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# E-Waste and the Telecommunication Industry: A 15-Year Bibliometric Mapping of Research Progress

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**ABSTRACT**

The rapid growth of e-waste resulting from technological advancements in telecommunications has intensified research on efficient management strategies, particularly in recycling, environmental impact, and sustainable disposal methods. To provide a comprehensive bibliometric analysis, this study employs Bibliometrix and VOSviewer 1.6.20 to graphically map key insights into the telecom sector's role in e-waste management between 2000 and 2024. The findings reveal that: (1) publications increased exponentially, peaking at 95 in 2024 after nearly doubling from 38 in 2019 to 61 in 2020; (2) Zeng Xianlai emerged as the most influential author, averaging 149.63 citations per article across eight publications; and (3) the National Environmental Engineering Research Institute (NEERI) demonstrated the greatest research influence, followed by the Academy of Scientific and Innovative Research (128) and the State Key Joint Laboratory of Environment Simulation and Pollution Control (135.38). Overall, the study underscores the growing urgency of addressing e-waste in telecommunications and emphasizes the need for sustainable solutions to minimize environmental impact and advance the 2030 SDGs.

## 1. Introduction

E-waste management is the environmentally responsible method of dealing with abandoned electronics. Devices such as TVs, laptops, and cell phones must be methodically collected, recycled, and disposed of to protect human health and the environment [1,2]. E-waste management supports sustainability by carefully handling dangerous elements like mercury and recovering valuable resources like metals [3-5]. In addition to lessening the amount of waste in landfills, [6] this technique also conserves natural resources and lowers pollution. By adopting e-waste management techniques, we can make the planet greener and cleaner, benefiting future generations.

Managing e-waste is crucial for safeguarding both human health and the environment. Pollutants like lead and mercury are released into the soil and water when electronic waste is improperly

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disposed of, threatening ecosystems. [7-9]. Serious health problems, such as brain damage and respiratory disorders, can also result from exposure to dangerous substances found in e-waste. In addition to saving precious resources, efficient e-waste treatment lessens the need for new mining by recovering commodities like gold and rare earth metals. Reducing the amount of waste that is dumped in landfills encourages sustainability and eases the strain on waste management systems [10,11]. Recycling e-waste also ensures responsible trash disposal methods, conforms with rules, and generates economic opportunities.

Governments and telecom companies must work together to implement sustainable practices, including strict regulations, mandatory recycling programs, and eco-friendly product designs [12-14]. The telecom industry has a significant impact on e-waste management because of the rapid turnover of electronic devices and infrastructure, which results in vast amounts of e-waste, including networking gear, antennas, and cables, as older technologies become obsolete [15]. Improper disposal of this e-waste can release harmful toxins like lead, mercury, and cadmium into the environment, posing risks to human health and ecosystems. Furthermore, inefficient recycling leads to the loss of valuable resources like gold, silver, and copper.

In 2022, a record 62 million tons (Mt) of e-waste were produced, an increase of 82% from 2010, according to the United Nations' Global E-Waste Monitor 2024 [16,17]. Less than a quarter (22.3%) of the total quantity of e-waste generated during the year was, however, reported to have been appropriately collected and recycled (Figure 1). By 2030, it is predicted that 82 million tons of e-waste will be generated unless immediate action is taken [18]. Worldwide, more than 57 million metric tons of e-waste were produced in 2021. It is predicted to reach 75 million metric tons by 2030, which equals the weight of 9.5 million African elephants. But just 17% of this electronic garbage is recycled [19,20].

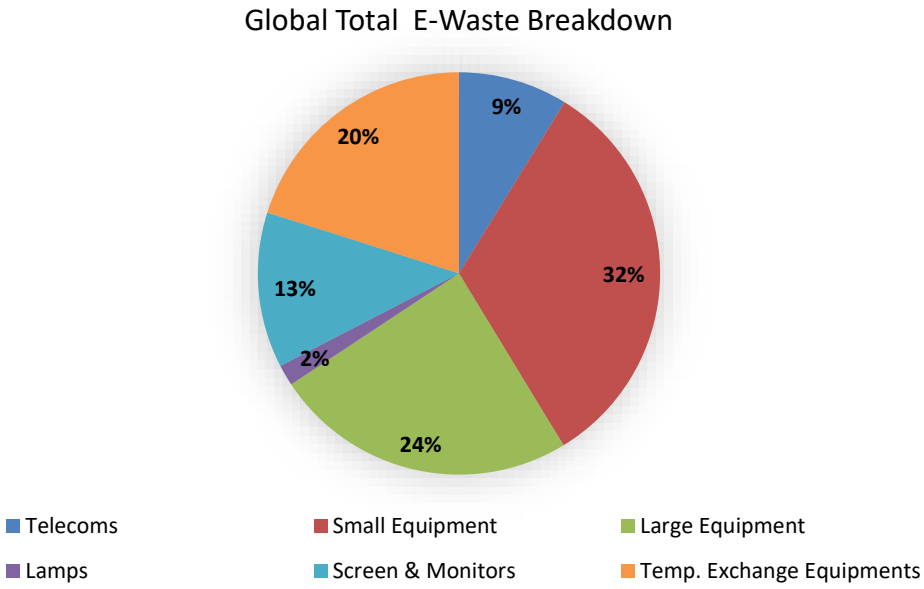


**Fig. 1.** Total e-waste breakdown in global level

### *1.1 Application of E-waste Management in the Telecom Industry*

Recycling of Used Telecom Equipment – To recover valuable metals like copper, gold, and silver, old mobile phones, routers, servers, and network cables are gathered and recycled [21,22].

Proper Disposal of Hazardous Materials – Electronic parts, circuit boards, and batteries are disposed of properly to avoid contaminating the environment [23,24].

Refurbishment & Reuse – To reduce electronic waste and promote sustainability, used telecom devices and components are fixed and resold [25-27].

EPR (Extended Producer Responsibility) Compliance – Telecom businesses are responsible for recycling and disposing of end-of-life products by government laws [28,29].

Energy-Efficient Waste Processing – Modern waste management methods, like material separation and shredding, guarantee effective recycling with little harm to the environment [30,31].

### *1.2 Past literature on E-waste management*

In e-waste management, bibliometric analysis has been widely used to evaluate research trends, seminal publications, and emerging themes. In the last twenty years, researchers have used bibliometric techniques to analyze publication growth, important contributors, citation networks, and research hotspots about recycling, policies, sustainable practices, and the production of electronic trash. While contemporary research has broadened to encompass circular economy strategies, cutting-edge recycling technologies, and digital solutions, early studies mostly concentrated on regulatory frameworks and environmental impact. Global research patterns have been mapped using important bibliometric markers as citation analysis, co-authorship networks, and keyword co-occurrence. This review summarizes previous bibliometric research on e-waste management, emphasizing noteworthy findings and pointing out areas that require more investigation, as shown in Table 1.

**Table 1**
Past literature on bibliometric analysis on e-waste management in the telecommunication industry

| No. | Reference | Research title | Tool | Description |
|---|---|---|---|---|
| 1 | [32] | E-waste in construction: A comprehensive bibliometric analysis and review of the literature | VOS Viewer | E-waste improves the sustainability of buildings, but it needs to be optimized. Research on the effects on the environment, economics, regulations, innovation, and the potential of the circular economy is required. |
| 2 | [33] | Using the Circular Economy to Mitigate the Global Electronic Waste Challenge: A Systematic Literature Review Approach | VOS Viewer | E-waste research grew significantly, highlighting circular economy benefits, key research clusters, and policy recommendations. |
| 3 | [34] | A comprehensive analysis of the barriers to effective construction and demolition waste management: A bibliometric approach | R Studio Bibliometrix | The study identifies five key C&D waste management barriers, using quantitative analysis to provide insights for sustainable construction practices. |
| 4 | [35] | Policy pathways to sustainable E-waste management: A global review | VOS Viewer | Effective e-waste policies, including EPR and WEEE directives, enhance recycling, reduce environmental harm, and support sustainable waste management efforts globally. |

**Table 1**
Continued

| No. | Refernce | Research title | Tool | Description |
|---|---|---|---|---|
| 5 | [36] | Conceptualising Management Practices for Mapping Mobile Phone Waste Through Scientometric, Bibliometric and Visual Analytic Tools | R Studio Bibliometrix | MPW is rising, requiring financial incentives, urban mining, consumer awareness, and stricter management to protect health, environment, and sustainability. |
| 6 | [37] | Current Trend, Future Direction, and Enablers of E-waste Management: Bibliometric Analysis and Literature Review | VOSviewer and Biblioshiny | E-waste management is driven by policy, economy, social, environmental, and technology factors, analyzed using bibliometric tools and thematic analysis. |
| 7 | [38] | Bibliometric review of electro-electronic waste (WEEE) in the Web of Science database: groups' production and main themes | VOS viewer and RStudio | WEEE research has grown, focusing on recycling, sustainability, circular economy, environmental impacts, and efficient management, with global contributions. |
| 8 | [39] | Exploring Industry-Specific Research Themes on E-Waste: A Literature Review | VOS viewer | E-waste research in supply chains highlights trends in closed-loop systems, sustainability, WEEE, and circular economy, guiding future studies. |
| 9 | [40] | A bibliometric analysis of the effects of electronic waste on the environment | VOS viewer | Research on e-waste emphasizes the circular economy, health concerns, recovery methods, and environmental impact; China leads the world in publications and policy proposals. |
| 10 | [41] | Consumer e-waste disposal behaviour: A systematic review and research agenda | VOS viewer | E-waste disposal behavior lacks systematic study; research highlights consumer reluctance, key theories, gaps, and strategies to improve recycling practices. |
| 11 | [42] | Waste management and green technology: future trends in circular economy leading towards environmental sustainability | VOS viewer | Research identifies key waste management themes, emphasizing circular economy, innovation, lifecycle assessment, and policy guidance for sustainable waste treatment. |
| 12 | [43] | Bibliometric Analysis of Municipal Solid Waste Management Research: Global and South African Trends | VOS viewer | Global municipal solid waste research focuses on waste-to-energy, life-cycle assessment, and circular economy, while South Africa lags in trends. |
| 13 | [44] | Characterization of top 100 research on e-waste based on bibliometric analysis | Microsoft Excel 2016 and VOS viewer | E-waste research focuses on environmental impact, recycling, management, and processing, with China, India, and Nigeria leading influential studies. |

**Table 1**
Continued

| No. | Refernce | Research title | Tool | Description |
|---|---|---|---|---|
| 14 | [45] | Scientometric Analysis of Research on End-of-Life Electronic Waste and Electric Vehicle Battery Waste | VOS viewer | E-waste and EV battery waste pose environmental risks; research is limited, with USA, China, and Germany leading funded projects. |
| 15 | [46] | Mapping the Research Trends of Household Waste Recycling: A Bibliometric Analysis | RStudio | Household waste recycling research is growing, focusing on behavior, psychology, economics, sustainability, circular economy, and interdisciplinary approaches. |
| 16 | [47] | Research Trends in the Economic Analysis of Municipal Solid Waste Management Systems: A Bibliometric Analysis from 1980 to 2019 | VOS viewer | Economic analysis of municipal solid waste focuses on methodologies, externalities, waste-to-energy technologies, and global research trends using bibliometric analysis. |

### *1.3 Research Gap of Proposed Study*

Few studies explicitly address the role of the telecommunications sector in e-waste generation, recycling, and sustainability, even though e-waste research is growing. The majority of research ignores issues with mobile devices, network infrastructure, and data centers in favor of focusing on generic e-waste streams [48]. Furthermore, there aren't enough studies on consumer disposal behavior, company sustainability programs, or policy analyses tailored to the industry. Geographical differences further emphasize the need for studies in emerging nations where the growth of telecom surpasses the control of e-waste [49,50]. By outlining research trends over the previous 15 years, pointing out unexplored fields, and making recommendations for future directions, this bibliometric evaluation fills in these gaps.

### *1.4 Novelty of Proposed Study*

This study offers a distinctive worldwide perspective on the development of e-waste management in the telecommunications sector through an innovative bibliometric analysis of 15 years of research. This work uses advanced bibliometric techniques, such as co-citation analysis, and thematic clustering, to map research progress, identify knowledge gaps, and find emerging themes, in contrast to previous studies that concentrate on generic E-Waste trends. It integrates knowledge from sustainability and circular economy frameworks and places a particular emphasis on telecom-related E-Waste, such as abandoned mobile devices, network infrastructure, and IoT components. This study offers an organized roadmap for future research by integrating quantitative bibliometric analysis with qualitative thematic insights. It highlights corporate responsibilities, recycling innovations, and policy implications, making it an invaluable resource for scholars, decision-makers, and industry stakeholders.

### *1.5 Contribution of this Paper*

The global e-waste situation has been greatly exacerbated by our increasing reliance on telecommunications. This review study maps important trends, significant works, and developing

themes to give a bibliometric analysis of research development over the last 15 years. This paper examines the relationship between e-waste management and the telecom sector, highlighting areas that require further investigation and legislative interventions.

Comprehensive Bibliometric Analysis: Using information from top academic databases like Web of Science and Scopus, this analysis finds important research clusters, citation networks, and publishing patterns [51].

Thematic Classification of Research Trends: Research is divided into main categories, such as the production of e-waste, disposal techniques, recycling technologies, and policy frameworks. The telecommunications sector's contribution to e-waste mitigation is given particular attention.

Geographical Distribution and Research Hotspots: Maps of global research contributions highlight top nations and institutions. Regional differences in the focus of research and the application of policies are noted, emphasizing areas that need more concentration.

Challenges and Gaps in Existing Literature: Data availability constraints, methodological irregularities, and a deficiency of multidisciplinary approaches are noted. It is stressed that the telecom industry needs standardized e-waste reporting parameters.

Future Research Directions: The following topics are recommended for additional research: blockchain for monitoring disposal, AI-driven e-waste sorting, and sustainable product design. It is noted that a crucial area for more research is the function of corporate social responsibility (CSR) in the management of e-waste.

## 2. Data Sources and Data Analysis

Bibliometric analysis is a quantitative approach that uses mathematical and statistical methods to examine the effect, trends, and influence of research [52]. Keyword analysis, bibliographic coupling, co-authorship analysis, citation analysis, and co-citation analysis are all used to find trends in academic publishing [53]. This approach helps in evaluating academic production, gauging the impact of research, improving literature reviews, tracking the development of scientific areas, and assisting in the decision-making process for hiring professors, allocating funds, and creating policies. For researchers, academic institutions, and politicians, it is an essential instrument for expanding scientific knowledge and innovation since it aids in identifying research gaps, comparing institutional performance, and spotting new trends [54].

### *2.1 Data Source*

Bibliometric analysis uses citation and publication data from a variety of academic databases and indexing services. Important resources include Web of Science (WoS) and Scopus, which give thorough journal metrics and citation tracking, while Google Scholar offers more extensive coverage, including books and conference proceedings. CrossRef, Lens.org, Dimensions, and other open-access sources also provide useful citation information. These resources let researchers conduct successful analyses of research impact, author partnerships, and publishing trends.

On March 10, 2025, we used the database to gather data for this study from Dimension.ai. To ensure comprehensive coverage and accuracy in our search, we mainly focused on "topic" search citations containing titles and abstracts. For example, we used search items like "E-Waste Management" AND "Telecommunication Industry" OR "Telecom Company." Until December 2024, 1447 papers published between 2010 and 2024 were gathered, including contributions from as early as 2010, according to the literature indicated in Table 2.

**Table 2**
Types of documents for publication

| No. | Classification | Count | Percentage |
|---|---|---|---|
| 1 | Article | 994 | 64% |
| 2 | Proceeding | 345 | 22% |
| 3 | Chapter | 140 | 9% |
| 4 | Edited Book | 45 | 2% |
| 5 | Preprint | 18 | 1.1% |
| 6 | Monographs | 05 | 0.3% |

### *2.1.1 Inclusion Criteria*

Inclusion criteria for this bibliometric analysis encompassed research articles published within the last 14 years (2010-2024) in peer-reviewed journals of UGC-CARE List Group II which includes Scopus database and Web of Science data base (Arts and Humanities Citation Index Source Publication, Science Citation Index Expanded Sources Publication, Social Science Citation Index Source Publication).

Articles were required to have a primary focus on the subject of "E-Waste Management" AND "Telecommunication Industry" OR "Mobile Company", with relevant keywords and phrases identified through a preliminary literature review. Only articles available in English were considered to ensure uniformity in language comprehension. Additionally, Inclusion was limited to articles presenting original research findings, excluding proceeding, chapter, edited books, preprint, and Monograph [55]. This inclusive approach aimed to provide a comprehensive overview of the scholarly landscape surrounding the proposed study and facilitate robust analysis and interpretation of bibliometric data [56].

### *2.1.2 Exclusion Criteria*

Exclusion Criteria for this bibliometric analysis involved articles that did not meet the specified inclusion criteria outlined previously. Specifically, articles published before 2010 or after December 2024 were excluded to maintain focus on recent developments within the field. Non-English articles were also excluded to ensure consistency in language comprehension and interpretation. Additionally, studies categorized as reviews, commentaries, editorials, or meta-analyses were excluded to prioritize original research contributions. Articles lacing a primary focus on the subject of the proposed study, as determined through initial screening of titles, abstract, and keywords, were excluded from further analysis. Furthermore, articles presenting incomplete or insufficient data, or those inaccessible through academic databases or institutional subscriptions, were excluded to ensure data integrity and reliability [57]. By applying these exclusion criteria, the analysis aimed to streamline the dataset, focusing on high-quality, relevant research articles that align closely with the objectives of the bibliometric study [58].

### *2.2 Analysis Method*

Bibliometric analysis includes a number of techniques to comprehend the dynamics of academic research [59]. In addition to predicting future research directions, this entails monitoring development trends, author contributions, institutional connections, publishing sources, and highly cited literature.

Development Trend Analysis: Development trend analysis looks at how a field's research changes over time. Tracking publishing trends to spot growth trends, keyword analysis to find new themes, and citation trends to identify notable works are all part of it [60]. Visualizing links between subjects and approaches is made easier with the aid of network analysis [61]. Research on e-waste management, for example, may have moved from landfill disposal to environmentally friendly recycling methods.

Research Author Analysis: Key contributors to a field of study are identified using this examination. While co-authorship networks show patterns of collaboration, highly cited writers are acknowledged for their influence [62]. Measures such as the h-index evaluate influence and productivity. Analysis of geographic dispersion shows the locations of top researchers [63]. Author research may indicate that while professionals in underdeveloped regions concentrate on implementation techniques, those in rich nations dominate in technology innovation when it comes to e-waste management.

Analysis of Research Institutions: Institutions are essential to the production of research. This investigation evaluates the impact of funding agencies, looks at inter-institution collaborations, and identifies the leading universities and organizations that contribute [64]. Research on e-waste management is frequently dominated by top universities in rich nations, however collaborations with organizations in developing nations aid in the implementation of solutions [65].

Source of Literature and Research Output Analysis: This method categorizes research sources, including journals, conference proceedings, book chapters, and reports [66]. It assesses the impact of open-access versus subscription-based publications. Identifying leading journals, such as Waste Management and Environmental Science & Technology, helps researchers understand where the most significant studies on E-waste management are published [67].

Highly Cited Literature Analysis in E-Waste Management: The identification of influential articles that influence the area is facilitated by the analysis of highly referenced literature [68]. This involves analyzing the number of citations, identifying seminal research, and analyzing co-citations to ascertain the conceptual relationships among various works. Studies on e-waste management that are often mentioned may concentrate on environmental effects, policy frameworks, and cutting-edge recycling technology.

Forecasting Research Trends: Research trend forecasting includes applying time-series analysis, AI-based forecasts, and keyword evolution studies to predict future changes [69]. Methods of expert opinion, such the Delphi methodology, are also applied. Future studies on e-waste management might concentrate on circular economy models, AI-driven recycling systems, and sustainable materials recovery [70].

## 3. Analysis of Document Characteristics in E-waste Management in the Telecommunication Industry

### *3.1 Development of Trend Analysis*

In our proposed study, Research on E-Waste and the Telecommunications Industry has seen a notable increase in scholarly interest over the last 15 years (2010–2024), according to a bibliometric analysis of the literature (Figure 2). Initially, research output was quite low, ranging from 4 to 23 publications per year between 2010 and 2014. However, a consistent upward trend began in 2015 and culminated in a sharp increase after 2020. The number of publications increased exponentially, reaching a peak of 95 in 2024, after nearly doubling between 2019 (38) and 2020 (61). This dramatic acceleration is a result of heightened environmental concerns, more stringent laws, and developments in circular economy models, which have led to a greater emphasis on managing e-

waste globally. This trend sets e-waste research as a crucial and quickly developing field, highlighting the need for sustainable solutions for the telecom sector.

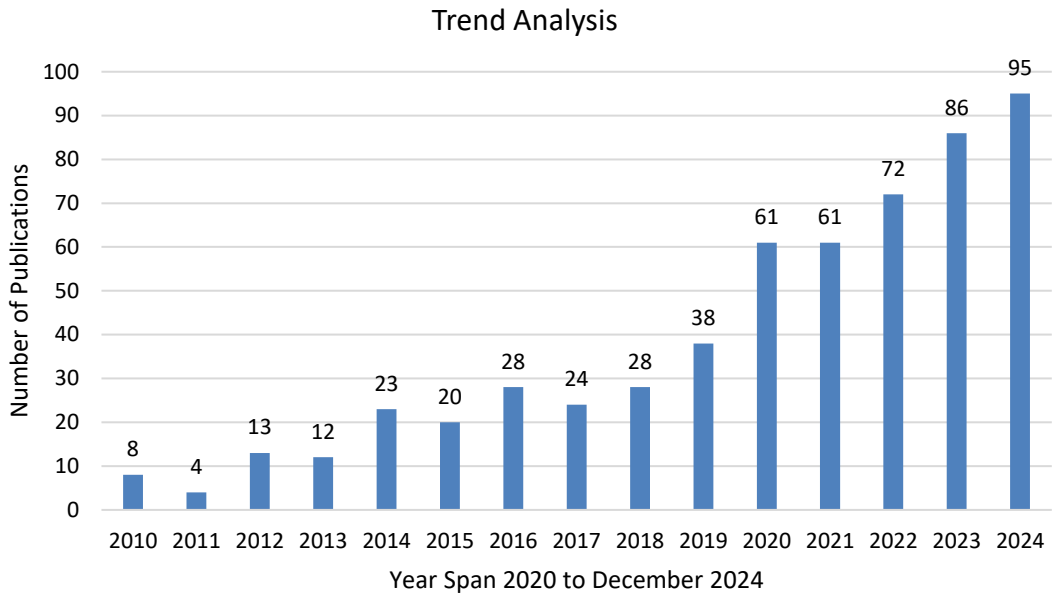


**Fig. 2.** Trend analysis in the context of publications

*3.2 Co-Author Analysis*

Co-author analysis is a bibliometric method in VOSviewer used to visualize and examine the collaborative relationships among researchers. It creates networks with nodes standing in for authors and links between nodes signifying co-authorship on works that have been published. Collaboration frequency is reflected in the strength of these links, which are frequently shown by the thickness of the lines. This analysis sheds light on the social structure of scientific communities by identifying key figures, research clusters, and collaboration patterns within a particular field. It shows who is collaborating with whom and how closely they are related.

In this analysis, 1903 authors are found by ignoring documents with 25 maximum of authors per document. Only 141 authors meet the threshold with 2 maximum number of documents and citations by author. Out of 141 authors, 14 authors have the largest set of connected items as shown in Figure 3.

Co-author analysis is a bibliometric method that uses co-authored publications to analyze cooperative relationships between researchers, institutions, and nations in VOSviewer.

At the author level, it focuses on individual researchers, identifying networks of collaboration, and highlighting influential authors within a specific field.

The data provided in Table 3 represents a ranking of top 10 authors based on total citations and average citations per article. The bibliometric analysis of research on e-waste and the telecom sector over the previous 15 years identifies important contributors and their contributions. Zeng, Xianlai is the most influential author among the top-ranked authors, with an astounding average of 149.63 citations per article across eight publications. Sunil Kumar (128) and Li, Jinhui (120.29), who also has the most publications (14), are next in line. With an average of 74.71 citations per article across seven publications, Anwesha Borthakur exhibits considerable academic recognition and influence. Similarly, despite having fewer publications, Madhav Govind (89.6) and Abhishek Kumar Awasthi (85.2) continue to have high citation performances. The existence of writers with comparatively

lower citation averages (9.11 and 11.57, respectively), such as Ahmed Wasif Reza and Mohammad Shamsul Arefin, indicates varying degrees of research impact. While some researchers consistently contribute to the field, the ranking emphasizes the dominance of a small number of highly cited researchers. Through contributions ranging from policy viewpoints to technological developments, this analysis highlights the changing landscape of e-waste research in telecommunications and shapes future research directions in sustainable e-waste management and circular economy principles.

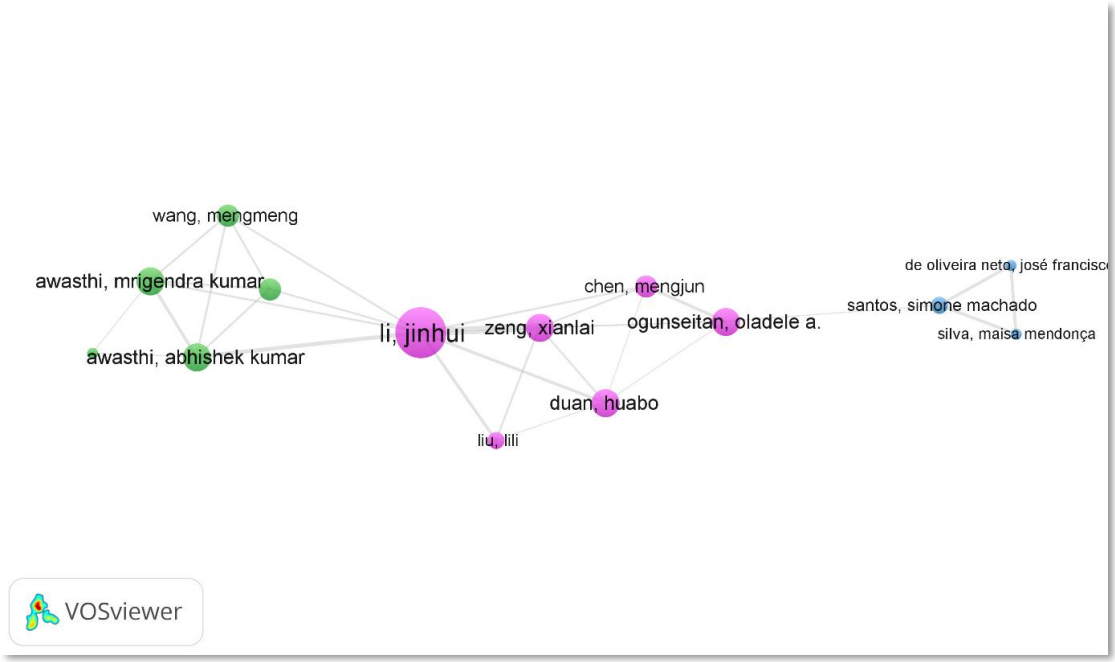


**Fig. 3.** A Screenshot of the bibliometric map created based on co-authorship with the Network visualization model based on the author as the unit of analysis

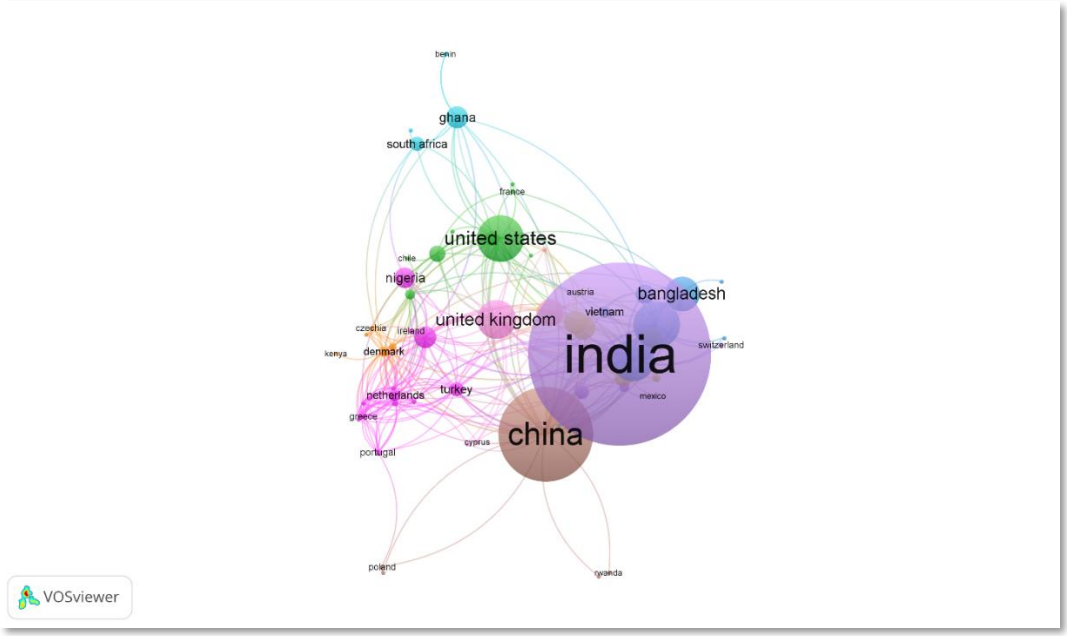


**Fig. 5.** A Screenshot of the bibliometric map created based on co-authorship with the Network visualization model based on the countries as the unit of analysis

**Table 3**
Top 10 authors publication, citation, and average citation per article

| Rank | Author | Publication | Citation | Average citation per article |
|---|---|---|---|---|
| 1 | Li, Jinhui | 14 | 1684 | 120.28 |
| 2 | Reza, Ahmed Wasif | 9 | 82 | 9.11 |
| 3 | Zeng, Xianlai | 8 | 1197 | 149.62 |
| 4 | Arefin, Mohammad Shamsul | 7 | 81 | 11.57 |
| 5 | Borthakur, Anwesha | 7 | 523 | 74.71 |
| 6 | Kumar, Sunil | 6 | 768 | 128 |
| 7 | Awasthi, Abhishek Kumar | 5 | 426 | 85.2 |
| 8 | Govind, Madhav | 5 | 448 | 89.6 |
| 9 | Ilankoon, I.M.S.K. | 5 | 297 | 59.4 |
| 10 | Ogunseitan, Oladele A. | 5 | 167 | 33.4 |

At the organizational level (Affiliation), it analyses institutional affiliations and maps research partnerships between universities, research institutes, or other organizations to understand how knowledge is co-produced across institutions. In this analysis, 882 organizations are found by ignoring documents, with a maximum of 25 organizations per document. Only 79 organizations meet the threshold with a maximum of 3 documents and citations by organizations. Out of 79 organizations, 24 organizations have the largest set of connected items, as shown in Figure 4.

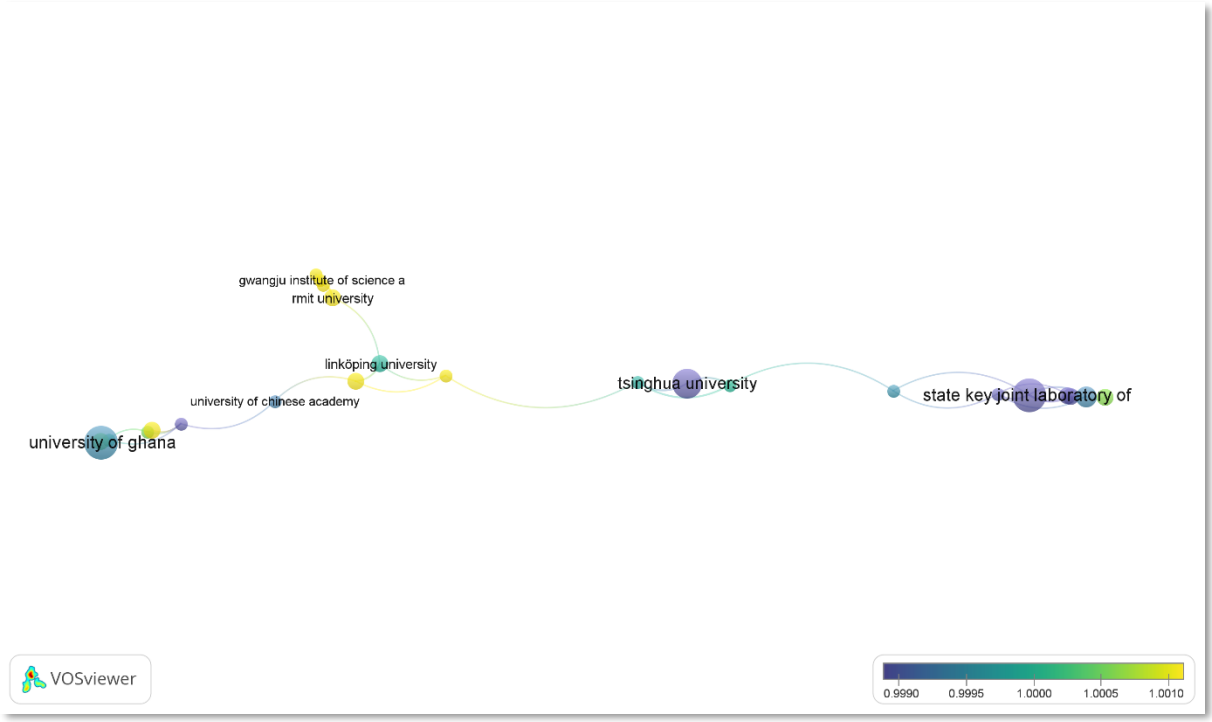


**Fig. 4.** A Screenshot of the bibliometric map created based on co-authorship in the form of Organizations with the Overlay visualization model based on the organizations as the unit of analysis.

The data provided in Table 4 represents a ranking of the top 10 organizations based on total citations and average citations per article. There are notable differences in the research impact between institutions that have contributed to e-waste and telecommunications research over the last 15 years, according to bibliometric analysis. At 140.5 citations per article across eight publications, the National Environmental Engineering Research Institute (NEERI)has the most

research influence, followed by the Academy of Scientific and Innovative Research (128) and the State Key Joint Laboratory of Environment Simulation and Pollution Control (135.38). Institutions with a strong academic influence include Jawaharlal Nehru University (73) and Tsinghua University (86.14). Most of the publications are from East West University (10), but their citation impact is still low (8.2 per article). The dominance of internationally renowned research centers in influencing the sustainability and policy discourse surrounding the management of e-waste is highlighted by this analysis.

**Table 4**
Top 10 Organizations publication, citation, and average citation per article

| Rank | Organization | Publication | Citation | Average citation per article |
|---|---|---|---|---|
| 1 | East West University | 10 | 82 | 8.2 |
| 2 | Daffodil International University | 8 | 109 | 13.625 |
| 3 | National Environmental Engineering Research Institute | 8 | 1124 | 140.5 |
| 4 | State Key Joint Laboratory of Environment Simulation and Pollution Control | 8 | 1083 | 135.375 |
| 5 | University Of Ghana | 8 | 269 | 33.625 |
| 6 | Chittagong University of Engineering & Technology | 7 | 81 | 11.57142857 |
| 7 | Jawaharlal Nehru University | 7 | 511 | 73 |
| 8 | Tsinghua University | 7 | 603 | 86.14285714 |
| 9 | University Of Ibadan | 7 | 144 | 20.57142857 |
| 10 | Academy Of Scientific and Innovative Research | 6 | 768 | 128 |

At the country level, co-author analysis explores international collaboration patterns, showing how researchers from different nations work together, helping to identify leading countries in a field and the extent of their global research networks. By visualizing these relationships, VOSviewer enables a better understanding of research collaboration structures and their impact on scientific output. In this analysis, 73 countries are found by ignoring documents with 25 maximum of countries per document. Only 71 countries meet the threshold with 01 maximum number of documents and citations by countries. Out of 71 countries, 63 countries have the largest set of connected items, as shown in Figure 5.

The provided data in Table 5 represents a ranking of the top 10 countries based on total citations and average citations per article. India is the most prolific country, with 141 publications and 5,349 citations, according to a bibliometric analysis of country-wise contributions to e-waste and telecommunication research over the previous 15 years. However, its average citation per article (37.94) is moderate. China comes in second with 73 publications, but its research impact is significantly greater, with 5,246 citations and an average of 71.86 citations per article. In a similar vein, despite having fewer publications (36 each), Australia (70.89) and the US (54.08) exhibit significant research influence. Bangladesh (37.07), Malaysia (43.45), and Brazil (42.43) continue to make consistent contributions, suggesting that emerging economies are becoming more interested in e-waste research. Though their citation impacts are comparatively lower, the United Kingdom (33.97), Canada (36.42), and Pakistan (27.22) also play important roles. These findings highlight that while some countries dominate in volume, others excel in impact, reflecting regional research strengths in policy, technology, and sustainability aspects of e-waste management.

**Table 5**
Top 10 Countries publication, citation, and average citation per article

| Rank | Country | Publication | Citation | Average citation per article |
|---|---|---|---|---|
| 1 | India | 141 | 5349 | 37.94 |
| 2 | China | 73 | 5246 | 71.86 |
| 3 | Australia | 36 | 2552 | 70.89 |
| 4 | United States | 36 | 1947 | 54.08 |
| 5 | Malaysia | 33 | 1434 | 43.45 |
| 6 | United Kingdom | 30 | 1019 | 33.97 |
| 7 | Bangladesh | 27 | 1001 | 37.07 |
| 8 | Brazil | 21 | 891 | 42.43 |
| 9 | Canada | 19 | 692 | 36.42 |
| 10 | Pakistan | 18 | 490 | 27.22 |

### *3.3 Citation Analysis*

For bibliometric analysis, VOSviewer is an effective tool that lets researchers see citation networks. VOSviewer's citation analysis comprises various units of analysis, such as documents, sources, authors, organizations, and nations. Different perspectives on citation patterns and scholarly influence are offered by each unit.

Documents as a Unit of Analysis: This analysis focuses on the number of citations in individual research papers. Examining how often a paper is cited by other studies, assists in determining which papers are the most influential in a particular field of study. Citation analysis enables researchers to identify foundational works, monitor research trends, and assess the significance of individual studies. VOSviewer also shows the relationships and influences between papers by visualizing citation links between documents. In this analysis, 573 documents were found. Only 429 documents meet the threshold with a 03-maximum number of documents and citations by documents. Out of 429 documents, 380 documents have the largest set of connected items, as shown in Figure 6.

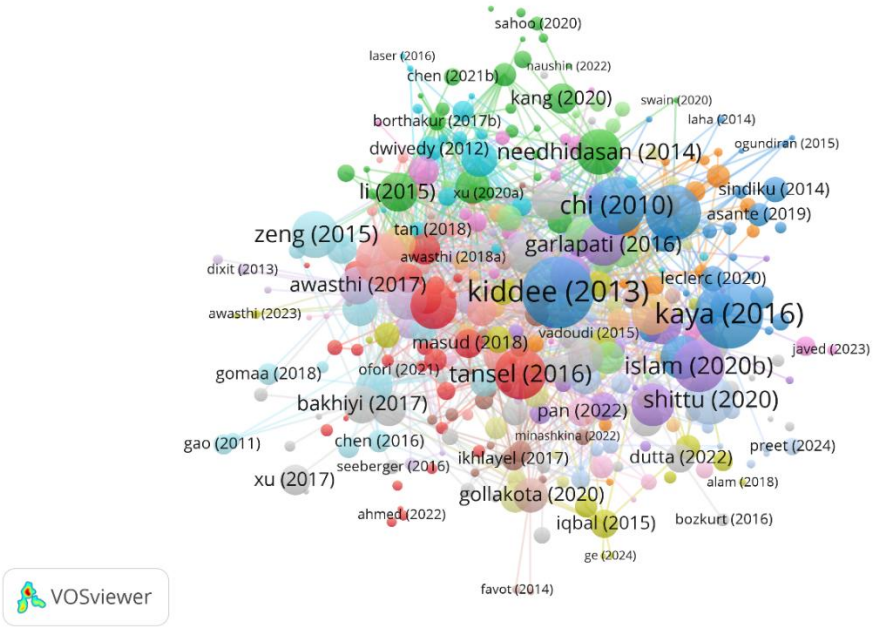


**Fig. 6.** A Screenshot of the bibliometric map created based on co-citation with the Network visualization model based on the documents as a unit of analysis

The provided data represents the top 10 most cited documents related to E-Waste and the Telecommunication Industry, showcasing key research contributions over the past 15 years. The highest-ranked document, Kiddee *et al.* [71] contains findings that toxic substances harm the environment and health. Effective management includes LCA, MFA, MCA, and EPR, emphasizing eco-design, safe recycling, proper disposal, and policy interventions like Extended Producer Responsibility (EPR). Kaya [72] reviews e-waste recycling, highlighting hazards, management strategies, and recovery methods. It emphasized sustainable urban mining, efficient recycling technologies, and eco-friendly processes for extracting valuable metals while reducing environmental impact. Chi *et al.* [73] examined China's informal e-waste recycling, highlighting environmental and health risks. It emphasizes integrating informal sectors into formal recycling systems through policies, incentives, and improved working conditions to enhance efficiency and sustainability. Tsydenova and Bengtsson [74] examined chemical hazards in e-waste recycling, incineration, and landfilling, highlighting health and environmental risks. It compares management practices in developed and developing countries, identifying knowledge gaps and recommending future research directions. Echegaray and Hansstein [75] reviewed e-waste recycling behavior in Brazil using the Theory of Planned Behavior. It highlights positive recycling intentions but low actual adoption, influenced by income, social acceptance, and regional disparities. Islam *et al.* [76] explored Material Flow Analysis (MFA) in e-waste management, highlighting trends, challenges, and applications. It emphasizes data needs, country-wise analysis, policy support, and future research directions for improved waste management strategies. Tansel [77] highlighted challenges in e-waste management, including rising quantities, raw material demand, unregulated recycling, and infrastructure gaps, emphasizing the need for effective recovery technologies and sustainable product design. Shittu *et al.* [78] examined global WEEE management, highlighting trends, policies, challenges, and future scenarios. It recommended circular economy principles, stronger regulations, enforcement, and harmonization to improve WEEE collection, recycling, and resource efficiency worldwide . Li *et al.* [79] compared e-waste legislation in China and the EU, highlighting differences in enforcement, stakeholder involvement, and eco-design policies. It outlined China's four-phase e-waste management evolution from the 1980s to 2020. Kumar and Rawat [80] examined the key factors that led consumers to replace functional mobile phones, highlighting the increasing reliance on smart gadgets and the resulting e-waste generated due to obsolescence and inefficiency. This ranking provides insight into the most influential studies driving research on sustainable E-waste management in telecommunications, integrating policy, technology, and environmental perspectives.

Sources as a Unit of Analysis: Citation metrics are used to assess the influence of journals, conference proceedings, and other publication sources in this kind of analysis. It assists in identifying high-impact journals by examining the frequency of citations in scholarly works. Researchers can determine the most reliable sources for publishing their work and evaluate journal rankings by charting the citation relationships between various journals. This analytical unit is especially helpful for comprehending the impact of particular journals within a given field of study. In this analysis, 241 documents were found. Only 66 documents meet the threshold with a 02-maximum number of documents and citations by documents. Out of 66 documents, 64 documents have the largest set of connected items, as shown in Figure 7.

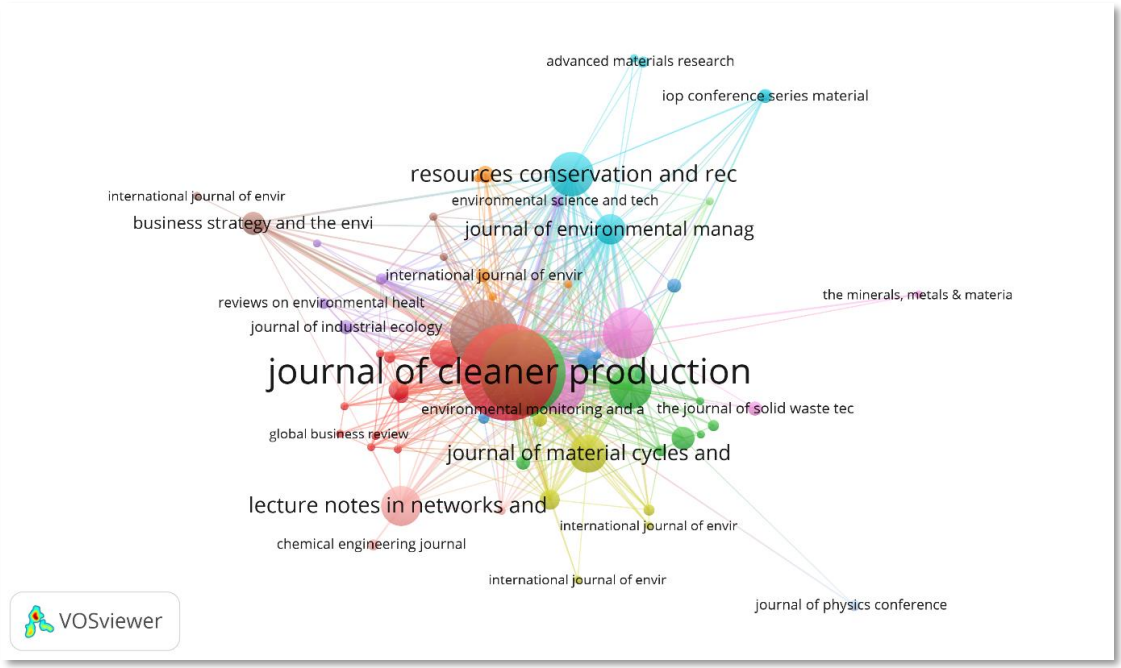


**Fig. 7.** A Screenshot of the bibliometric map created based on co-citation with the Network visualization model based on the sources as a unit of analysis

The provided data highlights the top 10 sources, emphasizing their citation impact, quality, and influence. The highest-ranking category is Waste Management (3342 citations, Impact Factor 7.1, Q1), which emphasizes environmentally friendly disposal and recycling practices for telecom e-waste. Eco-friendly production and circular economy strategies are highlighted in the Journal of Cleaner Production (3292 citations, IF 9.8, Q1). The telecom industry's regulatory frameworks, hazardous waste management, and pollution control are examined in The Science of the Total Environment (1428 citations, IF 8.2, Q1) and Environmental Science and Pollution Research (1344 citations, IF 5.8, Q1). Energy recovery from e-waste is evaluated by Renewable and Sustainable Energy Reviews (1078 citations, IF 16.3, Q1). Other sources, including Environment International and Resources Conservation and Recycling, highlight global e-waste policies and material recovery. The prevalence of Q1-ranked journals, mostly from Springer and Elsevier, indicates how much research interest there is in managing e-waste sustainably (Table 6).

**Table 6**
The topmost productive sources with the most cited articles

| Rank | Source | Publication | Citation | Cite score (2023) | Quartile | Impact factor | Publisher | SNIP | SJR | H-index |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Waste Management | 19 | 3342 | 15.6 | Q1 | 7.1 | Elsevier | 1.804 | 1.734 | 220 |
| 2 | Journal Of Cleaner Production | 42 | 3292 | 20.4 | Q1 | 9.8 | Elsevier | 2.236 | 2.06 | 309 |
| 3 | The Science of The Total Environment | 15 | 1428 | 17.6 | Q1 | 8.2 | Elsevier | 1.82 | 1.998 | 353 |
| 4 | Environmental Science and Pollution Research | 27 | 1344 | 8.7 | Q1 | 5.8 | Springer Nature | 1.141 | 1.006 | 179 |

**Table 6**
Continued

| Rank | Source | Publication | Citation | Cite score (2023) | Quartile | Impact factor | Publisher | SNIP | SJR | H-index |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Renewable And Sustainable Energy Reviews | 5 | 1078 | 31.2 | Q1 | 16.3 | Elsevier | 3.592 | 3.596 | 421 |
| 6 | Sustainability | 36 | 974 | 6.8 | Q1 | 3.3 | MDPI | | | 169 |
| 7 | Resources Conservation and Recycling | 16 | 905 | 22.9 | Q1 | 11.2 | Elsevier | 2.633 | 2.77 | 196 |
| 8 | Environment International | 3 | 630 | 21.9 | Q1 | 10.3 | Elsevier | 2.312 | 3.015 | 252 |
| 9 | Journal Of Environmental Management | 10 | 544 | 13.7 | Q1 | 8 | Elsevier | 1.719 | 1.771 | 243 |
| 10 | Journal Of Material Cycles and Waste Management | 13 | 478 | 5.3 | Q2 | 2.7 | Springer Nature | 0.869 | 0.661 | 60 |

### *3. 3. Authors as a Unit of Analysis*

Citation analysis at the author level looks at specific researchers according to their h-index and number of citations. By analyzing the frequency and significance of their published works, this analysis assists in identifying the top contributors in a particular field of study. It also provides insights into author collaboration networks, showing how researchers interact and contribute collectively to a field. Identifying possible research partners and comprehending the distribution of expertise among various scholars are two more benefits of this analysis.

### *4. 4. Organizations as a Unit of Analysis*

The citation impact of organizations, universities, and research centers is the main focus of this analytical unit. An institution can determine the best-performing companies in a particular field by looking at the citations that its research has received. The mapping of institutional collaboration networks, which illustrates the ways in which various research centers and universities collaborate, is another benefit. The research productivity and impact of institutions are also highlighted in this analysis, which is helpful for funding decisions and university rankings.

### *5. 5. Countries as a Unit of Analysis*

Citation analysis, which looks at citations received by studies from other nations, offers insights into the influence of research at the national level. This aids in determining which nations are at the forefront of a field of study and comprehending their role in the creation of knowledge worldwide. Citation links between nations are visualized in the analysis to further highlight trends in international collaboration. For researchers and policymakers looking to strengthen international research collaborations and raise their nation's academic profile, this is especially helpful.

### *3.4 Forecasting on Research Trend*

The E-Waste and the Telecommunication Industry forecasting trend analysis shows a notable and steady increase in research output over the next 20 years. Research on telecom E-waste was comparatively scarce between 2010 and 2019, with fewer than 40 publications per year. But starting in 2020, there is a discernible uptick, with publication counts surpassing 60 annually, indicating a greater awareness of the problems associated with e-waste worldwide. Following 2025, the trend picks up speed, with research output expected to reach 205 publications by 2040 (Figure 8). This underscores growing concerns regarding innovative recycling techniques, policy interventions, and sustainable telecom waste management. Given this upward trajectory, it is likely that future research will concentrate on circular economy practices, extended producer responsibility (EPR), and the integration of IoT and AI in e-waste management. The rapid advancement of technology and more stringent environmental regulations have led to an exponential growth in scholarly interest, which highlights the urgency of addressing e-waste in the telecom sector.

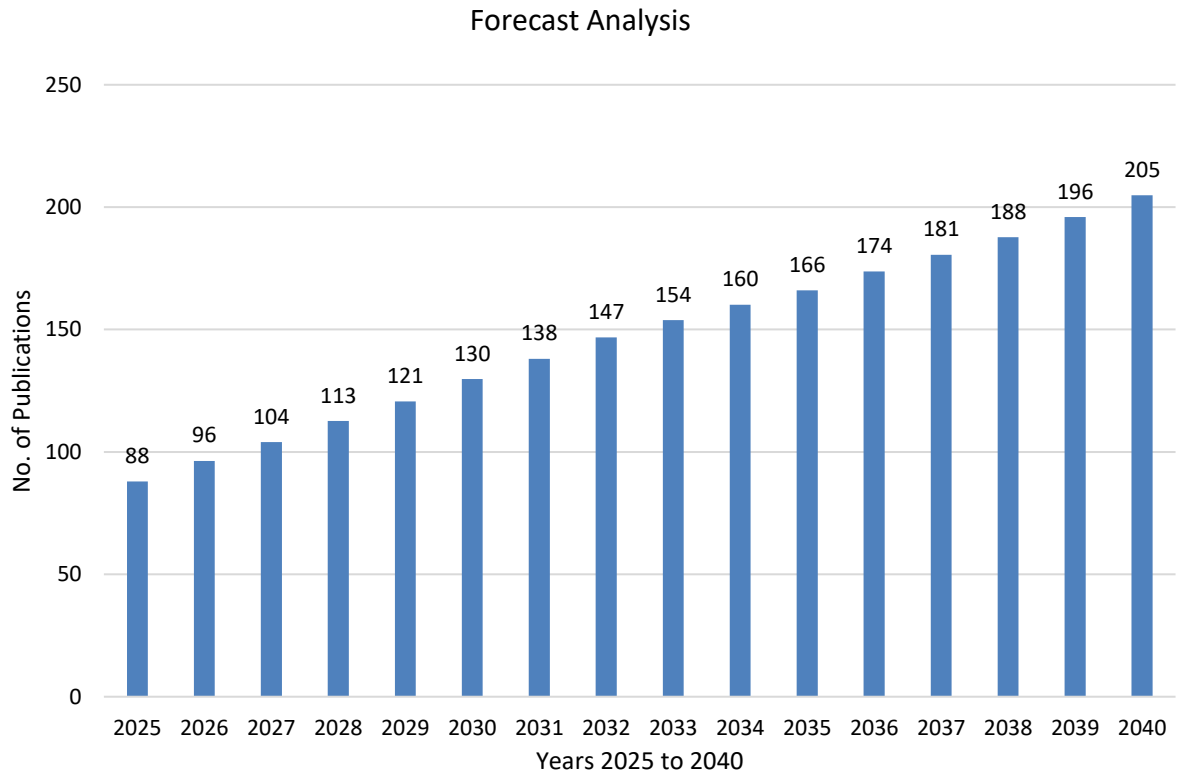


**Fig. 8.** Number of Forecasted Publication from 2010-2024

## 4. Discussion

A bibliometric analysis of e-waste and the telecom sector over the last 15 years reveals a notable increase in research output, which has been fueled by regulatory frameworks, technological advancements, and growing environmental concerns. India leads the world in research volume, but China and Australia have greater influence, as evidenced by their higher citation impact. Zeng Xianlai and Li Jinhui are two important contributors, and organizations like NEERI and Tsinghua University have influenced the conversation about extended producer responsibility (EPR), circular economy principles, and sustainable e-waste management. Analysis of co-authorship shows that both developed and emerging economies are increasingly collaborating internationally to develop policies,

recover materials, and innovate recycling. The preponderance of high-impact journals, like Waste Management and the Journal of Cleaner Production, highlights the academic emphasis on green sustainability. The need for scalable and internationally standardized e-waste solutions is further highlighted by research trends that predict exponential growth beyond 2025.

## 5. Conclusion

A significant increase in scholarly contributions over the past 15 years has been attributed to growing environmental concerns, regulatory frameworks, and advancements in recycling technologies, according to a bibliometric analysis of e-waste research in the telecommunications sector. Even though China, India, and the U.S. produce the most research, China and Australia have a greater impact on citations. Prominent establishments like NEERI and Tsinghua University are essential in forming sustainable e-waste management plans. The study highlights important research topics that are essential for reducing the environmental impact of telecom waste, such as circular economy models, extended producer responsibility (EPR), and material recovery techniques. To address the long-term sustainability challenges of telecom e-waste, it will be crucial to implement scalable solutions and promote interdisciplinary collaborations as research continues to grow.

### *5.1 Limitations*

This study has certain limitations even though it offers a thorough bibliometric mapping of e-waste research in the telecom sector. Due to the analysis's limitation to indexed databases, pertinent research from non-indexed journals, industry reports, and policy documents may be missed. Furthermore, citation metrics do not adequately reflect the caliber, inventiveness, or practical impact of research, even though they do highlight significant works. Additionally, the study ignores viewpoints from industry and regulatory organizations in favor of concentrating mostly on academic collaborations. Moreover, regional differences in research output point to possible underrepresentation worldwide, especially in developing countries where the problems associated with managing e-waste are most pressing. For a more comprehensive understanding, future research should include qualitative evaluations and larger data sources.

### *5.2 Future Works*

Future studies on e-waste in the telecom sector should concentrate on cutting-edge technologies like blockchain, AI, and IoT for effective waste tracking, recycling automation, and supply chain transparency. Global practices will be standardized with the aid of comparative studies on regional policies, regulatory frameworks, and producer responsibility models. Reducing environmental impact requires more research into eco-friendly device designs, sustainable materials, and sophisticated recycling methods. Increasing cooperation between academia, business, and the government can improve the efficacy of policies and the uptake of new technologies. Interdisciplinary studies combining economics, environmental science, and digital innovation will be essential to advancing sustainable telecom e-waste management, as research output is expected to increase exponentially.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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