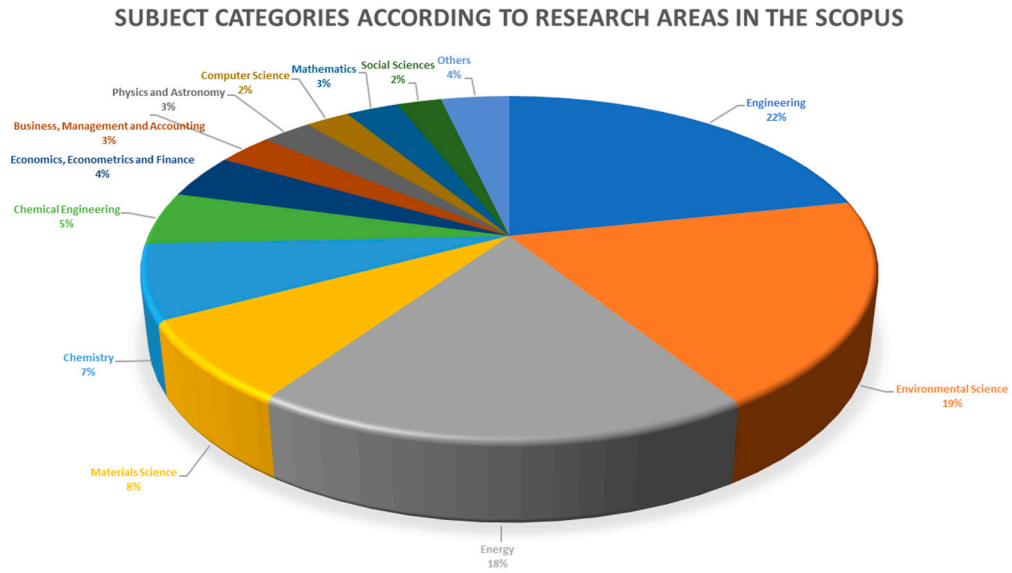

Figure 7. Subject Categories according to the Research Area.

3.9. Object Categories

The object categories explain the electronic components of electric vehicles that have been researched. In this paper, these categories are divided into four parts: batteries, charging stations, power electronics, and permanent magnets. The discussion of batteries is the most researched, as seen in [18,19,23,26,48–63]. In global electronic component waste research, there is still a dominant focus on battery waste, while research concerning electronic power component waste remains limited. For more details, please refer to Table 4.

Table 4. Object Categories.

No	Battery	Charging	Power Electronics	Permanent Magnet	Authors
1	✔				[18,19,23,26,48–63]
2	✔		✔		[63]
3			✔		[64]
4				✔	[65]
5		✔			[66,67]

3.10. Most Relevant Authors' and Production over Time

The data were analyzed to determine the most relevant authors. Based on Figure 8, Wang Y, with 18 documents, is the leading author, followed by Li J and Li Y, with 17 and 13 documents. The data were examined to determine the authors' output over time.

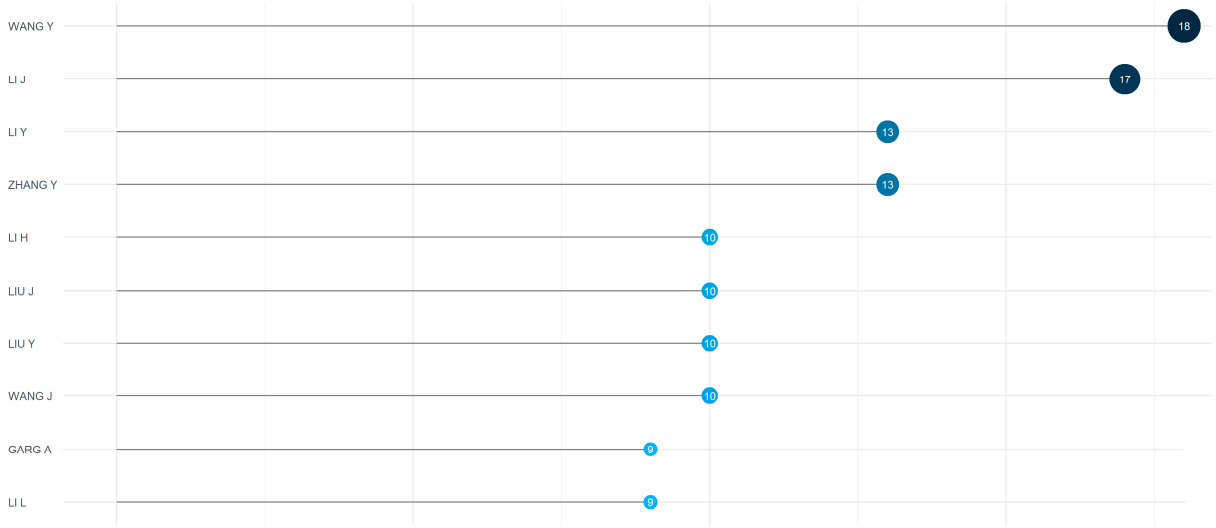

Figure 8. Most Relevant Authors'.

Wang Y published one article in 2016, 2017, and 2018—two in 2019 and 2021. There were three articles in 2020 and four in 2022 and 2023 (Figure 9). The dot color in Figure 9 shows the number of publications. The paper from Wang Y with the most citations is titled "Recent Progress on the Recycling Technology of Li-ion Batteries" in 2021, with 169 citations. The total citations from 18 documents are 856 citations.

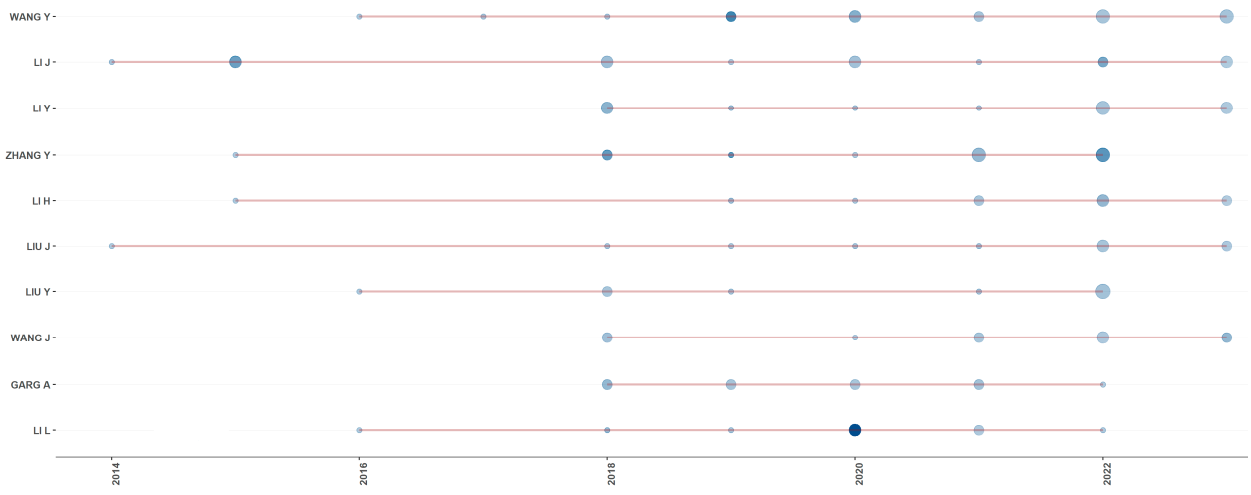

Figure 9. Author's Production over Time.

3.11. Most Frequent Words

The frequent words evolve as research advances. According to Bibliometrix, the most frequently occurring words in 1995 were "lead acid", "metal hydride electrode", and "cadmium electrode". In 2023, the most frequently used word in the literature was "recycling", totaling 678 occurrences, followed by "electronic waste", which had 603 occurrences, and "lithium-ion batteries", with 381 occurrences. The darker the color of the dot, the more citations obtained. The total number indicates that research on recycling and e-waste is evolving. For more details regarding the most relevant affiliations, see Figure 10.

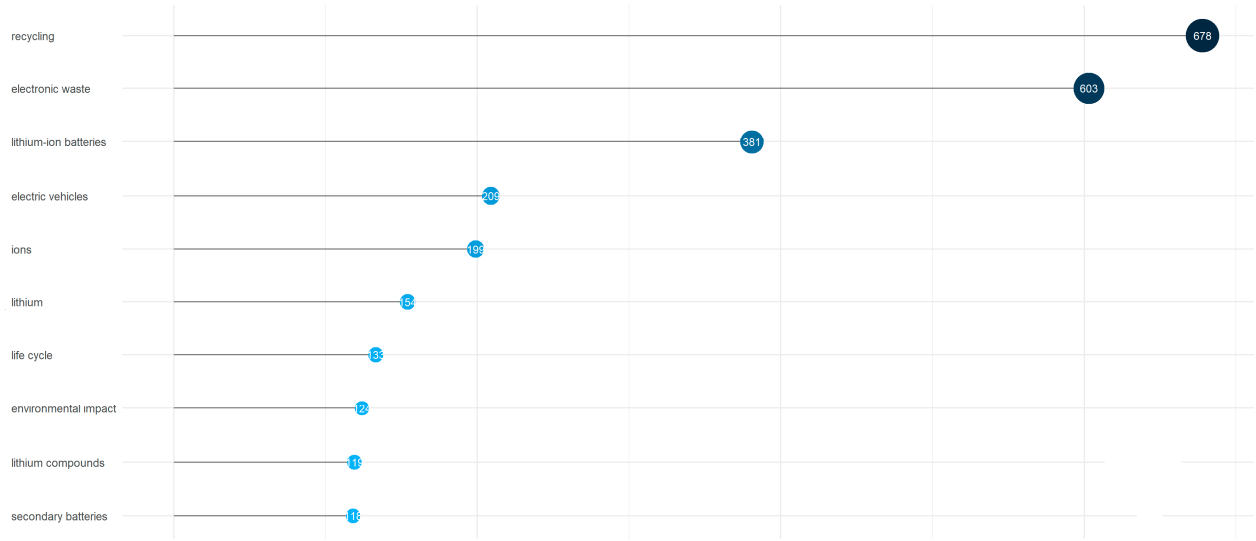

Figure 10. Most Frequent Words.

3.12. Trending Topics

Trending topics are analyzed based on the authors' keyword frequency. Frequency refers to the count of keyword usage in papers for a particular year. Based on Table 5, in 2010, the keyword "Vehicle Technology" became trending with a total frequency of 4. In 2014, the keywords "Integrated Approach", "Regenerative Braking", and "Recycling Rate" became trending with frequencies 4, 4, and 5. In 2015, the keyword "lithium alloys" became a trending topic with a total frequency of 7. In 2018, the keywords "vehicle", "hybrid vehicles", and "nickel metal hydride batteries". Each frequency of 28, 23, and 12 becomes a trending topic. Keywords "secondary batteries", "electric vehicles", and "electrodes" with frequencies 118, 45, and 29 became a trending topic in 2019. In 2020, the keywords "automotive batteries", "waste management", and "battery management systems". Each frequency of 63, 54, and 46 became a trending topic. Keywords "recycling", "electronic waste", and "lithium-ion batteries" became a trending topic in 2021, with a total frequency of 678, 603, and 381. And in 2022, the keywords "battery recycling", "cathodes", and "leaching". With a total frequency of 113, 104, and 90, they became trending topics. Furthermore, in mid of 2023, the keywords "industrial ecology", "recycled materials", and "closed loop". With a total frequency of 6, 6, and 7, they became trending topics. For more details see Figure 11.

Table 5. Trending Topic Based on Authors' Keyword.

Years	Frequent Word	Term Frequency
2010	Vehicle Technology	4
2014	Integrated Approach	4
	Regenerative Braking	4
	Recycling Rate	5
2015	Hybrid Energy Storage Systems (Hess)	3
	Leaching Solution	3
	Lithium Alloys	7
2016	Nickel Metal Hydride	4
	Policy Makers	4
2017	Plug-in Hybrid Vehicles	15
	Recovery	18
	Electric Batteries	32

Table 5. *Cont.*

Years	Frequent Word	Term Frequency
2018	Nickel Metal Hydride Batteries	12
	Hybrid Vehicles	23
	Vehicles	28
2019	Electrodes	29
	Electric Vehicles (EVS)	45
	Secondary Batteries	118
2020	Battery Management Systems	46
	Waste Management	54
	Automotive Batteries	63
2021	Lithium-ion Batteries	381
	Electronic Waste	603
	Recycling	678
2022	Spent Lithium-ion Batteries	90
	Cathodes	104
	Battery Recycling	113
2023	Industrial Ecology	6
	Recycled Materials	6
	Closed-Loop	7

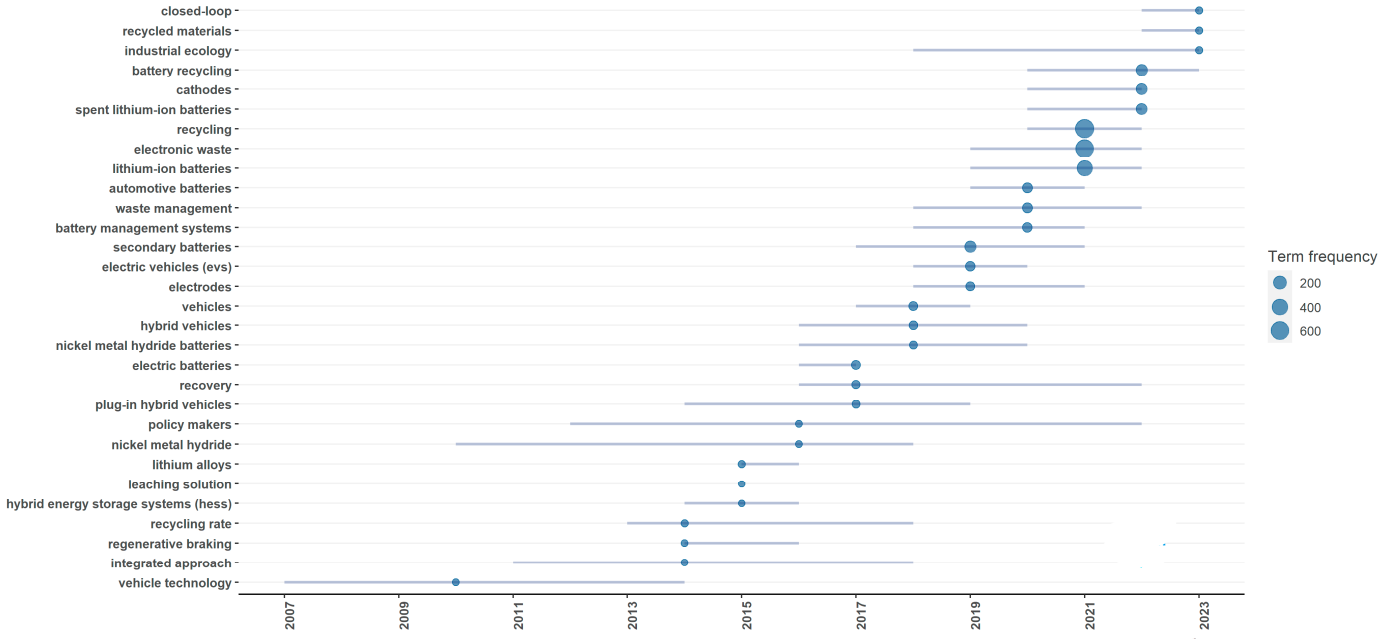

Figure 11. Trending Topics based on Authors' Keywords.

3.13. TreeMaps

The treemap depicts words frequently used as keywords in research on electric vehicles and electronic waste. For example, the graph shows that recycling ranks first at 14% with 681 occurrences, electronic waste second at 12% with 603 occurrences, lithium-ion batteries at 8% with 381 occurrences, and electric vehicles and ions at 4% each with 209 and 199 occurrences. TreeMaps can be observed in greater detail in Figure 12.

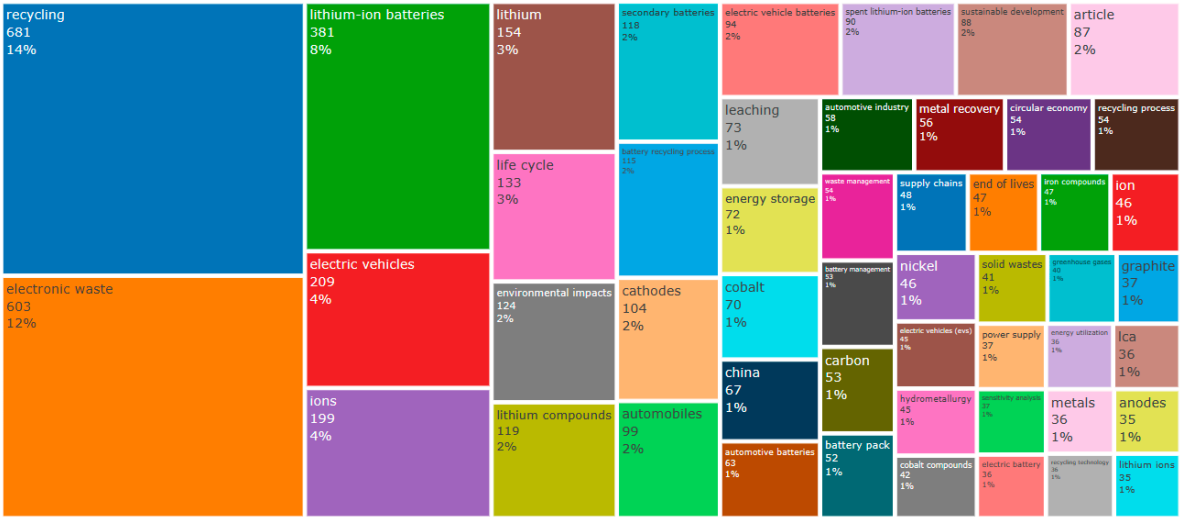

Figure 12. TreeMap Words.

3.14. Bibliometric VOSviewer

The result is divided into seven clusters. Cluster 1 (red) contains 136 keywords: lithium-ion batteries, lithium compounds, recycle, leaching, and hydrometallurgy. Cluster 2 (green) includes 131 keywords, such as lithium, nickel, metal recovery, and renewable energies. Cluster 3 (blue) contains 120 keywords: electric vehicles, energy storage, energy efficiency, economic analysis, and end-of-life batteries. Cluster 4 (yellow) includes 112 keywords: battery recycling, secondary batteries, sustainable development, and solid waste. Cluster 5 (Violet) contains 80 keywords: life cycle, life cycle analysis, life cycle assessment, environmental impact, and sensitivity analysis. Cluster 6 (green turquoise) has 73 keywords: electronic waste, recycling process, battery pack, and charging batteries. Finally, cluster 7 (orange) contains 72 keywords: waste management, electronic equipment, circular economy, and sustainability. According to Figure 13, the terms with the highest frequency include electronic waste, electric vehicles, recycling, lithium-ion batteries, battery recycling, and others.

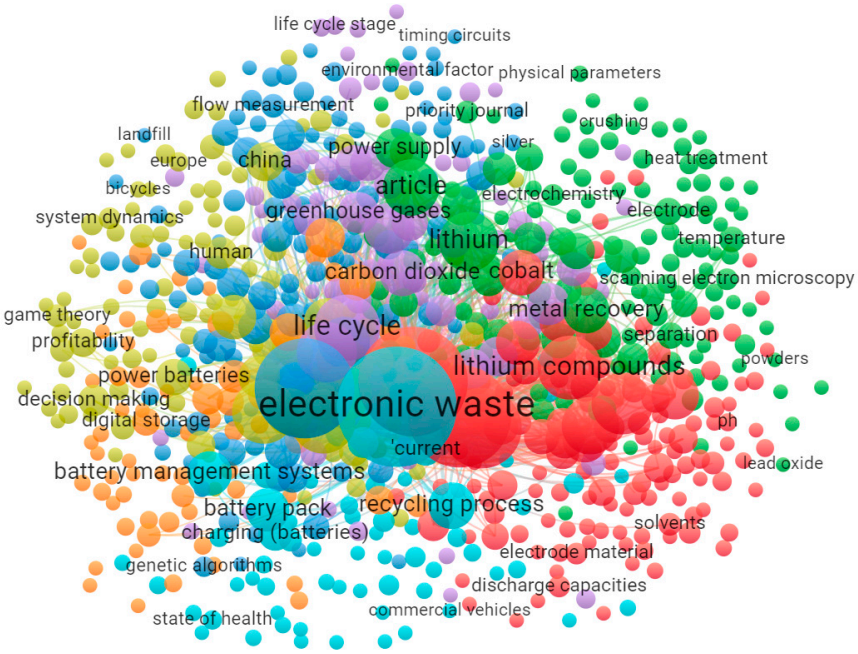

Figure 13. Bibliometric VOSviewer.

4. Discussion

Research in many diverse disciplines has begun adopting bibliometric analysis [68–70]. This study technique can show how articles published in databases are distributed throughout various topics, industries, organizations, and nations. Moreover, many databases, like Scopus, Web of Science, etc., can be utilized to retrieve the raw data for the bibliometric study. We took the source information for this research out of the Scopus Core Collection. The documents were published between 1995 and 20 September 2023, and came from 234 sources (books, journals, etc.).

There were 593 documents overall, of which 363 were articles. A total of 1944 authors have contributed to this field of study. The fundamental data about the documents were extracted using the Biblioshiny Bibliometrix sub-tool and VOSviewer. We observed a significant annual growth rate of 17.71% in the number of articles. Based on the Scopus database, the first publication related to waste electronic components for electric vehicles was found in 1995, with one document published. None of the documents from 1996, 1997, or 1999 were published. Two documents were contributed to the literature in 1998, and one was added in 2000. Throughout the following nine years, not a single new document was released. In 2010, there were two contributing documents. In 2011 and 2012, there were 3 and 2 documents, respectively. Subsequently, there was a consistent increase in the number of documents in the following years. In 2013, there were 4 documents. In 2014, there were 9 documents. In 2015, there were 16 documents. In 2016, there was a decrease to 7 documents. In 2017, there was a significant rise to 27 documents. In 2018, there were 48 documents. In 2019, there were 58 documents, and in 2020, there were 83 documents. The number of documents added to the literature increased in 2022 with a total of 118, then in 2021 with 117. Each year, the number of documents published has been steadily rising. A total of 593 documents were released in 2023.

Few publications were published at the start of the research period, and the research literature was declining. Only 11 citations were provided in 1995; from 2001 to 2009, none were accessible. There were exponential growth in the number of citations in 2013. Citations significantly increased in the year 2020. The most prolific university overall, Tsinghua University, has published 79 publications. China is the leading country regarding corresponding authors, with 37 papers published in multiple countries (MCP) and 147 documents published in a single country (SCP). The USA ranks second, with five MCP documents and 49 SCP documents. With 822 citations, Wang Y. was the author with the most significant influence. From 1998 until now, the word "recycling" has been used the most frequently in the literature, leading to a total count of 678.

Trending topics are analyzed based on the author's keywords. From the last three years in 2020, the keywords "automotive batteries", "waste management", and "battery management systems". Each frequency of 63, 54, and 46 became a trending topic. Keywords "recycling", "electronic waste", and "lithium-ion batteries" became trending topics in 2021, with a total frequency of 678, 603, and 381. And in 2022, the keywords "battery recycling", "cathodes", and "leaching". With a total frequency of 113, 104, and 90, they became trending topics. Furthermore, in mid-2023, the keywords "industrial ecology", "recycled materials", and "closed loop".

5. Conclusions

Municipal electronic waste issues are gaining momentum, and several studies have thoroughly studied the field of connected subjects. This paper used the open-source R language and the bibliometrix package to do a bibliometric analysis based on the data from 593 scientific publications received from Scopus.

An analysis of scientific output reveals that the research area of recycling electronic waste from electric vehicles is still experiencing annual sales growth that is accelerating rapidly. The findings indicate that China and the United States have the most publications, whereas Tsinghua University and Central South University produce the most work. However, when using the number of citations to indicate academic influence, China, with

6177 citations, surpasses the United States's 3334 citations and the United Kingdom's 1415 citations. With 856 citations and 18 published documents, Wang Y was the author with the most significant influence. Additionally, over the past three years, in 2021, the keywords "recycling", "electronic waste", and "lithium-ion batteries" all attained a frequency of 678, 603, and 381, respectively. "Battery recycling", "cathodes", and "leaching" are other significant terms for 2022. The subjects with the highest frequency were 113, 104, and 90. The keywords "industrial ecology", "recycled materials", and "closed loop" will also be used in the middle of 2023. Each issue becomes a trending topic six times in total. We can determine the terms frequently used in studying electric vehicles and electronic trash using TreeMaps. Recycling is mentioned 681 times (14% of all usage), electronic waste 603 times (12%), lithium-ion batteries 381 times (8%), electric vehicles 209 times (4%), ions 199 times (4%), etc. It should be mentioned that this research has significant limitations despite the in-depth investigation. For instance, this analysis is based on data from Scopus, which is unquestionably one of the most reliable and accurate sources of information; however, the trend may be different when other search engines or databases are added, as well as when manuscripts from outside core collections are taken into account. Therefore, more in-depth research in this area is required.

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