Nano World Journal

https://doi.org/10.17756/nwj.2023-s1-069

Review Article

Open Access

E-waste: A Review

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Received: November 24, 2022
Accepted: April 19, 2023
Published: April 20, 2023

Citation: Vaibhav K and Awasthi M. 2023. E-waste: A Review. *NanoWorld J* 9(S1): S354-S358.

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Published by United Scientific Group

Abstract

This study examines current trends, obstacles, and the potential for electronic waste (e-waste). There is a brief discussion regarding some e-waste related topics, such as collection, pre-treatment, and recycling. Europe is the top contributor for e-waste collection. Asia, America, Africa, and Oceania come after in the race. E-waste raw materials are thought to be worth $57.0 billion in total. To offset 15.0 million tons (Mt) of CO_2, e-waste of only around $10.0 billion is sustainably recovered for materials and recycled. The process of collection, then sorting the dynamic range of e-waste with lower emission, energy requirement, prevention of inflow of waste generation, and cheaper recycling processes are the main difficulties in treating e-waste. There are currently only 78 nations around the world with laws regarding e-waste. In most places, such laws are not effectively enforced. Northern Africa and South-East Asia are developing nations with little to no e-waste legislation. Therefore, it becomes important to treat the e-waste properly so that it can play a significant participation in circular economy, through public awareness, effective implementation, country-specific standards and legislation, and government participation for cost-effective technologies developments.

Keywords

Electronic waste, Category, Collection, Management, Recycle

Introduction

New ICT products are constantly being released, while old ones become obsolete [1]. Every year, e-waste production grows exponentially. Baldé et al. [2] define e-waste as all discarded electronic and electrical equipment (EEE). In some regions, it's called electronic scrap and WEEE [3]. "E-waste" includes consumer electronics, leisure and sports equipment, computers, mobile phones, lighting equipment, toys as well as large-household items, automatic dispensers, monitoring and control devices, medical devices and communications and IT equipment [4, 5].

E-waste generated by modern lifestyles, technological development, and global economic progress is a major health and the surrounding environmental concern [6, 7]. This accounts for approximately 53.6 Mt of the world's 2 billion tons of waste by Statista (2020) [8]. Generation of e-waste globally has reached 53.6 Mt in 2019, up by 21 percent since 2015 [8]. According to Statista (2020), approximately 83.0 percent of e-waste produced could not be documented in 2019 which may be burned or illegally dumped, endangering the surrounding environment and human health [8]. Merely 17 percent of e-waste got recycled in 2019. Massive e-waste quantity was generated by Asia (i.e., 46.4 percent in 2019), America, Europe, Africa, and Oceania [9]. Even though, Asia produced the most e-waste, it produced less per resident (5.6 kg/inh) than Europeans (16.2

kg/inh), Oceania (16.1 kg/inh), and Americans (13.3 kg/inh) (4.40 billion people). Africa's e-waste rate was the lowest i.e., 2.5 kg/inh. Recycling e-waste has been always very important and may prove to be very valuable as it comprises metals, plastics, and glass. Due to its complex and composite nature merely 17.4 percent of e-waste got recycled globally [9]. This includes hazardous halogen metals and other physicochemical elements, making recycling difficulties [10]. These dangerous compounds could harm the environment if no proper disposal options are carried out [5]. The matter is now internationally recognized to properly manage all types of waste to reduce the health and environmental risks from improper landfilling practices [11].

Methods like incineration and open burning, acid baths, metal acid stripping for e-waste recycling produce heavy metals, dioxins, and furans. E-waste contains a considerable amount of metals and elements that can offer employment and business opportunities if recovered sustainably in an environmentally friendly manner. But managing this huge amount of waste through insufficient infrastructure and not so effective technologies again hampers the operation [12]. 21st century is experiencing a very serious environmental and health threat in terms of e-waste management due to very rapid advancement of technology and very swiftly upgrading devices with newer updated models and very limited lifespan for these devices [13].

Extensive literature on e-waste has been reviewed by many researchers. Few of them focused on region. Meem et al. [14] assessed the e-waste disposal and its health and environmental consequences in Bangladesh. Murthy and Ramakrishna [15] focused on the best practices of all around the world to manage the e-waste and mention the need to implement the policies to meet technological requirements and raise public awareness to achieve a circular and sustainable economy. Review study was performed by Abdelbasir et al. [16] regarding variety of methods for recycling evaluable waste's metals. Ahirwar and Tripathi [17] and Doan et al. [18] reported on the latest trend globally in e-waste generation, recycling, and health impact before proposing solutions for improving e-waste management. A brief discussion on the harmful effects of hazardous e-waste or recycling components has been given by Gupta et al. [19]. From 1992 to 2014, Perez-Belis et al. [20] analyzed literature on e-origins, waste's composition, management, and disposal. Most e-waste reviews focus on topics that don't accurately depict management. This review covered e-waste collection, pretreatment, challenges, and the future prospects. This review provides researchers and policymakers with the latest information on e-waste recycling and management.

E-Waste Categories

Waste from electronic devices and electrical equipments can be grouped into different categories based on where it came from and what it was used for. Ten distinct e-waste types are recognized globally (Figure 1) [21-23]. Depending on several variables, such as socioeconomic conditions, consumer behavior, population, reliance of businesses and households on EEE, the average percentage of each category of e-waste can change.

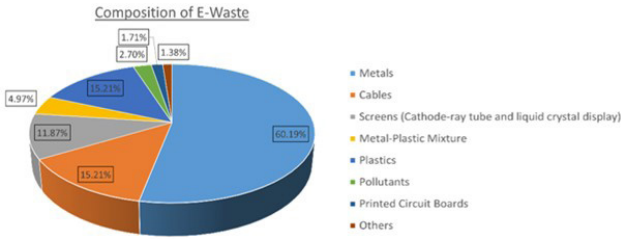

Figure 1: Composition chart of e-waste.

However, the largest electronic waste source (i.e., 42.1 percent) comprises large household items, which are then followed by consumer electronics (13.7 percent), IT and telecommunications (33.9 percent), and smaller household appliances (4.6 percent) [24]. In order to make the data more readable, other categories have lower contributions of 2 percent for electrical, medical, lighting and electronic tools and only 1 percent for monitoring and control devices, automatic dispensers, sports and toys. Computers, televisions, and mobile phones make up majority for the e-waste in developing nations [25].

Collection of E-Waste

The first step for managing e-waste includes collecting waste from homes and businesses. Waste is then pre-treated prior to being delivered to treatment facilities or disposal landfills in the second step. E-waste collection could be perform in numerous methods few of them are official take back system in which a costumer will be given an option to return his/her old device that he /she is intended to purchase in return for some credits or some rewards, mixed residual waste, e-waste collection without official take-back system for the nations with developed organized waste management and collection for the nations not having properly developed waste management outside official take-back system [26]. Designated collectors, councils, or producers collect first category e-waste as per national laws [2]. This collection method is considered best as this employs pre-treatment procedures prior being sent to cutting-edge treatment facilities. Mixed residual waste is the second collection category for consumers who discard the e-waste along with their other household or commercial waste. This WEEE will likely be incinerated or thrown away with other trash. Third, registered individuals or businesses collect e-waste and sell it to recyclers. This way outside take-back collection for e-waste is carried out. Finally, countries without legislation for e-waste, like in Bangladesh, manage their electronic waste informally, using unofficial collectors and recyclers.

Table 1 shows global collection statistics for e-waste, worth of recyclable material, and collection techniques for each region. In 2019, European countries collected 5.1 Mt (42.2 percent of e-waste globally) worth $5.48 billion. Asia had 2.9 Mt (11.7 percent), then America with 1.2 Mt (9.4 percent), Oceania with 0.06 Mt (8.8 percent), and Africa with 0.03 Mt (0.9 percent). Global e-waste is $57.0 billion, out of which only e-waste sustainably recycled worth of $10 billion,

offsetting 15.0 Mt of CO_2 [9].

Legislation of different regions, economic conditions, e-waste management infrastructure and person's awareness regarding e-waste affect how collection methods have evolved. Most developing nations lack e-waste statistics because Northern Africa and South-East Asia have little or can say no legislation for e-waste [2]. Underprivileged and self-employed people gather, then recycle the e-waste in such areas. These individuals collect e-waste door-to-door, separate it, and sell it to be recycled or refurbished to city vendors. Even though the way to treat e-waste is not appropriate as many health risks are associated and poor collection and management only aggravate the problem, many unskilled people use it to make a living. Bangladesh's annual informal e-waste collection rate was 0.95 Mt. In Dhaka most of the small-scale recycling businesses could make $3,410 per month unofficially, according to estimates [27].

Methods for Pre-treatment and Recovery Treatment

E-waste is first pre-treated after collection before being fully processed in treatment facilities. Pre-treatment aims to separate various recyclable components out of the collected e-waste then sent to the proper treatment site for recovering the material to maximize the profit out of the business. Three types of pre-treatment procedures are possible: (i) manual dismantling; (ii) mechanical dismantling and separation; and (iii) processes that combine manual with mechanical actions [28]. E-waste dismantling using manual manner sometimes be time-consuming and expensive, frequently separates hazardous and valuable materials like batteries, casing, PCBs, and monitors [29]. Size reduction, shredding, crushing, and metal and non-metal separation are all included in mechanical pre-treatment [28]. It must be pointed out that combining the manual and mechanical pre-treatment processes can save time and money when dealing with complex mixtures of different pieces of technology. Pre-treatment in developed nations typically does not consist of fully automatic (i.e., manual and mechanical) separation accompanied by metal recovery in cutting edge facilities [30].

In developing nations, manual separation is the most common technique accompanied by recovery of metals in private small workshops. Generally, magnet disk of weaker intensity is used to procure ferrous metals from e-waste, and non-ferrous metals are taken out from non-metals with the help of electrical conductivity-based separation methods [28]. Sifting and other methods to separate out various materials, such as the water flow tables, gravity method using airflow are also frequently employed. After being separated from other materials, metals are shifted for subsequent and final step to recover metals where two recovering techniques, pyrometallurgy and hydrometallurgy, are frequently employed [31]. High temperatures are used in the pyrometallurgy process to extract and purify metals. The processes of refining, smelting, burning, and incineration are some examples of pyrometallurgy [32]. The goal of hydrometallurgy is to extract recoverable metals using aqueous solutions out of the concentrated mixtures or various materials combination. In a broader sense, hydrometallurgy helps to recover non-ferrous metals, such as zinc, lead and copper, while pyrometallurgy helps frequently to take out ferrous metals out from e-waste.

Challenges and Opportunities

Managing e-waste presents opportunities but with many challenges. E-waste legislation possesses a critical issue being valuable and toxic at the same time. Most developing nations lack e-waste legislation besides developed countries. In 2014, 61 nations had e-waste laws (i.e., 44 percent of the world's population). In 2019 78 countries regulated e-waste for 71 percent of the world's population. E-waste regarding rules and regulations are there in China and India, but Bangladesh and Pakistan don't have any such law [2]. Recently, Pakistan prohibited the import from other countries of the e-waste, but its effectiveness is uncertain [27]. Bangladesh's DoE published the 2019 Hazardous Waste Management Rules to limit EEE products to 15 hazardous substances (WTO 2020).

E-waste of hazardous, priceless, base, and other materials makes it difficult to handle and process, despite collection and recycling laws. 40 percent of e-waste is metal, 30 percent oxides, and 30 percent polymers [31]. Due to uneven EEE distribution in e-waste, these amounts can vary between countries. E-waste includes hazardous material (Hg, Pb, As, Be, and Cd), precious metals (Pd, Au, and Ag), base metals (Al Cu, Ni,

Table 1: Showing countries with e-waste collection method and associated worth.

Country	E-waste Collected (Mt)	Estimated Monetary Value (USD)	Collection Method
Europe	5.10 (42.3%)	5.48 billion	Formal collection by private operators and municipal councils
Americas Caribbean	1.20 (9.4%) 0.001 (1%)	1.30 billion -	a) Formal collection by private operators b) Informal collection by individual registered companies
Asia	2.90 (11.7%)	3.07 billion	a) Formal collection by private operators b) Informal collection by individual registered companies c) Non-registered informal collectors and recyclers
Oceania	0.06 (8.8%)	0.06 billion	a) Formal collection by private operators b) Informal collection by registered companies
Africa	0.03 (0.9%)	0.03 billion	Dominantly non-registered informal collectors and recyclers

Fe, Zn, Sn, Sb, In, and Bi), ceramics, plastics, and glass [33]. Recovering valuable, rare earth, There are limited eco-friendly chemical liquids approved for e-waste management, a lack of infrastructure facilities, thermo-dynamic limits on the ability to separate complex mixtures of materials, which creates a cost-effective recovery a challenge to financial and policy support, for particularly developing countries, and unbiased fair laws are additional e-waste management challenges [33].

E-waste's potential and opportunities are crucial if recycled properly. E-waste urban mining can recover precious metals. One Mt of circuit boards can yield gold weighing around 1.5 kg and copper around 210 kg [34]. Primary mining from ores has a lower precious metal concentration. Conventional gold mining yields 5 g/t gold and 5.25 kg/t copper [33]. Urban mining provides 30 to 40 times more copper and gold if compared to their respective natural ores. A larger profit is expected if precious metals are recovered with the right business models. A proper managing e-waste model can have many benefits regarding environmental and health [35]. Health and the environment are top concerns. E-waste management has never been taken seriously in developing nations, resulting in poor health and unstable environments around disposal sites [27]. Better policies and strategies with proper government laws can improve the e-waste situation and problem associated with it.

Conclusion

Metals comprises around 40 percent of e-waste, followed by plastic polymers at 30 percent and oxides of other metals at 30 percent. The essential steps in recycling of e-waste and metal recovery involve collection, washing, sorting, pre-treatment, and treatment. Large household appliances along with consumer small household appliances and IT telecommunication devices are the three main branches of e-waste. Currently, Europe (5.10 Mt, or 42.3 percent of global e-waste production) is the region that collects the most of this waste after this Asia covered the most (2.9 Mt, or 11.7 percent), then America (1.2 Mt, or 9.4 percent), Oceania (0.06 Mt, or 8.8 percent), and Africa (0.03 Mt, or 0.9 percent). Various precious, base, hazardous materials, plastics, glass, ceramics, and other halogens are involved in manufacturing of electrical and electronic products which become e-waste once the device is discarded. All around the world Asia produces the most electronic waste, however, the waste generation is 5.6 kg/inh less waste per person if compared to that of America, Europe, and Oceania. Unluckily, 83 percent of e-waste produced worldwide is not documented anywhere, which means that it will either be burned or dumped illegally, putting a serious risk to the environment and public health. For managing this e-waste properly estimating the waste generation for some future timeline would help in proper management. Managing the e-waste, which will be a critical contributor to the continuous circular economy, national as well as international organizations must work together and raise public awareness.

Acknowledgments

The author would like to thank Dr. Mamta Awasthi and Dr. N.S. Thakur for their support and guidance in this project at NIT Hamirpur.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Kumar Vaibhav: Conceptualization, Writing - original draft preparation, Writing - review and editing; Mamta Awasthi: Supervision. All the authors read and approved the manuscript.

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