

E-Waste on Sustainability: A Bibliometric Analysis

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Abstract

Research on e-waste and its environmental implications dates back over two decades, with early regulatory frameworks such as the EU's Waste of Electronic and Electrical Environment (WEEE) Directive (2000) and RoHS restriction (2003) marking foundational milestones. Globally, scholars have long documented the release of toxic compounds - including lead, mercury, cadmium, and brominated flame retardants - into soil, air, and water systems via informal recycling and improper disposal. According to the Global E Waste Monitor, only about 17–18 % of e-waste is formally recycled worldwide, leading to the annual release of tens of thousands of kilograms of mercury and millions of kilograms of brominated plastics. Despite this longstanding global awareness, developing countries like Indonesia remain understudied, even as Indonesia generated approximately 1.9 million tons of e-waste in 2022 - with just 17 % managed properly. Most domestic research has been limited to snapshots of informal recycling practices or policy reviews, lacking the depth and methodological rigor seen in global studies. This review synthesizes foundational and contemporary global literature on e-waste's environmental impacts, juxtaposed with the Indonesian context. Through this comparative lens, it highlights the wide research gap in Indonesia and underscores the need for comprehensive studies, robust data collection, and enhanced regulatory frameworks. Ultimately, it calls on researchers and policymakers to elevate Indonesia's academic and practical response to e-waste, aligning it more closely with global best practices.

Keywords

E-Waste, WEEE, Sustainability, Indonesia, Developing Countries.

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Introduction

Waste Electronic and Electric Equipment (WEEE) or E-Waste is one of the biggest wastes right now due to shorter lifespan of a product and increase on demand (Liu et al., 2023). Examples of Electronic and Electric Equipment (EEE) are phones, laptops, televisions, refrigerators, cars, etc. Besides shorter lifespan, the difficulty finding part replacement, accessibility to fix, also fast charging technology are some reasons for the surging of WEEE (Ahirwar & Tripathi, 2021). For example, Apple, the iPhone maker launched iPhone 15 on 22nd of September 2023 (Apple Inc., 2023), then they launched iPhone 16 on 20th of September 2024 (Apple Inc., 2024), the lifespan of the product is only 1 year. Even though there is no limitation or whatsoever on the iPhone 15, but people tend to follow the trend (Yin et al., 2014), especially for 'Apple Fanboy'. As competition in the market is intense, other technology companies such as Samsung, Xiaomi, Huawei need to step up their game, by following rapid innovation in the market (Turnbull et al., 2000). This has a big impact on the development of E-Waste or WEEE.

Based on Global E-Waste Monitor, in 2010 the world generated 34 billion kg of E-Waste and in 2022 the world generated 62 billion kg of E-Waste (Baldé et al., 2024), in just 12 years, the E-Waste generated almost doubled. Every year, the E-Waste generated increase around 2.5 billion. Based on figure 1, Europe produced most of the E-Waste around the world, almost 30% of the world E-Waste. But this is also evidence that E-Waste documentation around Europe is better because by data, the biggest consumer and producer of mobile phone is China (Yin et al., 2014) while documentation around Asia and Africa may not be the best.

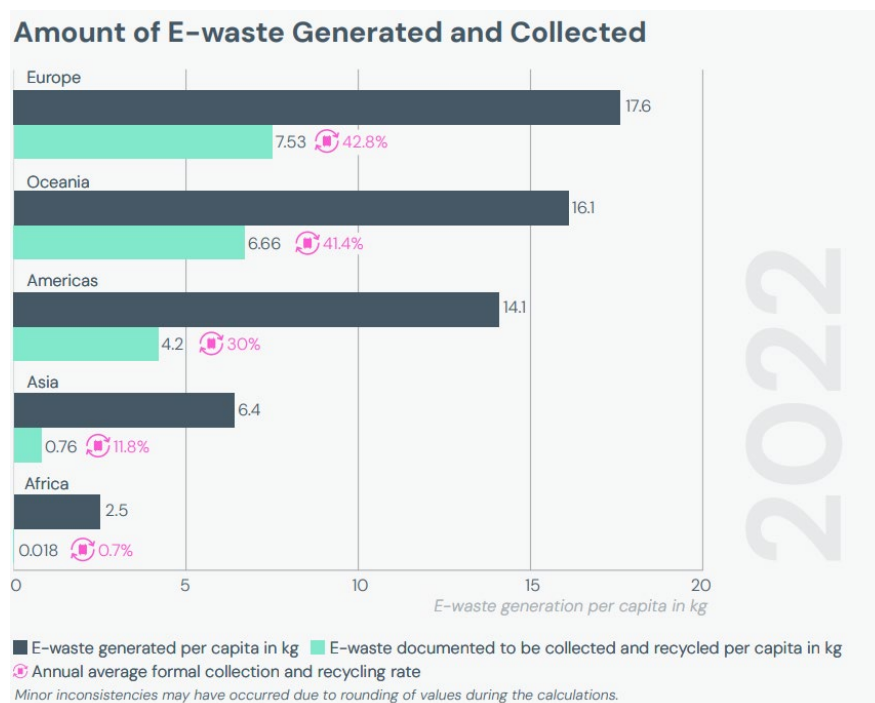


Figure 1: E-Waste Generated (Baldé et al., 2024)

The issue of e-waste is directly linked to several targets within the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (Anuardo et al., 2023; Bhaskar & Kumar, 2019; Ghosh et al., 2022; S. Kumar et al., 2022). Improper disposal and management of e-waste not only threaten environmental sustainability but also human health due to toxic exposure and pollution (S. Kumar et al., 2022). Addressing e-waste through sustainable production, recycling systems, and consumer awareness therefore plays a crucial role in achieving global sustainability objectives (Anuardo et al., 2023; Bhaskar & Kumar, 2019). Furthermore, understanding how countries like Indonesia manage e-waste contributes to measuring progress toward these SDG targets at both national and international levels (Soesanto et al., 2022).

In Indonesia, there still lack of system of e-waste management. Indonesia itself generated a lot of e-waste since Indonesia is one of the highest population countries, nearly all the people use smartphone and they also change it almost every year (Nunuk et al., 2020; Sari et al., 2021). This also increase the e-waste in Indonesia.

Many technological companies and politicians realize this problem if not handle fast, will cause major impact to many sectors. For example, Apple removed their battery charger because Apple thought that people already have so many chargers back in their home, for the sake of environment Apple not giving anymore charger in the iPhone package (Orth et al., 2025). Even though this moved was seen as a way for apple to make more money by selling more charger. Politicians in European Union also force all electronics gadget need to use universal cable charge, in this case the implementation of USB-C is a must to charge the gadget. If the electronic gadget cannot be charged with USB-C, that gadget is not allowed to be sold in European continental (European Commission, 2024). As the result, after 11 years of using lightning connector, iPhone 16 finally uses USB-C as the charging method.

European Union, United States, China, Japan and many 'powerhouses' country can persuade big company to follow the rules. But for developing country such as Indonesia, the rule about E-Waste is non-existent (Santoso et al., 2019) until 2024. Ministry of Environment and Forestry finally address this issue more formally (Ministry of Environment & Forestry, 2024). The regulation concerning electronic waste (e-waste) in Indonesia is stated in Government Regulation (PP) No. 27 of 2020, which categorizes e-waste as specific waste, and in the Ministry of Environment and Forestry Regulation (Permen LHK) No. 9 of 2024 on the management of hazardous and toxic (B3) waste (Ministry of Environment & Forestry, 2024).

The objective of this research is to identify and analyze the main themes, approaches, and findings of existing studies on e-waste through a systematic literature review. By synthesizing prior research, this paper seeks to map the current state of knowledge, highlight key theoretical and methodological trends, and reveal research gaps that require further exploration. In addition, this study specifically aims to examine how e-waste

research has been conducted in the Indonesian context, where scholarly attention remains limited compared to global studies. Through this dual focus, the research contributes to both a broader understanding of e-waste literature and a localized perspective that is highly relevant for Indonesia's growing challenges in managing e-waste.

Conceptual Framework

Some studies show that E-Waste will greatly impact human health (Ahirwar & Tripathi, 2021; Perkins et al., 2014). E-Waste can give bad benefit to human's health. E-waste that is managed in most countries is managed by dumping, formal collection by government, and informal collection by retailers (Ahirwar & Tripathi, 2021). E-waste contains hazardous substances including heavy metals (such as lead, cadmium, mercury, and arsenic), persistent organic pollutants (POPs) like polychlorinated biphenyls (PCBs), brominated flame retardants, dioxins, and furans, as well as various acids and toxic gases released during informal recycling processes (Ahirwar & Tripathi, 2021; Halim & Surhayanti, 2019). Exposure to these substances can occur through direct occupational contact, inhalation of contaminated air, ingestion of polluted water or food, or dermal absorption from contaminated soil and dust. Numerous studies indicate that such exposures lead to a range of acute and chronic health effects: respiratory illnesses, skin disorders, impaired lung function, kidney and liver diseases, hormonal and immune disruption, developmental and cognitive deficits in children, lower birth weights, spontaneous abortions, and increased cancer risk (Liu et al., 2023; Perkins et al., 2014).

The health consequences observed in populations living near e-waste processing sites, especially in low- and middle-income countries where informal recycling is prevalent, include elevated levels of lead and other heavy metals in the blood, increased cases of DNA damage, oxidative stress, genotoxicity, birth defects, and chronic diseases. (Ahirwar & Tripathi, 2021; Liu et al., 2023) Informal recycling practices, such as open burning of plastics or circuit boards and the use of acid baths for metal recovery, releasing toxic compounds into the environment, contaminating air, water, and food chains. These conditions can lead to severe health outcomes for both workers and residents, with long-term impacts on child growth, cognitive function, and overall community well-being (Liu et al., 2023).

Consumer behavior is a critical factor influencing electronic waste (e-waste) management, particularly determining whether end-of-life devices are channeled into formal recycling systems or handled through informal avenues. Scholars have frequently utilized frameworks such as the Theory of Planned Behavior (TPB), Value-Attitude-Behavior (VAB) theory, and models extending TPB to examine the determinants of responsible e-waste disposal (Kosarkar & Barthwal, 2025; Mohamad et al., 2022; Nauman et al., 2025; Sari et al., 2021). Key behavioral drivers include environmental awareness, attitudes toward e-waste reduction, perceived behavioral control, and subjective norms. Enhanced awareness of the environmental and health impacts of improper e-waste disposal is generally associated with increased intentions to donate,

recycle, or properly dispose of obsolete electronics (Mohamad et al., 2022; Nauman et al., 2025). However, various barriers, such as lack of information about formal collection channels, infrastructure inadequacies, and habitual reliance on informal collectors often inhibit pro-environmental action, creating what some researchers term “consumer inertia” (Kosarkar & Barthwal, 2025).

Socioeconomic and cultural factors substantially shape consumer practices. For instance, convenience, perceived immediate financial benefit, and strong cultural attachment to long-held devices commonly encourage consumers to opt for informal sector disposal or accumulate unused electronics at home (Sengupta et al., 2023). Economic factors such as household income and inflation also impact recycling decisions, with higher average income linked to more frequent participation in formal recycling programs (Abha et al., 2025). Social influence from peers or family can further encourage formal recycling, though its impact varies considerably by context (Mohamad et al., 2022; Nauman et al., 2025). Moreover, research shows that personality traits and cultural context moderate the translation of awareness and intentions into behavior: collectivist cultures heighten the role of social norms, while certain personality profiles (such as lower extraversion and higher emotional stability) reinforce pro-environmental attitudes (Nauman et al., 2025). Effective interventions—such as targeted awareness campaigns, incentive-based collection, and improved transparency, are widely recommended to overcome behavioral and infrastructural barriers, thereby fostering responsible e-waste disposal and recycling (Kosarkar & Barthwal, 2025; Sengupta et al., 2023).

Research Methodology

This study employs a bibliometric analysis to identify, categorize, and visualize global research trends on electronic waste (e-waste). Bibliometric methods are used to quantitatively analyze publication patterns, keyword co-occurrences, and research collaborations over time (Donthu et al., 2021; Gao et al., 2019). Through this approach, the study aims to map the intellectual structure and thematic evolution of e-waste research, highlight dominant clusters of knowledge, and identify potential research gaps, particularly in the context of developing countries and Indonesia. Although this study adopts a systematic and transparent search process like a systematic literature review, its focus is on the quantitative mapping of scientific literature rather than qualitative synthesis (Chain et al., 2019).

Bibliographic data was collected from the Scopus database, which is widely recognized for its extensive coverage of peer reviewed international journals. The search was conducted in August 2025, using the following search strings:

1. “E-waste”
2. “E-waste” AND “Developing Countries”
3. “E-waste” AND “Indonesia”

The search was limited to articles and reviews written in English, published between 2010 and 2025. However, an exception was made for the search using the keywords “E-waste”

to integrate behavioral, social, and economic perspectives—especially in Indonesia and other developing nations.

Future studies should:

- Explore consumer behavior and disposal practices using behavioral models such as the *Theory of Planned Behavior* (TPB).
- Investigate the role of awareness, convenience, and perceived responsibility in influencing recycling behavior.
- Examine the informal recycling sector and its interaction with formal systems and government policy.
- Assess digital campaigns and community engagement programs that encourage responsible e-waste management.
- Develop comparative studies between countries with established systems (e.g., EU) and those still developing frameworks (e.g., Indonesia).

By incorporating these perspectives, future research can move beyond describing the e-waste problem and begin addressing the human and systemic drivers that sustain it. For Indonesia, this means developing strategies that connect policy design, business innovation, and consumer participation - a necessary step toward a circular and sustainable electronic economy.

Conclusion

This bibliometric analysis provides a comprehensive overview of the global research landscape on electronic waste (e-waste) from 2010 to 2025, highlighting thematic developments, research patterns, and emerging gaps in literature. The results reveal that global e-waste research has primarily focused on topics such as waste management systems, recycling technologies, environmental pollution, and sustainability policies. When the analysis was narrowed to developing countries, the focus shifted toward challenges in infrastructure, informal recycling, and socio-economic impacts. However, in the Indonesian context, research output remains limited and fragmented, emphasizing the need for more locally grounded and policy-relevant studies.

The analysis also shows that while global awareness of e-waste is increasing, there is still a lack of integration between technological innovation, policy implementation, and consumer behavior, especially in developing economies. Consumer attitudes toward product lifespan, repair behavior, and device replacement are critical yet underexplored determinants of e-waste generation. Future research should therefore examine consumer behavior, behavioral intentions, and digital consumption patterns to better understand how individual choices contribute to e-waste accumulation.

Finally, the study underscores that e-waste management is not only a technical and regulatory issue but also a vital component of achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 on good health and well-being, SDG 12 on responsible consumption and production, SDG 11 on sustainable cities and

communities, and SDG 13 on climate action. Strengthening collaboration between researchers, policymakers, and industry stakeholders will be crucial to advancing sustainable e-waste practices and closing the gap between global progress and local implementation, especially in countries like Indonesia.

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