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Circular Economy Approaches and Sustainable Management of E-Waste in India: An Analysis

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Abstract

The rapid expansion of the electronic sector, driven by technological advancement and rising consumer demand, has led to an unprecedent increase in electronic waste worldwide. Electronic waste contains valuable materials such as precious metal and rare earth elements, but improper disposal practices create serious environmental health and economic challenges. Traditional linear economic models (Linear Economy) based on the "take-make-dispose" approach are increasingly proving to be unsustainable in managing this growing waste stream. As a substitute of linear economy, the concept of circular economy has emerged as a promising framework for sustainable electronic waste management by emphasizing resource efficiency, waste minimization, and material recovery. The concept of circular economy in relation to electronic waste management analyzes the major challenges associated with its implementation. It further explores various management options, including policy interventions, technological solutions and institutional mechanisms, that can support the transition of a circular economy model. Based on secondary data and conceptual analysis, the study highlights the circular economy strategies which create significant environmental and economic benefits and their effective implementation requires coordinated efforts among governments, producers, recyclers, and consumers also. This paper explains the need for stronger regulatory frameworks, innovation, and awareness to promote sustainable electronic waste management.

Keywords: Circular Economy, Electronic Waste (E-waste), Sustainable Management, Resource Recovery, Waste Management.

Introduction

The increasing penetration of electronic devices in everyday life has significantly transformed modern economies, lifestyles and growing consumer demand for new electronic products has resulted in a sharp rise in electronic waste generation. Electronic waste includes discarded electrical and electronic equipment such as computers, mobile phones, televisions, and household appliances substances like lead, mercury, and cadmium, as well as valuable materials such as gold and copper. E-waste poses complex challenges for environmental sustainability and public health.

Conventional approaches of waste management are largely based on a linear economic model where resources are extracted, processed into products, consumed and eventually discarded as waste i.e. Take-Make-Dispose. This model has contributed to resource depletion, environmental pollution and inefficiency in material use. In the case of electronic waste, linear systems often lead to uncontrolled dumping, informal recycling practices and the loss of valuable secondary resources. As global concerns regarding sustainability and resource scarcity intensity, there is a

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growing need to adopt alternative economic models that prioritize long-term environmental and economic viability.

The circular economy has emerged as a strategic and substitute approach in the place of Linear Economy. Unlike the linear economy, the circular economy emphasizes reducing resource inputs, extending product lifespans, promoting reuse and repair, and recovering materials through recycling. When applied to electronic waste management, circular economy principles can significantly reduce environmental impacts through enhancing resource efficiency and economic opportunities.

The concept of the circular economy, in the context of sustainable electronic waste management, seeks to identify the key challenges that hinder the effective implementation of circular economy practices and to explore feasible management options that can support a transition toward sustainability. By synthesizing existing studies and policy frameworks, this paper contributes a better understanding and also explains the circular economy strategies can be leveraged to address the growing e-waste problem.

Circular Economy and E-Waste Management

The circular economy proposes a fundamental restructuring of production and consumption systems by replacing linear resource flows with closed-loop processes. Its primary objective is to minimize waste generation, optimize resource use, and retain material within the economic system through repeated cycles of use, recovery and regeneration. Core circular strategies include extending product lifespans, improving resource efficiency and promoting sustainable design practices that reduce material intensity and environmental impacts.

The electronics and electrical equipment sector are particularly well suited to circular economy interventions due to its reliance on scarce, high-value, and critical materials. Within a circular economy framework, e-waste management involves systematic collection, dismantling, recycling, and reintegration of recovered materials into manufacturing processes. This approach contrasts sharply with conventional linear waste management systems that prioritize disposed over recovery, often resulting in resource loss and environmental degradation.

Circular e-waste management also emphasizes preventive and life-cycle-based measures such as eco-design, durability, repairability, and extended producer responsibility, which assigns producers for managing post-consumer electronic waste. Efficient and well-coordinated collection systems are the backbone of this framework, where the effectiveness of recycling and material recovery depends largely on the availability of segregated and traceable e-waste streams.

Significance of the Study

In emerging economies such as India where digitalization and electronic consumption are expanding rapidly, the application of circular economy principles to e-waste management is both environmentally and economically significant. The coexistence of formal and informal recycling systems presents challenges related to environmental safety, labor conditions, data transparency, but also offers opportunities for inclusive circular growth of the economy.

Circular Economy Approach for E-Waste and Sustainable Development

The expansion of the electronics sector has significantly transformed into modern economies, but it has also intensified the problem of electronic waste generation. Shorter product life cycles, frequent technological upgrades, and changing consumer preferences have led to the accumulation of discarded as e-waste. E-waste is characterized by a complex composition of recoverable materials and toxic elements, making its management both an economic opportunity and an environmental concern. The circular economy framework redefines e-waste not as an end-of-life burden but as a valuable resource stream. Instead of relying on disposal-oriented practices, circular systems encourage the continuous circulation of materials through improved product design, efficient collection mechanisms, and advanced recovery technologies. By prioritizing durability, modularity, and recyclability in electronic products, the circular economy seeks to reduce waste generation at the source while maximizing material recovery at later stages. From a sustainable development perspective, circular e-waste management supports long-term environmental stability and economic resilience. Environmentally sound recycling reduces soil, air, and water contamination caused by hazardous components of e-waste. At the same time, the recovery of critical metals decreases reliance on mining activities, which are often associated with ecological degradation and high energy consumption. Economically, circular practices stimulate innovation and create employment opportunities across formal recycling, refurbishment, and repairing sectors. The adoption of circular economy principles in e-waste management also strengthens social sustainability by improving working conditions and minimizing health risks, particularly in developing countries where informal recycling is prevalent. By integrating regulatory frameworks, technological advancement, and stakeholder participation, circular economy–based e-waste management can contribute effectively to inclusive growth and sustainable development objectives.

Objectives of the Study -The main objectives of this study are:

1. To explain the concept of the circular economy in relation to e-waste management.
2. To know the trends of e-waste generation.
3. To analyse the major challenges in implementing circular economy principles for e-waste.
4. To highlight the contribution of circular economy approach to e-waste management and sustainable development.

Research Methodology

The present study is descriptive and analytical in nature and is based entirely on secondary data. The study examines the status of e-waste generation, recycling, and circular economy practices in India. Data collected from reliable sources such as the Ministry of Environment, Forest and Climate Change (MoEFCC), United Nations Environment Programme (UNEP), Global E-Waste Monitor, Ministry of Electronics and Information Technology, Organization for Economic Co-operation and Development (OECD), Central Pollution Control Board (CPCB), NITI Aayog,

Government Reports, Research Articles, and other published documents for the period 2017-18 to 2023-24. The collected data were organized, classified, and analyzed using descriptive statistical techniques such as percentages, tables, graphs, and trend analysis to examine changes in e-waste generation, recycling, and resource recovery. These methods were selected because they effectively present trends, facilitate policy analysis, and help evaluate the role of circular economy approaches in achieving sustainable management of e-waste in India.

Literature Review

- **Chaurasia (2025)** examined the role of artificial intelligence (AI) and Internet of Things (IoT) technologies in improving e-waste tracking and recycling systems in India. The study highlighted that smart technologies could enhance collection efficiency, traceability, and resource recovery within a circular economy framework. The study also emphasized that technological innovation and policy support are important for strengthening sustainable e-waste management in India.
- **Debnath et al. (2024)** focused on sustainable e-waste supply chain management and advanced recycling techniques. The study emphasized that technological innovation and efficient recycling systems can improve material recovery and reduce environmental pollution.
- **Forti et al. (2024)** in the Global E-waste Monitor 2024 reported that global e-waste generation is increasing much faster than formal recycling. The study emphasized that circular economy practices such as repair, reuse, refurbishment, and urban mining are essential for improving resource recovery and reducing environmental impacts.
- **Parajuly et al. (2023)** highlighted that effective implementation of circular economy principles requires stronger producer responsibility, efficient collection systems, and consumer participation to achieve sustainable e-waste management.
- **Awasthi (2023)** discussed the role of circular economy practices in managing waste electrical and electronic equipment (WEEE). The study emphasized recycling and material recovery for reducing environmental damage and conserving natural resources. It concluded that sustainable recycling systems are essential for developing countries like India.
- **Srivastav et al. (2023)** examined circular economy approaches for sustainable e-waste management. The study highlighted that recycling, reuse, and resource recovery can reduce environmental pollution and improve resource efficiency. It also identified informal recycling and weak collection systems are the major challenge in Indian scenario.
- In India, the informal sector plays a major role in e-waste collection and recycling activities. However, these practices are often unsafe and environmentally harmful. Integration with the formal sector is necessary for improving efficiency and safety **(Central Pollution Control Board, 2023)**.
- **According to Ministry of Environment, Forest and Climate Change,**

(2022), "Weak enforcement, lack of infrastructure, and limited data hinder effective e-waste management. Like this, financial and technological barrier also restrict adoption of circular economy practices. Addressing these issues is essential for achieving sustainability goals."

- **World Bank (2022)** emphasized that circular economy strategies can improve resource efficiency, reduce dependence on virgin materials, create green jobs, and support sustainable economic development through recycling and material recovery.
- **Sengupta et al. (2022)** found that the informal sector plays a dominant role in India's e-waste management. The study recommended integrating informal collectors with formal recycling systems under Extended Producer Responsibility (EPR) to improve collection efficiency and resource recovery.
- **Goel, A. (2022)** reviewed the application of circular economy principles in Indian e-waste management and concluded that the adoption of the 3Rs (Reduce, Reuse, Recycle), reverse logistics, and urban mining can significantly enhance sustainable e-waste management.
- **Sharma and Joshi (2022)** discussed the challenges of implementing circular economy in India's e-waste sector and stressed the need for better policy coordination, stakeholder collaboration, and investment in recycling infrastructure.
- The circular economy is widely recognized as an effective approach to manage e-waste sustainably, which focuses on reuse, repair, recycling, and reducing resource extraction. This model helps in minimizing waste and promoting efficient use of materials **(NITI Aayog, 2021)**.
- **Sharma, Joshi and Govindan (2021)** examined urban mining in India and found that low public awareness, weak collection systems, and the dominance of informal recycling are major barriers to circular economy implementation. They recommended strengthening formal recycling networks and awareness programmes.
- **According to Forti et al., (2020)** "E-waste is one of the fastest-growing waste streams globally due to rapid technological advancement and increasing consumption of electronic devices. Due to Shorter product life cycles and frequent upgrades further accelerate waste generation and this rising trend creates serious environmental and resource management challenges."
- **United Nations Environment Programme (2019)** studies highlight that consumer awareness and disposal behaviour significantly influence e-waste management outcomes. Improper disposal leads to loss of valuable materials and environmental damage. Therefore, awareness and participation are crucial for circular practices.

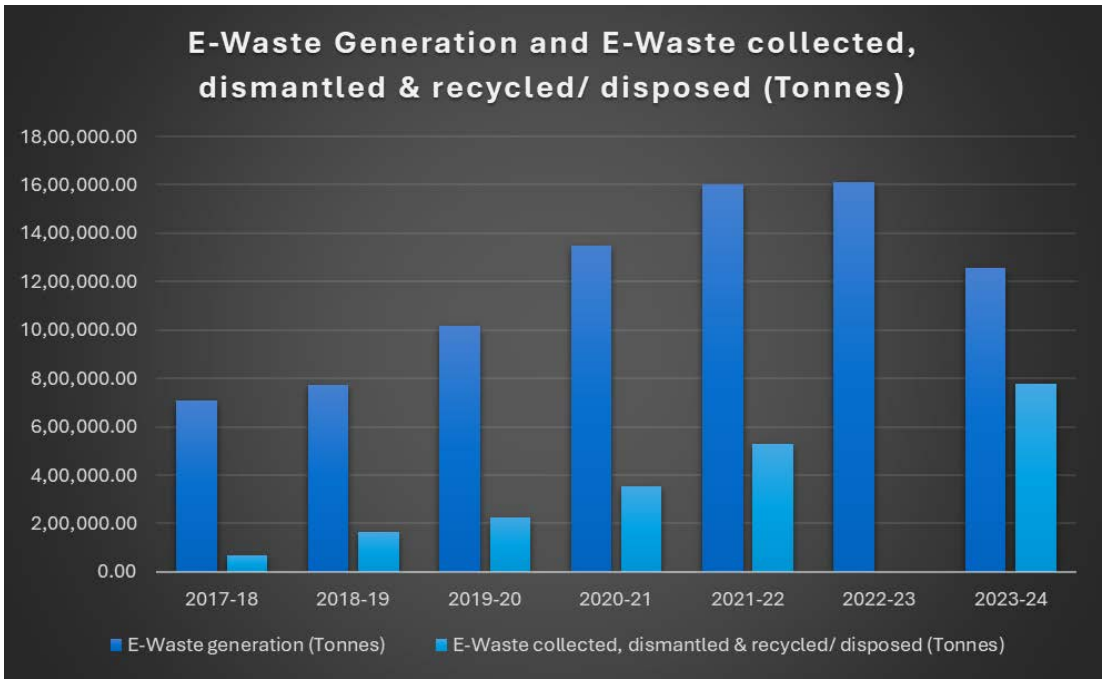
E-Waste Generation Trends Statistics in India

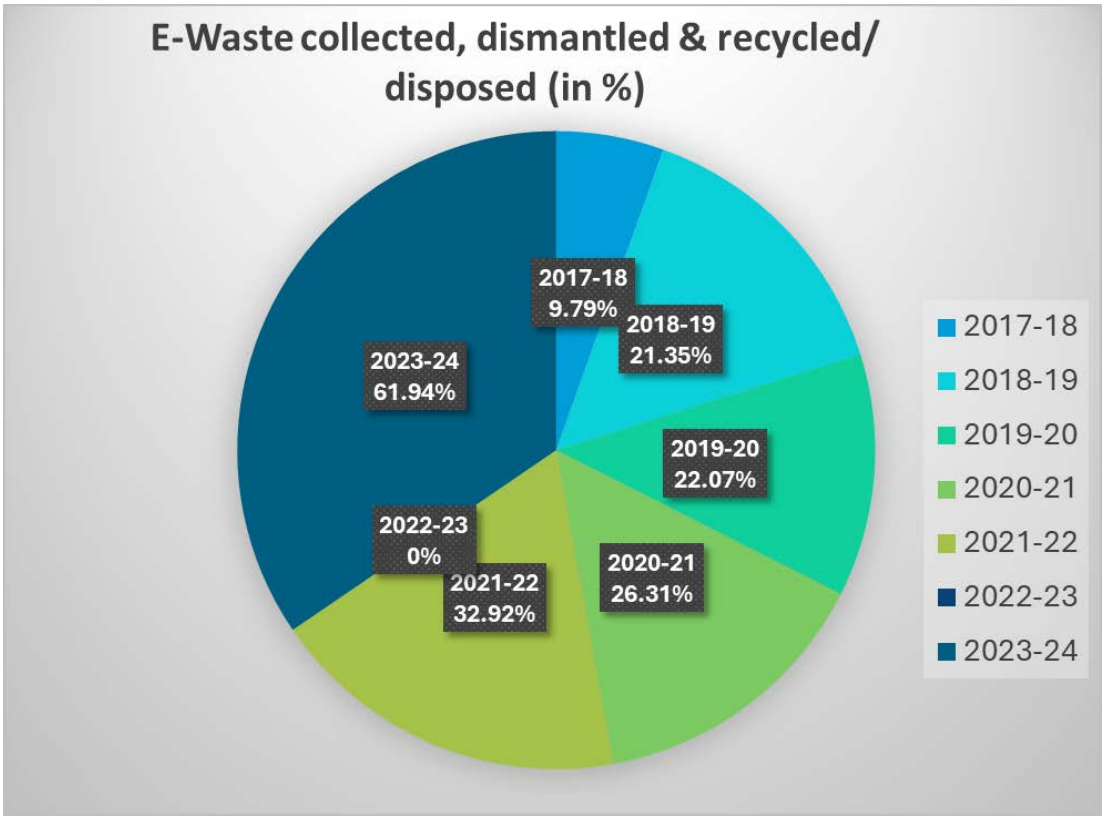
India is the third-largest e-waste generator in the world after China and the United States of America. India has witnessed a rapid and sustained increase in the generation of electronic waste (e-waste) over the past decade, driven by accelerated

digitalization, rising household incomes, urbanization and reduced lifecycles of electrical and electronic equipment (EEE). According to official data presented by the Government of India in the Rajya Sabha, the total e-waste generated in the country increased from 10,14,961.21 tonnes in 2019–20 to 12,54,286.55 tonnes in 2023–24, representing an increase of approximately 23.57% over five years. The sharp rise highlights the growing environmental burden associated with expanding consumption of electronic products such as mobile phones, computers, television, refrigerators, air conditioners, and other consumer appliances.

Fiscal Year	E-Waste generation (Tonnes)	E-Waste collected, dismantled & recycled/ disposed (Tonnes)	E-Waste collected, dismantled & recycled/disposed (in %)
2017-18	7,08,445.00	69,414.0	9.79
2018-19	7,71,215.00	1,64,663.0	21.35
2019-20	10,14,961.21	2,24,041.0	22.07
2020-21	13,46,496.31	3,54,291.22	26.31
2021-22	16,01,155.36	5,27,131.57	32.92
2022-23	16,09,117	NA	NA
2023-24	12,54,286.55	7,76,905.089	61.94

Source- Press Information Bureau-PIB





Understanding of E-Waste Generation and Recycling in India (2017–18 to 2023–24)-

The data provided by the Ministry of Environment, Forest and Climate Change (MoEFCC) helps us clearly understand how e-waste generation and its management have changed in India over the years. When we look at the data year by year, it becomes easier to see how policies, awareness, and infrastructure have improved over time.

Starting with 2017–18, India generated around 7,08,445.0 tonnes of e-waste, but only about 9.79% of it was properly collected, dismantled, and recycled. This shows that at that time, the formal system was not very strong. Most of the e-waste was probably handled by the informal sector, where recycling is often done in unsafe and unorganized ways. This low percentage clearly indicates a lack of awareness, weak collection systems, and limited government control.

In 2018–19, the total e-waste increased slightly to 7,71,215.00 tonnes, but the recycling rate improved i.e. from 9.79% to 21.35%. This is a big jump compared to the previous year. It suggests that government rules, especially the E-Waste Management Rules, started showing some positive results. Producers and recyclers may have become more responsible, and awareness among people also likely increased. Still, the system was not fully stable.

Moving to 2019–20, e-waste generation crossed 10,14,961.21 tonnes, which is a significant rise. However, the recycling percentage dropped to 22.07%. This decline shows that even though more waste was being produced, the system was not able to

manage it efficiently. There could be several reasons for this, such as poor implementation of rules, lack of proper monitoring, and the continued dominance of informal recycling channels.

In 2020–21, the amount of e-waste increased further to around 13,46,496.31 tonnes. The recycling rate improved slightly to 26.31%. This year is important because it was the time of the COVID-19 pandemic. Despite disruptions in many sectors, the e-waste management system still managed to improve a little. This indicates that the formal recycling sector was slowly becoming more stable and capable. During COVID-19, the e-waste sector was affected in both negative and positive ways. On the negative side, lockdowns and movement restrictions disrupted collection and transportation systems. Many recycling units were temporarily closed or operated with limited capacity due to labour shortages and safety concerns. Informal sector workers, who play a major role in e-waste handling in India, were especially affected because they depend on daily income and physical collection activities. As a result, a large amount of e-waste remained stored in households or was not properly collected during this period. On the positive side, there was a rise in the use of electronic devices. Work-from-home, online classes, and increased digital dependence led to higher consumption of laptops, mobile phones, and other electronic equipment. This indirectly contributed to the growth in e-waste generation.

However, despite these challenges, the formal recycling sector showed some improvement. This is because authorized recyclers are more organized and better regulated. They gradually adapted to the situation by following safety protocols and restarting operations. Also, government focus on formal systems and compliance helped maintain some level of recycling activity. So, the slight increase in recycling rate to 26.31% in 2020–21 indicates that even during a crisis, the formal sector was becoming more stable and capable. It shows the beginning of a shift where organized recycling systems started performing better compared to the informal sector. In 2021–22, e-waste generation reached 16,01,155.36 tonnes, and the recycling efficiency increased to 32.92%. This shows a steady improvement. During this period, the government and other stakeholders seemed to take more serious steps to improve the system. More recyclers may have been authorized, and better compliance mechanisms were likely introduced. This year can be seen as a transition phase where the system started becoming more organized and structured.

For 2022–23, the recycling data is not available (NA). This gap is important and may indicate that there was a shift happening in the system. Around this time, India was moving towards a new framework based on Extended Producer Responsibility (EPR) with more digital monitoring. Because of these changes, data collection and reporting might have been affected. Finally, in 2023-24, there is a clear improvement in e-waste management in India. The total e-waste generated was about 12,54,286.55 tonnes which is the highest level reported in official data by the Press Information Bureau (PIB). At the same time, the recycling rate increased sharply to 61.94%, which is much higher than earlier years. Based on this percentage, the amount of e-waste collected, dismantled recycled & disposed is estimated at around 776905.089 tonnes. This value is calculated by applying the given percentage to the total e-waste generated, because the exact number is not directly available in official reports. This improvement shows that recent policy changes, especially the e-waste management

rules,2022 and the EPR system are working well. These measures have made producers more responsible and have improved the performance of the formal e-waste management system.

Overall, if we look at the entire period, we can see a clear improvement in India's e-waste management system. In the beginning years, the system was weak and unorganized, with low recycling rates. Gradually, it moved into a development phase where improvements were visible but not consistent. In recent years, especially after 2022, there has been a strong shift towards a more formal, efficient, and regulated system.

Challenges in Implementing Circular Economy Approaches for E-Waste Management: The Indian Context-

Circular economy offers a sustainable framework for managing electronic waste. Its implementation in India faces multiple country-specific challenges rooted and institutional capacity, market structure, and socio-economic conditions. One of the foremost challenges is the low rate of formal e-waste collection.

According to Central Pollution Control Board (CPCB), Only a fraction of the total E-waste generated in India is channeled through authorized collection and recycling systems with a large share remaining uncollected or diverted to informal pathways. The dominance of the informal recycling sector represents a critical structure challenge in India E-waste landscape. Informal workers are heavily involved in collection, dismantling and material recovery due to their extensive networks and low opportunities costs. However, these activities are often conducted using fundamental techniques such as open burning and acid leaching which result in severe environmental pollution and health hazards. The limited integration of informal actors into the formal circular economy framework leads to material leakages and reduces overall recovery efficiency.

Regulatory implementation under the Extended Producer Responsibility (EPR) regime also faces practical constraints. Although India has introduced E-Waste (Management) Rules and strengthened EPR targets issues such as inadequate enforcement, insufficient verification of recycling claims and double counting of E-waste by Producer Responsibility Organization (PROs) persist. These gaps weaken accountability mechanisms and reduce trust in the formal recycling system.

Technological and financial barriers further create problem in the context of circular economy adoption in India. Environmentally sound recycling technologies require substantial capital investment, which remains unattainable bound to many small and medium recyclers. As a result, advanced recovery of critical and precious metals such as rare earth elements, gold and copper remains limited despite their strategic importance for India's manufacturing and digital economy. Additionally, product design and consumption patterns in India are increasingly aligned with rapid replacement and limited repairability. The absence of widespread design-for-circularity practices such as modular electronics and right-to-repair mechanism restrict opportunities for reuse, refurbishment and life extension of electronic products. Addressing these India- specific challenges is essential to enable effective policy tools and best practices for a circular economy transition in the electronic and electrical sector.

However, even with this progress, some challenges still remain. Since a large part of E-waste may still be handled by informal workers, so proper integration of this sector is needed. Despite the regulation, India faces significant infrastructure gaps, with a large portion of E-waste still handled by the informal sector, causing environmental & health hazard. Also, continuous monitoring, better awareness, and strict enforcement of rules are necessary to maintain for the improvement of the system. In the future, focusing on sustainable practices and circular economy approaches will be very important for managing e-waste effectively.

Some Successful Circular Waste Management Initiatives: Several countries and cities have begun implementing circular waste management systems with notable success. These case studies highlight innovative strategies and practices that can serve as models for others seeking to transition to a more sustainable waste management approach.

I. Sweden: Sweden is renowned for having one of the most advanced recycling systems globally. Nearly 99% of household waste is either recycled or converted into energy. The Swedish government has implemented robust waste management policies, including extended producer responsibility (EPR), which holds manufacturers accountable for the entire lifecycle of their products. Additionally, the country has developed a comprehensive waste-to-energy infrastructure, converting non-recyclable waste into heat and electricity. These initiatives have not only significantly reduced landfill waste but have also contributed to Sweden's commitment to sustainability and carbon neutrality.

II. Japan: Japan's commitment to creating a "Sound Material-Cycle Society" is evident in its comprehensive policy framework encouraging sustainable resource use and waste reduction. The country has implemented strict laws regarding waste sorting and recycling, particularly in managing electronic waste, which has been a significant environmental concern. For instance, the Home Appliance Recycling Law mandates that manufacturers take back and recycle old appliances, effectively closing the loop on electronic waste. Furthermore, Japan promotes community-based recycling initiatives, where local governments work with residents to enhance recycling rates and reduce waste generation. This multi-faceted approach has made Japan a leader in effective waste management practices.

III. Circular Economy Examples from India: India’s rapid urbanization makes circular innovation essential. Fortunately, several organizations and startups are leading by example, showing how circularity can balance growth and responsibility.

- **RaceEcoChain– Digitizing India’s Waste Ecosystem**: To begin with, **RaceEcoChain** connects recyclers, manufacturers, and waste generators through a unified digital platform. The system ensures traceability, transparency, and accountability across the recycling process. As a result, waste becomes a resource, and companies meet EPR targets efficiently.
- **Banyan Nation– Plastic Recycling at Scale**: Banyan Nation, based in Hyderabad, uses data analytics to streamline plastic collection and recycling. Consequently, major brands like Unilever use its recycled plastic in packaging, reducing their dependence on virgin materials.

- **Goonj – Reusing Urban Waste for Rural Development**: Goonj collects surplus materials such as clothing and household goods from cities. It then redistributes them to rural areas, turning urban waste into valuable community resources. Therefore, it promotes both reuse and social equity.
- **Graviky Labs– Turning Air Pollution into Ink**: Through an inventive process, Graviky Labs captures soot from vehicle exhaust and converts it into "Air Ink." This innovation reduces pollution and provides a market-ready, sustainable product.
- **Attero Recycling– E-Waste Recovery and Metal Extraction**: Attero Recycling handles electronic waste from across India. By extracting precious metals from discarded electronics, it prevents toxic pollution and recovers valuable resources for manufacturing.

Policy Tools and Best Practices for Enabling a Circular Economy in Electrical and Electronic Equipment Sector

Governments, all over the world, are adopting a range of policy tools to promote a circular economy in the Electrical and Electronic Equipment (EEE) Sector because of its rapid growth, high resource intensity and contribution to e-waste generation. One of the most important instruments is Extended Producer Responsibility (EPR), which places legal responsibility on producers for the collection, recycling, and environmentally sound disposal of end-of-life electronics products. EPR encourages eco-design, material recovery and investment in formal recycling infrastructure and is a cornerstone of e-waste regulation in countries like India.

Another key policy tool is eco-design regulation which mandates manufacturers to design products that are durable, repairable, upgradable, and recyclable. Eco-design standards reduce material consumption, extend product lifespans, and facilitate easier recycling. Complementing this right -to-repair policies and repair incentives aim to counter planned obsolescence by promoting repair services, reuse and refurbishment of electronic goods.

Economic instruments, such as recycling subsidies, differential taxation, deposit-refund schemes, and green public procurement further support circular practices by making environmentally responsible choices economically attractive. These instruments help bridge the cost of gap between informal and formal recycling systems particularly in developing economies.

Best practices for circularity in the EEE sector also include the development of reverse logistics systems, formalization of the informal recycling sector and strengthening of collection networks through public-private partnerships (PPP). Digital tools such as product passports and tracking systems enhance transparency and accountability across the product lifecycle. Additionally, consumer awareness programs play a critical role in improving collection rates by informing users about proper disposal channels and environmental risks associated with improper e-waste handling.

Overall, an effective transition to a circular economy in the EEE sector integrated policy mix combining regulatory, economic, technological and social measures. Strong enforcement reliable data systems and coordination among stakeholders are

essential for circular economy policies specially for tangible environmental and economic benefits.

Conclusion and Suggestions

The rapid growth of the electronics and electrical equipment sector has intensified the challenge of e-waste management, particularly in developing economies like India. Traditional linear models of production and consumption have proven inadequate in addressing the environmental, economic, and social consequences of mounting electronic waste. In this context, the circular economy emerges as a viable and sustainable alternative that in context of resource efficiency, waste minimization, and material recovery throughout the product life cycle. Integrating circular economy principles into e-waste management offers multiple benefits aligned with sustainable development. Environmentally, it reduces pollution and conserves finite natural resources by promoting recycling and reuse of valuable materials embedded in electronic products. Economically, it supports secondary raw material markets, reduces dependence on imports of critical minerals, and generates employment opportunities across formal repair, refurbishment, and recycling sectors. Socially, a structured circular framework can help transition informal recycling activities into safer and more regulated systems, thereby improving occupational health and livelihoods.

India's evolving policy landscape, including Extended Producer Responsibility (EPR) mechanisms and proposed circular economy frameworks for the electronics and electrical sector, reflects growing recognition of these benefits. However, effective implementation remains contingent upon improved collection systems, accurate data reporting, technological capacity building, and stronger coordination among stakeholders. Adopting a circular economy–based approach to e-waste management will be essential for achieving environmentally sound growth, digital inclusion, and long-term sustainability in India.

The circular economy presents a viable pathway to a future where waste is minimized, resources are conserved, and environmental impacts are reduced. By embracing circular principles, especially strengthening regulatory enforcement, improving institutional coordination, and integrating informal actors into formal circular systems, we can ensure a healthier planet for future generations while promoting economic resilience and social well-being. This shift not only contributes to ecological balance but also positions societies to thrive in an increasingly resource constrained world, paving the way for sustainable development and enhanced quality of life for all.

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