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E-WASTE MANAGEMENT: A BIBLIOMETRIC ANALYSIS FROM 2019 TO 2025

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Abstract:

The current study is an elaborate bibliometric report on trends in international research on electronic waste (e-waste) management from 2019 to 2025 using data extracted from the Scopus database. The objective is to evaluate publication trends, identify influential authors, institutions, and countries, and explore thematic developments through co-occurrence, co-authorship, and citation network analyses. The analysis includes 3,317 publications focused on key environmental, engineering, and technological subject areas. Results demonstrated a substantial upward trajectory in research output, with a maximum of publications in 2024, because the problem of e-waste is being increasingly considered by researchers. India, China, and the United States emerge as leading contributors, while the Chinese Academy of Sciences, as well as the Ministry of Education of China, dominate institutional output. Keyword co-occurrence analysis highlights major research clusters, including metal recovery, environmental risks, policy implementation, and technological innovations such as Internet of Things (IoT) and Artificial Intelligence (AI). Country collaboration and co-authorship networks underscore strong research linkages in Asia and Europe, although disparities in global participation persist. This work highlights the relevance of further interdisciplinary and international collaboration to resolve the growing problem of e-waste. It offers researchers, policymakers, and stakeholders findings that are of great relevance to enhancing sustainable waste management practices.

Keywords:

E-waste Management; Bibliometric Analysis; VOS Viewer; Scopus Data

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Introduction

Electronic waste, also known as e-waste, is a rapidly expanding type of waste worldwide due to excessive change in technology and the demand of consumers for electronic goods. E-waste refers to a broad source of discarded electronic materials, computers, smartphones, television sets, as well as other consumer electronics products that contain harmful substances like lead, mercury, and cadmium. They include harmful chemicals that can be very dangerous to the environment and health when their handling is not well conducted (Jhariya, Sahu, and Raj, 2014; Idris, Shams, and Yusof, 2023; Sarkhoshkalat et al., 2024). Inappropriate disposal of e-waste may result in soil, water, as well as air pollution, which makes substantial ecological and health impacts on the population, particularly in growing countries in which a significant part of e-waste is exported because of affordable labor (Phogat, Kumar, and Wan, 2025; Sarkhoshkalat et al., 2024).

E-waste management entails various vital procedures, which include collection, recycling, as well as disposal. Nevertheless, the efficiency of such processes varies significantly across different regions. Developed countries have established stringent regulations and advanced recycling infrastructures to manage e-waste, whereas developing nations often struggle with inadequate policies, lack of infrastructure, and limited public awareness (Pariatamby and Victor, 2013; Rautela and Yadav, 2023; Salhofer, 2018). For instance, domestic e-waste generation and imported e-waste from the growing countries in India complicate the country with serious environmental and health issues (Jhariya, Sahu, and Raj, 2014; Zainuddin et al., 2024). Similarly, in Latin America and Asia, it is made worse by the lack of proper e-waste management systems as well as massive informal recycling facilities, highlighting the need for comprehensive policies and sustainable solutions (Pariatamby and Victor, 2013; Salhofer, 2018).

This paper presents a bibliometric analysis of e-waste management research published between 2019 and 2025 using data extracted from the Scopus database. The objectives are to identify the trends in research output over time, determine the most influential authors and institutions, assess international collaboration networks, as well as examine the major thematic areas through co-occurrence, co-citation and co-authorship mapping. The results aim to inform future research directions and support policymakers as well as practitioners in reinforcing sustainable and good strategies for e-waste management.

Literature Review

The excessive production and usage of electronic devices have become a global concern about how they should be treated, as the world faces an explosion in the use and manufacture of such devices. The rapid pace of technological advancement, coupled with shorter product life cycles and increased consumer demand, has resulted in a mounting stream of rejected electrical as well as electronic equipment worldwide (Ahirwar and Tripathi, 2021; Shahabuddin et al., 2023a; Bazargan, Lam, and McKay, 2012; Rautela et al., 2021). E-waste consists of a highly complex combination of precious materials, like silver, gold, and rare earth metals, as well as toxic chemicals, like heavy metals (mercury, cadmium, lead) and persistent organic pollutants. The inappropriate treatment and disposal of e-waste, especially in developing countries, have led to significant environmental contamination and public health risks. Toxic elements from e-waste can leach into soil and water or be released into the air, causing adverse effects on ecosystems and human populations. Informal recycling practices, for example, open burning as well as manual dismantling, are prevalent in many regions and exacerbate exposure to

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hazardous substances, undermining efforts toward sustainable management (Ahirwar and Tripathi, 2021; Arya and Kumar, 2020; Bazargan, Lam, and McKay, 2012; Rautela et al., 2021).

The management of e-waste should arguably be handled through a multi-faceted, broad approach with rules and regulations interacting in collaboration with the kind of technology development and stakeholder engagement. Developed countries have made progress by implementing stringent legislation, establishing formal recycling facilities, and encourage Extended Producer Responsibility (EPR) programs where the manufacturers are held liable the overall products's process (Arya and Kumar, 2020; Bhagat-Ganguly, 2021; Kiddee, Naidu, and Wong, 2013; Shahabuddin et al., 2023a; Thakur and Kumar, 2022). These measures encourage the design of products with longer lifespans and facilitate the safe collection as well as recycling of end-of-life electronics. However, in many developing nations, challenges such as inadequate infrastructure, lack of enforcement, limited public awareness, and the dominance of informal recycling persist (Arya and Kumar, 2020; Rautela et al., 2021; Shahabuddin et al., 2023a; Thakur and Kumar, 2022).

Strategies to discuss these issues involve formalizing the informal sector, improving data collection and inventory systems, and fostering partnerships between government, industry, and civil society. The implementation of the principles of the circular economy, including eco-design, resource efficiency, as well as the 4R approach (Reduce, Reuse, Recycle, Recover), can help minimize waste generation and maximize resource recovery (Arya and Kumar, 2020; Shahabuddin et al., 2023a; Kiddee, Naidu, and Wong, 2013).

Looking ahead, the transition to sustainable e-waste management hinges on global cooperation, technological advancement, and inclusive policy development. Examples of international agreements that attempt to control transboundary shipment of waste in hazardous materials and thereby adopt environmental stewardship of waste include the Basel Convention (Thakur and Kumar 2021; Shahabuddin et al., 2023a; Ghulam and Abushammala, 2023; Bakhiyi et al., 2018). Investment in research and development of green recycling technologies, i.e., bioleaching and more advanced material recovery procedures, should also be invested to lower the green e-waste-recycling burden (Ahirwar and Tripathi, 2021; Arya and Kumar, 2020). Public education campaigns and incentives for responsible consumer behavior can further support these efforts. Ultimately, a holistic and adaptive approach combining regulatory, technical, economic, and social dimensions is necessary to lower the risks correlated with e-waste as well as strengthen its potential as a resource for sustainable development (Ahirwar and Tripathi, 2021; Arya and Kumar, 2020; Shahabuddin et al., 2023b; Ghulam and Abushammala, 2023; Bakhiyi et al., 2018; Kiddee, Naidu, and Wong, 2013).

This study also set out to do scientific mapping and a bibliometric study on the studies conducted on E-waste Management. To outline the trends of e-waste management, one can suggest the following questions:

Q 1 What are the trends of research in e-waste management according to the year?
Q 2 What are the most cited articles?
Q 3 What are the most influential countries?
Q 4 Which are the top affiliations of organizations, institutions, or universities?
Q 5 What are co-occurrence, co-citation, and country collaboration?

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Q 6 What are co-occurrence, co-authorship, and country collaboration?

Methodology

Bibliometrics describes the integration, manipulation, as well as exploration of bibliographic data sourced from publications that are empirical (Debackere et al., 2002). It includes both common descriptive techniques, i.e., publication year, publishing journals, main author classification, as well as more difficult methods, i.e., document co-citation analysis (Wu and Wu, 2017). A cyclic process of suitable keywords, literature search, as well as analysis is essential in successful review of literature, literature building of bibliography, and realization of reliable output, respectively (Fahimnia, Sarkis, and Davarzani, 2015). The next segment involves the usage of search terms, preliminary scanning of the search results, and refinement of search results. Here, the journal providing Clarivate Analytics Journal Citation Reports (JCR) impact factor denotes the journal's high quality (Meier, 2011). Therefore, the research made an attempt to confine itself to the highest degree of publication because it could help it in forming knowledge on the theoretical side of the study on the evolution of all research areas. As a consequence, the research depends on the Scopus database to collect data. In addition, in order to ensure that the best publication outcomes are ensured, only the articles published in high-quality, as well as peer-reviewed academic journals, have been chosen, to the exclusion of books and conference proceedings.

Data Search Strategy

The research employed a screening sequence to establish the search terms to be used in retrieving the articles. The study began with the query in Scopus database online TITLE-ABS-KEY (("electronic waste" OR "e-waste" OR "WEEE waste") AND management) AND (LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "COMP")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "bk")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "b") OR LIMIT-TO (SRCTYPE , "p") OR LIMIT-TO (SRCTYPE , "k")) AND (LIMIT-TO (LANGUAGE , "English")) threby assembling 5587 articles. Afterwards, the query string was revised so that the search terms "electronic waste" OR "e-waste" OR "WEEE waste" should focus on e-waste management. This process yielded 3317 results, which were further analyzed to obtain the research articles written in English, and article reviews were not included. The ultimate refinement of search strings consisted of 3317 articles that were utilised in bibliometric analysis. By July 2025, the study comprised all articles that appeared in the Scopus database, encompassing the subject matter of e-waste management.

Data Analysis

Scopus database was used to obtain its data in the form of data sets with the study publication title, publication year, journal, author name, keyword as well as citation in PlainText format based on the 2019 to 2025 period. They were analyzed with the help of VOSviewer software (version 1.6.15). Analysis and map-making were done using this software by applying the VOS clustering and mapping method. VOSViewer has been used as an alternative to Multidimensional Scaling (MDS) method (van Eck and Waltman, 2010) that is also

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comparable to the former in that they both focus on the items' placement in a 2- or 3-dimensional space in a way that is related to each other and similar in terms of distance between them (Appio, Cesaroni, and Di Minin, 2014). As opposed to MDS, which is centred on the calculation of measures of similarity, for example, Jaccard indexes and cosine, VOS adopts an adequate method to normalize co-occurrence frequencies, like the Association Strength (ASij), whose calculation is formulated as (Van Eck and Waltman, 2007):

ASij ¼ Cij
Wiwj,

where "proportional to the ratio between on the one hand the observed number of co-occurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (Van Eck and Waltman, 2007). Thus, thanks to the assistance of this index, the VOS viewer arranges objects in the shape of a map by decreasing the weighted sum regarding the squared distances between all pairs of objects. The use of the LinLog/modularity normalization took place as described by Appio et al. (2016). Next, using the data set, the procedures of visualisation employing the VOSviewer tool revealed the patterns relying on mathematical relationships, as well as analyses like the co-occurrence of the keywords, co-citation, and citation analyses were conducted (Appio et al., 2016).

Therefore, the VOS viewer, through the aid of this index, is able to position items in a mapping form once the weighted sum regarding the square differences of all pairs concerning the items is minimized. As Appio et al. (2016) stated, the LinLog/modularity normalization was adopted. Moreover, following the application of visualisation methods to the data set utilizing VOSviewer, patterns based on mathematical rules were obtained, as well as studies like keyword citation analysis, co-occurrence, and co-citation analysis were performed (Appio et al., 2016). Analysis of keyword co-occurrence may be utilized to learn the evolution of the research field over the specified time, and is efficient when informing about what is popular in various domains. Meanwhile, citation-based research satisfies the needs of discerning useful issues in the research, trends/methods, as well as examining the historical significance of a particular field of knowledge (Allahverdiyev, Yucesoy, and Baglama, 2017). Among the bibliometric techniques that are commonly used is document co-citation analysis (Appio et al., 2016; Fahimnia, Sarkis, and Davarzani, 2015), where the output is dependent on a map of the network theory to determine a relevant structure of information.

Result and Discussion

Q 1 What Are the Trends of Research in E-Waste Management According to The Year?

Figure 1 and Table 1 reveal that, lately, the interest of academics in e-waste management has increased, which may be observed in the increasing number of research documents indexed in Scopus over recent years. In 2019 and 2020, the number of publications remained relatively stable at around 320 documents, indicating consistent but moderate engagement with the topic. A noticeable increase emerged in 2021, with approximately 385 publications, although this was followed by a slight dip in 2022 to about 375 documents. However, between 2022 and 2023, research activity surged significantly, climbing to over 520 publications representing a growth of nearly 39%.

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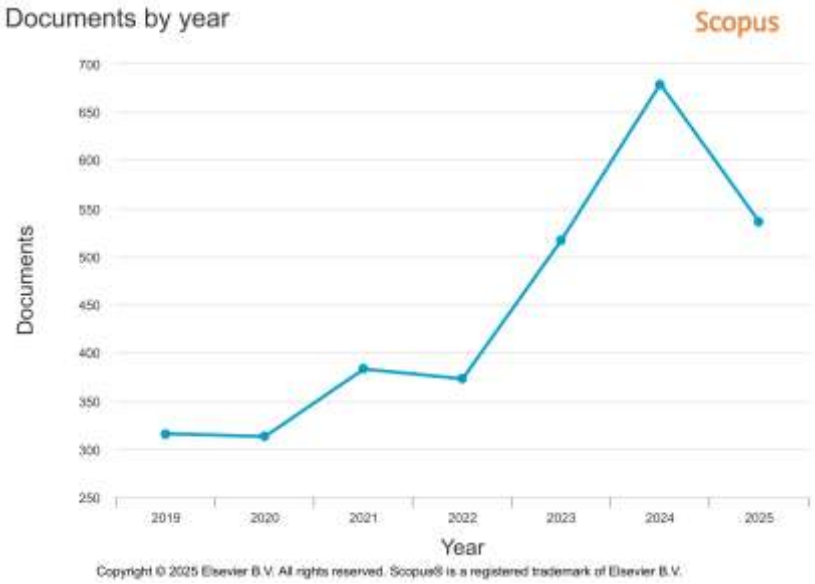

Figure 1: Trend of Research in E-Waste Management by Years Source: (Scopus.com)

This momentum peaked in 2024, reaching close to 690 documents, signaling a heightened global concern and intensified academic focus on e-waste-related issues. Although the output declined slightly in 2025 to around 560 publications, it still marks a considerably higher level of scholarly attention compared to earlier years, demonstrating that e-waste remains a pressing and relevant research area.

Table 1: Trend of Research

Year	Documents
2025	536
2024	679
2023	517
2022	373
2021	383
2020	313
2019	316

Source: (Scopus.com)

Q2 What Are the Most Cited Articles?

Figure 2 and Table 2 compare the most prolific authors in the e-waste management field using the Scopus-indexed publications. Among the top contributors, Li, J., is the most active author, having 17 publications, suggesting a substantial contribution to scholarly discourse in this area.

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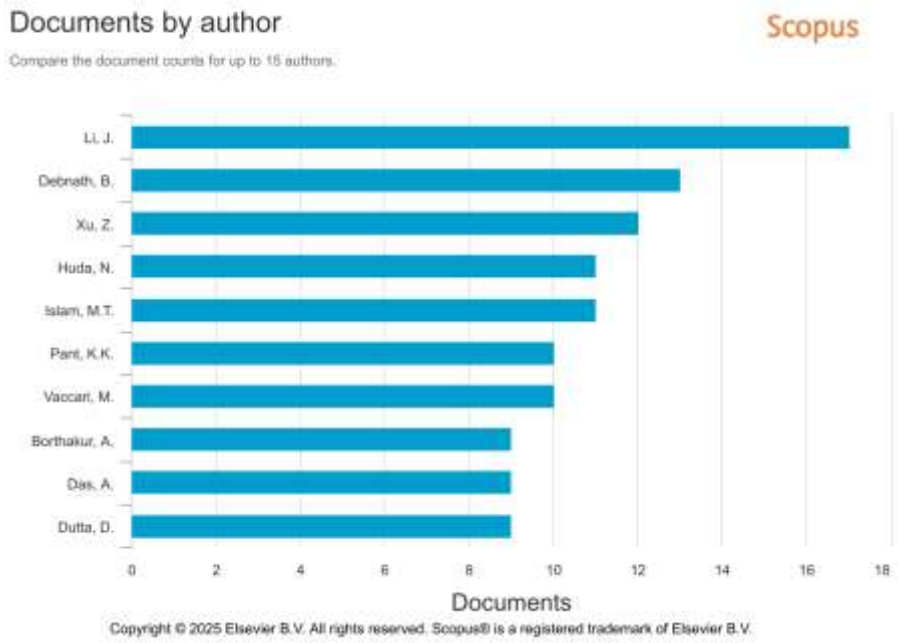

Figure 2: The Most Cited Author

Source: (Scopus.com)

Following closely are Debnath, B., and Xu, Z., each with approximately 13 and 12 documents, respectively. Other notable contributors include Huda, N., and Islam, M.T., who each have around 11 documents, showing sustained engagement with the topic. A group of authors, including Pant, K.K., Vaccari, M., and Das, A., contributed between 9 and 10 papers each, reflecting their ongoing involvement in various aspects of e-waste research. Meanwhile, Borthakur, A., and Dutta, D. also appear among the top contributors with about nine documents each.

Table 2: The Most Cited Author

Author	Documents
Li, J.	17
Debnath, B.	13
Xu, Z.	12
Huda, N.	11
Islam, M.T.	11
Pant, K.K.	10
Vaccari, M.	10
Borthakur, A.	9
Das, A.	9
Dutta, D.	9

Source: (Scopus.com)

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Q3 What Are the Most Influential Countries?

Figure 3 and Table 3 show that India is the leading contributor to e-waste management research with 871 documents, followed by China (571) and the United States (251), highlighting their significant academic focus on addressing e-waste challenges.

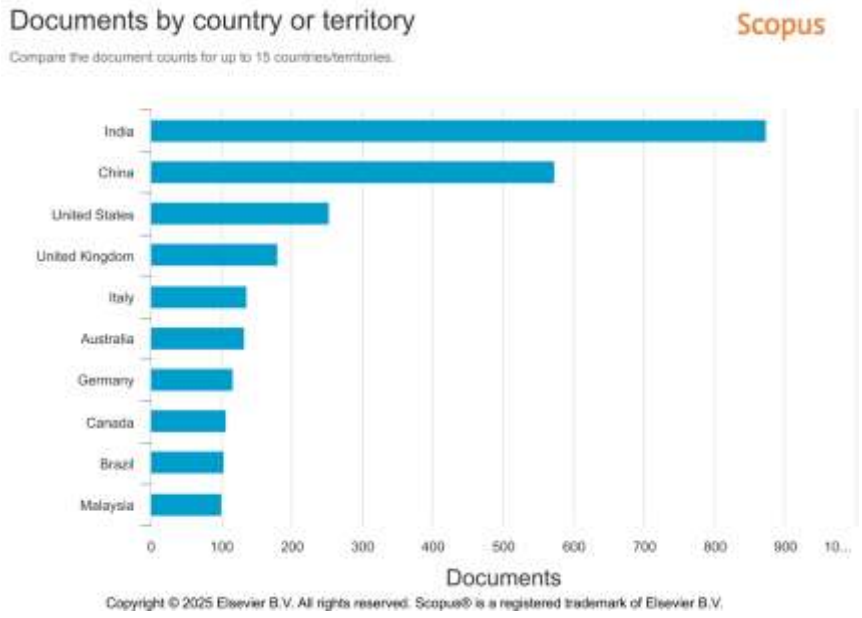

Figure 3: The Top Countries

Source: (Scopus.com)

The United Kingdom (178), Italy (134), and Australia (132) also demonstrate strong involvement, likely influenced by national policies and environmental priorities. Germany (116), Canada (105), Brazil (103), and Malaysia (99) complete the top ten, reflecting growing awareness and research activity in both developed and developing nations. This distribution indicates that e-waste is a globally recognized issue, with active research being conducted across diverse geopolitical regions to develop sustainable and effective management strategies.

The data on e-waste management research by country or territory additionally demonstrates the prevalence of academic studies in this field. India leads significantly with 871 documents, demonstrating its strong academic as well as policy interest in solving the issues of e-waste, likely driven by its large population and growing electronics consumption. China follows with 571 publications, reflecting its role as both a major producer and recipient of global e-waste, along with its progression in recycling technologies and environmental regulation. The United States ranks third with 251 documents, showing active research in sustainable waste management, innovation in recycling technologies, and environmental health impacts. The United Kingdom (178) and Italy (134) also contribute substantially, likely influenced by European Union regulations on e-waste (e.g., WEEE Directive), which have spurred extensive academic inquiry and practical application. Among the Asia-Pacific nations, Australia (132) and Malaysia (99) show notable engagement. Malaysia's presence in the top 10 reflects increasing national awareness of e-waste issues and growing academic output in environmental and sustainability sciences. Other leading contributors include Germany (116), Canada (105),

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and Brazil (103)—all of which maintain active environmental research communities and government-supported waste management policies.

Table 3: The Top Countries

Country/Territory	Documents
India	871
China	571
United States	251
United Kingdom	178
Italy	134
Australia	132
Germany	116
Canada	105
Brazil	103
Malaysia	99

Source: (Scopus.com)

Q4 Which Are the Top Affiliations of Organizations, Institutions, or Universities?

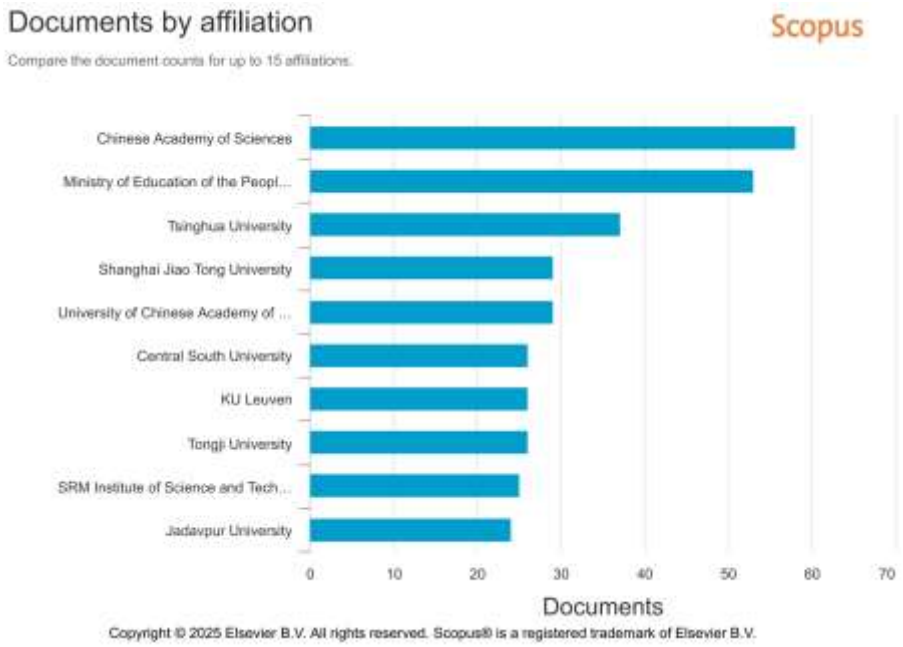

Figure 4: Top Affiliation and University

Source: (Scopus.com)

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Figure 4 and Table 4 show the data on research affiliations in e-waste management. It reveals that the Chinese Academy of Sciences leads with 58 publications, reflecting its prominent role in environmental and technological research in China. This is closely followed by the Ministry of Education of the People's Republic of China with 53 documents, indicating strong governmental support for academic research on sustainability. Tsinghua University, a top-tier research institution, contributes 37 publications. In contrast, other leading Chinese universities, such as Central South University, Tongji University, Shanghai Jiao Tong University, as well as the University of Chinese Academy of Sciences, each contribute between 26 and 29 documents, emphasizing China's extensive academic involvement in the field. Internationally, KU Leuven in Belgium also stands out with 26 publications, showing significant European engagement. In India, the SRM Institute of Science and Technology and Jadavpur University contribute 25 and 24 documents, respectively, reflecting India's academic focus on addressing e-waste through research and innovation. This distribution of affiliations highlights the dominance of Chinese and Indian institutions in advancing e-waste research, while also showcasing global collaboration through contributions from other leading universities.

Table 4: Top Affiliation and University

Affiliation	Documents
Chinese Academy of Sciences	58
Ministry of Education of the People's Republic of China	53
Tsinghua University	37
Shanghai Jiao Tong University	29
University of Chinese Academy of Sciences	29
Central South University	26
KU Leuven	26
Tongji University	26
SRM Institute of Science and Technology	25
Jadavpur University	24

Source: (Scopus.com)

Q5 What Are Co-Occurrence, Co-Citation, And Country Collaboration?

Figure 5 shows a bibliometric visualization that illustrates the keyword co-occurrence network within the field of e-waste research. The largest nodes, such as “electronic waste,” “e-waste,” “metal recovery,” “lithium-ion batteries,” and “humans,” represent the most frequently occurring terms, indicating key areas of scholarly focus. The different colors denote thematic clusters: the green cluster emphasizes management and policy-related topics like "supply chains," "government," and "life cycle"; the red cluster is centered on material and recovery processes, including “metal recovery,” “copper,” and “lithium-ion batteries”; the blue cluster addresses environmental and health impacts, with terms such as “heavy metals,” “soil,” and “health risk.” This mapping reflects the multidisciplinary nature of e-waste research, varying from public health, environmental science, policy, and materials recovery.

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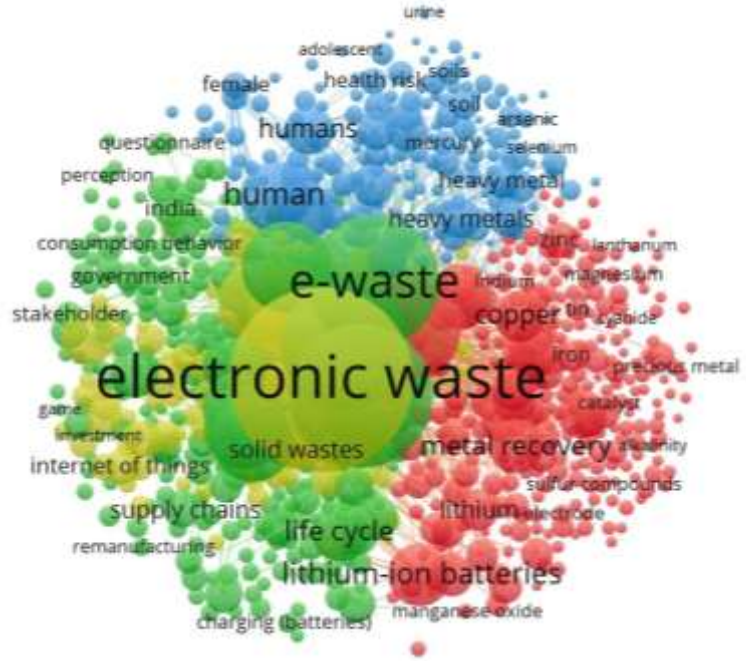

Figure 5: Keywords Co-occurrences of Network Visualization

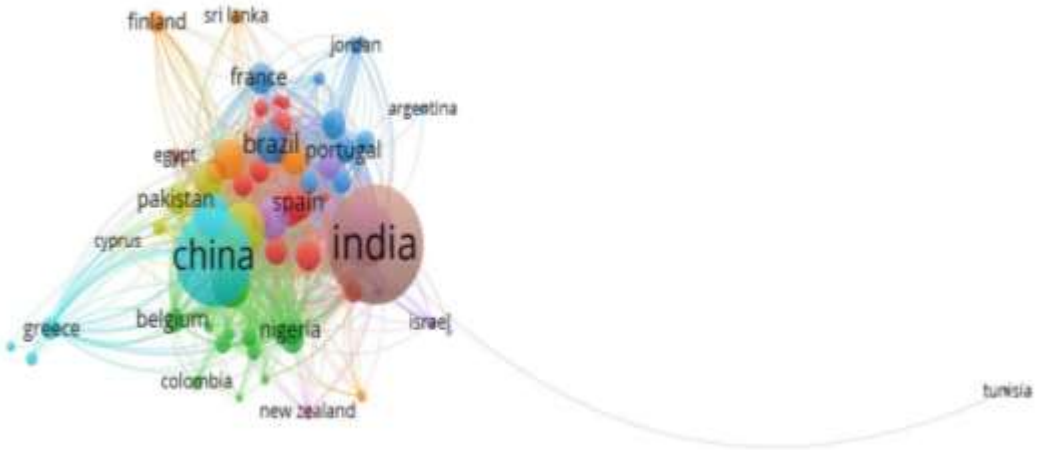

Figure 6: International Research Collaboration based on co-citation between countries

Figure 6 shows a bibliometric visualization illustrating international research collaboration on e-waste, based on co-citation between countries. Larger nodes like India and China indicate higher publication output, reflecting their dominant roles in this research field. The dense clustering of countries such as Brazil, Portugal, Spain, France, and Nigeria around China and India suggests strong regional and intercontinental collaborations. The color-coded clusters represent groups of countries that frequently work together, with visible interlinkages indicating a well-connected global research network. However, Tunisia appears isolated with only a weak link to the main network via Israel, highlighting its limited engagement in global

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e-waste research collaboration. Overall, this map reveals that while global e-waste research is growing and interconnected, certain regions remain less integrated into the international research community.

Q6 What Are Co-Occurrence, Co-Authorship, And Country Collaboration?

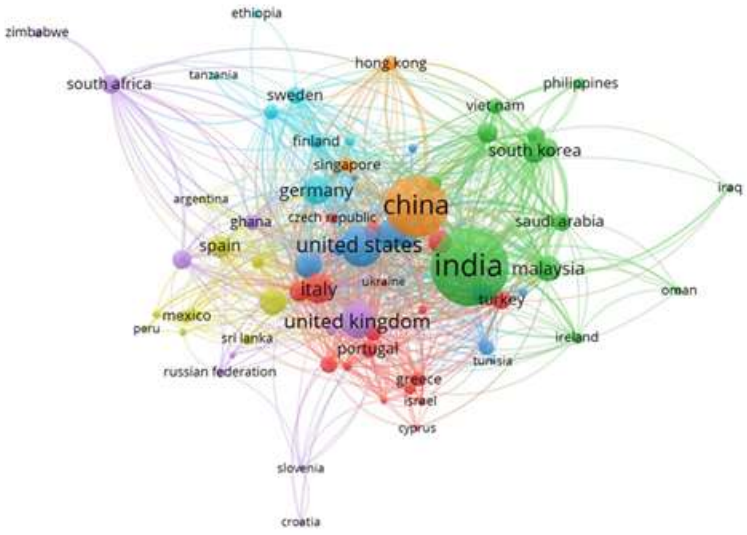

Figure 7: Co-authorship between Countries

Figure 7 show the bibliometric analysis map visualizes the global research collaboration network on e-waste based on co-authorship between countries. The size of nodes seems to represent the quantity of work that a country generates, in terms of publications, and such nodes as India, China, the United States, as well as the United Kingdom are large, being characterized by an impressive volume of research. The different colours represent distinct clusters of countries that tend to collaborate more closely with each other. For instance, the green cluster centred around India includes countries like Malaysia, South Korea, Saudi Arabia, and the Philippines, indicating regional partnerships in Asia. The red cluster highlights collaboration between European countries like the United Kingdom, Italy, Portugal, and Greece. Meanwhile, countries like South Africa and Zimbabwe form a smaller, more isolated cluster, suggesting limited collaboration with the broader global network. Overall, the visualization highlights strong international linkages in e-waste research, particularly between leading research nations and their regional partners.

Conclusion

We performed the analysis on 5587 publications on e-waste management between 2019 and 2025. Overall, the bibliometric analysis performed in this research emphasizes the increasing scholarly interest in e-waste management between 2019 and 2025. The steady rise in the number of publications, particularly in 2023 and 2024, reflects growing global concern over the environmental, economic, and health implications of e-waste. India, China, and the United States emerged as the most active contributors, supported by leading institutions such as the

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Chinese Academy of Sciences and Tsinghua University. Keyword co-occurrence mapping revealed that recent research had focused heavily on themes such as metal recovery, recycling technologies, policy implementation, environmental risks, and health hazards, with growing attention toward technological solutions like artificial intelligence and IoT.

Moreover, the collaboration networks indicate that e-waste research is globally interconnected, with strong partnerships among Asian and European countries. However, disparities remain in terms of research contributions from certain regions, highlighting the need for broader participation and policy-driven support. The findings of this analysis give an informative insight into the research field and provide a strategic direction for future studies. Emphasis on public awareness, formal recycling systems, and sustainable practices remains essential to achieving effective e-waste management and aligning with circular economy goals. This study is thus a good source of information for practitioners, academics, as well as policymakers seeking to strengthen research, collaboration, and action in e-waste management.

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