GLOBAL E-WASTE MANAGEMENT FRAMEWORKS: A COMPARATIVE ANALYSIS OF LEGISLATIVE APPROACHES AND REGULATORY MECHANISMS

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ABSTRACT

The increasing generation of electronic waste (e-waste) has become a major global environmental and regulatory concern, requiring effective legislative frameworks and sustainable management practices. This study examines and compares e-waste management frameworks adopted by Switzerland, Germany, the European Union, the United States, Japan, South Korea, Taiwan, Singapore and India. It focuses on legislative provisions, Extended Producer Responsibility (EPR), financing mechanisms, collection systems, recycling obligations and regulatory enforcement. The study also highlights international experiences and policy approaches that can provide valuable insights for strengthening India's e-waste management framework, improving resource recovery and promoting environmental sustainability through circular economy practices.

Keywords: E-Waste Management, Extended Producer Responsibility, Global Regulatory Frameworks, Circular Economy.

INTRODUCTION

In recent years, the Government of India has introduced policies to promote circularity and ensure responsible management of E-waste. However, a robust circular ecosystem is yet to materialize due to multiple factors. For instance, Extended Producer Responsibility (EPR) coverage in E-waste recycling is limited to Gold, Copper, Iron, and Aluminum, restricting investment and innovation in the recovery of other valuable and critical minerals. Weak enforcement allows spurious and non-operational recyclers to distort EPR markets through fraudulent certification. Low skills, and limited accessibility of advanced recycling processes also restrict the scalability and efficiency of the sector. Collection inefficiencies, low consumer awareness, and inadequate financing further exacerbate systemic challenges, which risk resource leakages and environmental hazards, and undermine India's long-term energy security by deepening its dependence on critical mineral imports.

Despite the rapid accumulation of these waste streams, India's formal recycling infrastructure remains inadequate and fragmented. Most waste is either exported or abandoned in informal channels, representing both an economic loss and a resource security vulnerability, as India is entirely import dependent for Lithium and Cobalt, and relies on imports for 75-80% of its Nickel and rare earth requirements (Eninrac, 2025[1]; EXIM Bank, 2025[2]). With a geopolitically volatile global supply chain, India's clean energy ambitions face critical supply-side vulnerabilities.

India has taken preliminary steps toward establishing a circular economy framework under the E-Waste (Management) Rules, 2022, and the Batteries (Management and Handling) Rules, 2022, for E-waste and end-of-life Lithium-ion Batteries, respectively. Despite these initiatives, implementation remains inconsistent, and the gap between waste generation and formal management reflects systemic deficiencies in India's circular economy framework. Under Schedule V of the EWMR, 2022, SPCBs are responsible for conducting random inspections of recyclers and refurbishers, as well as for monitoring the utilisation of recycling capacity. Under Rule 12(1) of the BWMR, 2022, SPCBs shall verify the compliance of entities involved in the refurbishing and recycling of waste batteries through inspection and periodic audits. As per the

[1] Eninrac. (2025). India Critical Minerals Market 2025-2030: Domestic, Export, Value Chain, Investment Trends and China Comparison. https://www.eximbankindia.in/ sites/default/files/2025-07/211file (1).pdf
[2] EXIM Bank. (2025). India's Need to Secure Critical Minerals for Energy Transition (No. 230; Occasional Paper). https://www.eximbankindia.in/sites/default/files/2025- 07/211file (1).pdf

directives of the CPCB and the National Green Tribunal (NGT), SPCBs are required to conduct random inspections of recyclers and refurbishers registered on the EPR portal.

Despite an established regulatory framework under the EWMR, 2022, the informal sector remains dominant in the recycling ecosystem and processes ~78% of India's total E-waste. While the informal sector demonstrates significant reach in collection, its operations often involve hazardous practices (Monday et al. 2025)[3], defy compliance, and compromise safety, recovery value, and value retention, contrasting with the benefits offered by the formal sector and leading to environmental degradation. This creates massive inefficiencies, with the informal sector achieving only 10-20% material recovery rates compared to 95-97% in formal recycling facilities.

The rapid growth of the electronics industry, technological innovation and increasing consumer demand have significantly accelerated the generation of electronic waste (e-waste) across the world. The improper disposal and informal processing of discarded electronic equipment have created serious environmental and public health concerns, making effective e-waste management an important international policy priority. According to Baldé et al. (2024)[4], approximately 62 million tonnes of e-waste were generated globally in 2022, of which only 22.3% was formally collected and recycled in an environmentally sound manner. This situation highlights the importance of developing comprehensive legislative frameworks, effective collection mechanisms and sustainable recycling practices. Different countries have adopted diverse regulatory approaches, particularly through Extended Producer Responsibility (EPR), mandatory recycling obligations, consumer participation and financial incentives to improve the management of electronic waste.

International experiences demonstrate that countries have adopted different institutional and regulatory mechanisms according to their economic conditions, technological capabilities and environmental priorities. Switzerland and Germany emphasise producer accountability and organised collection systems, whereas the European Union promotes harmonised regulatory standards through its Waste Electrical and Electronic Equipment (WEEE) framework. Japan,

[3] Monday, S., Khajuria, A., Elliason, E. K., Gagan, & Kamanda, J. S. (2025). A Study on Heavy Metal Contamination in Workers Handling Electronic Waste in North India. OmniScience: A Multi-Disciplinary Journal, 15(2). https://journals.stmjournals.com/ osmj/article=2025/view=214877

[4] Baldé, C. P., Kuehr, R., Yamamoto, T., McDonald, R., D'Angelo, E., Althaf, S., Bel, G., Deubzer, O., Fernandez-Cubillo, E., Forti, V., Gray, V., Herat, S., Honda, S., Iattoni, G., Khetriwal, D. S., Luda di Cortemiglia, V., Lobuntsova, Y., Nnorom, I., Pralat, N., Wagner, M. (2024). The Global E-waste Monitor 2024. International Telecommunication Union and United Nations Institute for Training and Research.

South Korea and Taiwan have developed producer-oriented recycling mechanisms, while the United States follows a combination of federal guidance and state-level legislation. Singapore has incorporated producer responsibility into its Resource Sustainability Act, whereas India has introduced an EPR-based framework under the E-Waste (Management) Rules, 2022. Patil and Ramakrishna (2020)[5] highlight that although international e-waste legislation incorporates common principles, differences in implementation, regulatory enforcement and recycling infrastructure create varying management challenges. Therefore, a comparative examination of international frameworks can provide valuable insights into strengthening India's regulatory mechanisms and promoting sustainable e-waste management.

OBJECTIVES OF THE STUDY

To comparatively examine the legislative frameworks, regulatory mechanisms and implementation practices of e-waste management across selected countries and identify relevant international approaches that can strengthen India's e-waste management system and promote sustainable resource recovery.

RESEARCH DESIGN

The present study adopted a descriptive research design.

ANALYSIS

Table1: Table showing Global E-waste management frameworks

Country	Legislation/Framework	Mechanism	Outcomes and Learnings
Switzerland	Ordinance on Return, Takeback and Disposal of Electrical and Electronic Equipment	Full producer financial and operational responsibility; Mandatory producer registration; Strict collection targets and reporting.	Highest global collection and recovery rates; Economically viable high-cost, high-efficiency systems supported by robust regulation and consumer participation.
Germany	Electrical and Electronic Equipment	Differential EPR fees	Eco-design and design-for-recycling;

[5] Patil, R. A., & Ramakrishna, S. (2020). A comprehensive analysis of e-waste legislation worldwide. Environmental Science and Pollution Research, 27(13), 14412–14431.

	Act (ElektroG)	based on recyclability and hazardous content; Strong enforcement and tax incentives.	High compliance through strong enforcement and PPP.
European - Union (EU)	WEEE Directives (2002/96/EC and updates)	Harmonised EPR standards across member states with flexibility for national implementation.	Consistent high performance (Netherlands, Sweden); Strong consumer awareness; Convenient collection networks; Balance of common standards and national flexibility.
United States	EPA guidance under the Resource Conservation and Recovery Act; Regulation governed through 25+ State-level Acts	Consumers in California pay advance recycling fees at the time of purchase; Manufacturers in Oregon, New York, and Washington finance collection and processing based on the market/ return share.	Flexible implementation and strong privatesector participation; Uneven coverage and performance; Federal guidance and certification schemes give baseline environmental safeguards and encourage refurbishment and reuse.
Japan	Home Appliance Recycling Law	Consumer-pay model with disposal fees collected at end-of-life; Strict producer obligations.	~92% compliance and ~70% collection; Balance government oversight and private engagement; Importance of consumer awareness campaigns.
South Korea	Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles	Hybrid system of producer fees and government funding; Non-compliance penalties up to 130% of recycling cost	~88% compliance and ~75% collection; Regional processing hubs reduce per-ton costs by 25–30%.
Taiwan	Waste Disposal Act (EPR system)	Comprehensive producer registration and	Strong performance driven by rigorous oversight and penalties.

		strict enforcement	
Singapore	Resource Sustainability Act (2019)	Newly implemented EPR with IoT and blockchain tracking of waste flows	Technological innovation in waste tracking; Low consumer awareness is a challenge despite the use of advanced systems.
India	EPR under E-waste (Management) Rules, 2022	OEM's responsibility is to ensure E-waste recycling based on the quantity of Electrical and Electronic Equipment and its average lifespan. Obligations met through the purchase of EPR certificates from authorized recyclers.	National framework for producer responsibility with progressive recycling targets; EPR certificate gives market-based compliance and traceability; Strong enforcement and consumer awareness.

Table 1 presents a comparative overview of e-waste management frameworks adopted by nine countries and regional jurisdictions, highlighting their legislative provisions, implementation mechanisms and major outcomes. Switzerland and Germany have established producer-oriented systems that emphasise financial responsibility, organised collection and environmentally sound recycling. The European Union follows a harmonised WEEE regulatory framework that provides common standards while allowing flexibility in national implementation. In contrast, the United States adopts a decentralised approach through federal environmental guidance and state-specific legislation. Japan, South Korea and Taiwan have developed structured recycling systems involving producer obligations, consumer participation and regulatory enforcement. Singapore has introduced an EPR-based framework supported by technological tracking mechanisms. India follows an EPR-based approach under the E-Waste (Management) Rules, 2022, requiring producers to fulfil recycling obligations through authorised recyclers and EPR certificates. The comparison highlights the importance of strong regulatory enforcement, adequate recycling infrastructure, stakeholder accountability, consumer awareness and technological innovation in developing effective e-waste management systems. These international experiences offer useful policy insights for improving India's existing regulatory framework.

CONCLUSION

The comparative analysis demonstrates that effective e-waste management requires comprehensive legislation, producer accountability, efficient collection systems and strong regulatory enforcement. Countries such as Switzerland, Germany, Japan and South Korea provide valuable insights into implementing structured recycling mechanisms and Extended Producer Responsibility. The experiences of Singapore and the European Union further highlight the importance of technological innovation and harmonised standards. India can strengthen its existing framework by adopting suitable international practices, improving formal recycling infrastructure, enhancing consumer awareness and ensuring effective implementation of EPR obligations to achieve sustainable e-waste management.

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