iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** I **Month of publication:** January 2026

DOI: https://doi.org/10.22214/ijraset.2026.77226

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue I Jan 2026- Available at www.ijraset.com

E-Waste Crisis and Mitigation: Generation Trends, Recovery Techniques, and Policy Interventions

Anvesha Deshmukh[1], Pankaj Ramawat[2], Gokul Kalwane[3], Prakash Bhange[4]
Department of Electronics & Telecommunication Engineering Savitribai Phule Pune University

Abstract: E-waste has outpaced processing capabilities as phones, computers and other electronics are replaced at an increasingly rapid rate. Although these types of devices have "recoverable" metals, they are also relied upon to be cheap and those precious metals will elicit a significant fraction of their weight in recovery also transport chemicals that are hazardous if spilled, dumped or burned. This review looks at what countries manage e-waste; the recycling techniques currently employed, and the rules that seek to contain the quandary. Concepts such as the circular economy and Extended Producer Responsibility (EPR) are also discussed. In general, the review findings imply that smarter collection systems cleaner recycling, better enforcement can reduce waste harms to environment. The review emphasizes that improved collection efficiency, cleaner recovery technologies, and stricter enforcement of regulatory frameworks are essential for sustainable e-waste management in developing economies
Keywords: E-waste Management, Electronic Waste Recycling, Circular Economy, Extended Producer Responsibility, Resource Recovery, Informal Recycling Sector

I. INTRODUCTION

Electronic waste, or simply e-waste, refers to items like mobile phones, laptops, and circuit boards that people have stopped using. Technical advances, coupled with their quick obsolescence, and a reduction in the number of repair shops, are among the reasons why massive amounts of e-wastes are being generated annually [3], [4].

The device once thrown away may contain metals such as copper and gold that are still useful, but at the same time, it has toxic substances like lead and mercury. Improper recycling practices, if carried out, will result in these materials contaminating the environment through soil and water and exposing workers to toxic fumes. Several countries have low e-waste collection rates, little policy enforcement, and are heavily dependent on informal recycling. As a result of these problems, the development of better e-waste collection, processing, and regulation systems is necessary, which would contribute to a reduction in the environmental harm as well as the recovery of valuable materials.

II. LITERATURE SURVEY

Streicher-Porte et al. [8] have conducted a study on the issue of rapidly growing electronic waste on a global scale and its connection with the informal recycling practices. They focused on the toxic substances from e-waste that contaminate soil, water, and air and emphasized the necessity of having formal collection and environmentally friendly recycling system for their study. Sinha-Khetriwal et al. [9] carried out a comparative study of the e-waste recycling systems in Switzerland and India. The authors remarked that Switzerland is following a regulated, producer, responsibility model, whereas India is heavily dependent on the informal sector for its e-waste management. The paper has reached a conclusion that the enforcement of laws and provision of infrastructure are important factors for enhancing the recovery rates. Jain [11] reviewed the e-waste policies already in place in India and pointed out the major lapses in their implementation. The paper has demonstrated that although there are guidelines and rules, the lack of awareness, collection mechanisms and formal recycling units are the main reasons that e-waste has not effectively been managed in India. Chatterjee [5] shed light on the e-waste situation in India and brought out the fact that a vast majority of the recycling is carried out through the informal sector. The report has highlighted that workers being exposed to heavy metals and toxic chemicals due to the improper treatment is one of the reasons why there is such a strong need for regulatory strengthening in order to protect public health.

III. E-WASTE GENERATION IN INDIA

E-waste has become an enormous environmental issue and public health problem due to shorter product life cycles, increased use of electrical and electronic equipment (EEE), and rapid advances in technology. India is currently the third largest producer of e-waste in the world, with nearly 2 million metric tonnes of e-waste generated each year [1], [2], and also receives additional e-waste from illegal imports.

The growing volume of discarded electronics is putting tremendous strain on the current recycling and waste management infrastructure. Historically, information technology and computer equipment has made up about 70% of total e-waste generated in India, and currently represents the majority of e-waste that is generated. It is followed by telecommunication equipment (approximately 12%), medical electronics (approximately 8%), and other consumer electronics (approximately 7%) contribute to the total e-waste generated. The majority of e-waste has been generated by government organizations, public-sector enterprises, and private-sector entities as a source. The contribution of individual households to total e-waste generation is approximately 16%. In total, government organizations, public sectors and/or private businesses account for nearly 75% of e-waste generation. The state-wise breakdown of e-waste generation in India is shown in Figure 1, which shows the regional differences of e-waste generation due to urbanization and industrialization. All of the electrical or electronic goods that are at or nearly at "end of life" are referred to as e-waste. E-waste typically includes, but is not limited to, computers, televisions, video recorders, audio systems, photocopiers and fax machines. The rapid development of consumer electronics has greatly expanded the definition of e-waste to include smart phones, tablets, laptops, digital cameras, video game consoles, and electric mobility devices. The importance of establishing a systematic means for recovering valuable materials from e-waste is highlighted by the fact that a substantial amount of e-waste still has value that can be recovered via reuse or refurbishment, as well as material recycling. Telecommunications and the growth of mobile phone subscriptions have exacerbated the e-waste issue. According to data from January 2025, there are approximately 1.12 billion mobile connections in India, with a continually increasing number. The volume of e-waste has continued to grow rapidly, largely due to the increasing number of devices being replaced quickly, and the growing numbers of smart devices in circulation. This underscores the necessity of creating sustainable product designs and implementing best management practices to manage products at end-of-life.

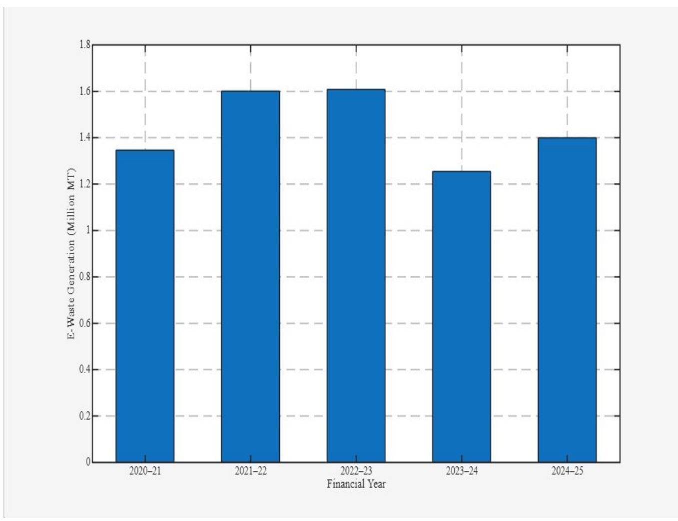

Fig. 1 E-waste generation in India
Source: CPCB and MoEFCC Reports

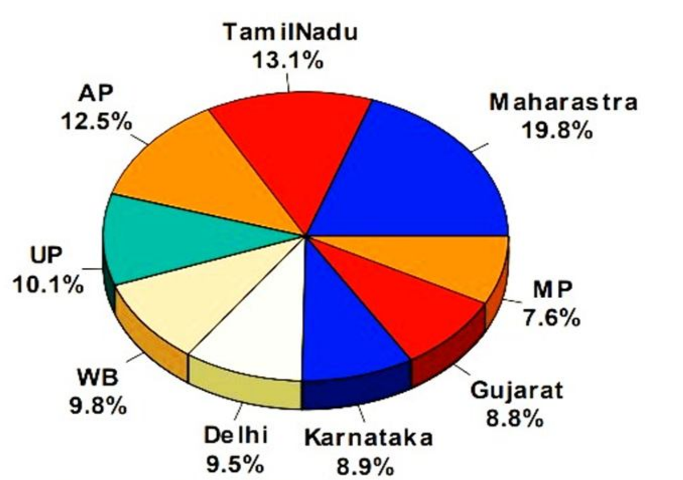

Fig. 2 State wise e-waste generation in India
Source: CPCB and MoEFCC Reports

IV. E-WASTE SOURCES

India generates a large amount of its e-waste due to the large increase in that country's use of electronics and information technology in all economic sectors. Overall, there are two primary contributors to India's e-waste: Domestic e-waste generation through: Individual households and small businesses; Larger businesses, commercial establishments, or government agencies; and Manufacturer/distributors/retailers of computers. Also, as a result of e-waste being sold as second-hand and re-conditioned product in the secondary market. There is also a large amount of e-waste coming into the country from outside via transboundary movement, whereby the disposal of old electronic equipment occurs and often through informal or unregulated channels from this perspective, the large number of sources of e-waste from commercial/institutional sources highlights the need for formal collection systems and EPR.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue I Jan 2026- Available at www.ijraset.com

V. E-WASTE MANAGEMENT METHODS

Fig. 3 E-waste management methods [17]

A. *E-Waste Management Hierarchical Framework*

The development of electronic waste (e-waste) management systems has led to the creation of structured hierarchical systems for e-waste management with the aim of reducing waste, maximising the recovery of recyclable materials, and minimising environmental and health risks. Three types of e-waste management systems have been established, which are Related to Advanced Material Recovery Technology, Collection and Logistics Integration, and Prevention and Life-Extension.

B. *Life-Extension through Prevention*

Preventing the generation of e-waste is the most effective way to reduce e-waste volumes. Effective inventory control and waste reduction practices in production reduce the creation of hazardous waste, increase the quantity of raw material used in the production of goods, and decrease the risk of overstocking through improved process management and product evaluation. Models of Service-Based Ownership, such as Device as a Service and Product as a Service encourage an emphasis on producing durable, modular, and repairable products because they shift lifecycle responsibility from customer to provider. Rental and subscription-based models also increase asset utilization efficiency by spreading assets amongst multiple users. Refurbishment-first strategies have become the preferred method for many authorised recyclers of e-waste, as they extend the economic life of the product and only send irreparable products to a materials reclamation facility.

C. *System Integration, Logistics, and Collection*

One of the biggest barriers to e-waste management has been and still is the lack of effective collection. Due to the high prevalence of informal collection networks, interface agency-type models integrating informal collectors into the formal system have been developed. This has enabled better compensation, training and registering informal collectors in the formal system, which in turn has reduced the amount of risky handling/disposal practices of e-waste as well as improved traceability. Market-based compliance mechanisms are being utilized through the digitization of Extended Producer Responsibility (EPR) wherein producers meet their EPR obligations through the use of centralized trading platforms and authorized recyclers can create digital certificates based on verified recovery of materials. In addition, the introduction of price regulation has improved system transparency and has stabilized the market.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue I Jan 2026- Available at www.ijraset.com

D. Recovery and Recycling Technologies

Once e-waste has been collected, it typically requires specialized processing to extract valuable materials from it. The use of mechanical disassembly and automated sorting has improved the level of worker safety and sorting efficiency through increased use of artificial intelligence (AI)-based computer vision systems and robotics within the sorting process.

In general, there are two primary processes used for the recovery of materials: hydrometallurgy and pyrometallurgy. Hydro-metallurgy utilizes considerably less energy than pyrometallurgy and is more selective in terms of the materials that can be recovered. By using environmentally benign solvents, such as ionic liquids and deep eutectic solvents, hydrometallurgy reduces the overall environmental impact of the recovery process. As such, the effective recovery of critical materials (i.e. rare earth elements, precious metals and batteries) from e-waste can be tantamount to reducing the world's reliance on primary minerals and ensuring that these minerals are managed in a sustainable manner.

E. Environmental & Human High-Risk Factors Associated with Improper Wastes of Electrical and Electronics

Proper management of electronic wastes can play a role at every stage of the recycling process in reducing Soil Contamination, Air and Water Pollution, and worker's exposure to hazardous materials. Regulatory enforcement, worker safety, the development of cleaner recycling methods, and control of where the processes occur are some of the available methods to reduce overall risks.

Table 1. Comparative Analysis of E-Waste Recovery Methodologies

Feature	Pyrometallurgy (Smelting)	Hydrometallurgy	Bio-metallurgy (Hybrid Bio-leaching)
Process Mechanism	Thermal treatment at high temperatures (>1000 °C)	Aqueous chemical extraction using acids or solvents	Microbial solubilization followed by mild chemical extraction
Energy Consumption	Very high	Medium	Low
Primary Output	Mixed metal alloys (requires further refining)	High-purity precipitated metals	Metal-rich solutions or precipitates
Environmental Risk	Dioxin/furan emissions; slag generation	Acidic wastewater; toxic sludge	Low; biodegradable residues
Gold Recovery Efficiency	Moderate	High (≥90%)	Very high (up to 95% in hybrid processes)
Suitability	Large-scale, mixed waste streams (e.g., PCBs)	Targeted recovery (Li-ion batteries, precious metals)	Low-grade waste, dusts, and sustainable processing

VI. LAWS & REGULATIONS OF THE RECYCLING PROCESS

The E-Waste (Management) Rules have established the 'Extended Producer Responsibility' (EPR); it is the responsibility of the manufacturers of electronic equipment that their products after their useful life are collected and recycled responsibly and in an environmentally safe way. The E-Waste (Management) Rules, 2022, which will be applied beginning April 2023, provide further improvements to capture the needs to address issues regarding traceability and enforcement by mandating that stakeholders (Manufacturers, Importers, Brand Owners, and Processors) register for the tracking of their products and establishing an EPR digital portal (regulated by the Central Pollution Control Board [CPCB]), which will provide manufacturers with a [Certificate] of Compliance regarding events of collecting E-Wastes. Although the E-Waste (Management) Rules provide an increased level of accountability and participation by formal-sector companies regarding the Collection and Recycling of E-Waste, there are still challenges regarding the continuity of the enforcement of these rules across the various States in India, the integration of informal recycling companies, and the efficiency of the collection of E-Wastes in the country. The establishment of stronger monitoring systems, increasing consumer awareness about E-Waste, and supporting Eco-design and establishing a Formal Recycling Infrastructure will greatly contribute to improving the success of the enforcement of the E-Waste (Management) Rules.

VII. CASE STUDIES

A. Bangalore, India: Hybrid Transition Model

Bangalore is a city that represents a 'middle ground' between the extremes of formal (completely regulated) and informal (completely unregulated) e-waste recycling. A large number of recyclers are authorized and have a recycling system in place that allows them to recycle e-waste in a responsible manner and export high/value recycled fractions to state-of-the-art smelters in other countries.

However, authorized recyclers face stiff competition from unlicensed e-waste collectors offering higher cash prices, resulting in chronic long-term supply shortages for authorized recyclers.

Some potential routes to greater use of more environmentally responsible recycling and authorized recyclers are demonstrated through pilot projects involving NGOs and partial integration of unregulated e-waste collectors, but limits on scalability of these efforts remain due to pricing differences and lack of immediate and significant consumer-based incentive programs.

B. Seelampur, India: Informal Market-Driven Recycling

Seelampur is an example of an informal (unregulated) recycling model for e-waste in the Global South. Significant efficiencies are achieved due to the high degree of collection and near-whole recovery of materials from the manual dismantling of e-waste through decentralized networks of waste collectors and dismantlers. However, these types of recovery methods, although cost-effective, involve the externalization of occupational and environmental health costs, resulting in the presence of child labour, in addition to significant levels of contamination of ambient air, soil and water. The continued presence of informal e-waste recycling activities can largely be attributed to the fact that e-waste has positive market value and provides an instant return on investment that formal systems cannot match.

C. Guiyu, China: Industrial Transformation Under State Direction.

The way in which strong state intervention has transformed an unregulated recycling environment into a highly controlled industrial activity demonstrates the effectiveness of state intervention at rapidly moving the recycling industry. Beginning in 2013, China ordered that all e-waste processing activities take place in a centrally located Circular Economy Industrial Park, establishing actual infrastructure to control pollution and enforce strict standards. As a result of this approach, pollution was greatly reduced; however, it also led to a consolidation of the workforce and the economic elimination of small businesses within Guiyu. Thus, Guiyu serves as another example of how rapidly improving the environment can occur through command-and-control type policies although there are great social and economic costs involved.

D. Switzerland's Formal Producer Responsibility Model

Switzerland is an excellent example of an industrialized country that has developed an Extended Producer Responsibility (EPR) based e-waste management system that is compliance based. At the point of purchase, consumers are required to pay a nominal Advance Recycling Fee (ARF) to provide stable revenue for recycling, whereas no matter what happens to the cost of the physical raw material, there remains a reliable source of revenue. The combination of certified recycling facilities, transparent material flow tracking and high collection rates enables recovery of the highest possible percentage of the material recycled and processing methods that are environmentally sound. Even though Switzerland's EPR model is very effective in recovering resources from e-waste, it cannot be easily replicated in developing countries due to the lack of developed institutions, consumer awareness and willingness to pay for such programs.

VIII. CONCLUSIONS

The purpose of this study is to provide an overview of the major challenges and trends impacting e-waste management in India, as well as identify the potential hazards to both the environment and human health that are created by the increasing use of electronic and electrical goods. Furthermore, this review demonstrates a need for the adoption of innovative recycling technologies; improved collection strategies; and the proper implementation of circular economy regulatory frameworks. The present study provides a unified perspective to guide future research, innovation of technology, and policy formulation on the sustainable and responsible management of e-waste. Ultimately, the findings will aid in closing the gaps in e-waste management practices in rapidly developing countries by assisting researchers, engineers and policy makers.

IX. ACKNOWLEDGMENT

Besides, the authors take this opportunity to thank all the researchers, the organizations and the government bodies whose work, in the form of reports, journal papers, and technical documents, have greatly contributed to the authors' gaining comprehensive knowledge about the topics of e-waste management, recycling technologies, and environmental policies.

REFERENCES

[1] Government of India, Ministry of Environment, Forest and Climate Change, "Parliamentary Reply on E-waste Generation and Recycling," Rajya Sabha Unstarred Question No. 535, New Delhi, India, 2025. (Source: _annex_268_AU535...pdf)

[2] Ministry of Environment, Forest and Climate Change, Annual Report 2024-25, Government of India, New Delhi, India, 2025. (Source: English_Annual_Report_2024-25.pdf)

[3] R. Garg and P. Adhana, "E-waste management in India: A review on health and environmental impacts," Int. J. Med. Public Health, vol. 9, no. 4, pp. 1264–1271, 2019. (Source: 228. 2222. IJMEDPH...pdf)

[4] The Energy and Resources Institute (TERI), "E-Waste Management in India: Challenges and Opportunities," TERI, New Delhi, India, Discussion Paper, 2019. (Source: E-Waste Management in India... TERI.pdf)

[5] S. Chatterjee, "Electronic Waste and India," New Delhi, India, Rep., Jul. 2023. (Matches your text citation)

[6] M. Kumar, "A scientometrics study of advancing sustainable metal recovery from e-waste: Processes, challenges, and future directions," RSC Sustainability, vol. 2, pp. 1–15, 2024. (Source: A scientometrics study...pdf)

[7] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), "Systemic Integration of Informal Sector in E-Waste Management in India," GIZ GmbH, New Delhi, India, 2017. (Source: giz2017-en-formal-informal...pdf - **Crucial for your "Formal vs Informal" section**)

[8] M. Streicher-Porte, R. Widmer, A. Jain, H. P. Bader, R. Scheidegger, and S. Kytzia, "Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi," Environmental Impact Assessment Review, vol. 25, no. 5, pp. 472–491, 2005. (Matches your "Widmer et al." citation)

[9] D. Sinha-Khetriwal, P. Kraeuchi, and M. Schwaninger, "A comparison of electronic waste recycling in Switzerland and in India," Environmental Impact Assessment Review, vol. 25, no. 5, pp. 492–504, 2005. (Matches your "Sinha-Khetriwal" citation)

[10] "Circular Economy Approaches in E-Waste Management," in Proc. Int. Conf. on Sustainable Waste Management, 2023. (Source: Circular-Economy-Approaches...pdf)

[11] A. Jain, "Development and evaluation of existing policies and regulations for e-waste in India," in Proc. IEEE Int. Symp. on Sustainable Systems and Technology, May 2009, pp. 1–4. (Matches your "Jain (2009)" citation)

[12] Central Pollution Control Board (CPCB), "Guidelines for Environmentally Sound Management of E-Waste," Ministry of Environment, Forest and Climate Change, New Delhi, India, 2008.

[13] C. Hicks, R. Dietmar, and M. Eugster, "The recycling and disposal of electrical and electronic waste in China—legislative and market responses," Environmental Impact Assessment Review, vol. 25, no. 5, pp. 459–471, 2005. (Matches your China case study)

[14] P. Barnand, "Managing electronics and electrical waste, swiss experience and the EU WEEE Directive," Waste Management World, vol. 11, pp. 20–30, 2002. (Matches your Switzerland case study)

[15] W. Scharnhorst, H. J. Althaus, M. Classen, O. Jolliet, and L. M. Hilty, "The end of life treatment of second generation mobile phone networks," Environmental Impact Assessment Review, vol. 25, no. 5, pp. 540–566, 2005.

[16] H. Gaule, A. Gupta, and A. K. Mungray, "E-waste Management: A Profit Making Industry," Dept. Chem. Eng., SVNIT, Surat, India.

[17] OMR Solutions, "E-Waste Management," OMR Solutions. [Online]. Available: http://www.omrsolutions.com/omr_web/solutions/government/e-waste-management.php.

[18] "State-wise E-waste generation in India," ResearchGate. [Online]. Available: https://www.researchgate.net/figure/State-wise-E-waste-generation-in-India_fig2_33257247.