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TOWARDS SUSTAINABLE E-WASTE MANAGEMENT IN INDIA: CHALLENGES AND OPPORTUNITIES FOR ENVIRONMENTAL GOVERNANCE

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Abstract

The rapid growth of the electronics sector has made electronic waste (e-waste) one of the fastest-growing waste streams globally, and India faces serious challenges in ensuring its environmentally sound management. This article examines the issues and challenges posed by e-waste in India, including the environmental and public-health hazards of improper disposal and recycling, and analyses the legal and regulatory framework governing e-waste — specifically the E-Waste Rules of 2011, 2016, and 2022, and the Battery Waste Management Rules, 2022, which now regulate end-of-life lithium-ion batteries from electric vehicles. It critically evaluates the Extended Producer Responsibility regime, whose implementation has been constrained by infrastructural gaps, the dominance of the informal sector, and illegal trade, and assesses the enforcement roles of the Central and State Pollution Control Boards and the National Green Tribunal. The article identifies opportunities for sustainable e-waste management — including circular-economy integration and formalisation of informal recyclers — while cautioning that urban mining must be evaluated through life cycle assessment. It concludes that the e-waste challenge can be converted into an opportunity for environmental sustainability and resource conservation only through effective implementation, accountable enforcement, and LCA-informed policy.

Keywords: E-Waste; E-Waste Management; Extended Producer Responsibility; Lithium-ion Batteries; National Green Tribunal; Life Cycle Assessment.

Introduction

E-waste is one of the rapidly proliferating waste streams globally, adversely affecting the environment and posing health and ecological hazards (Ghulam & Abushammala, 2023). Every electronic product has a stipulated life; millions of electronic devices are discarded every year as products break or become obsolete. Once any electronic product reaches the end of its useful life, it becomes e-waste (Canavati, Toweh, Simon, & Arbic, 2022, p. 100435).

Rapid technological advancement in the electrical and electronic sector, combined with the reduced lifespan of equipment (Santhanam, Samuel, & Chidambaram, 2014, p. 36) and increased consumption, has generated large quantities of e-waste in a short period. However, the infrastructure and processes to manage this waste have not developed at the same pace: India produced 1.6 million tonnes of e-waste in fiscal 2021–22, ranking third in the world, yet only about half a million tonnes (0.5 million tonnes) was gathered and treated (M. B., & -, R. N. 2024). Estimates suggest that India will generate over 161 million tonnes of e-waste by 2050 (Sengupta, Ilankoon, Kang, & Chong, 2022). In this regard, urban mining of materials through recycling holds significant economic value and offers employment opportunities; for example, mobile phone printed circuit boards contain precious metals such as gold in far higher concentrations than primary ores (Gómez, Grimes, Qian, Feng, & Fowler, 2023).

Discarded devices threaten health and the environment if not disposed of and recycled appropriately, owing to the toxic elements and pollutants they contain, which can leach into soil and water or be emitted into the air (Ghulam & Abushammala, 2023). Under the E-Waste Rules, 2022, which came into effect on 1 April 2023 and introduced a new EPR system for recycling e-waste (M. B., & -, R. N. 2024), the definition of e-waste spans the electrical and electronic equipment listed in Schedule I of the Rules — including information technology and telecommunication devices, consumer electrical products, lamps, and medical equipment. More broadly, electronic waste includes a wide range of discarded electrical and electronic equipment that has reached the end of its useful life (Perkins, Drisse, Nxele, & Sly, 2014, p. 286), ranging from household appliances such as refrigerators, washing machines, and air conditioners to ICT equipment such as computers, laptops, printers, and mobile phones, as well as consumer electronics, lighting equipment, electrical tools, and medical devices (Wath, Dutt, & Chakrabarti, E-waste scenario in India, its management and implications, 2010, p. 249). The diversity and increasing volume of these products make their collection, recycling, and environmentally sound disposal a significant challenge for regulatory authorities and stakeholders (Perkins, Drisse, Nxele, & Sly, 2014, p. 286).

Globally, rules and regulations govern the import and export of waste, yet policy frameworks intended to protect populations from inappropriate e-waste recycling exist but are not effectively applied (Perkins, Drisse, Nxele, & Sly, 2014, p. 286). One reason for the limited response is that the electronics industry is regarded as the engine of communications and economic growth; devices are intentionally designed with short working lifetimes to sustain demand for the "next big thing" (Canavati, Toweh, Simon, & Arbic, 2022, p. 100435).

Legal and Regulatory Framework for E-Waste Management

Globally, mounting e-waste piles have forced many countries to draft laws and regulations for effective implementation and sustainable e-waste management. The journey of e-waste regulation in India began with the notification of the E-Waste Rules, 2011, by the Ministry of Environment, Forest and Climate Change (Singh, Dasgupta, & Routroy, 2021, p. 10590). These rules were the first of their kind in South Asia and aimed to provide a structured approach to e-waste management.

India has developed a comprehensive legal framework for regulating electronic waste with the objective of ensuring environmentally sound collection, recycling, and disposal of discarded equipment. The principal legislation governing environmental protection in India is the Environment Act, 1986, enacted in the aftermath of the Bhopal Gas Tragedy (Manomaivibool, Extended producer responsibility in a non-OECD context: The management of waste electrical and electronic equipment in India, 2008, p. 173). The Act empowers the Central Government to take measures for protecting and improving environmental quality and serves as the parent legislation for various waste management rules, including those relating to electronic waste.

The E-Waste Rules, 2011, which came into force in 2012, constituted the first dedicated regulatory framework for e-waste management in the country, imposing responsibilities on producers, consumers, collection centres, dismantlers, and recyclers. Owing to implementation challenges, they were replaced by the E-Waste Rules, 2016, which expanded the scope of covered products, introduced staged collection targets (rising from 30% in the first two years to 70% from the seventh year), and formally incorporated the concept of Extended Producer Responsibility (Rizvee, 2020, p. 292). Subsequently, the Government notified the E-Waste Rules, 2022, effective 1 April 2023, marking the beginning of a new EPR system for recycling e-waste, with digitised compliance mechanisms, online registration of manufacturers, producers, refurbishers, and recyclers, and generation of EPR certificates by authorised recyclers (M. B., & -, R. N. 2024)

A significant feature of India's e-waste regulatory regime is EPR, under which producers must ensure the collection, recycling, and environmentally sound management of products after the end of their useful life, thereby shifting responsibility from consumers and local authorities to producers and promoting resource efficiency and the circular economy (Herat, 2021, p. 49). Implementation and monitoring are entrusted primarily to the Central Pollution Control Board and State Pollution Control Boards, which are responsible for registration, authorisation, monitoring, and random inspections, and together constitute the backbone of India's regulatory framework for sustainable e-waste management (Singh, Dasgupta, & Routroy, 2021, p. 10591).

Extending the framework: end-of-life lithium-ion batteries and the Battery Waste Management Rules, 2022

India's green governance strategy now extends producer responsibility beyond conventional e-waste to the batteries powering its electric mobility transition. End-of-life lithium-ion batteries from electric vehicles pose critical risks to ecosystems through toxic heavy metals and improper disposal, and their regulation intersects environmental law, biodiversity risk, and circular-economy policy (Rakshit, et al., 2025). The Battery Waste Management Rules, 2022, mandate EPR for battery manufacturers, aim for a minimum of 90% material recovery by 2027, and require 5% recycled content in new batteries by 2027, rising to 20% by 2030–31 (Sathyan, Pandi, Deepa, & Sulthan, 2024, p. 84). The scale of the challenge is substantial: projections estimate annual end-of-life battery waste of 37–80 GWh by 2030, growing sevenfold by 2040 and tenfold by 2050, even as recovered materials could supply 28–43% of India's critical battery material needs between 2030 and 2050 (Bhattacharya, Nair, Ali, Verma, & Singh, 2025). Yet formal recycling remains embryonic — under 5% of end-of-life batteries are formally recycled, while nearly 90% are processed informally through hazardous methods, amid enforcement lapses in EPR and infrastructural voids (Mehta, 2025). Battery recycling nonetheless represents a market estimated at \$3.5 billion, with recovered materials offering cost savings of up to 40% (Mehta, 2025); realising this potential depends on formal–informal integration, digital tracking mechanisms, and return-based incentives (Mehta, 2025; Jayaraman, 2024).

Challenges in Effective E-Waste Management

Despite a comprehensive regulatory framework, India faces persistent challenges in e-waste management. One of the most noteworthy is the informal recycling sector, which processes e-

waste through rudimentary and uncontrolled methods — such as open burning of cables and acid-bath treatment of waste — endangering environmental quality and public health (Manomaivibool, Extended producer responsibility in a non-OECD context: The management of waste electrical and electronic equipment in India, 2008, p. 147). Lack of awareness among consumers regarding proper disposal practices often results in e-waste being discarded along with municipal waste, while implementation has been hindered by weak enforcement and inadequate compliance monitoring. The country also suffers from insufficient collection centres and limited formal recycling infrastructure, and from the illegal import of hazardous electronic waste contrary to national regulations and international obligations under the Basel Convention (Jeyaraj, 2021, p. 212).

The implementation record of Extended Producer Responsibility

EPR has been celebrated as the centrepiece of India's e-waste regime, yet its implementation record qualifies this optimism. Formal recycling processes account for less than half of total e-waste management in India, and studies document persistent compliance gaps (Newar & Deka, 2025). Two structural obstacles undermine the EPR mechanism from the outset: large grey markets for electronic products, and illegal imports of WEEE, which sustain an informal sector that competes directly with the formal recycling chain (Manomaivibool, Lindhqvist, & Tojo, Extended Producer Responsibility in a non-OECD Context: The management of waste electrical and electronic equipment in India, 2007). Consumer behaviour compounds the difficulty — because Indian consumers expect monetary returns when disposing of e-waste, the EPR model as practised in developed economies is prone to failure in the country (Borthakur & Govind, How well are we managing E-waste in India: evidences from the city of Bangalore, 2017, p. 226). The informal sector's robust collection logistics further complicate the achievement of EPR goals, and partially dismantled products frequently end up landfilled (George & Cekuls, 2024, p. 301). Infrastructural hurdles — limited collection centres, the high cost of advanced recycling technology, and a formal sector that largely performs only pre-processing before exporting precious-metal-bearing fractions for smelting abroad (Jeyaraj, 2021, p. 212) — mean that EPR targets cannot be met through registration and certificate generation alone.

Opportunities for Sustainable E-Waste Management

The growing volume of e-waste, although posing significant environmental and regulatory challenges, also presents considerable opportunities for sustainable development. Sustainable e-waste management not only facilitates environmental protection but also contributes to resource efficiency, employment generation, and the development of a circular economy.

One of the most promising opportunities lies in the circular economy model, which emphasises reducing, reusing, repairing, refurbishing, and recycling electronic products. Electronic waste contains precious metals such as gold, silver, copper, palladium, and rare earth elements that can be extracted and reintroduced into the production cycle (Vidyadhar, 2016, p. 30). Efficient resource recovery reduces dependence on virgin raw materials, conserves natural resources, and minimises environmental degradation associated with mining (Zeng, Mathews, & Li, 2018). A further opportunity lies in the formalisation of the recycling sector: integrating informal workers into the formal system through training, licensing, and institutional support can improve recycling efficiency while ensuring occupational safety and social security, and would facilitate better compliance with the EPR framework (Manomaivibool, Extended producer responsibility in a non-OECD context: The management of waste electrical and electronic equipment in India, 2008, p. 147).

Sustainable e-waste management also offers substantial economic and employment opportunities, since recycling businesses provide employment to urban low-skilled workers (Borthakur & Govind, Management of the challenges of electronic waste in India: an analysis, 2018). Organised collection centres, dismantling facilities, refurbishing units, and recycling plants can generate green jobs; refurbishment and repair can extend the useful life of products and promote affordable access to technology. Technological innovations have further expanded the possibilities for effective management: modern recycling technologies enable the safe extraction of valuable metals, and urban mining has gained prominence as a sustainable alternative to conventional mining (Shahabuddin, et al., 2022, p. 4518). Advances in artificial intelligence, automation, and digital tracking can improve the efficiency and transparency of collection and processing. Public-private partnerships — such as collaborative models involving households, corporate funders, NGOs, and civic authorities — can mobilise investment in infrastructure and awareness (Bhat & Patil, 2021, p. 62114), while active consumer participation through take-back programmes, recycling initiatives, and responsible consumption is essential to the success of the EPR regime (Islam, et al., 2021, p. 128298).

Urban mining under a life cycle assessment lens

The sustainability claims of urban mining, however, must be subjected to life cycle assessment rather than assumed. Recycling processes are themselves energy- and chemical-intensive: life cycle assessments of formal printed wiring board recycling chains identify metal leaching in the refining stage as the critical process posing most of the environmental impact, with global warming potential the most significant impact category, and show that variations in the power source and chemical reagent consumption most strongly influence environmental performance (Xue, Kendall, Xu, & Schoenung, 2014). Hydrometallurgical treatment of e-waste — the dominant route for recovering precious metals — has accordingly been evaluated through ISO 14040/14044-compliant, cradle-to-gate life cycle assessment to quantify its environmental burdens (Zubiani, et al., 2016, p. 1210). Comparative tools such as ESCAPE, which measure carbon footprint and embodied energy, have been developed to benchmark emerging recovery technologies against primary production before they are scaled (Francini, et al., 2025). The policy implication is not that urban mining should be abandoned — recycling demonstrably saves primary resources, with desktop and laptop recycling consuming 80% and 87% less natural resources respectively than landfilling (Eygen, Meester, Tran, & Dewulf, 2016) — but that its environmental benefit is conditional on process design, energy mix, and reagent chemistry (Xue, Kendall, Xu, & Schoenung, 2014). LCA-informed technology standards should therefore complement EPR targets so that recovery grows in environmental performance as well as in volume.

Thus, the transition towards sustainable e-waste management in India should not be viewed merely as a regulatory necessity but as an opportunity to promote resource efficiency, economic growth, environmental protection, and social inclusion (Nigam, 2026).

Judicial Perspective and Environmental Principles

The Indian judiciary has played a pivotal role in the evolution of environmental jurisprudence by incorporating internationally recognised environmental principles into domestic law (Nisha, 2025). Through judicial activism, the Supreme Court has interpreted Article 21 of the Constitution to include the right to a clean and healthy environment and has consistently emphasised the importance of sustainable development and environmental protection.

(i) Vellore Citizens' Welfare Forum v. Union of India

This landmark case arose from the environmental degradation caused by tanneries in Tamil Nadu, which discharged untreated effluents into agricultural lands and water bodies, thereby

affecting public health and the livelihood of local communities. The Supreme Court recognized that environmental protection and economic development are not mutually exclusive and adopted the concept of Sustainable Development as an integral part of Indian environmental law. The Court also expressly incorporated the Precautionary Principle and the Polluter Pays Principle into Indian jurisprudence, holding that industries causing environmental harm are liable to compensate affected persons and bear the cost of restoring ecological balance. The judgment significantly strengthened environmental governance and established the principle that developmental activities must be pursued in a manner consistent with environmental sustainability.

(ii) Indian Council for Enviro-Legal Action v. Union of India

In this case, several chemical industries in Rajasthan had discharged toxic sludge and untreated waste, causing severe contamination of soil and groundwater in surrounding villages. The Supreme Court held the polluting industries absolutely liable for the environmental damage caused by their activities. The Court emphasized the Polluter Pays Principle, stating that the responsibility for remedying environmental degradation rests upon those who create the pollution. The industries were directed to bear the expenses incurred in cleaning the contaminated area and compensating affected persons. This judgment reinforced the accountability of industries and established that environmental costs cannot be shifted to society at large.

(iii) Research Foundation for Science, Technology and Natural Resource Policy v. Union of India

This case concerned the import of hazardous waste into India and the improper disposal of toxic materials, raising concerns regarding compliance with international environmental obligations. The Supreme Court examined India's commitments under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and emphasized the need for strict regulation of hazardous waste imports. The Court directed the authorities to establish appropriate mechanisms for monitoring, treatment, and environmentally sound disposal of hazardous waste. The decision underscored the importance of preventive environmental measures and strengthened the regulatory framework governing hazardous and electronic waste management in India.

These judicial pronouncements have significantly contributed to the development of Indian environmental jurisprudence by reinforcing the principles of sustainable development, precaution, and polluter responsibility. Although these cases primarily dealt with industrial and hazardous waste, the principles laid down therein are equally relevant to the contemporary

challenges posed by electronic waste management and provide a strong legal foundation for promoting environmentally sound and sustainable disposal practices.

(iv) The National Green Tribunal and day-to-day enforcement

Beyond the Supreme Court's constitutional jurisprudence, day-to-day enforcement of environmental standards in India is driven by the National Green Tribunal, established in 2010 as the world's third specialised environmental court (Biju, 2025). The Tribunal has transformed India's environmental adjudication landscape through expeditious case disposal, innovative application of the precautionary and polluter-pays principles, and enhanced access to environmental justice, while its efficacy remains constrained by structural limitations including enforcement challenges, jurisdictional ambiguities, and resource constraints (Biju, 2025). Its significance for e-waste governance lies in its continuous, order-by-order supervision of regulatory authorities — Tribunal rulings on pollution and illegal disposal direct compliance, compensation, and remediation. Analyses of India's regulatory processes, however, caution that enforcement mechanisms themselves can create impediments to accountability, underscoring that judicial supervision cannot substitute for administrative enforcement capacity (Shery, 2025). Even as the Tribunal's contribution is recognised, enforcement gaps, delays, and accessibility issues continue to limit its effectiveness (Nisha, 2025). Strengthening the NGT — through specialised benches, monitoring of compliance with its orders, and clearer jurisdictional boundaries — is therefore as important to sustainable e-waste management as the substance of the rules themselves (Biju, 2025).

Recommendations and Conclusion

The growing challenge of e-waste and end-of-life battery waste in India necessitates a comprehensive and sustainable approach that balances technological advancement with environmental protection. Although India has established a robust legal framework through the E-Waste Rules, 2022, and the Battery Waste Management Rules, 2022, effective implementation remains the key to environmentally sound waste management. EPR should be strengthened through stricter compliance measures, improved traceability, and greater accountability of producers, while recognising that EPR alone cannot neutralise grey markets, illegal imports, or informal-sector competition (Manomaivibool, Lindhqvist, & Tojo, Extended Producer Responsibility in a non-OECD Context: The management of waste electrical and electronic equipment in India, 2007). Since a substantial portion of e-waste and end-of-life batteries is processed by the informal sector (Mehta, 2025), efforts should be made to integrate

informal workers into the formal recycling framework through training, financial support, and institutional recognition. For batteries specifically, policy should prioritise second-life applications, minimum recycled-content mandates, and digital traceability from sale to recycling, in line with the recovery targets of the 2022 Rules (Sathyan, Pandi, Deepa, & Sulthan, 2024; Bhattacharya, Nair, Ali, Verma, & Singh, 2025, p. 84).

Enhancing public awareness and promoting consumer responsibility are essential for proper segregation and disposal (Islam, et al., 2021, p. 128334); awareness campaigns, take-back programmes, and educational initiatives can encourage responsible consumption (Jabbour, Colasante, D'Adamo, Rosa, & Sassanelli, 2023, p. 139263). Regulatory authorities should strengthen monitoring and enforcement to prevent illegal disposal and non-compliance (Wath, Vaidya, Dutt, & Chakrabarti, 2010, p. 26). Investment in collection centres, recycling infrastructure, and technological innovation would further enhance efficiency (Newar & Deka, 2025), and LCA-based technology standards should guide such investment so that recovery processes themselves become environmentally sound (Xue, Kendall, Xu, & Schoenung, 2014). The National Green Tribunal's supervisory role should be supported through effective compliance monitoring of its orders (Biju, 2025). Promoting a culture of repair, reuse, refurbishment, and recycling, in accordance with circular-economy principles, can significantly reduce pressure on natural resources (Islam, et al., 2021, p. 128298).

In conclusion, sustainable e-waste management is not merely an environmental necessity but an essential component of responsible governance and sustainable development. As India continues to experience rapid technological growth and digital transformation — including the electrification of mobility — it is imperative that economic progress does not come at the cost of ecological balance and public health. A collaborative approach involving the government, producers, recyclers, consumers, and civil society is indispensable for transforming the growing e-waste and battery-waste challenge into an opportunity for resource conservation, green employment, and sustainable development.

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