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Review

Current Trend, Future Direction, and Enablers of e-Waste Management: Bibliometric Analysis and Literature Review

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Abstract

In the current decade, effective management of electronic waste (e-waste) has emerged as a critical research area. Therefore, this research aimed to identify the current trend, future directions, and key enabler factors for e-waste management by conducting bibliometric analysis and literature review. Using the Scopus database, 441 peer-reviewed papers from 2012 to 2021 were collected for bibliometric analysis. To visualize the data, research mapping tools such as Biblioshiny and VOSviewer were employed. In addition to the bibliometric analysis, a literature review was conducted on the top ten articles to identify enabler factors influencing e-waste management. The analysis showed keywords such as "e-waste", "recycling", "e-waste management", "sustainability", "e-waste", and "circular economy". Additionally, some key motor themes of e-waste management field were identified, including "policy", "human health", "developing countries", "e-waste management", and "strategies" through thematic analysis. This research suggests that there are five dimensions of enablers in e-waste management: policy, economy, social, environmental, and technology. The combination of VOSviewer and Biblioshiny tools for bibliometric analysis along with a literature review proved to be a powerful and beneficial approach for scientific mapping and identifying the driving factors of e-waste management.

Keywords: bibliometric, e-Waste management, circular economy, Biblioshiny, research mapping

Introduction

E-waste management or Waste Electrical and Electronic Equipment (WEEE) is one of the most pressing environmental problems in the world [1]. In terms of preserving and protecting the environment, the ability to recycle metals from e-waste is beneficial for both the economy and ecology [2]. In 2019, only 17.4% of e-waste was legally collected and adequately recycled out of a total production of 53.6 million metric tons (Mt) worldwide [3]. Subsequently, as consumer technology is constantly evolving, the amount of e-waste is increasing rapidly, and technical innovation

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leads to rapid obsolescence, resulting in large amounts of e-waste [1]. Meanwhile, unofficial actors in recycling e-waste can have a serious impact on the environment [4]. Therefore, e-waste management is needed.

E-waste management in developing countries requires more strategies than in developed countries in order to achieve Sustainable Development Goals (SDGs). Currently waste management leads to the achievement of circular economy concept [5]. In China, e-waste management is developed through big data, the Internet of Things (IoT), and cloud computing, especially in collection and recycling [4]. In India, on the other hand, an inventory of e-waste is required to realize a sustainable smart city using a cloud-based framework [6]. In the context of public services, the use of big data [6] and digital technology can help to increase efficiency in e-waste management [7]. The primary goal of E-waste management strategies is the recovery of metals [8].

In recent years, researchers around the world have paid more attention to research on e-waste management [9]. Numerous research carried out use bibliometric analysis to examine the theme of e-waste. Scientific publications are the primary means for knowledge transfer, and bibliometric is becoming an increasingly significant component of research methodology [10]. Information visualization technology has been used for capturing and research mapping [11]. Meanwhile, information visualization technology for bibliometric analysis is VOSviewer [12-14] and Biblioshiny [15, [16]. Many researchers in various fields use bibliometric analysis, such as in the areas of supply chain management [17, 18], blockchain technology [19], urban planning and development [20], text mining [21], environmental, social, and governance [22, 23], economy [24], machine learning [25], IoT [26], and municipal waste management [27].

Bibliometric methodologies differ from previous literature reviews, systematic reviews, or meta-analyses [10]. Bibliometric analysis typically consists of creating bibliometric maps and plotting the maps [28] using quantitative methods [29], and it helps assess research performance [30]. There are many articles dedicated to e-waste reviews. Bibliometric analysis was used to compile a summary of articles published between 2008 and 2020 on e-waste related to circular economy idea [31]. Another research uses bibliometric analysis to provide a comprehensive review of the scientific literature on the environmental impact of e-waste [32]. Bibliometric analysis of Web of Science e-waste research was checked with VOSviewer [33].

Although there have been numerous research on e-waste, many of these papers do not address the specific aspect of e-waste management. Subsequently, it is important to note that e-waste management is different from e-waste processing. Therefore, it is crucial to use a combination of VOSviewer and Biblioshiny applications to map out e-waste management from various research. The following are the specific research questions:

1. What are the current trend in the field of e-waste management?
2. What is the future direction of e-waste management?
3. What are the enablers of e-waste management?

This research aimed at the current trend, enabler factors, and future direction of e-waste management. The breakthrough combination of methods in this research area provides a unique perspective and contributes to better e-waste management.

Materials and Methods

This research design is a descriptive research based on the literature with bibliometric analysis. In this research, information visualization technology was used, specifically, the VOSviewer and Bibliometric R-package software (Biblioshiny). These open-source tools, developed by Aria and Cuccurullo, provide a range of features for performing bibliometric analyses in a quantitative manner [34, 35].

This research used Scopus database publication data relevant to e-waste management. The Scopus database is a high criterion indexing around the world. The search terms were "e-waste management" in the complete data set. On September 29, 2022, a search was carried out which retrieved 441 articles published between 2012 and 2021 on e-waste management. The data from these articles including information authors, keywords, sources, papers, and knowledge structures (both conceptual and social), were analyzed using VOSviewer and the R-based Biblioshiny.

Visualization of the co-occurrence network of keywords was carried out using VOSviewer [24, 34-36], while descriptive statistics such as numbers, percentages, and rankings were used to present these findings. Descriptive statistical analyzes were carried out to show the development over time and the distribution of the articles and performance analysis was also conducted to analyze the number of publications, citations, and primary publication sources [15, 37]. After obtaining the most cited documents from bibliometric analysis, the top ten articles were reviewed. A full-text review was conducted to obtain information on the factors that drive the implementation of e-waste management.

Descriptive statistical analyzes were carried out to show the development over time and the distribution of the articles.

Results and Discussion

Annual Scientific Production

Fig. 1 shows the progression of Scopus articles on e-waste management. It can be observed that the number of publications has increased over the last ten years, with a potential watershed moment in 2018 when

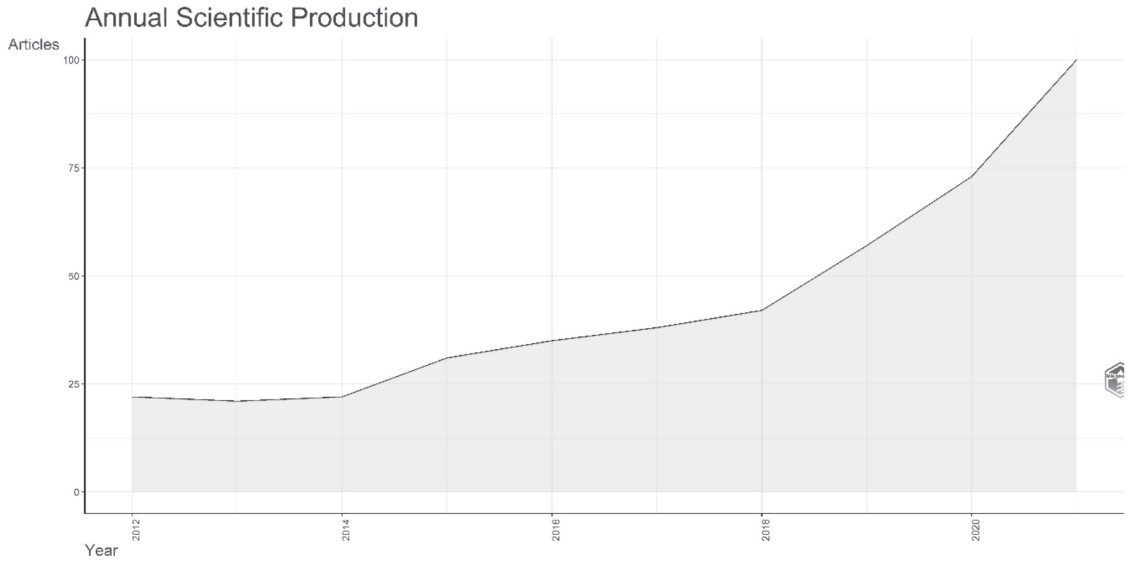

Fig. 1. Annual scientific production from 2012 to 2021.

there was a significant increase in authors' interest in getting published in Scopus-indexed journals.

Country Production

Fig. 2 shows national production over time from 2012 to 2021. Five countries (India, China, Malaysia, Indonesia, and the USA) have always been at the forefront of the research on how to deal with e-waste. Subsequently, it was observed that India has taken a dominant position in the last ten years with more than 300 publications.

The results above show the detailed bibliographical features of e-waste management-related articles published in Scopus-indexed journals. Research into e-waste management has increased rapidly in recent years with increased public awareness of environmental issues. This shows that the interest of researchers in the field of e-waste management publishing in international publications has increased over the decade. Interestingly, developing countries like India, China, Indonesia, and Malaysia are among the top five science countries, alongside developed nations like the United States. Indonesia, for example, 2021 produced nearly 100 publications in the field of e-waste management and was ranked fourth for the year.

Organizations Production

The affiliations or organizations that produce the most articles in the field of e-waste management are presented in Table 1. Interestingly, the University

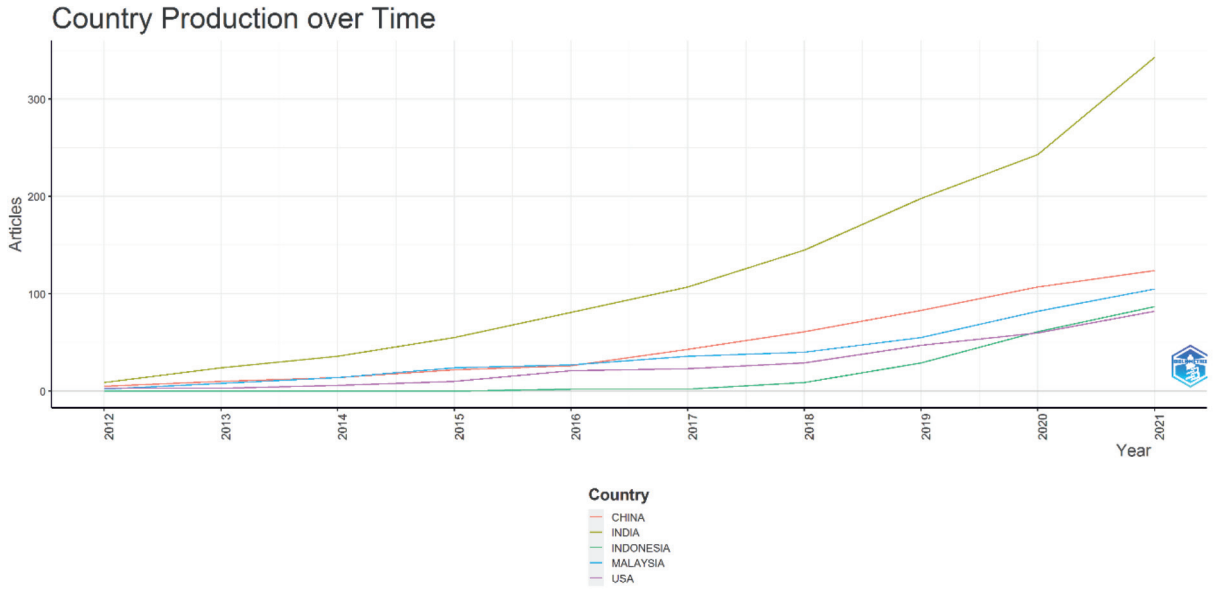

Fig. 2. Country production over time from 2012 to 2021.

Table 1. Most relevant affiliations.

No	Affiliation	Articles
1	University of Indonesia	19
2	University of Technology Malaysia	17
3	University of Ibadan	15
4	Tsinghua University	13
5	University of Nigeria	12
6	Tabriz University of Medical Sciences	11
7	University of Malaya	11
8	Yildiz Technical University	11
9	Shanghai Jiao Tong University	10
10	Umeå University	10

of Indonesia, ranks first among other organizations, followed by the University of Technology Malaysia and the University of Ibadan. This performance indicates that universities from developing countries can compete with universities from developed countries.

The Co-Occurrence Network of Keywords

Fig. 3 illustrates the distribution map of keywords in e-waste management articles using VOSviewer. There are 5 clusters of 22 items with a minimum number of occurrences of a keyword of 8. Fig. 3 illustrates a network in which the size of the node is related to the number of releases and the width of the edge, and the color represents the cluster where the keyword element is located. Furthermore, grouping information is particularly beneficial because it offers a broad overview of how items are assigned to clusters and how those groups of items are related to one another [38].

According to the cluster analysis in Fig. 3, these words are fundamental to the theme of e-waste management and connect the other domains. Words were classified into clusters based on their frequency of occurrence and association in the literature. The subjects of e-waste, management, the environment, heavy metals, and extended producer responsibility were the focus of research in Cluster 1 (blue). Cluster 2 (red) shows research concepts related to recycling, sustainability, e-waste management system, India, China, and the informal sector. The research focus was on e-waste in developing countries and green computing, according to the terms of cluster 3 (green). Cluster 4 topics include circular economy, waste management, reverse logistics, and were (yellow). Investigation in Cluster 5 (purple) was primarily concerned with issues of awareness and disposal.

From the net map of e-waste management keywords created by the author, it can be seen that there are still many themes yet to be connected. The unconnected themes illustrate that no paper uses these topics. Therefore, many future research opportunities in the field of e-waste management can be carried out. For example, green computing (green cluster) regarding

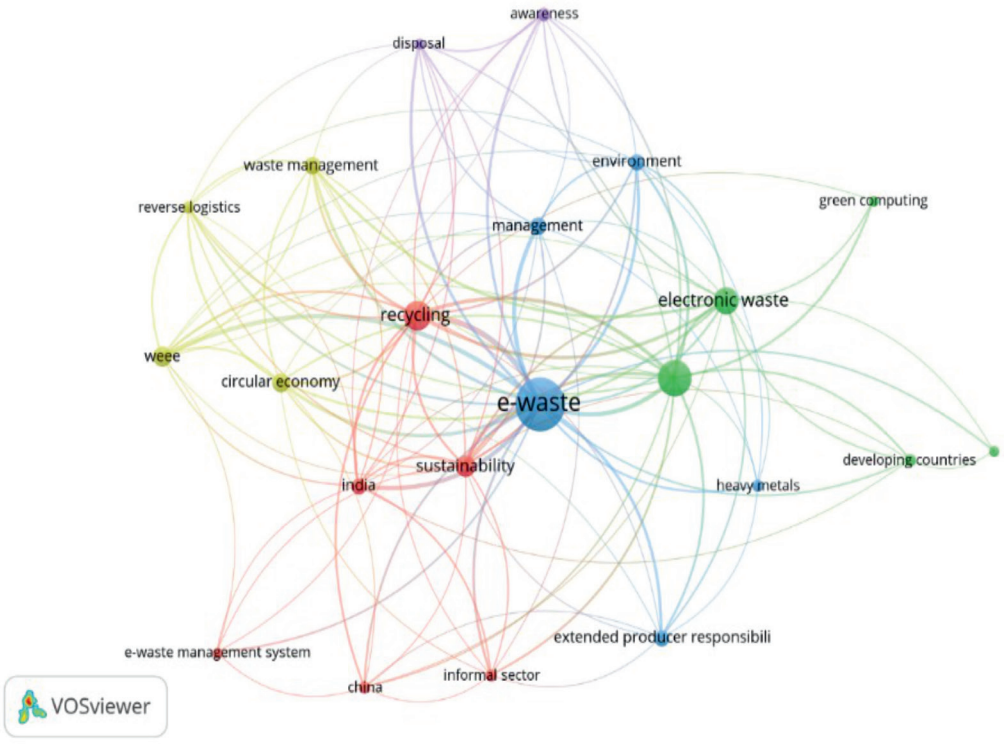

Fig. 3. Netmap of author's keywords on e-waste management.

e-waste (blue cluster) in developing countries (green cluster) has not yet been connected or a circular economy (yellow cluster) in the informal sector (red cluster) using an e-waste management system (red cluster). Based on this map, there are many opportunities for a combination of topics that can be researched in the future in the field of e-waste management.

Authors Production

In this research, about 1,269 authors were identified to have published articles on e-waste disposal. Fig. 4 shows the top ten authors' production over time from 2012 to 2021. This diagram provides information on the number of articles from the authors (red circle). The bigger the circle, the more the author publishes the articles.

Borthakur and Kumar are authors who consistently published articles in the field of e-waste management every year from 2013 to 2021. Next is Li, who started publishing articles in 2014 but was only consistent until 2019. In line with Li, Xu is the same, and only published articles from 2012 to 2016. Other authors such as Rimantho, Effendi, and Eriyatno published their research in the last two years, from 2019 to 2020.

Three Fields Plot

The three fields plot illustrated in Fig. 5 is a three-item representation of a list of keywords, authors, and journal titles. These plots are shown with grey links, beginning with the key, then the authors, and each author is then connected to the journal name. The size of the rectangular shape on the list indicates the number of articles associated with that item.

The sources or journals are the first items on the left in Fig. 5. The top seven journals with the most published articles on the topic of e-waste management were the journal of the material cycle and waste management, environmental science and pollution research, waste management and research, journal of cleaner production, international journal of environment and waste management, ACM international proceeding series, and waste management.

The middle element is the names of the authors, and those who have published articles in reputable journals, like Bortakur, linked to preceding elements, including Environmental Science and Pollution Research as the source or journal elements. Furthermore, Kumar as the author on the center side connected with ACM international proceeding series (left side) and associated with e-waste, e-waste management, India, recycling, management, were, and circular economy (keywords).

Each author is also linked to frequently searched keyword themes on the right. This plot lists the top ten authors, and the size of the rectangle represents the number of papers produced by each author. Subsequently, Bortakur, Kumar, Li, and Rimantho had the most giant rectangles in this plot. The third component includes the most frequently appearing topic-related keywords in the articles. The length of the green rectangle shows that the most common term was "e-waste".

Most Globally Cited Documents

In Table 2, it can be observed that the top 10 most cited e-waste management documents in the world are from other scientists from 2012 to 2021. Subsequently, Kiddee's article was the most mentioned in the review of e-waste management, and the article is titled "e-Waste Management Approaches: An Overview". The article describes the dangerous compounds contained in e-waste, their potential health and environmental impacts, and the current management strategies applied in different countries [1]. The article was cited 454 times (total citations), which is significantly higher than the number of citations for other articles.

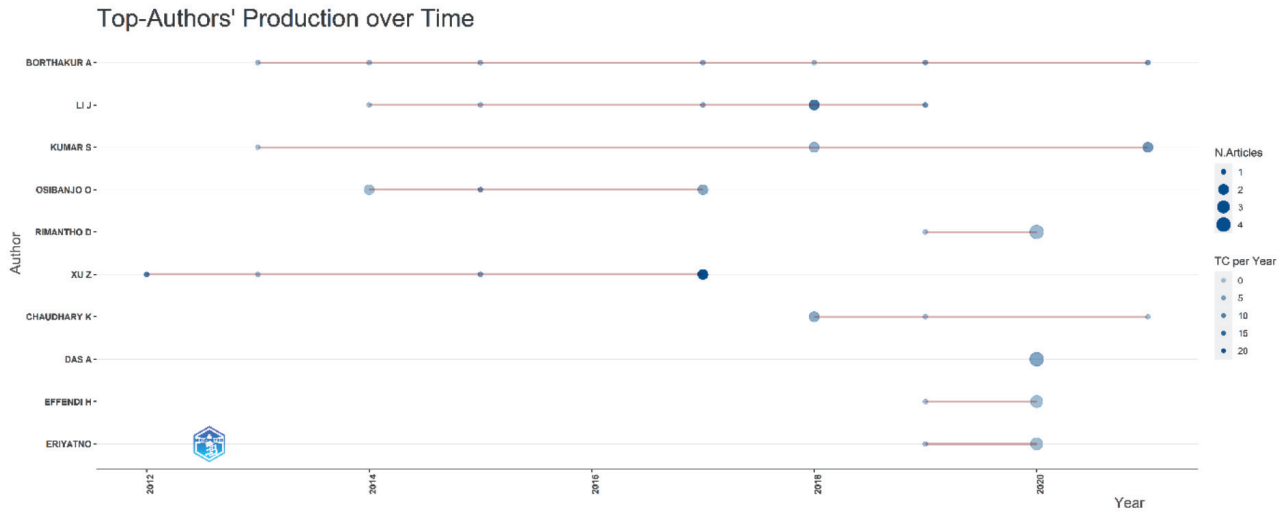

Fig. 4. Top ten authors' production over time from 2012 to 2021.

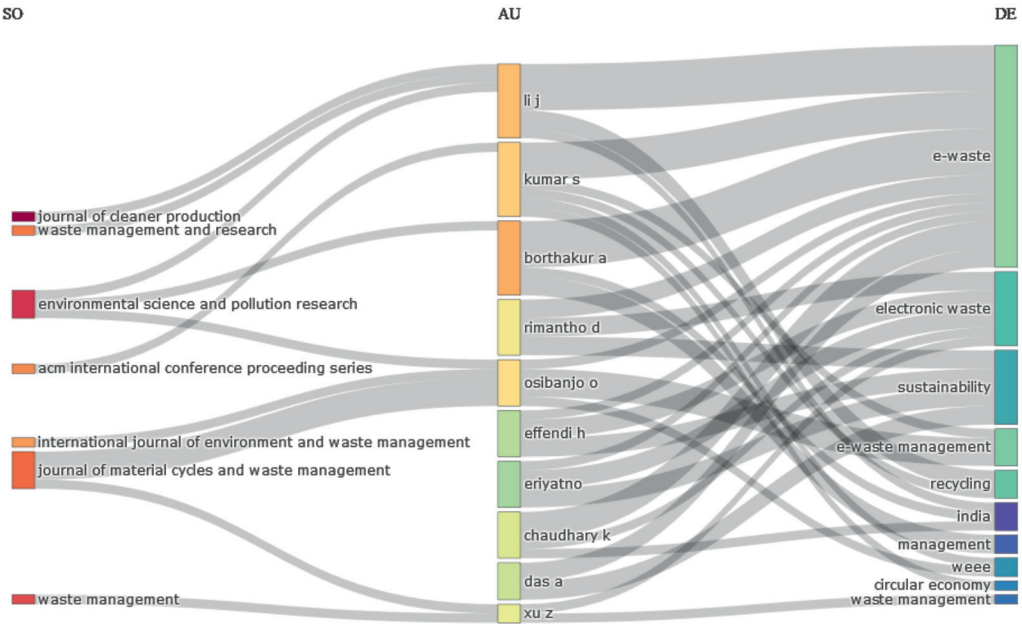

Fig. 5. Three-Fields Plot.

The second-ranking article is written by Echegaray and is published in the cleaner production journal. The article discusses the factors influencing consumer behavior toward recycling e-waste using the Theory of Planned Behavior, especially in Brazil [39]. The article has been cited a total of 192 times. Meanwhile, the third paper widely cited is Reig's article in Construction and Building Materials, and it was cited 180 times discussing Red clay brick waste, especially its properties and characteristics [40].

The article that ranks fourth was written by Kumar, with a total of 144 citations. The paper discusses the obstacles in managing e-waste [41]. Furthermore, Zhou published an article in the Environment Science and Technology journal with a total of 133 citations. The paper discusses the regulatory system, formal system, and the idea of an integrated system for managing e-waste in China [42].

The following article is titled "Utilizing Waste Cable Wires for High-Performance Fiber-Based Hybrid Supercapacitors: An Effective Approach to e-Waste Management". The article was written by Nagaraju in the Journal of Advanced Energy Materials in 2018. The paper discusses that Cu fibers are used as a current collector, and this is cost-effective because it comes from leftover/waste power cable cables. Then it was synthesized by becoming a high-performance supercapacitor [43].

Then, article number 8 was written by Dwivedy, titled "Willingness of Residents to Participate in e-Waste Recycling in India", published in the journal Environmental Development. This paper discusses the factors influencing consumers' desire to participate in e-waste recycling programs, especially in India [44]. The article "Integrated Approach to Building e-Waste Management Systems for Developing Countries" discusses integrated e-waste management [45]. The article written by Ikhlayel was published in the Journal of Cleaner Production.

The last article in the top ten rankings is a document written by Xu in the waste management journal. This paper discusses the global reverse supply chain, especially regarding waste collection, carbon emissions, and transportation costs [46].

The Thematic Map on E-Waste Management (Conceptual Structure)

Fig. 6 uses the thematic map to illustrate the diverse research directions in the literature on coping with e-waste management. The thematic map or strategic diagram [47] uses density and centrality in 4 quadrants [48, 49]. The most important problems in the disposal of e-waste are represented in the graphic by four quadrants, with the y- and x-axes representing centrality and density, respectively. The top left quadrant niche theme has strong internal connections with minor and external relationships. The article is not critical for e-waste recycling and extended producer responsibility. Topics in the bottom-right quadrant (base topics) are important to the research area but less established; hence, this quadrant combines transversal and fundamental topics such as "e-waste" and "e-waste management" and "recycling," as well as "circular economy" and "waste management" and "reverse logistics".

The top-right quadrant's main topics include well-organized research areas like "human health" and "policy", "developing countries", "e-waste management", and "strategies". The faded or emerging themes in the bottom-left quadrant show that the issues

Table 2. Most globally cited documents on e-waste management.

No	Paper	DOI	TC
1	Kiddee P, 2013, Waste Manage	10.1016/j.wasman.2013.01.006	454
2	Echegaray F, 2017, J Clean Prod	10.1016/j.jclepro.2016.05.064	192
3	Reig L, 2013, Constr Build Mater	10.1016/j.conbuildmat.2013.01.031	180
4	Kumar A, 2018, Sustain Prod Consum	10.1016/j.spc.2018.01.002	144
5	Zhou L, 2012, Environ Sci Technol	10.1021/es203771m	133
6	Oliveira Crd, 2012, Waste Manage	10.1016/j.wasman.2012.04.003	129
7	Nagaraju G, 2018, Adv Energy Mater	10.1002/aenm.201702201	108
8	Dwivedy M, 2013, Environ Dev	10.1016/j.envdev.2013.03.001	103
9	Ikhlayel M, 2018, J Clean Prod	10.1016/j.jclepro.2017.09.137	102
10	Xu Z, 2017, Waste Manage	10.1016/j.wasman.2017.02.024	90

are in the development phase of marginal relevance and mainly demonstrate faded or promising topics such as "blockchain" and "green computing".

The evaluative analysis, which includes a thematic map, a factorial analysis, and a social map, demonstrates the scope of research in the field of e-waste management. A thematic map is used to get an overview of the current status of the field and its future viability [50]. The thematic maps show that the motor themes of e-waste management field are "policy", "human health", "developing countries", "e-waste management", and "strategies". According to the theme analysis, more efforts are required to address concerns such as "e-waste recycling", "extended producer responsibility", "heavy metals", and "informal recycling".

The conceptual structure map unifies keywords by considering their homogeneity in the network developed from Multiple Correspondence Analysis (MCA). Fig. 7 shows a classification of common keywords into two categories. Subsequently, dim is a small particle, a term

Fig. 6. Thematic maps on e-waste management (conceptual structure).

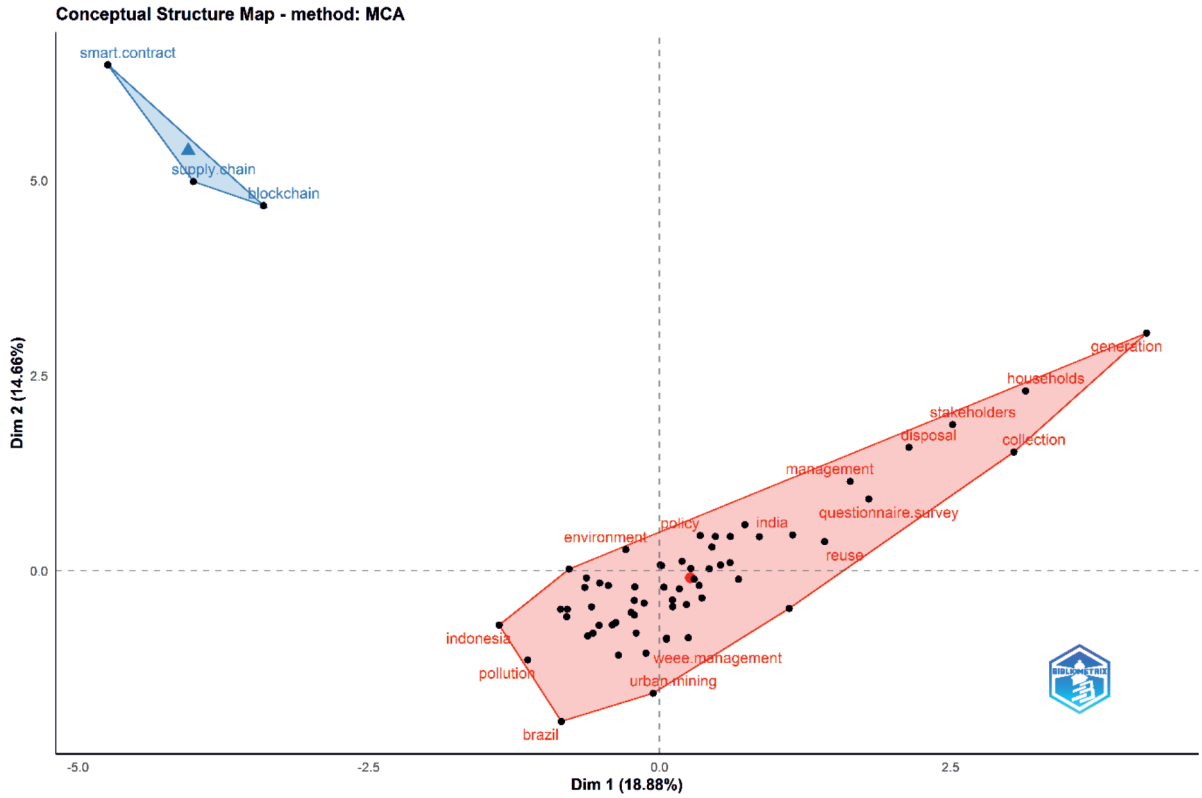

Fig. 7. Factorial analysis on e-waste management (conceptual structure).

used in bibliometric science to create an association between words with similar values [51].

Cluster 1 in blue on the left side of the conceptual structure map shows the most commonly used keywords in research papers on the same research topic. The keywords such as "smart contract" "supply chain" and "blockchain". For example, blockchain and smart contracts combined by research such as a blockchain-enabled IoT solution for tracking all post-production business operations in e-waste recycling utilizing smart contracts [49].

On the other hand, Cluster 2 on the right of the map displays keywords such as "politics" "environment" and "household" as well as "collection" "waste management" and "reuse". The use of keywords such as "collection", "environment", "household", and "waste management" can be seen, for example, in Banaszkiewicz's article on "household e-waste management" [52].

Collaboration Map on E-Waste Management (Social Structure)

The maps of the cooperation networks displayed between the countries result from bibliometric analysis of e-waste management. In Fig. 8, the thickness of the red link reflects the frequency of cooperation, the dark blue color represents high cooperation productivity, and the light blue color represents low cooperation productivity. The stronger the links between countries, the more frequently people collaborate. Subsequently, China has the most common research collaboration links with the USA and Australia. India has the most common research collaboration relationships with Korea and the USA. Nigeria has the most common research collaboration link with South Africa and Germany. The e-waste collaboration map shows that developed and developing countries from Europe, Asia, Africa, Australia, North America, and Latin America are collaborating on research in this field.

Enabler Factors in E-Waste Management

Based on the literature review of the top ten articles on bibliometric analysis, a five-dimensional extraction was obtained, which encourages better e-waste management, as presented in Table 3. On the policy dimension, there are factors: Specific regulations regarding e-waste, Use of tools LCA, MFA, MCA, and EPR, and Global reverse supply chain. On the policy dimension, there are factors: The economic level of the population, Special funds and subsidies for e-waste recycling systems, and Economic assessment of e-waste management techniques. Then on the social dimension, there are factors: Stakeholders are ready to accept and comply with government policies, Compliance behavior of citizens disposing of e-waste, and OEM electronics manufacturer's initiatives are voluntary in national roundups. On the Environment dimension, there are factors: Characterization of types of e-waste. Finally on the Technology dimension, there are factors:

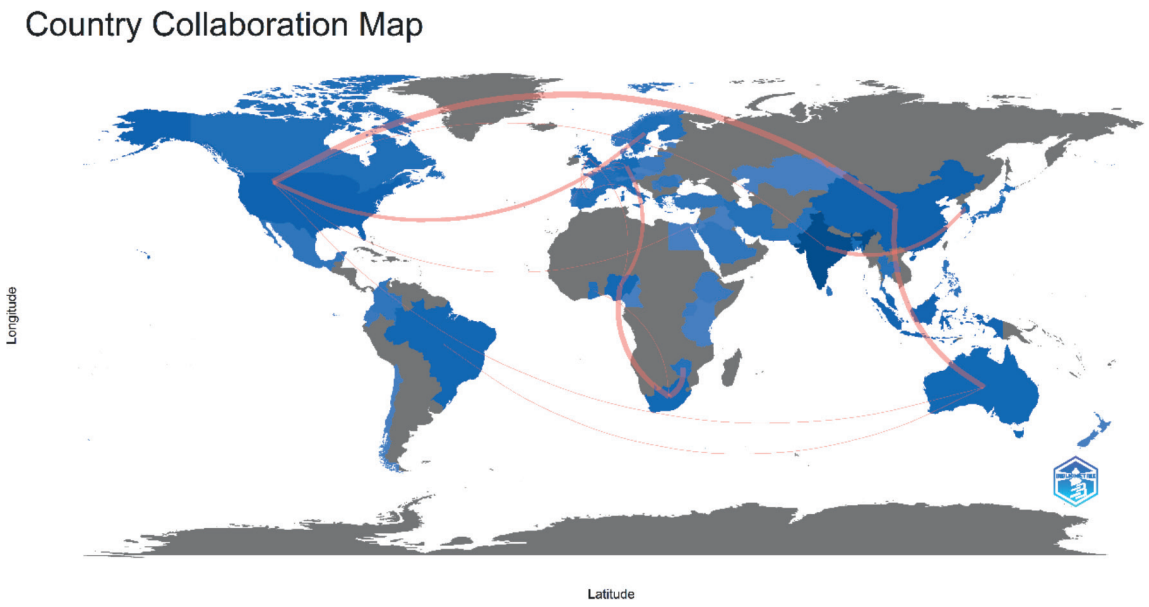

Fig. 8. Collaboration map on e-waste management (social structure).

Development of environmentally friendly electronic devices, and Environmentally friendly recycling technology.

In addition to the driving factors in managing e-waste, significant challenges are faced in managing e-waste, including the policy dimension, namely the need for cross-actor collaboration to make specific policies regarding e-waste, especially in developing countries. Then on the economic aspect, a sufficient budget is needed, especially for the government and businesses to manage e-waste. Incentives for responsible e-waste managers can be considered. Economic activity from e-waste management is directed towards a circular economy. Furthermore, on the social dimension, public awareness in sorting, disposing, and collecting electronic waste is a necessity that needs to have campaigned on an ongoing basis. The partnership of government, electronics manufacturers, communities, and other actors is worth doing. On the environmental aspect, determining the type of e-waste and the characteristics of its impact on the environment need further research. And finally, namely, the technological dimension, technological innovation in producing electronic equipment that is friendly to the environment and sustainable recycling technology is needed.

Table 3. Enabler factors in e-waste management.

Dimension	Enabler Factor	References
Policy	Specific regulations regarding e-waste	[1, 42, 44, 53]
	Use of tools LCA, MFA, MCA, and EPR	[1]
	Global reverse supply chain	[46]
Economy	The economic level of the population	[39]
	Special funds and subsidies for e-waste recycling systems	[42]
	Economic assessment of e-waste management techniques	[45]
Social	Stakeholders are ready to accept and comply with government policies	[1]
	Compliance behavior of citizens disposing of e-waste	[39]
	OEM electronics manufacturer's initiatives are voluntary in national roundups	[42]
Environment	Characterization of types of e-waste	[45]
Technology	Development of environmentally friendly electronic devices	[1]
	Environmentally friendly recycling technology	[42]

Conclusions

This research provided a comprehensive overview of scholarly publications worldwide in the field of e-waste management over time using a combination of bibliometric tools through VOSviewer and Biblioshiny. The number of e-waste management articles indexed by Scopus from 2012 to 2021 is substantial and has the potential to grow as e-waste management becomes more prevalent. Based on this finding, the performance of the country and organization's scientific publications, author's performance, co-occurrence keywords network map, thematic map, and collaboration map on the research of e-waste management was known. Furthermore, from enhancement analysis with a literature review from the top ten most cited articles, five dimensions of enablers in e-waste management were discovered such as policy, economy, social, environment, and technology. Subsequently, each aspect consists of enabler factors that influence e-waste management.

Another finding from this research shows that universities in developing countries can compete with universities in developed countries, especially in the field of e-waste management. Additionally, some of the most prolific authors, articles, and journals can serve as sources of information for researchers working on the topic. In this research, the limitations include the fact that only the Scopus database was searched for literature. Therefore, further research using databases such as Web of Science, Dimensions, and others is recommended. There is a need to inspire environmental management scientists to contribute to e-waste management research and to put this knowledge into practice.

Conflict of Interest

The authors declare no conflict of interest.

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