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E-Waste Management In India: Challenges and Roadmap for Sustainable Future

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Abstract

E-Waste management has become a global concern with the huge rise of technology, shortened product life cycles, and increasing consumption of electronic devices. It is the serious growing concern stream around worldwide. Improper e-waste disposal can lead to severe environmental and health issues because it contains toxic elements such as mercury, lead, and cadmium, which can seep into the soil and water. E-Waste management has become a significant undertaking, and if not managed properly, it can impose serious problems. So, it is highly required to address this issue for a healthy and sustainable future. Keeping in view this concern, the paper aims to analyze the global and Indian scenario of e-waste generation and to check what challenges India is facing for e-waste management as well as to suggest future roadmap of e-waste management for sustainable future . The study finds out that the informal sector dominates the e-waste collection and recycles process in India which is highly irregulated. Poor and inadequate infrastructure for recycling hampered the recycling process of e-waste in India. For sustainable e-waste management requires a comprehensive approach that involves regulatory reform, formalize the informal sector, run campaigns for public awareness, and investments in modern recycling infrastructure.

Keywords: e-waste, recycling, e-waste generation, environmental impact, WEEE, e-waste management

1. INTRODUCTION

Electronics is the world's biggest and most rapidly developing industry. Global demand and consumption have increased for electric appliances . Today's high use of electronic gadgets contributes to the global economy's rapid advancement of inventions and technologies. The fast growth of new technology has resulted in enormous amounts of electrical waste around the world. E-waste is a kind of garbage produced from electronic gadgets or devices in industrial environment. It is a complex and developing global issue [1]. E-waste, also known as Waste Electronic and Electric Equipment (WEEE), are obsolete components, subassemblies, IT and telecommunications equipment, lighting equipment, consumables from household appliances, and automatic dispensers that users no longer want [2].With increased access to technology and industrial expansion, worldwide e-waste creation will continue to rise.Higher GDP causes more electronic purchases, which increases e-waste production.The global expansion of electronic devices coincides with substantial advancements in information and technology [3]. A recent study suggests that the waste generated each year could build nearly 4500 Eiffel towers[4]. Approximately 20% of the world's waste is collected and recycled, while the remaining 80% is discarded[1].

The largest and most creative industry worldwide is electronics.Countless electrical and technological products are shipped across oceans every year. However, after use, they generate a complicated waste substance. It contains various toxic heavy metals, hazardous chemicals, acids, and non-biodegradable materials. Around 75% of e-waste has no clear purpose or potential reuse, such as repairing, remanufacturing, refurbishment [5]. India faces challenges in managing

both indigenous and imported e-waste, including those dumped by developed countries. E-waste is typically imported into India as used products for refurbishment. However, the clause requiring timely return to parent countries is often not followed[1]. India still remains devoid of responsible people across urban and rural areas who adopt sustainable e-waste management practices. Managing e-waste in India is complicated by cultural, sociological, economic, and environmental factors [6].

Thus, it is highly required to address this issue for a healthy and sustainable future. Keeping in view this concern, this paper aims:

- To analyze the global as well as Indian scenarios of e-waste management .
- To identify the challenges in India's is e -waste management.
- To suggest future roadmap of e-waste management for sustainable future.

2. LITERATURE REVIEW

This section contains review about e-waste, its components, and causes

2.1. Waste Electronic and Electric Equipment (WEEE)

E-Waste refers to discarded or rejected electronic and electrical items. Each year, tons of e-waste are generated. Disposing of electronic waste, such as laptops and batteries, might have negative consequences. It's crucial to be aware of both physical and electronic waste [5]. Technically, e-waste is a component of WEEE. E-waste refers to "Waste of Electrical and Electronic Equipment (WEEE)," which comprises obsolete computers and IT equipment. E-waste disposal raises problems because it contains dangerous elements.

European Directive 2002/96/EC covers the collection and destruction of waste electronic and electrical equipment, including its components, subassemblies, and consumables. The Directive 2002/96/EC classifies electronic waste into ten kinds: Large household equipment; Small household equipment; Telecommunications and IT equipment; Consumer Durables; Lighting items; Electrical, and electronic tools (E&E tools); Sports and electronic toys; Medical devices; Automatic dispensers; Monitoring and control instruments (M&C)[7].Electronic waste is a component of WEEE, a larger category. WEEE is defined by the "Organization for Economic Cooperation and Development"(OECD) as any appliance with an end-of-life electrical power supply.

2.2. Components of E -Waste in India

E-waste can originate from several sources, such as from government offices, households, business enterprises, manufacturers, and retailers.

As per India, Schedule I of the "E-waste (Management) Rules", 2016 electrical equipment's are divided in two categories:

1) "Information Technology and Communication"

2) "Consumer Electrical and Electronics"

[Refer Figure 1 and 2 here]

Figure 1: E-waste Components

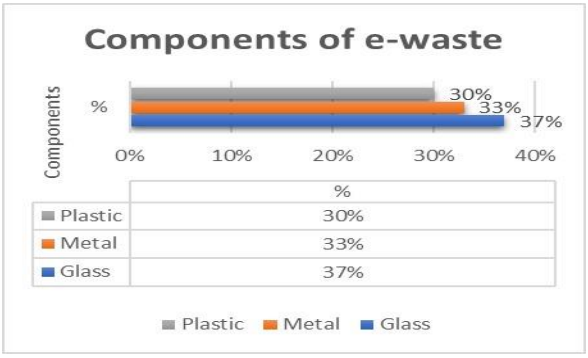
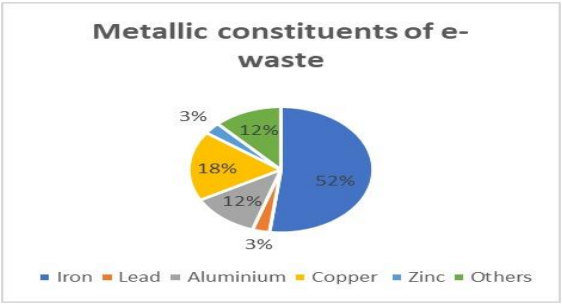


Figure 2: E-waste Metallic Constituents



2.3. Global causes of e-waste generation

The main causes of global e-waste generation are:

- Computers and mobile phones have varied expected lifespans. Innovative products are reducing product life cycles.
- Attractive market offerings encourage customers to purchase new products instead of upgrading existing ones. Early adopters of technology, who frequently replace their computers and mobile devices with new

capabilities, lead to a rise in e-waste generation [8], [9], [10] . Nowadays, most customers prefer to replace their computers rather than upgrade them. Few opt to submit items for repair and service [11].

- The rapid development of new technologies has resulted in the obsolescence of various electrical equipment which contributes a considerable amount of electrical waste around the world[1], [12].

3. RESEARCH METHODOLOGY

For the study, secondary data has been used. This study takes a systematic approach to collecting, analysing, and interpreting existing data from various sources. Data has been taken from academic journals, government reports, and trustworthy websites. Mainly data has been taken from the reliable sources such as the "Global E-Waste Monitor" report, the "World Health Organization" (WHO), the "Ministry of Electronics and Information Technology", and other reliable websites.

4. FINDINGS

4.1. The Global Scenario of E -Waste Generation

E-waste has become a serious global concern as with the rapid development and widespread usage of electronics and electrical items [13]. As reported by the WHO (World Health Organization), million tons of electronic waste get produced each year; it was reported that theworldwide, e-waste production surpassed 53.6 million metric tons in 2019, with only 17.4 percent of that amount being properly collected and recycled. In 2022, as per the "Global E-Waste Monitor" report, e-waste generation raised from 53.6 to 62 million tons globally[14]. Shorter gadget life cycles, increased gadget turnover, and rising consumer desire for the latest technologies are the primary causes of this rise. Consequently, parties engaged in the treatment and eradication of electronic waste face numerous challenges [15]. Without adequate management, the toxic substances found in discarded electronics—including cadmium, lead, and mercury—pose a threat to both human and environmental health.E-waste management is governed by a variety of laws and legal systems around the world. Many countries have passed laws to regulate the hazards of e-waste, including China's "Administrative Measure on the Control of Pollution Caused by Electronic Information Products" (founded in February 2006), the United Kingdom's "Waste Electrical and Electronic Equipment" legislation (enacted in 2007), and India's "Ministry of Environment and Forests" [16].

China has put forth considerable efforts to increase e-waste collection as well as recycling in both the public and private sectors[17], [18]. This has resulted for higher domestic and foreign investment in the recycling industry, in addition to the adoption of innovative treatment tools, and management techniques from other nations. Special resource recycling industrial parks have been developed in Tianjin, Taizhou, Taicang, Ningbo, and Zhangzhou, among other places, to promote environmentally friendly recovery of both indigenous and imported metallic waste. Many regions, including Beijing, Shanghai, and Jiangsu, have adopted local administrative processes for dealing with e-waste [19], [20]."The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and its Disposal" effectively governs e-waste transactions between OECD and non-OECD nations. The EU has enacted two directives to safeguard the environment from the risks of e-waste in Europe: the "WEEE directive" and the "Restriction of Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment Regulations". Many countries have adopted WEEE Directives that offer detailed instructions[16].

[Refer figure 3, 4 and 5 here]

Figure 3: E-Waste Generation, by different regions globally

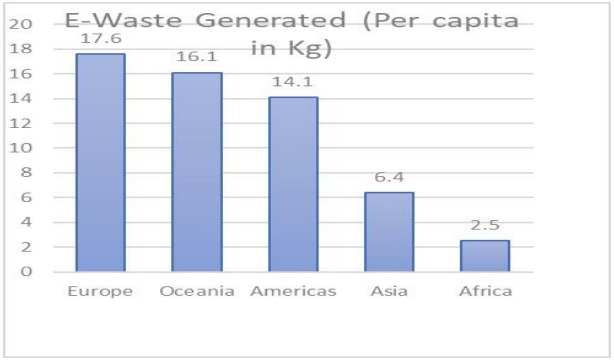
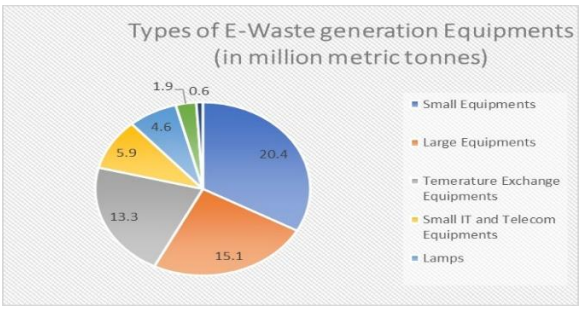


Figure 4: E- waste recycled, by different regions globally

Figure 5: E-Waste generation equipment



According to the "Global E-Waste Monitor" 2024 report, 62 million tons of e-waste were produced in 2022 which is increased 82% in comparison of 2010. And it is also forecasted that by 2030, the creationof e-waste would be 82 million tons, which show 32% addition of 2022.Only 22.3% of the electronic trash that was produced in 2022 was appropriately collected and recycled, which is a major problem on a global scale.In 2022, Europe (17.6 kg) produced the most e-waste per capita, followed by Oceania (16.1 kg), the Americas (14.1 kg), Asia (6.4 kg), and Africa (2.5 kg). Among different regions, African countries have lowest e- waste generation but it is also need to be consider that the recycle rate is also less than 1% whereas the regions Europe, Oceania and Americas are the highest e -waste generator since these regions have reported greatest per capita collection and recycling because they are the ones with the most developed infrastructure for collecting and recycling.In 2022, equipment such as air conditioners, refrigerators,accounted for 13.3 million metric tons of global electronic trash.Small equipment generated the most e-waste, which is in total (20.4 million metric tons).

4.2. India Scenario of E -Waste Generation

As per Environment Performance Act 2024 India rank 176th out of 180 countries, which shows the poor performance in terms of environmental health. Also, India is the 3rd largest e-waste producer globally after China and the USA due to its reliance on electronics and fast-growing digitization. "UN's Global E-Waste Monitor" reported that these three countries contributed 38% of the total 53.6 million tons e -waste in 2019[14]. The e-waste recycling rate in India is so low, which is 1%, that it is reason for alarm. In India, open dumpsites are extensively utilized for dumping, which can result in a number of problems, including contaminated groundwater and bad health. According to the "Associated Chambers of Commerce and Industry of India" (ASSOCHAM), computer equipment accounts for more than 70% of all electronic trash in India. Communication devices (12%), electrical appliances (8%), and medical equipment (7%) make up the top five categories, with domestic e-waste accounting for the remainder. The informal sector is in charge of e-waste collection, transportation, processing, reuse, and recycling. Almost 90 percent of e-waste is collected, processed, and recycled by the informal sector. This sector is majorly unregulated. Due to a lack of literacy and knowledge, India's recycling rate is extremely low. To handle with the growing volume of e-waste, India needs stronger infrastructure and more authorized recycling facilities.

[Refer figure 6 and 7 here]

Figure 6: E-Waste produced and recycled rate

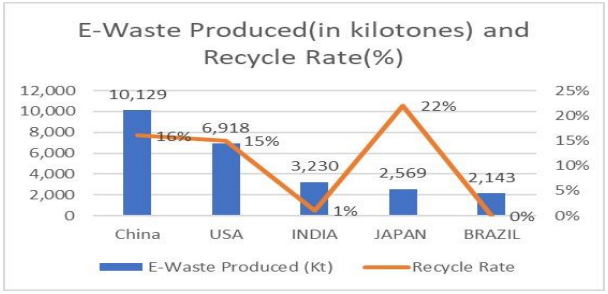
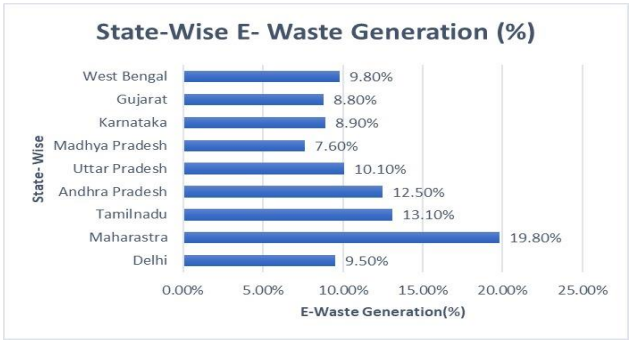


Figure 7: E-Waste generation trend of India

India produced approximately 1.6 million metric tons of e-waste in the financial year 2022. The volume was over two times higher than it was in 2018.

[Refer figure 8 here]

Figure 8: E-Waste generation, by State-wise



Maharashtra is India's leading producer of e-waste, with Tamil Nadu and Andhra Pradesh coming in second and third place, respectively. Mumbai generates the most e-waste among the top ten Indian cities, followed by Delhi, Bangalore. Ten states contribute 70% of the country's e-waste, with 65 cities accounting for more than 60% of the total.

[Refer Table 1 here]

Table 1: Progress of Legal Framework for E-Waste Management in India

Year	Outcomes
Before 2011	Prior to the implementation of e-waste management legislation, most e-waste management in India was unregulated. Informal recycling sectors played an important role, posing considerable environmental and health risks.
"E-Waste (Management and Handling) Rules", 2011	These rules were introduced by the "Ministry of Environment, Forest and Climate Change" (MoEFCC) and it was the first formal attempt to regulate e-waste in India. The EPR (Extended Producer Responsibility) idea was created, which holds producers accountable for the collection and disposal of e-waste.
"E-Waste (Management) Rules", 2016	The 2016 rules widened the scope of e-waste categories and included provisions for proper channelization and disposal. These rules allowed producers to engage PROs (Producer Responsibilities Organizations) to fulfill their EPR obligations. Deposit Refund Scheme was introduced where consumers could return end-of-life products and receive a refund, encouraging proper disposal.
(2018) Amendments to E-Waste (Management) Rules, 2016	The collection targets were revised to be more ambitious, aiming for a higher rate of e-waste collection. Stricter regulations were imposed regarding the usage of hazardous compounds in electronic products. The amendments also included stricter penalties for non-compliance by various stakeholders.
Draft E-Waste (Management) Rules, 2022	A revised draft was released, which generally focus on increasing the efficiency of e-waste management practices and enhancing role and importance of PROs. Emphasis is placed on promoting a circular economy model.

India has been the first South Asian country to pass specific e-waste legislation since 2011. The "E-Waste Handling Rules" establish criteria for trash transit, storage, and recycling, as well as the idea of "EPR (Extended Producer Responsibility)". EPR is a popular method that demands electronic device producers to assume financial and physical responsibility for devices that are no longer usable. The "The Hazardous Wastes Rules of 2008" and the "Central Pollution Control Board" were principally utilized to monitor and advise on E-waste management. In 2016, regulations were changed to create a "Producer Responsibility Organization" (PRO) to promote electronic waste collection and recycling.

4.3. Effect of E-waste on Environment:

"Waste Electrical and Electronic Equipment" (WEEE) is a worldwide growing concern. Toxic substances mixed with virgin soil and air have both direct and indirect effects on the biota. E-waste causes a considerable health hazards because of poor knowledge and awareness of proper treatment techniques. The growing volume of electronic garbage endangers both human well-being and the environment. Garbage can negatively impact physical and emotional health [21]. E-waste contains dangerous and hazardous substances, causing concern for the negative environmentalimpact as well as on human health. Proper management is crucial. In India, the e-waste market is generally unorganized, with businesses operating without registration or authorization[11].

In developing country like India, informal individual collectors (peddlers) continue to be the primary collectors of abandoned domestic electronics. They offer a doorstep service, paying minimal fee to e-waste owners before selling them to e-waste merchants. Most of the e-waste is collected by informal recyclers, which causes supply constraints in the professional recycling sector [19], [20]. Informal recyclers frequently lack basic disposal and treatment technologies and equipment, and regulations are not effectively enforced, resulting in significant hazards such as contaminated groundwater and soil and increased cancer rates[22].

E-waste is a growing concern for India as a result of modernity and consumerism. However, there is currently no scientific method in our country for disposing of E-waste. In India, open burning of plastic waste, prolonged contact with toxic substances, acid dumping, and other similar practices are common. Unscientific disposal spreads toxins into land, air, and water, producing significant environmental issues. Untrained workforce with limited

understanding of occupational and health hazards, work at low wages in dismantling and recycling operations[7]. Dismantling e-waste requires extensive work in nations such as China and India. The method comprises shredding, tearing, and flaming in addition to unscrewing. Smoke and dust include carcinogens and other dangerous compounds that can cause respiratory issues and skin irritation. Burning circuits used to extract valuable metals like gold, platinum, and cadmium can emit hazardous carbon particles from toners, causing lung and skin cancer.

As per the BBC (British Broadcasting Corporation) report, e-waste pollution causes notable health concerns to millions of people globally, particularly in developing nations such as Africa, Europe, and Asia. Pollution and environmental repercussions account for almost 23% of deaths in these countries. According to the survey, over 200 million individuals globally are at danger of exposure to toxic waste.As the demand for electrical and electronic items (EEE) rises, so does the amount of e-waste generatedglobally[5]. "Associated Chambers of Commerce and Industry of India" (ASSOCHAM) found, over 80% of e-waste workers in India suffer from serious health issues like breathing problem and coughing as a result of inadequate safety precautions.

In India, electronic waste is a major and dangerous waste stream. This is a sophisticated type of hazardous garbage. It has a significant concentration of heavy and precious metals, as well as Persistent Organic Pollutants (POPs). E-waste include harmful particles that are detrimental to both human wellness and the environmental health[23]. E-waste management necessitates careful consideration of both economic and environmental factors[24]. E-waste necessitates sustainable management techniques to prevent the loss of valuable materials while dealing with resource scarcity[25].

To address the growing hazard of e-waste, many countries' environmental agencies are developing and implementing environmentally appropriate ways for managing it. E-waste management is of paramount necessity for developed as well as developing countries, but it can be difficult to replicate in country like India due to country-specific variables such as socioeconomic conditions, a lack of infrastructure, a lack of appropriate legislation, and stakeholders' varying approaches and commitments[26].

5. CHALLENGES OF E-WASTE MANAGEMENT IN INDIA

- E- Waste management is the major concern worldwide. India faces significant challenges because of high technological advancement and increasing demand for demand for electronic devices among consumers. One of the challenges for the India is the poor and inadequate infrastructure for the recycling. According to "Global E-Waste Monitor" report of UN, the recycling rate of India is 1% of total e- waste production. One of the biggest reasons of it is that, India has very few governments recognized centers for the recycling purpose which constitute only of approximate of $1/5^{th}$ of the entire amount of e-waste created annually [6].
- Second major challenge for India is the Informal sector dominance in recycling. Almost 90-95% of collection, processing and e-waste recycling is managed by informal sector. In many areas, e-waste is managed through informal channels, which frequently entail hazardous and unsafe ways of electronic trash disposal. This not only create significant risk to the environment, even also compromises the health of individuals involved in recycling. To combat this problem, the recycling process needs to be formalized and regulated.
- Another challenge is the deficiencies of public knowledge about e-waste concerns in India, hence recycling is extremely low. Most consumers are unaware of or have little knowledge about the hazardous effects of e-waste components, as well as the penalties for incorrect disposal.

6. FUTURE ROADMAP FOR E – WASTE MANAGEMENT

- Above facts are clearly showing that , India is facing notable challenge in recycling the generated e- waste and the main reason of it is the poor and inadequate infrastructure of recycling. To address this problem ,the government should take a proactive stance and require electronic companies to develop recycling facilities for the products they sell. This technique has the potential to be extremely effective for managing e-waste. Implementing this regulation would be beneficial to both manufacturers and the government. Recovering valuable elements from discarded products could help manufacturers save money in the long run. Meanwhile, the government would benefit by leveraging the notion of "Extended Producer Responsibility" (EPR) and promoting the concept of a circular economy, as more job opportunities would be

created. This method not only bridges the physical gap, but it also promotes long-term e-waste management operations.

- Switzerland demonstrates effective e-waste management operations that India might learn from. In Switzerland, responsibility for e-waste management is shared by a variety of stakeholders rather than only producers. This comprehensive approach guarantees that all parties involved, including manufacturers, consumers, government agencies, and the companies that do recycling, should work together efficiently to handle e-waste responsibly. Adopting and properly executing a similar multi-stakeholder model can help India improve its e-waste management system and increase overall efficiency and effectiveness.
- In India, e-waste recycling is primarily done by informal sector workers.This sector is largely unregulated. This not only endangers the workers' health, but also has serious environmental effects, such as soil and water poisoning. To address these concerns, the government should work to legalize the informal sector. This includes registering and licensing informal workers, offering training and financial assistance, and developing collaboration among the government, private sector, and "Non-Governmental Organizations" (NGOs). Establishing suitable recycling hubs and logistics networks, as well as providing health and safety requirements, can help to accelerate this shift. Simplifying regulatory compliance and providing social security benefits will encourage informal workers to transition into the official sector, which will help in resulting a more efficient and environmentally friendly e-waste processing system in India.
- Current rules and regulation prohibit importing e-waste for final disposal, but allow for reuse or recycling. In the absence of adequate recycling facilities in the country, we should seriously consider banning all imports. To get accurate e-waste estimates, import data must be linked with an e-waste inventory.

7. CONCLUSION

E-waste management need careful consideration of costs and environmental impacts. Some of the countries have implemented systems for collecting, separating, recycling, dumping, and regulating e-waste. Whereas other countries are still seeking for a way to lessen the negative environmental impact of e-waste treatment.E-waste management is a critical challenge not only in India, but around the world, because of the rapid increase in electronic product consumption.Despite the establishment of rules such as the "E-Waste (Management) Rules" of 2016, implementation is inconsistent. Informal sector dominates the recycles process which is highly irregulated. Poor and inadequate infrastructure hampered the recycling process of e-waste in India. E-waste management requires a comprehensive approach that involves regulatory reform, formalize the informal sector, public awareness campaigns, and investments in modern recycling infrastructure. Integrating the informal sector into the formal system, promoting "Extended Producer Responsibility" (EPR), and encouraging innovation in recycling technology are all critical steps toward improving e-waste management. Addressing these concerns through a coordinated effort between government, industry, and civil society is critical to lessening the negative environmental and health implications of e-waste, ultimately leading India to a more sustainable future.

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