CBCS SCHEME

USN 1CR22CS030 **BEC755A**

Seventh Semester B.E./B.Tech. Degree Examination, Dec.2025/Jan.2026

E-Waste Management

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	Define E-Waste. Explain its sources, classification and characteristics with examples.	10	L2	CO1
	b.	Discuss global and Indian Scenario of E-waste generation of management.	10	L2	CO1
		OR			
Q.2	a.	Explain how the rapid growth of the electronics Industry in India and how it contributes to E-waste generation.	10	L2	CO2
	b.	Describe the challenges faced in defining and quantifying e-waste globally and nationally.	10	L2	CO1
		Module – 2			
Q.3	a.	Explain the basel convention and its importance in e-waste control.	10	L2	CO2
	b.	Explain the objective and impact of WEEE Directive.	10	L2	CO2
		OR			
Q.4	a.	Discuss the evolution of E-waste regulations in India from 2011 to 2016.	10	L2	CO2
	b.	Describe the regulatory compliance mechanisms for E-waste in India.	10	L2	CO2
		Module – 3			
Q.5	a.	Define EPR and explain its role in sustainable E-waste management.	10	L2	CO2
	b.	Explain in detail about E-waste value chain.	10	L3	CO2
		OR			
Q.6	a.	Describe in detail about E-waste collection system in India with examples.	10	L2	CO2
	b.	Discuss the role and importance of Producer Responsibility Organizations (PRO's).	10	L2	CO2
		Module – 4			
Q.7	a.	Explain key technique for sustainable E-Waste handling.	10	L2	CO3
	b.	Discuss hazards of improper E-Waste handling and suggest safety measures.	10	L2	CO3
		OR			
Q.8	a.	Describe the role of classification of characterization in e-waste handling.	10	L3	CO3
	b.	Explain in detail about worker safety measures during e-waste handling.	10	L2	CO3
		Module – 5			
Q.9	a.	Define ROHS directive. List restricted substances and their effects.	10	L2	CO3
	b.	Discuss ROHS compliance in India and compare it with global standards.	10	L2	CO3
		OR			
Q.10	a.	Explain the operations involved in E-Waste recycling.	10	L2	CO4
	b.	Describe major e-waste recycling technologies. Compare their merits and limitations.	10	L2	CO4

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Module-1

Q.1 **a**

E-Waste: Definition, Sources, Classification and Characteristics

i. Definition of E-Waste

E-waste (Electronic Waste) refers to discarded electrical and electronic equipment (EEE) and their components that have reached the end of their useful life or are no longer intended for reuse. This includes complete devices as well as parts, sub-assemblies, and accessories such as batteries, cables, and circuit boards. E-waste is considered a special category of waste because it contains both valuable materials and hazardous substances.

ii. Sources of E-Waste

The major sources of e-waste are:

1. **Households**
   Discarded televisions, mobile phones, refrigerators, washing machines, laptops, mixers, etc.

2. **Commercial establishments**
   Offices, banks, shops, hotels, and malls generating obsolete computers, printers, servers, and networking equipment.

3. **Industrial sector**
   Manufacturing units producing rejects, defective electronic components, and obsolete control equipment.

4. **Institutional sources**
   Educational institutions, hospitals, research labs, and government offices disposing of outdated electronic systems.

5. **Imports and illegal dumping**
   Used or obsolete electronic products imported from other countries, often under the label of second-hand goods.

iii. Classification of E-Waste

E-waste can be classified in different ways:

(a) Based on Product Type

- **Large household appliances: Refrigerators, air conditioners, washing machines**
- **Small household appliances: Irons, mixers, vacuum cleaners**
- **IT and telecommunication equipment: Computers, laptops, mobile phones, routers**
- **Consumer electronics: Televisions, audio systems, cameras**

- **Lighting equipment: CFLs, LED lamps, fluorescent tubes**
- **Electrical tools and medical devices**

(b) Based on Hazard Content

- **Hazardous e-waste: Contains lead, mercury, cadmium, chromium, brominated flame retardants**
- **Non-hazardous e-waste: Plastics, glass, aluminium, copper (comparatively safer but still require proper handling)**

iv. Characteristics of E-Waste

1. **Presence of hazardous substances**
   E-waste contains toxic materials such as lead (Pb), mercury (Hg), cadmium (Cd), and brominated flame retardants, which can harm human health and the environment.
2. **Resource-rich nature**
   It contains valuable metals like copper, aluminium, gold, silver, and palladium, making recycling economically important.
3. **Rapid generation rate**
   Due to fast technological advancement and short product life cycles, e-waste is one of the fastest growing waste streams.
4. **Complex composition**
   E-waste is made up of a mixture of metals, plastics, glass, ceramics, and chemicals, making recycling technically challenging.
5. **Environmental and health risks**
   Improper handling, open burning, and acid leaching can cause air, soil, and water pollution and lead to serious health issues.

v. Examples of E-Waste

- **Discarded mobile phones and chargers**
- **Old computers, CPUs, and keyboards**
- **Broken televisions and monitors**
- **Used batteries and printed circuit boards**
- **Obsolete medical and laboratory equipment**

	b	**Global Scenario of E-waste Generation**

		Global E-waste Management ● **Many countries follow Extended Producer Responsibility (EPR), making manufacturers responsible for collection and recycling.** ● **The European Union has well-defined WEEE and RoHS directives to regulate hazardous substances and ensure proper recycling.** ● **Despite regulations, challenges remain such as illegal trade, lack of awareness, and informal recycling practices in developing regions.** **Indian Scenario of E-waste Generation** ● **India is among the top producers of e-waste globally, generating over 3 million metric tonnes per year.** ● **Major contributors include:** ○ **IT and telecom equipment** ○ **Consumer electronics** ○ **Household appliances** ● **E-waste generation is highest in metropolitan cities like Mumbai, Delhi, Bengaluru, Chennai, and Hyderabad.** ● **Rapid urbanization, digitalization, and growth in mobile and internet usage have accelerated e-waste generation.** **E-waste Management in India** **Regulatory Framework** ● **India manages e-waste under the E-waste (Management) Rules, which emphasize:** ○ **Extended Producer Responsibility (EPR)** ○ **Authorization of recyclers and dismantlers** ○ **Environmentally sound management practices** ● **Producers are required to collect e-waste and ensure safe recycling.**
OR		
Q.2	**a**	**1. Growth of the Electronics Industry in India**

In recent years, India has witnessed rapid growth in the electronics industry due to economic development, digital transformation, and supportive government policies.

Key factors driving this growth are:

- **Digitalization and technological advancement**
  Expansion of IT services, online education, e-governance, digital payments, and smart devices has increased demand for electronic products.

- **Rising population and urbanization**
  A large and growing population with increasing urban lifestyles has led to higher consumption of electronic appliances.

- **Increase in income and living standards**
  Higher disposable income has made electronic gadgets affordable to a larger section of society.

- **Government initiatives**
  Programs like *Digital India*, *Make in India*, and growth of electronics manufacturing clusters have boosted production and consumption.

- **Expansion of IT and telecom sector**
  Growth in mobile phones, computers, networking equipment, and data centers has significantly expanded the electronics market.

2. Shorter Life Cycle of Electronic Products

- **Rapid innovation leads to frequent upgrades of devices.**
- **Products become obsolete quickly due to improved features and software incompatibility.**
- **Consumers replace devices even when they are still functional.**

This short product life cycle directly increases the volume of discarded electronics.

3. Consumer Behaviour and Replacement Culture

- **Preference for new models over repair or reuse.**
- **Decline in repair culture due to high repair costs and non-availability of spare parts.**
- **Easy availability of low-cost electronics encourages frequent replacement.**

4. Growth of Manufacturing and Imports

		● **Expansion of domestic manufacturing results in production rejects and defective components.** ● **Import of electronic products and components also adds to future e-waste generation.** ● **Bulk consumption by offices, institutions, and industries leads to large-scale disposal.** **5. Contribution to E-waste Generation** **Due to the above factors, the rapid growth of the electronics industry contributes to e-waste generation in the following ways:** ● **Increase in discarded computers, mobile phones, TVs, and household appliances.** ● **Accumulation of obsolete IT and telecom equipment.** ● **Rise in hazardous waste containing lead, mercury, cadmium, and plastics.** ● **Growth of informal recycling practices due to lack of proper disposal awareness.** **6. Environmental and Management Impact** ● **Improper disposal leads to air, soil, and water pollution.** ● **Informal recycling exposes workers to serious health risks.** ● **Existing collection and recycling systems struggle to keep pace with rising e-waste volumes.**
2	**b**	**1. Challenges in Defining E-waste** 1. **Lack of a uniform definition** **Different countries and organizations define e-waste differently. Some include only discarded electrical and electronic equipment, while others also include components, spares, and consumables. This lack of standardization creates confusion in data collection.** 2. **Ambiguity between waste and reuse** **Used electronics meant for reuse, repair, or refurbishment are often mixed with e-waste. It becomes difficult to decide the exact point at which a product turns into waste.**

3. **Variation in product classification**
   Categories of electrical and electronic equipment differ across countries. For example, certain devices may be classified as IT equipment in one country and consumer electronics in another.

4. **Rapid technological change**
   New electronic products and hybrid devices appear frequently, making existing definitions outdated.

2. Challenges in Quantifying E-waste

1. **Absence of reliable data**
   Many countries lack systematic data collection mechanisms for e-waste generation, collection, and recycling.

2. **Dominance of the informal sector**
   A large portion of e-waste, especially in developing countries like India, is handled by informal recyclers. Their activities are unrecorded, leading to underestimation.

3. **Illegal transboundary movement**
   E-waste is often illegally exported or imported under the label of second-hand goods. Such movements are rarely documented accurately.

4. **Hoarding and storage by consumers**
   Households and organizations tend to store obsolete electronics instead of discarding them, delaying their entry into the waste stream and affecting estimates.

5. **Difficulty in tracking product life cycles**
   Long and variable life spans of electronic products make it hard to predict when they will become e-waste.

3. Global Challenges

- **Differences in legislation, reporting standards, and monitoring systems across countries.**
- **Limited cooperation and data sharing between nations.**
- **Inconsistent reporting to international databases and agencies.**

4. National-Level Challenges (India)

- **Lack of awareness among consumers and bulk users about proper reporting and disposal.**
- **Weak enforcement of e-waste rules and limited monitoring capacity.**
- **Insufficient infrastructure for collection and documentation.**

		● **Incomplete producer responsibility implementation.**

Module-2		
Q.3	**a**	**Explain the Basel Convention and its importance to e-waste.** **The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and came into force in 1992. It is a global treaty under the United Nations Environment Programme (UNEP).** **Aim: To reduce hazardous waste generation, control its cross-border movement, and ensure environmentally sound disposal. It restricts the export of hazardous waste (including e-waste) from developed to developing countries, unless prior informed consent is obtained. It also promotes waste minimization, recycling, and recovery at the source of generation.** **Relevance to E-Waste - Recognition of E-Waste as Hazardous Waste:** **E-waste contains toxic substances like lead, mercury, cadmium, and brominated flame retardants, making it hazardous under Basel Convention guidelines.** **Control of Illegal E-Waste Trade:** **Many developing countries, including India, have been dumping grounds for e-waste from developed nations. The convention seeks to regulate and monitor such transboundary movement to protect human health and the environment.** **Policy Framework for Nations:** **Provides an international legal framework that influenced national legislations on e-waste. India's E-Waste** **Management Rules (2011, 2016, 2018) are aligned with Basel principles.** **Basel Ban Amendment (2019):** **Prohibits the export of hazardous wastes (including e-waste) from OECD/EU countries to non-OECD countries. Reinforces global efforts to stop unsafe dumping in poorer nations.**
	b	**Explain the objective and impact of WEEE directive** **The WEEE Directive stands for the Waste Electrical and Electronic Equipment Directive. It was first introduced by the European Union (EU) in 2003 (Directive 2002/96/EC) and later revised in 2012 (Directive 2012/19/EU). The directive provides a legal framework for the collection, recycling, and recovery of electrical and electronic waste within EU member states. Its main principle is the Extended**

		Producer Responsibility (EPR), which makes producers (manufacturers, importers, and distributors) responsible for the entire life cycle of their electronic products, including end-of-life take-back, recycling, and safe disposal.Categories of covered equipment include large/small household appliances, IT and telecom equipment,lighting, toys, medical devices, and monitoring instruments. **Impact on Global E-Waste Policy:** **Standard-Setting Role:** **The WEEE Directive became a benchmark for global e-waste legislation.** **Many countries, including India, China, and several African nations, have modeled their e-waste management rules on its EPR principle.** **Producer Responsibility & Take-Back Systems:** **The directive popularized the concept of producer take-back programs worldwide.It shifted responsibility away from municipalities alone and placed it on manufacturers and importers,influencing global supply chains.** **Recycling Targets:** **WEEE introduced clear collection and recycling targets for different categories of e-waste.This pushed many non-EU countries to adopt quantitative targets for recycling and recovery in their own policies.** **Trade & Compliance Pressure:** **Non-EU manufacturers exporting to Europe were forced to comply with WEEE requirements.This created a spillover effect, encouraging companies worldwide to integrate eco-design, safe materials, and e-waste management practices.** **Influence on Indian Policy:** **India's E-Waste (Management and Handling) Rules 2011, and the updated E-Waste Management Rules 2016 & 2018, borrowed heavily from the WEEE model, especially the EPR provisions and take-back mechanisms.**
OR		

<table>
<tr><td>Q.4</td><td>a</td><td>India's e-waste regulations evolved from the foundational <u>E-Waste (Management and Handling) Rules, 2011</u>, which introduced <u>Extended Producer Responsibility (EPR)</u> (EPR), to the significantly strengthened <u>E-Waste (Management) Rules, 2016</u>, replacing the 2011 rules to expand product scope (to 21 categories like CFLs), formalize Producer Responsibility Organizations (PROs), introduce penalties, and mandate deposit-refund schemes for better producer accountability and consumer involvement in collection, enhancing the framework for managing increasing electronic waste.

E-Waste (Management and Handling) Rules, 2011
First comprehensive rules: Introduced in 2011 and effective from May 2012, these were India's first structured e-waste regulations.
Introduced EPR: Made producers responsible for environmentally sound disposal, aiming to reduce hazardous substances and promote recycling.
Limited Scope: Primarily covered IT and consumer electronics.
E-Waste (Management) Rules, 2016
Replaced 2011 Rules: Notified in March 2016, superseding the previous regulations for better implementation.
Expanded Product Categories: Covered 21 categories, including CFLs, broadening the responsibility.
Strengthened EPR: Defined Producer Responsibility Organizations (PROs) as intermediaries, clarifying producer roles in collection and segregation.
New Mechanisms: Introduced:
Deposit Refund Scheme (DRS): Consumers paid an extra deposit, refunded upon returning end-of-life products.
Penalties: Added consequences for non-compliance.
Role for Local Bodies: Made Urban Local Bodies responsible for collecting "orphan products" (unclaimed waste).
Focus on Formalization: Required authorization for recyclers and dismantlers by State Pollution Control Boards, aiming to bring more formal structure to the sector.</td></tr>
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<table>
<tr><td></td><td>b</td><td>E-waste regulatory compliance, particularly under India's <u>E-Waste (Management) Rules 2022</u>, centers on <u>Extended Producer Responsibility</u> (EPR), mandating producers to register online with the <u>CPCB</u>, meet phased collection/recycling targets (e.g., 80% by 2025), and use authorized recyclers, all managed via a digital portal for returns, certificates, and audits, ensuring a formal, traceable system for collection, recycling, and disposal.

Key Compliance Mechanisms (India Focus):

1. <u>Registration</u>: All producers, manufacturers, refurbishers, and recyclers must register on the CPCB's online portal.
2. <u>EPR Targets</u>: Producers must meet annual targets for collecting and recycling e-waste, increasing towards 80% by 2025, often fulfilled through buying EPR certificates from recyclers.
3. <u>Authorized Recyclers</u>: E-waste must be processed by facilities authorized by State Pollution Control Boards (SPCBs).
4. <u>Digital Reporting</u>: Mandatory quarterly and annual returns (Form 3) are filed on the CPCB portal, detailing collection, recycling, and sales.
5. <u>Circular Economy</u>: Rules promote material recovery, discourage landfilling/incineration, and support a formal sector through mechanisms like minimum pricing for recyclers.

How Producers Comply:

• Register: Sign up on the CPCB EPR Portal.
• Plan: Calculate liability
• and form an e-waste management plan.
• Partner: Work with Producer Responsibility Organizations (PROs) or authorized recyclers.
• Track: Purchase and submit EPR certificates online.
• Report: File regular compliance reports via the portal. Enforcement:
• The CPCB and SPCBs oversee registration audits, and target monitoring, with penalties for non-compliance.</td></tr>
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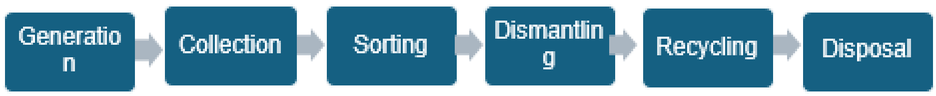
<tr><th colspan="3">Module-3</th></tr>
<tr><td>Q.5</td><td>a</td><td>EPR-A policy approach where producers (manufacturers, importers, brand owners) are accountable for managing their products after sale, covering collection, recycling, and disposal.</td></tr>
</table>

		● It shifts responsibility from consumers and local governments to the companies introducing products to the market. Role in Sustainable E-Waste Management ● Encourages Eco-Design: Producers design electronics to be more durable, repairable, and easier to recycle, reducing hazardous materials. ● Promotes Circular Economy: Drives initiatives for product reuse, component recovery, and material recycling, keeping resources in use longer. ● Ensures Proper Disposal: Mandates collection and safe handling through authorized recyclers, preventing e-waste from ending up in landfills or informal dumps. ● Reduces Environmental Burden: Minimizes pollution and resource depletion by recovering precious metals and reducing the need for new raw material extraction. ● Formalizes Waste Management: Integrates informal waste collectors (like *kabadiwalas*) into formal systems, improving collection and processing. ● Drives Accountability: Establishes legal frameworks with reporting and penalties to ensure compliance, giving regulators clear visibility into waste streams.
	b	**Explain in detail about E-Waste value chain.** **Solution:** The e-waste value chain represents the entire lifecycle of electronics from design to end-of-life processing.  The **e-waste value chain** describes the path e-waste follows from its generation to its final disposal: **Generation** – When a consumer or business discards an electronic product. **Collection** – Devices are gathered by formal collection centers or informal kabadiwalas. **Sorting** – Products are segregated by type (computers, mobiles, appliances). **Dismantling** – Manual or mechanical disassembly into components. **Recycling** – Valuable metals are extracted, plastics and glass processed, hazardous fractions treated. **Final Disposal** – Non-recyclable residues landfilled or incinerated.

A smooth value chain is crucial for ensuring **safe recycling, resource recovery, and pollution control**.

Generation

•Consumers discard old or obsolete devices (phones, laptops, TVs, etc.).

•E-waste generated at households, businesses, and institutions.

Collection

•Formal systems: Authorized collection centers, drop-off points, producer take-back programs.

•Informal systems: Scrap dealers, street collectors (common in India and developing countries).

Sorting & Dismantling

•Devices are separated into different categories.

•Dismantling into components: circuit boards, plastics, metals, batteries.

Refurbishing / Reuse

•Some items are repaired, refurbished, and resold.

•Extends product life and reduces waste.

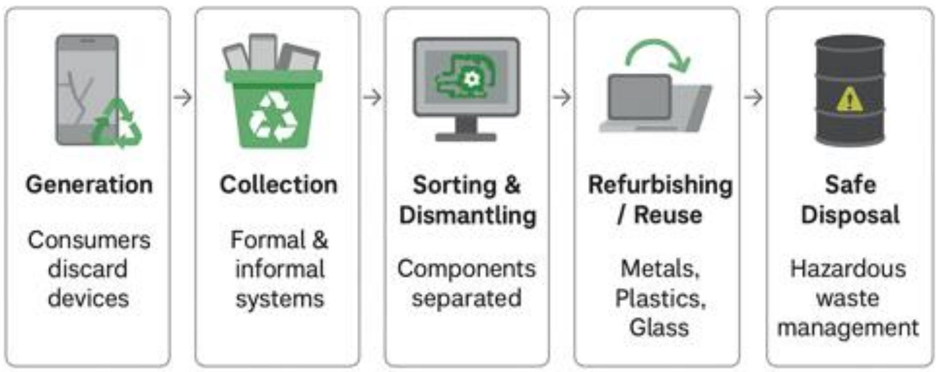
Recycling & Resource Recovery

•Valuable metals (gold, silver, copper, rare earths) extracted.

•Plastics and glass are recycled.

Safe Disposal

Hazardous fractions (batteries, mercury lamps, etc.) disposed of using scientific methods to avoid pollution.



•The value chain involves multiple stakeholders, each with specific roles:

•Producers: Responsible under EPR to manage end-of-life products.

•Consumers: Generate post-consumer e-waste; their behavior influences collection efficiency.

•Scrap dealers/kabadiwalas: Informal actors who collect and dismantle waste.

•Informal workers: Form the backbone of collection but often work under unsafe conditions.

•PROs (Producer Responsibility Organisations): Set up formal collection systems and compliance reporting.

•Recyclers: Formal units authorized to handle e-waste scientifically.

•Regulators: Pollution Control Boards, CPCB, and ministries monitor compliance.

		•The interaction between these actors determines whether e-waste is recycled safely or ends up as an environmental hazard. <u>**Informal Sector in Value Chain:**</u> •***Collects ~90% of Indian e-waste*** •***Unsafe methods: acid leaching, burning*** •***Employment source but hazardous*** •In India, the **informal sector dominates collection and dismantling**: •They are efficient in reaching households and businesses to buy old electronics. •However, they use **rudimentary methods** such as: •**Acid leaching** to extract metals → releases toxic fumes. •**Open burning** of wires → emits dioxins and heavy metals. •Provides **employment to thousands of urban poor**, but at the cost of **worker health and environmental safety**. •Example: Seelampur in Delhi is one of the largest informal e-waste hubs in South Asia. •Challenge: How to **integrate informal workers into the formal value chain** while ensuring safety and livelihoods. <u>**Formal Sector in Value Chain:**</u> •***Authorized collection centers & recyclers*** •***Safe recycling technologies*** •***Limited reach compared to informal sector*** •The **formal sector** is composed of government-authorized collection centers and recycling plants. •They use **environmentally sound management (ESM)** technologies such as: •Shredding & separation systems. •Mechanical/chemical processes for safe metal recovery. •Advantages: compliance with law, reduced pollution, safe working conditions. •Limitations: •Low accessibility (few centers in large cities only). •Higher costs discourage consumers from using them. •Cannot compete with the **convenience and cash incentives** of informal channels. •Thus, despite being safer, the **formal sector handles less than 10–20%** of India's e-waste.
	OR	
Q.6	**a**	**Describe in detail about E-Waste collection system in India with examples.** <u>**Solution:**</u>

•Producer Take-back Programs – Producers set up their own collection centers or return schemes.
•Retail Collection Points – Consumers can return old electronics at retail outlets.
•Authorized Collection Centers – Government- or PRO-registered facilities.
•Informal Sector Collection – Ragpickers, scrap dealers, door-to-door collection.
•Municipal Collection – Local bodies integrating e-waste with solid waste streams.
•Drop-off/Donation Programs – NGOs, community collection drives, donation initiatives.

E-Waste Collection Systems

Efficient **collection** is the foundation of successful e-waste management. The book highlights both **formal and informal** mechanisms.

System Type	Description
Drop-off Collection	Consumers deposit e-waste at designated bins or centers
Take-back Programs	Producers or retailers collect e-waste when new products are purchased
Door-to-door Pickup	Used by formal recyclers and PROs in urban centers
Informal Collection	Dominated by kabadiwalas and scrap dealers (major share in India's collection)
Bulk Collection Drives	Organized events for collection in institutions, offices, housing societies

Challenges:

- Lack of awareness among consumers
- Limited access to formal collection centers
- Competition between formal and informal sectors
- Low incentives for proper disposal

Collective Responsibility

•**Individual Producer Responsibility (IPR):** A producer sets up its own take-back and recycling mechanism.
•**Collective Producer Responsibility (CPR):** Producers pool resources through a PRO.

Role of PRO:
•Implements EPR obligations for single or multiple producers.
•Handles collection, transportation, recycling, and reporting.
•Ensures transparency, compliance, and proper treatment of e-waste.
•Builds networks involving informal collectors, recyclers, government, and bulk consumers.

Challenges in India:
•Low awareness of PROs among producers and consumers.
•Short-term contracts between producers and PROs create gaps in commitment.
•Issues like "paper trading" (fake e-waste collection data) and leakage to informal recyclers.

Formal Collection Systems

- **Producer take-back programs :** Manufacturers are legally required to provide collection facilities for their products after use. Example: Apple's iPhone recycling program.
- **Collection centers :** Authorized centers set up by producers, PROs, or recyclers to receive discarded electronics.
- **Buy-back and exchange schemes**: Incentivize consumers by offering discounts or cash in return for old products (common in mobile phone and appliance markets).
- These systems ensure e-waste is channelized into **formal recycling facilities** where it can be processed safely.

Informal Collection Systems

- **Door-to-door collectors**: Scrap dealers (kabadiwalas) visit homes, offices, and institutions to purchase old electronics.
- **Street-side markets**: Discarded electronics are sold, repaired, or dismantled in informal marketplaces (e.g., Seelampur in Delhi).
- Consumers prefer informal channels because:
  - They **receive immediate cash** for old devices.
  - The process is **convenient and accessible** compared to formal collection centers.

Barriers in Collection

- **Consumer unawareness :** Many people do not know about formal collection centers or the hazards of improper disposal.
- **Lack of infrastructure :** India has limited formal collection centers, mostly in metro cities, leaving rural and semi-urban areas underserved.
- **Informal sector dominance:** Informal collectors offer better incentives (cash), making formal schemes less attractive.
- **Weak enforcement**: Regulations mandate take-back, but implementation and monitoring are limited.
- **Cultural behavior**: In many households, old electronics are stored for years ("stockpiling") instead of being discarded.

Improving Collection Efficiency

- **Awareness campaigns**: Educating consumers on hazards of e-waste and benefits of safe disposal. Example: CPCB awareness programs, PRO-led workshops.
- **Incentives for consumers**: Trade-in discounts, reward points, and cashback schemes encourage return of used products.
- **Partnerships with informal collectors**: Integrating kabadiwalas into formal systems allows them to collect waste but channel it to authorized recyclers.
- **Digital tracking**: Use of apps and QR codes to track collection and recycling.
- **Extended Producer Responsibility (EPR)**: Producers must set annual collection targets, pushing them to innovate in collection systems.

b **Discuss the role and importance of Producer Responsibility Organisations (PRO's)**

Solution:

Producer Responsible Organization (PRO)

•E-waste collection and channelization
•Sets up collection centers, take-back points, and logistics to recover e-waste from consumers and bulk users.
•Works with informal collectors to reduce leakage outside formal systems.
•Recycling and disposal management
•Ensures collected waste is sent to authorized dismantlers and recyclers.
•Tracks environmentally sound management (ESM) of materials.
•Compliance and reporting
•Prepares and submits compliance documentation to regulators.
•Ensures producers meet EPR targets (in weight or product units).
•Awareness creation
•Runs campaigns to inform consumers about e-waste take-back and safe disposal.
•Educates bulk consumers and institutional buyers on returning end-of-life equipment.
•Financial management
•Pools contributions from multiple producers to fund collection, transport, and recycling.
•May operate cost-sharing schemes or product-based fees.

What are PROs?

- A **Producer Responsibility Organisation (PRO)** is a specialized, third-party entity that takes on the task of **fulfilling EPR obligations on behalf of producers.**
- Instead of each company running its own collection/recycling program, producers can outsource these tasks to a PRO.
- PROs act as **compliance managers**, ensuring that the collection, transportation, dismantling, and recycling of e-waste are carried out according to regulations.
- In India, PROs must be **registered and authorized** by the **Central Pollution Control Board (CPCB)**.
- They serve as a crucial link between **producers, consumers, recyclers, and regulators**.

Functions of PROs

- **Collection infrastructure**: PROs establish collection points, take-back systems, and reverse logistics.
- **Awareness programs**: They organize consumer awareness campaigns, workshops, and school/college drives to promote safe e-waste disposal.
- **Recycling contracts**: PROs partner with **authorized recyclers** who follow environmentally sound management practices.
- **Compliance reporting**: They maintain data and submit reports to regulators like CPCB, ensuring that producers meet their EPR targets.
- **Monitoring & traceability**: PROs often use digital platforms to track e-waste movement from consumer to recycler, ensuring transparency.

Role of PROs in Integration

- **Bridging informal–formal divide**: PROs help integrate informal waste collectors by linking them with authorized recyclers, reducing unsafe recycling practices.
- **Ensuring safe recycling**: They ensure e-waste is treated with **environmentally sound technologies** instead of crude methods like open burning.
- **Promoting transparency**: By tracking e-waste flows digitally, PROs help reduce leakages into the informal sector.
- **Compliance partner**: PROs ease the regulatory burden on producers by handling reporting and documentation.
- **Catalysts of change**: They contribute to the growth of India's **formal recycling industry** and move the system towards a **circular economy**.

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- **Awareness programs**: They organize consumer awareness campaigns, workshops, and school/college drives to promote safe e-waste disposal.
- **Recycling contracts**: PROs partner with **authorized recyclers** who follow environmentally sound management practices.
- **Compliance reporting**: They maintain data and submit reports to regulators like CPCB, ensuring that producers meet their EPR targets.
- **Monitoring & traceability**: PROs often use digital platforms to track e-waste movement from consumer to recycler, ensuring transparency.

Producer Responsibility Organization (PRO)

A PRO is a professional agency or organization authorized to fulfil EPR obligations on behalf of producers.

Producer Responsibility Organisations in South India

··Role of PROs:

- ❖ Collect e-waste from consumers and bulk generators.
- Channel waste to authorized recyclers.
- Submit documentation and audit reports to CPCB.
- Conduct awareness campaigns.
- Ensure reverse logistics and safe transportation.

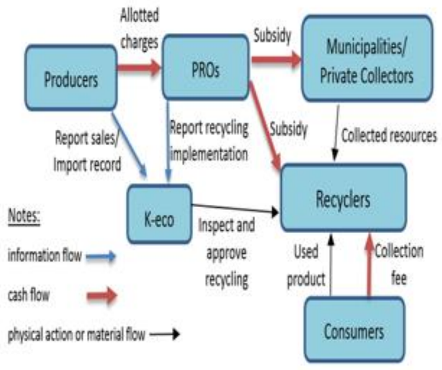
✅ Examples of PROs in India:

- Karo Shambhav
- Namo e-Waste
- CII-ITC Centre of Excellence for Sustainable Development (CESD)

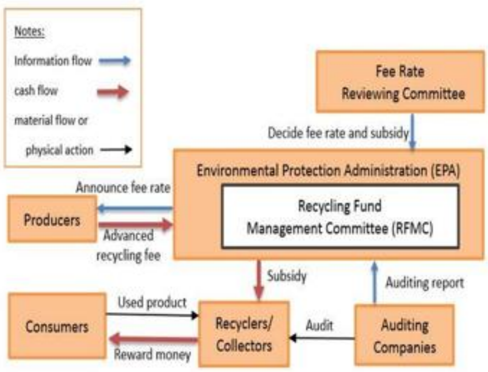
🔄 Importance of PROs:

- Eases the burden on individual producers.
- Promotes systematic and standardized e-waste flows.
- Enhances efficiency, transparency, and compliance in the ecosystem.

Example 1
EPR system in South Korea



Example 2
EPR system in South Korea



Module-4		
Q.7	**a**	**Explain key technique sustainable E -waste handling.**

Key Techniques for Sustainable E-Waste Handling

Sustainable e-waste handling refers to the systematic management of discarded electrical and electronic equipment in a manner that minimizes environmental harm, protects human health, and maximizes resource recovery. Based on established e-waste management frameworks, the following techniques are considered fundamental.

1. Extended Producer Responsibility (EPR)

Extended Producer Responsibility is a cornerstone of sustainable e-waste management. Under EPR, producers are made responsible for the collection, recycling, and environmentally sound disposal of end-of-life electronic products. This shifts the burden away from municipalities and encourages manufacturers to adopt eco-design, reduce hazardous substances, and improve recyclability. In India, EPR is mandated under the E-Waste Management Rules, promoting structured take-back systems and formal recycling channels

2. Formalized Collection and Channelization

A sustainable system requires organized collection mechanisms such as authorized collection centers, dealer take-back points, and bulk consumer returns. Proper channelization ensures that e-waste reaches registered dismantlers and recyclers instead of the informal sector, where unsafe practices dominate. Formal collection improves traceability, regulatory compliance, and material recovery efficiency

3. Environmentally Sound Recycling Technologies

The adoption of advanced recycling technologies—such as mechanical shredding, magnetic separation, hydrometallurgical, and pyrometallurgical processes—is critical. These methods enable safe extraction of valuable materials (gold, copper, rare earth elements) while minimizing toxic emissions.

		Sustainable recycling contrasts sharply with informal techniques like open burning and acid leaching, which pose severe environmental and health risks 4. Integration of the Informal Sector **In developing countries, informal recyclers handle a major share of e-waste. Sustainable handling strategies emphasize training, capacity building, and gradual integration of informal workers into the formal recycling ecosystem. This approach improves occupational safety, reduces pollution, and enhances overall recycling efficiency while addressing social equity concerns** 5. Circular Economy Practices **Sustainable e-waste handling is closely linked to the circular economy model, which prioritizes reuse, refurbishment, remanufacturing, and recycling. Extending product life cycles reduces raw material extraction and landfill pressure. Compared to the linear "take–make–dispose" model, circular practices significantly lower environmental footprints and support long-term sustainability goals** 6. Consumer Awareness and Participation **Consumer behavior plays a decisive role in sustainability. Awareness campaigns, labeling (such as the crossed-out wheeled bin symbol), and incentive-based return schemes encourage responsible disposal. Without informed consumer participation, even robust policy frameworks fail to achieve desired outcomes.**
	b	**Discuss hazards of improper E-waste handling and suggest safety measures.** 1. Hazards of Improper E-Waste Handling **Improper handling of electronic waste poses significant environmental, occupational, and public health risks due to the presence of hazardous substances and unsafe recycling practices.** 1.1 Environmental Hazards **E-waste contains toxic elements such as lead, mercury, cadmium, hexavalent chromium, and brominated flame retardants. When e-waste is dumped in open landfills or processed through informal methods such as open burning and acid leaching, these substances contaminate soil, groundwater, and surface water. Persistent pollutants bioaccumulate in ecosystems, leading to long-term ecological degradation and loss of biodiversity. Air pollution from burning insulated wires and plastics releases dioxins and furans, which are highly carcinogenic** 1.2 Human Health Hazards **Workers in informal recycling units are directly exposed to toxic fumes, heavy metals, and corrosive chemicals without protective equipment. Chronic exposure can result in respiratory disorders, neurological damage, kidney failure, reproductive toxicity, and increased cancer risk. Vulnerable populations, including women and children, are disproportionately affected in**

unregulated recycling clusters, making improper e-waste handling a serious environmental justice issue

1.3 Occupational and Safety Hazards

Manual dismantling without safety protocols exposes workers to cuts, burns, electric shocks, and musculoskeletal injuries. Handling batteries and capacitors without proper discharge mechanisms increases the risk of fires and explosions. The absence of standardized operating procedures further amplifies accident rates in informal recycling environments

1.4 Resource and Economic Loss

Improper disposal leads to the loss of valuable materials such as gold, silver, copper, and rare earth elements. Inefficient recovery not only increases dependency on virgin resource extraction but also results in economic losses, undermining the principles of sustainable resource management and circular economy practices

2. Safety Measures for Sustainable E-Waste Handling

2.1 Strengthening Formal Collection and Recycling Systems

Establishing authorized collection centers and ensuring proper channelization of e-waste to registered recyclers is essential. Formal recycling facilities use environmentally sound technologies that minimize emissions and safely manage hazardous fractions, thereby reducing health and environmental risks

2.2 Implementation of Extended Producer Responsibility (EPR)

EPR mandates producers to take responsibility for end-of-life management of electronic products. Effective EPR implementation improves take-back systems, enhances recycling rates, and incentivizes eco-design, reducing the toxicity and complexity of future e-waste streams

2.3 Occupational Health and Safety Measures

Workers involved in e-waste handling must be provided with personal protective equipment (PPE) such as gloves, masks, goggles, and protective clothing. Regular health check-ups, safety training, and mechanized dismantling processes significantly reduce occupational hazards.

2.4 Integration and Training of the Informal Sector

Given the dominance of informal recyclers in countries like India, integrating them into the formal system through training, certification, and financial incentives is critical. This approach improves safety standards while preserving livelihoods and increasing overall recycling efficiency

2.5 Public Awareness and Consumer Participation

Awareness campaigns educating consumers about hazardous impacts and safe disposal methods encourage responsible behavior. Incentive-based take-back

		programs increase participation and reduce the flow of e-waste into unsafe channels. 2.6 Regulatory Enforcement and Monitoring **Strict enforcement of e-waste management rules by regulatory bodies such as CPCB and SPCBs ensures compliance. Digital tracking systems and periodic audits improve transparency and accountability across the e-waste value chain**
OR		
Q.8	**a**	**Describe the role of classification of characterization in e-waste handling.** 1. Role of Classification in E-Waste Handling **Classification refers to the systematic grouping of e-waste based on product type, functionality, size, and hazard potential. It plays a critical role in organizing e-waste flows and determining appropriate treatment pathways.** 1.1 Regulatory Compliance **E-waste classification enables compliance with national and international regulations such as the E-Waste Management Rules and WEEE-type frameworks. Categorizing equipment into groups (e.g., IT and telecom equipment, consumer electronics, large household appliances) helps regulators define collection targets, recycling responsibilities, and reporting requirements** 1.2 Streamlined Collection and Segregation **Classification supports efficient segregation at the collection stage. Separating e-waste into categories such as hazardous components (batteries, CRTs, PCBs) and non-hazardous fractions reduces contamination risks and improves downstream recycling efficiency.** 1.3 Selection of Appropriate Recycling Technologies **Different categories of e-waste require different dismantling and recycling techniques. For example, printed circuit boards demand metal-recovery-intensive processes, whereas plastic-dominated equipment requires polymer separation and treatment. Classification ensures that e-waste is routed to suitable facilities using compatible technologies.**
		2. Role of Characterization in E-Waste Handling **Characterization involves the detailed analysis of the physical, chemical, and material composition of e-waste. It is essential for risk assessment, process optimization, and sustainability evaluation.** 2.1 Identification of Hazardous Substances **Characterization helps identify toxic constituents such as lead, mercury, cadmium, brominated flame retardants, and lithium compounds. Accurate**

		identification enables safe handling protocols, proper storage, and environmentally sound disposal, minimizing health and environmental risks 2.2 Resource Recovery and Economic Valuation **By quantifying valuable materials such as gold, silver, copper, aluminum, and rare earth elements, characterization supports efficient resource recovery and economic feasibility analysis. This information is crucial for designing recycling processes that maximize material yield and minimize losses.** 2.3 Process Design and Optimization **Detailed material characterization guides the selection of mechanical, hydrometallurgical, or pyrometallurgical recycling routes. It allows recyclers to optimize recovery efficiency, energy use, and emission control, contributing to environmentally sound recycling operations.** 2.4 Environmental and Health Risk Assessment **Characterization data are essential for evaluating potential leaching behavior, emission profiles, and exposure pathways. Such assessments inform regulatory standards, workplace safety measures, and environmental impact mitigation strategies.** 3. Integrated Role in Sustainable E-Waste Management **When combined, classification and characterization create a scientific decision-making framework for sustainable e-waste handling. Classification provides structural organization, while characterization delivers technical depth. Together, they:** ● **Enhance traceability and accountability under Extended Producer Responsibility (EPR)** ● **Support circular economy practices through targeted reuse, refurbishment, and recycling** ● **Reduce dependence on informal recycling by improving process efficiency and safety** ● **Enable evidence-based policymaking and monitoring**
	b	**Worker Safety Measures During E-Waste Handling** **E-waste contains hazardous substances such as lead, mercury, cadmium, brominated flame retardants and toxic fumes. Therefore, strict worker safety measures are essential during handling, dismantling and recycling.**

		1. **Use of Personal Protective Equipment (PPE):** Workers must use gloves, masks, goggles, protective clothing and safety shoes to avoid direct contact with toxic materials. 2. **Proper Training and Awareness:** Workers should be trained about hazards of e-waste, safe handling techniques, and emergency procedures. 3. **Safe Dismantling Practices:** Manual breaking, open burning of wires and acid leaching should be avoided. Only scientific and authorised recycling methods must be used. 4. **Ventilation and Dust Control:** Workplaces must have proper ventilation systems to reduce inhalation of toxic dust and fumes released during dismantling. 5. **Health Monitoring:** Regular medical check-ups should be conducted to detect respiratory, skin and neurological disorders at an early stage. 6. **Segregation of Hazardous Components:** Components like batteries, CRTs, PCBs and mercury lamps must be separated and handled carefully. 7. **Prohibition of Child Labour:** Children must not be engaged in e-waste handling due to severe health risks. 8. **Hygiene Facilities:** Availability of clean drinking water, washing areas and sanitation facilities to prevent contamination. 9. **Compliance with Safety Regulations:** Recycling units must follow E-Waste (Management) Rules and occupational safety norms. 10. **Formalisation of Recycling Sector:** Integrating informal workers into the formal sector improves safety, accountability and working conditions.

Module-5		
Q.9	**a**	**The RoHS (Restriction of Hazardous Substances) Directive is a regulation originally introduced by the European Union to restrict the use of certain hazardous substances in electrical and electronic equipment (EEE).** **Its main objective is to reduce environmental pollution, protect human health, and promote environmentally sound recycling of electronic waste.** **Restricted Substances under RoHS and Their Effects**

		Restricted Substance / **Effects on Human Health and Environment**

Restricted Substance	Effects on Human Health and Environment
Lead (Pb)	**Causes nervous system damage, kidney failure, brain disorders; contaminates soil and water**
Mercury (Hg)	**Damages brain and kidneys; affects fetal development; bio-accumulates in food chain**
Cadmium (Cd)	**Causes lung damage, bone fragility, kidney failure; highly toxic even in small amounts**
Hexavalent Chromium (Cr^{6+})	**Carcinogenic; causes skin ulcers, respiratory problems**
Polybrominated Biphenyls (PBB)	**Endocrine disruption; affects immune and nervous systems**
Polybrominated Diphenyl Ethers (PBDE)	**Hormonal imbalance; affects brain development and liver**
DEHP (Phthalate)	**Reproductive toxicity; developmental disorders**
BBP (Phthalate)	**Impairs fertility; endocrine disruption**
DBP (Phthalate)	**Causes hormonal imbalance and reproductive harm**

b

RoHS Compliance in India

India follows RoHS principles under the E-Waste (Management) Rules, enforced by the Ministry of Electronics and Information Technology (MeitY).

Key features of RoHS compliance in India:

1. **Restriction of hazardous substances in EEE similar to EU norms**
2. **Mandatory compliance for manufacturers, producers, and importers**
3. **Self-declaration and documentation of RoHS conformity**
4. **Monitoring by CPCB and SPCBs**
5. **Linked with Extended Producer Responsibility (EPR)**
6. **Focus on environmentally sound manufacturing and recycling**

		Comparison: India vs Global RoHS Standards

Aspect	India	Global (EU / International)
Legal framework	**E-Waste (Management) Rules**	**EU RoHS Directive**
Number of restricted substances	**Same core substances**	**Same + faster updates**
Enforcement	**Developing stage**	**Strict and mature**
Testing infrastructure	**Limited**	**Advanced laboratories**
Industry compliance	**Gradually improving**	**Highly standardized**
Market surveillance	**Moderate**	**Very strict**
Awareness level	**Growing**	**High**

OR

Q.10	**a**	

1. Collection and Transportation

- **E-waste is collected from households, industries, offices, and institutions.**
- **Collection is done through take-back systems, collection centers, bulk consumers, and authorized agencies.**
- **Proper labeling and safe transportation are essential to avoid breakage and release of toxic substances.**

2. Segregation and Sorting

- **E-waste is manually or mechanically sorted based on:**
    - **Type of equipment (IT equipment, household appliances, telecom devices)**
    - **Material composition (metals, plastics, glass)**

- **Hazardous components such as batteries, CRTs, and mercury lamps are separated first.**

3. Dismantling (First-Level Treatment)

- **Devices are dismantled manually or semi-mechanically.**
- **Components such as:**
  - **Printed Circuit Boards (PCBs)**
  - **Wires and cables**
  - **Plastics and metal frames**
 are separated.
- **Reusable parts are identified for refurbishment or reuse.**

4. Size Reduction and Mechanical Processing (Second-Level Treatment)

- **Dismantled parts are shredded or crushed into smaller pieces.**
- **Mechanical processes such as:**
  - **Magnetic separation (for ferrous metals)**
  - **Eddy current separation (for non-ferrous metals)**
  - **Screening and air classification**
 are used to separate materials.

5. Material Recovery (Third-Level Treatment)

- **Metals recovery:**
 Copper, aluminium, iron, gold, silver, and palladium are extracted using:
  - **Hydrometallurgical processes (acid leaching)**

		○ **Pyrometallurgical processes (smelting)** ● **Plastics recovery:** **Clean plastics are recycled, while contaminated plastics are treated or disposed of safely.** ● **Glass recovery:** **Glass from CRTs and screens is treated to remove lead and reused.** **6. Treatment of Hazardous Components** ● **Batteries, mercury lamps, and capacitors are treated separately using specialized processes.** ● **Toxic residues are disposed of in secured landfills or treated to neutralize harmful effects.** **7. Final Disposal** ● **Non-recyclable and toxic residues are disposed of in environmentally safe landfills.** ● **Emphasis is placed on minimizing landfill waste through maximum recovery.**
	b	**Describe major e waste recycling technologies . Compare their merits and limitations.** **E-Waste Flow and Recycling Scenarios in India** **1. E-Waste Flow in India:** **Generation: India is one of the largest producers of e-waste globally, generating over 3 million metric tons annually, mainly from discarded consumer electronics, IT equipment, and household appliances.** **Collection:** **Formal Sector: Less than 20% of e-waste is collected through formal mechanisms, like authorized e- waste collection centers and take-back programs by producers.** **Informal Sector: The remaining majority (~80%) is handled by informal recyclers, including scrap dealers and small workshops.** **Transport: E-waste is transported from consumers to collection centers or dismantling units.**

		Informal recyclers often use local networks for collection. **2. Recycling Scenarios in India:** **Formal Recycling: Authorized e-waste recyclers follow environmental regulations and use advanced technologies to recover valuable materials like gold, silver, copper, and rare earth metals. E-waste management rules (2016) encourage producers to partner with formal recyclers under Extended Producer Responsibility (EPR).** **Informal Recycling: Informal recyclers use rudimentary methods, such as acid leaching and open burning, to extract metals. These processes are hazardous to both human health and the environment, causing pollution and exposure to toxic substances like lead and mercury.** **3. Challenges in E-Waste Recycling:** **Lack of consumer awareness about proper disposal methods. Limited infrastructure for formal recycling, especially in rural areas. Inadequate enforcement of e-waste management rules, allowing informal recycling to dominate.** **4. Emerging Trends:** **Growth of formal e-waste recycling units with better technology and adherence to environmental norms. Increasing partnerships between producers and recyclers under EPR to improve collection and recycling efficiency.** **Implementation of e-waste take-back campaigns by companies like Nokia and Dell to promote safe disposal.** **E-Waste Recycling Process** **Segregation:** **E-waste is sorted manually or mechanically into categories such as plastics, metals, and glass.** **Dismantling:** **Devices are dismantled to extract usable components like circuit boards, cables, and batteries.** **Formal Recycling:** **Advanced technologies such as shredding, magnetic separation, and hydrometallurgical processes are used to recover valuable materials safely.** **Recyclers ensure proper disposal of hazardous substances.** **Informal Recycling:** **Hazardous practices like acid leaching and open burning are used to recover metals like gold and copper, causing pollution and health risks.**

		Material Recovery: **Precious metals (gold, silver) and base metals (aluminum, copper) are recovered, and plastics are often repurposed for other products.** **Limitations in E-Waste Management** **❖ Lack of Consumer Awareness: Many consumers are unaware of formal collection centers or the environmental hazards of informal recycling.** **❖ Dominance of Informal Sector: Informal recyclers handle approximately 80% of e-waste, using hazardous practices like acid leaching and open burning.** **❖ Insufficient Infrastructure: Limited formal collection and recycling facilities, especially in rural and semi-urban areas.** **❖ Regulatory Challenges: Weak enforcement of e-waste management rules and lack of monitoring mechanisms.** **❖ High Costs: Formal recycling technologies are expensive, making them less competitive compared to the informal sector.** **❖ Fragmented Supply Chain: Lack of a cohesive and efficient supply chain for collection, transportation, and recycling of e-waste.** **❖ Producer Accountability: Non-compliance by many manufacturers with EPR obligations.**