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# Analysis for recycling of electronic waste using the VOSviewer Tool

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**Abstract** **Original Research Article**

Nowadays, electronic waste management and recycling are becoming increasingly important in the recycling of expensive raw materials and in the prevention of environmental pollution. Therefore, it is necessary to identify the research directions for electronic waste management and recycling and to take the necessary measures. Past research papers on e-waste management and recycling are important basis for scientific electronic waste management. This paper sets 'electronic waste management' and 'electronic waste recycling' as key keywords and summarizes 131 papers published in recent decades (2014-2023). Using these raw data, we constructed the necessary database, visualized the results using the VOSviewer tool, and then selected ten key factors with large weights. These factors were ranked in a high order of total link strength and occurrences, and six major items (Behavior, Metal, Scenario, Theory, Human, health, Variable) with the greatest impact were found. These items are the main factors contributing significantly to future research directions and policy-making on electronic waste management and recycling.

**Keywords:** electronic waste; recycling; management; impact assessment; analysis.



## 1. Introduction

Due to the rapid adoption and obsolescence of consumer electronics, electronic waste (e-waste) is increasing rapidly. According to the data, 50 million tonnes of e-waste is obtained annually worldwide (UNEP, 2019). At present, however, only 20% of this waste is recycled. This is quite surprising given that by 2030 global e-waste production is expected to reach 75 million tons per year (Islam et al., 2021).

The discarded e-waste is mostly terrestrial, and toxic and hazardous substances such as mercury, arsenic, lead, and cadmium contained in these wastes not only damage the environment but also negatively affect human health (Kochan et al., 2016; Siddiqua et al., 2022). Moreover, these substances can lead to cancer, allergy and other serious health problems (Kochan et al., 2016).

In addition to adverse effects on human health and the natural environment, inadequate recovery of e-waste results in substantial loss of valuable raw materials with limited reserves including gold, platinum, cobalt, and rare earth elements. Currently, the annual value of raw materials discarded as e-waste is estimated to be approximately $57 billion (Siddiqua et al., 2022). Compared with the amount of gold obtained from e-waste and one ton of gold ore, the amount of gold produced from e-waste accounts for 100 times that of gold ore, and the world's production of gold from e-waste accounts for 7% of the world's gold reserves (UNEP, 2019). Therefore, governments and organizations around the world are proposing innovative ways to manage e-waste (Rautela et al., 2021).

Due to the rapid expansion of digitization worldwide, e-waste accounts for a large proportion of municipal solid waste (Kumar and Dixit, 2018a). Hence, scientific management strategies and accurate implementation strategies for effective management of e-waste are currently being developed (Blengini, 2009).

A review of the e-waste management and recycling can find a reasonable way to improve the recycling efficiency of e-waste (Huang et al., 2018).

Recently, there has been a lot of research on the management and recycling of e-waste. V. Ravi used the MultiAttribute Global Inference of Quality (MAGIQ) technology to evaluate the recycling performance of end-of-life (EOL) computers. Pia Tanskanen pointed out that the lack of a collection system for e-waste and consumer perceptions of e-waste recycling have hindered the management and recycling of e-waste. S.N.M. Menikpura presented an effective recycling methodology for WEEE to mitigate greenhouse gas (GHG). Van Eck described a methodology to visualize the bibliographic network to identify interdisciplinary impact relationships. Sabah M. Abdelbasir analyzed the composition of different e-wastes and how harmful they are. Jenni Yl-Mella analyzed consumer perceptions of mobile phone recycling based on the theory of Theory of Planned Behavior (TPB) and value-belief-norm (VBN). Nur Shafeera Mohamad found that it is possible to improve e-waste recycling using the Theory of Planned Behavior (TPB) and Structural equation modeling (SEM) methods. Amandeep Dhir investigated consumer e-waste recycling intentions using a consumer behavior framework called Behavioral Reasoning Theory (BRT). Ville Lahtela reported on the composition of WEEE polymer materials that have many recyclable values. Md Tasbirul Islam used the LCA methodology to find the best way to treat e-waste Print Circuit Board (PCB). Charbel Jose Chiappetta Jabbour identified seven criteria for how users should act to recycle e e-waste, and the most appropriate among them. Kirby illustrates a methodology for analyzing bibliographic data using the VOSviewer tool. Quddus Tushar analyzed waste management practices for 30 years (1994-2023) using VOSviewer and SciMAT. Sai Preetham discusses policies and regulations to mitigate e e-waste management issues, the government's efforts to stimulate recycling, and the role of sustainability, circular economy and communication.

Although the results of the past studies indicate that there are studies on e-waste management and recycling, there are a few studies on the impacts assessment for managing and recycling of e-waste.

Research on the management and recycling of e-waste is widespread. To improve the effectiveness of these studies, the overall research task and the corresponding step-by-step task must first be clearly defined. On this basis, the influence of factors affecting e-waste management and recycling should be explored. Then, the main factors with high impact index should be correctly identified and studied. It will also be of great help to develop strategies and policies for e-waste management and recycling.

Thus, after reviewing the results of the last decade's research on e-waste management and recycling, the study was carried out using the VOSviewer tool to identify the main factors affecting e-waste management and recycling, and their implications.

## 2. Methodology

In the past, studies on conventional waste management and recycling have been conducted using the VOSviewer tool to confirm the research direction, but the scope of the project is too wide, and the characteristics of the project have not been accurately characterized (Salisbury, 2009). In addition, the analysis of e-waste management and recycling issues has not helped to scientifically identify future research directions (Alam et al., 2022), as it discusses local e-waste generation practices and policy-making. Specifically, we did not find a clear answer to what are the main factors affecting e-waste management and recycling and what are the implications of those factors. In addition, studies in the past have failed to clarify the order of influence of factors (Salisbury, 2009).

Hence, the paper aims to summarize the results of studies on e-waste management and recycling with different impact factors over the past decade (2014-2023) to highlight a shortcut to scientific management and recycling of e-waste.

We summarize 131 papers in the last decade and analyze them using VOS viewer, with eight major journals having relatively high impact factors and many published studies on e-waste. In addition, based on the results of the analysis, we intend to provide a basis for identifying directions for effective e-waste management and recycling. In this paper, “e-waste management” and “e-waste recycling” are set as key keywords. The literature review refers to papers published between 2009 and 2024. However, our database (journalmap.txt) in order to clarify the impact relationship was constructed from papers published in the last decade (2014-2023).

## 3. Results and analysis

### 3.1. Database construction

Summarizing the major journals published on e-waste management and recycling can provide the basis for identifying the correct direction of research. Hence, we summarize the results of the last decade’s research on the management and recycling of e-waste (Table 1).

Table 1 Analysis of major journals on e-waste management and recycling

| No | Journals names(IF) | Documents | Citations |
|---|---|---|---|
| 1 | Journal of Cleaner Production(9.7) | 30 | 2476 |
| 2 | Science of the Total Environment(8.2) | 48 | 2112 |
| 3 | Resources Conservation and Recycling(11.2) | 9 | 933 |
| 4 | Sustainability(3.3) | 16 | 365 |
| 5 | Journal of Environmental Management(8) | 7 | 127 |
| 6 | Science of the Total Environment(8.2) | 5 | 68 |
| 7 | Journal of Industrial Ecology(4.9) | 3 | 44 |
| 8 | Environmental Science and Pollution Research(5.2) | 13 | 39 |

There are a few journals published on e-waste, but the main journals that have focused on the management and recycling of e-waste are eight journals. Among these eight journals, the number of "Documents" did not decrease proportionally if the number of "Citations" was ranked in large order. For example, as shown in Table 1 the number of "Documents" and "Citations" related to e-waste in each journal are different. In particular, the number of "Documents" of "Science of the Total Environment" is the largest, but the number of "Citations" is less than that of "Journal of Cleaner Production".

One hundred and thirty-one journals cited above are analyzed annually, as shown in Fig. 1. As shown in the figure, the papers on e-waste management and recycling published in eight journals show an increasing trend annually, especially after 2020, with a clear upward trend.

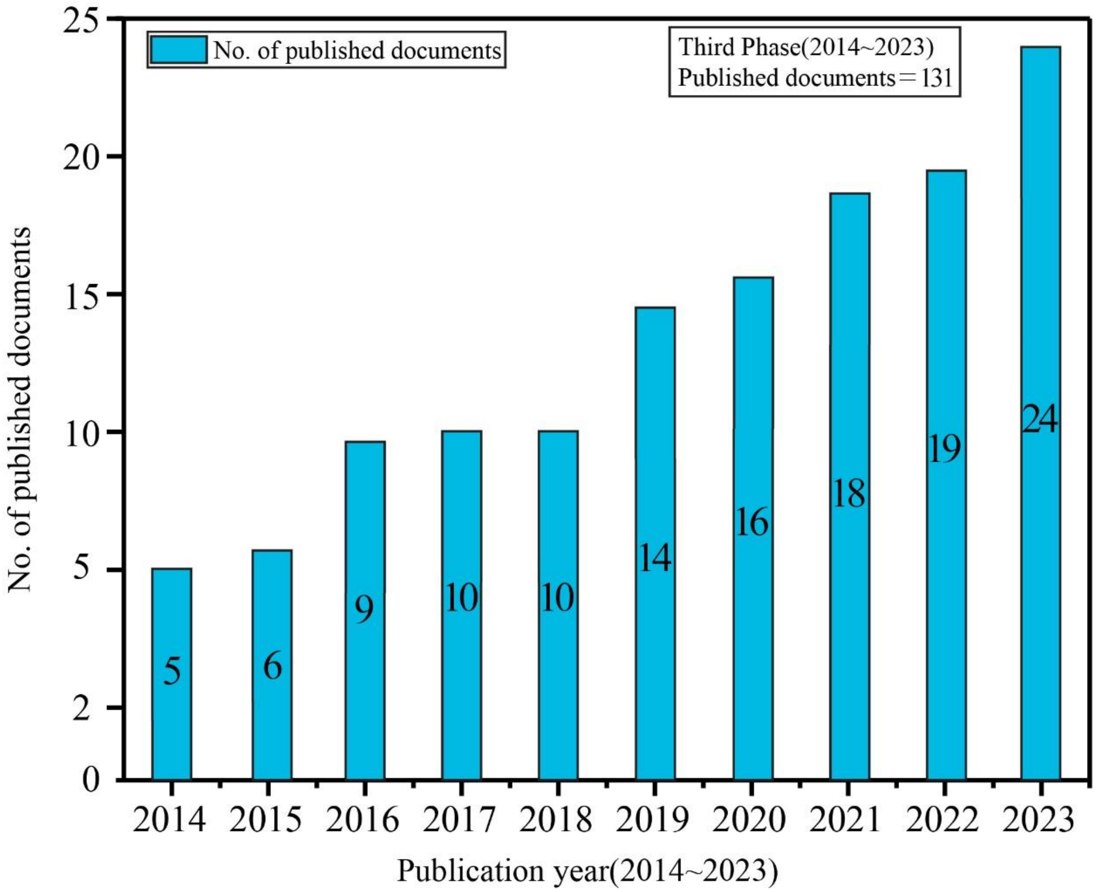


Fig 1. Number of published journals on e-waste management and recycling from 2014 to 2023

### 3.2. Data analysis using VOSviewer

First, we use 131 papers collected to visualize the results of e-waste management and recycling studies. To open the corresponding file in the VOS viewer, click the "Create" button in the action partition, select the Jornalmap.txt work file, and click OK.

In item density visualization, each point has a color indicating the density of the item at that point. By default, the color ranges from blue to green and yellow. The more the number of items in a point is arranged and the greater the weight of these items, the closer the color of that point is to yellow. On the other hand, the smaller the number of items at that point and the smaller the weight of the item, the closer the color of that point is to blue (Van Eck and Waltman, 2010).

The results of the field density visualization of 131 papers on e-waste management and recycling are shown in Fig. 2.

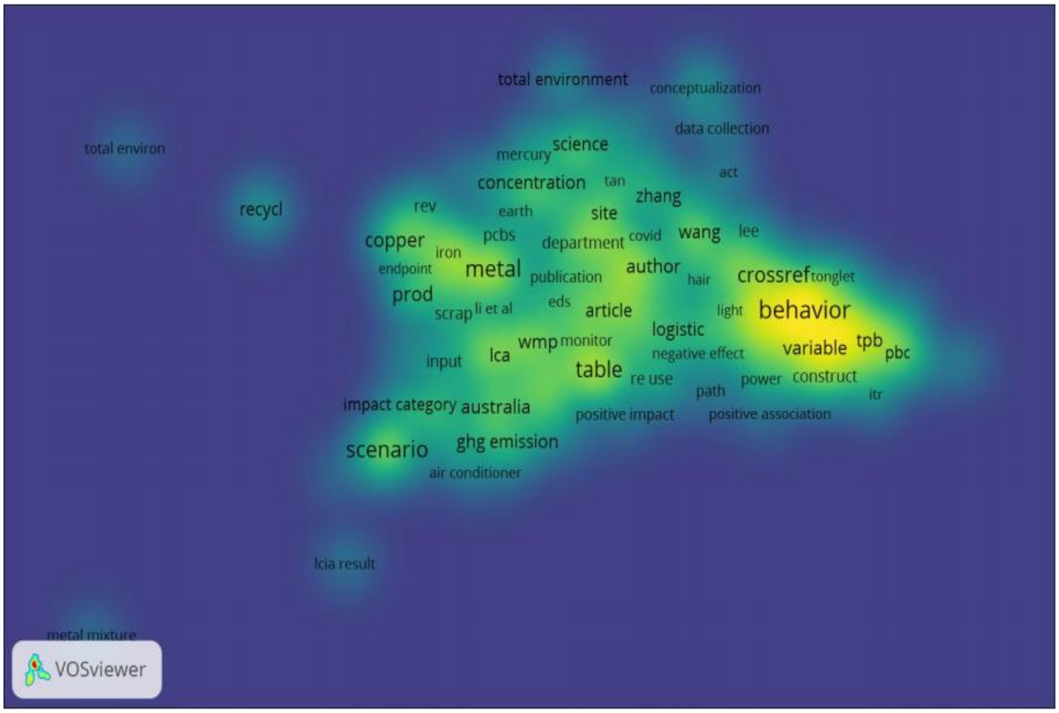


Fig. 2. Co-occurrence density visualization of research themes in e-waste management and recycling.

As shown in the figure, “Behavior”, “Metal” and “Scenario” have a deep yellow color. This suggests that such points are considerable objects to have high weighted. "Data collection", "Positive association" and "Positive impact" are blue due to their low weight. This indicates that such points are not of high importance.

In network visualization, items are usually represented by their labels, defaults, and circles. The size of the label and the circle of the item are determined by the weight of the item (Perianes-Rodriguez et al., 2016). The larger the weight of an item, the larger the label and circle of that item. The label for some items may not be displayed. This is to avoid overlapping markings. The color of an item is determined by the cluster that the item belongs to. The line between items represents the connection. By default, you can display a maximum of 1000 lines and represent the 1000 strongest links between items. In visualization, the distance between the two journals refers mostly to the relationship of journals with respect to public access links. Generally, the closer the two journals are, the closer their relationship is. The strongest co-citation links between journals are also represented by lines (Van Eck and Waltman, 2014).

The results of network visualization for e-waste management and recycling are shown in Fig. 3.

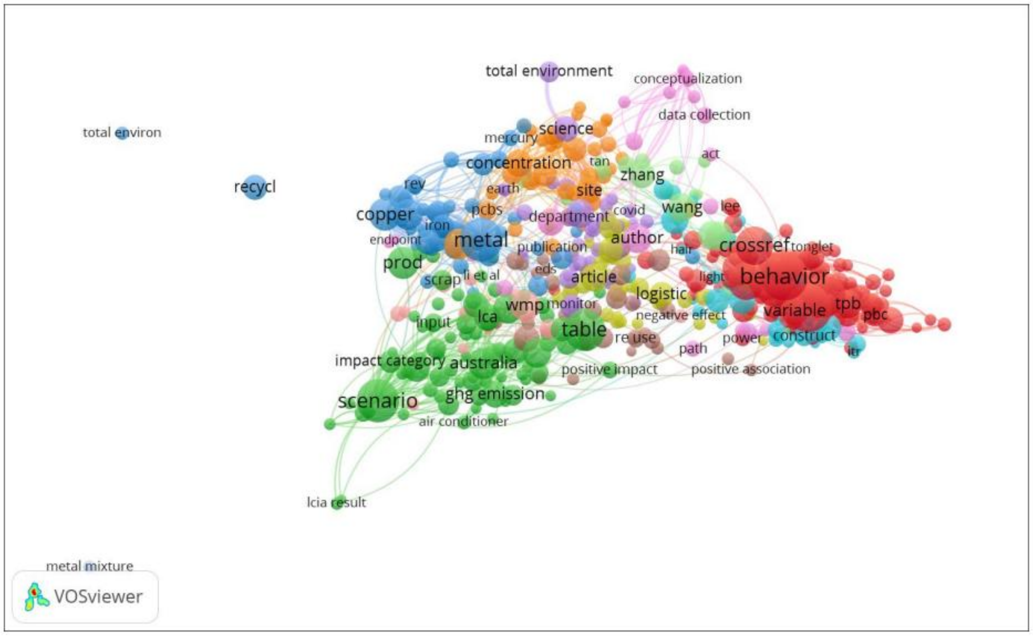


Fig. 3. Co-occurrence network visualization of research themes in e-waste management and recycling.

As shown in the figure, “Behavior”, “Metal”, and “Scenario” have the largest label size. This suggests that this item is the most weighted. On the other hand, the distance between “Behavior” and “Metal” is short compared to “Behavior” and “Scenario”. This clearly indicates that the relationship between the papers addressing “Behavior” and “Metal”’s research question is closer than the research questions addressing “Behavior” and “Scenario”.

### 3.3. Identification of research directions for e-waste management and recycling

Summarizing Fig. 2 and Fig. 3, it can be seen that the ten items listed in Table 2 show the highest generation characteristics and joint strength. Items not listed in Table 2 are those that tend to weaken the generation characteristics and bond strengths. Therefore, Table 2 shows only ten major items.

Table 2. Ten major items regarding e-waste management and recycling

| No | Label | Total link strength | Occurrences |
|---|---|---|---|
| 1 | Behavior | 748 | 336 |
| 2 | Metal | 664 | 263 |
| 3 | Scenario | 519 | 262 |
| 4 | Theory | 420 | 151 |
| 5 | Human health | 320 | 105 |
| 6 | Variable | 255 | 99 |
| 7 | Association | 252 | 90 |
| 8 | Methodology | 248 | 84 |

| | | | |
|---|---|---|---|
| 9 | Precious metal | 239 | 72 |
| 10 | Impact category | 190 | 53 |

Observing the magnitude variation with respect to the main items according to total link strength and occurrences mentioned in Table 2 are shown in Fig. 4. The numbers 1 through 10 in Fig. 4 represent the main items shown in Table 2.

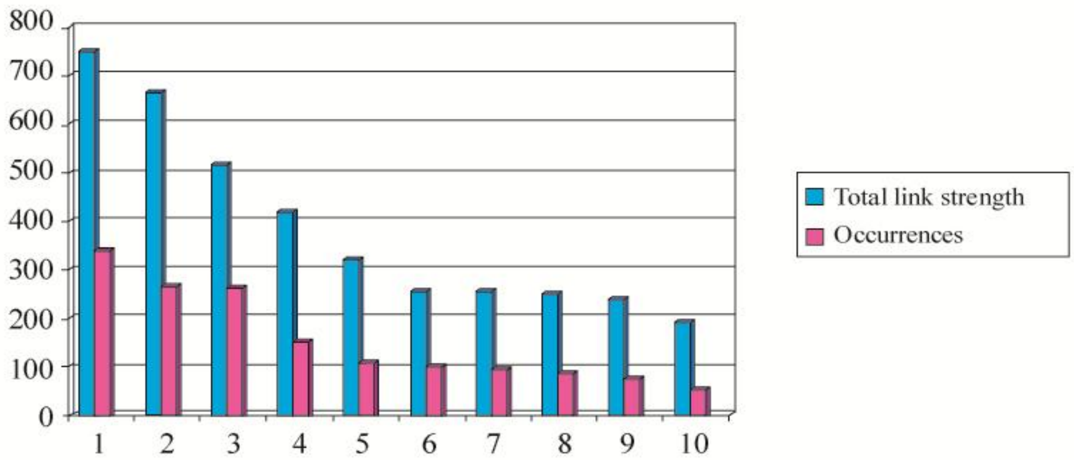


Fig. 4. Scheme of variation of strength and generation characteristics of the general association according to key items.

As shown in Fig. 4, the total link strength and occurrences along the main items show a gradually decreasing trend. In order to observe in more detail, the trends of the incremental changes in the total link strength and occurrences according to the main items, the following figure is shown.

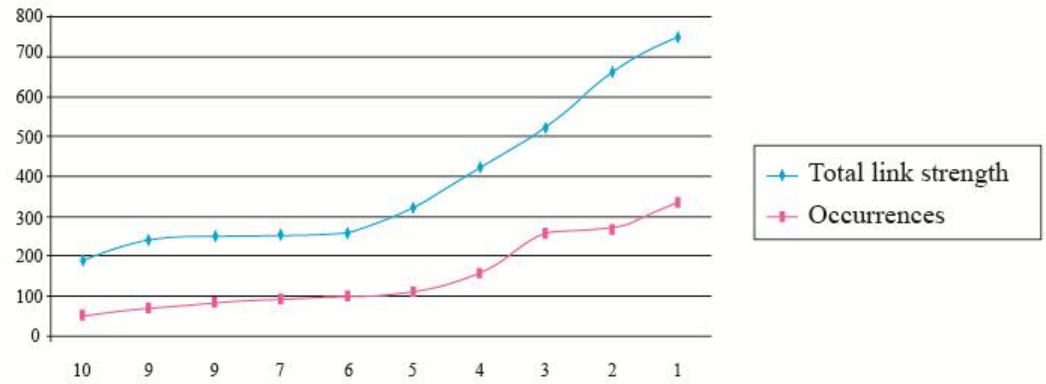


Fig. 5. General strength and generation characteristic variation curve according to key items.

As can be seen in Fig. 5, the overall strength and generation characteristics gradually increase from 10 to 6 and rapidly increase from 6. This suggests that the main factors to be considered in e-waste management and recycling policy are factors from 1 to 6. Of course, factors from 10 to 7 are also included in the main category, but the impact on e-waste management and recycling is not so high.

## 4. Conclusion

We set 'e-waste management' and 'e-waste recycling' as key keywords for the evaluation of the impact on e-waste management and recycling, and summarized the papers published in the last decade (2014-2023). In 131 papers published in eight major journals focusing on e-waste management and recycling, journalmap.txt was constructed to build a database for using the VOSviewer tool.

Using the VOSviewer tool, 131 papers were visualized and density visualization and network visualization results were obtained. In addition, ten major items of interest in e-waste management and recycling were identified and sequenced according to their total link strength and occurrences.

Observing the magnitude change with respect to the main item, the intensity and occurrence characteristics of the association captured the points of interest. We selected six major items that showed a sharp upward trend and concluded that these items were the points that had the greatest impact on e-waste management and recycling. These six major issues (Behavior, Metal, Scenario, Theory, Human, health, Variable) will contribute greatly to the research direction and policy making of e-waste management and recycling.

## Declaration of competing interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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