



## **SDG 12, responsible consumption and production:**

### **Ensure sustainable consumption and production patterns**

#### **E-Waste Management**

##### **Turning E-Waste into Strategic Value**

Electronic waste has become one of the fastest-growing and most complex waste streams worldwide, driven by rapid digitalisation, electrification, and the proliferation of connected devices. In 2022, global e-waste reached 62 billion kg, an average of 7.8 kg per person, yet only 22.3% was formally collected and recycled in environmentally sound conditions. This imbalance is widening: while formal recycling volumes have grown from 8 billion kg in 2010 to 13.8 billion kg in 2022, e-waste generation has outpaced them by a factor of five, and projections indicate a surge to 82 billion kg by 2030 if current trends persist. E-waste is not merely a disposal challenge – it is a paradoxical mix of opportunity and risk. On the one hand, it contains 31 billion kg of metals, 17 billion kg of plastics, and other valuable materials worth an estimated USD 91 billion; on the other hand, mismanagement releases 58,000 kg of mercury and 45 million kg of toxic plastics annually, imposing severe health and environmental costs. Beyond the immediate hazards, the failure to recover critical raw materials undermines supply chain resilience for renewable energy and digital technologies. Addressing this challenge requires a systemic shift from linear consumption to circular resource management, positioning e-waste management as a strategic lever for sustainability, climate action, and economic competitiveness.

The economic and environmental stakes are significant. Current practices impose USD 78 billion in externalised costs on health and the environment, plus USD 10 billion on treatment costs, resulting in a net global loss of USD 37 billion. These costs stem from toxic emissions, plastic leakage, and greenhouse gases from refrigerants. Conversely, effective e-waste management offers substantial benefits: recycling avoids 900 billion kg of ore extraction and 52 billion kg of CO<sub>2</sub>-equivalent emissions, while compliant refrigerant management prevents an additional 41 billion kg of CO<sub>2</sub>-equivalent emissions. Under an aspirational scenario where global formal recycling reaches 60% by 2030, net benefits could exceed USD 38 billion annually, driven by higher resource recovery and reduced externalities. E-waste management is therefore not just an environmental necessity – it is a strategic opportunity to unlock economic value, secure critical raw materials, and advance global sustainability goals.



Despite its potential, the e-waste ecosystem faces structural gaps. Collection and recycling rates vary widely: Europe leads with 42.8%, while Africa remains below 1%. Only 81 countries have e-waste legislation, and just 46 set collection targets. Informal recycling dominates in many low-income regions, recovering some metals but using unsafe methods such as open burning and acid leaching. Consumer behaviour compounds the problem: small devices and lamps, which account for a large share of e-waste, have global recycling rates of only 12% and 5%, respectively. Transboundary flows add complexity – 5.1 billion kg of e-waste were shipped across borders in 2022, with 65% moving through uncontrolled channels. In the EU, the WEEE Directive (2012/19/EU) and its 2024 amendment impose strict obligations on producers under Extended Producer Responsibility (EPR), yet most member states fail to meet the 65% collection target, highlighting the urgency for harmonised and enforceable frameworks.

These challenges demand coordinated action across the value chain: product design for durability and recyclability, robust EPR systems, convenient collection infrastructure, advanced treatment technologies, and formalisation of the informal sector. To ensure accountability and measure progress, clear performance indicators must guide implementation. Success will be reflected in higher global collection and recycling rates, measured as a percentage of e-waste generated and kilograms per capita collected. Environmental impact should be tracked through reductions in mercury emissions, plastics containing brominated flame retardants, and CO<sub>2</sub>-equivalent emissions avoided. Economic performance will be assessed by the value of recovered metals, which should rise from USD 28 billion today to more than USD 50 billion by 2030, and by the shift from a net global loss of USD 37 billion to a positive balance exceeding USD 30 billion. Social and governance indicators will include the number of informal workers integrated into formal systems, compliance rates among producers under EPR schemes, and the proportion of transboundary shipments documented under international conventions.

Looking ahead, three scenarios illustrate the stakes. A business-as-usual trajectory would see formal recycling stagnate at 20% and global losses deepen to USD 40 billion annually. A progressive scenario, with rates rising to 38%, would bring the system close to break-even. An aspirational pathway, achieving 60% formal recycling, would deliver net benefits of USD 38 billion per year. Realising these outcomes requires coordinated investment, robust legislation, and active public engagement. Governments, producers, and recyclers must collaborate to build circular systems that recover resources, minimise hazards, and create inclusive economic opportunities. E-waste management is not merely a compliance issue – it is



a strategic lever for sustainability, climate resilience, and competitiveness in a resource-constrained world.

The complexity of e-waste management becomes evident when we move from global targets to operational realities. Electronic waste is not a uniform stream; it is a heterogeneous mix of metals, plastics, glass, and hazardous substances embedded in intricate designs. Among the most challenging components are Printed Circuit Boards (PCBs), which serve as the backbone of modern electronics. They contain significant amounts of copper, tin, aluminium, and silicon, alongside precious metals such as gold and silver, but these materials are locked within resin matrices and layered structures that complicate recovery.

Efficient recycling strategies must therefore go beyond generic approaches. Studies of material composition reveal substantial variability between different PCB types – motherboards, RAM modules, and CPUs – and even among models within the same category. Copper content, for example, can range from 6% to over 26%, while silicon and aluminium fluctuate similarly. These differences have direct implications for recovery economics: treating all PCBs as equal leads to wasted resources and missed opportunities. Tailored strategies, informed by precise data, are essential to maximise recovery rates and profitability.

Technology offers solutions, but not without trade-offs. Hydrometallurgical processes, widely used for metal recovery, achieve moderate efficiency when applied to untreated PCB fragments. Introducing a solvent pre-treatment phase can dramatically improve outcomes – raising copper recovery from below 50% to nearly 88% for mid-sized particles and even 100% for fine powders. Yet these gains come at a cost: additional chemicals, energy consumption, and operational complexity. Decision-makers must weigh these factors carefully, considering not only technical feasibility but also environmental impact and economic viability. This is where integrated decision-support tools become critical. Systems that consolidate knowledge across the material, process, and hazard domains can guide stakeholders towards optimal solutions, aligning operational choices with circular economy principles.

### **Strategic Outlook**

E-waste management is more than a compliance obligation; it is a strategic opportunity to transform a growing environmental challenge into a source of economic and technological advantage. The path forward demands a shift from fragmented practices to data-driven, systemic solutions. Companies that invest in advanced recovery technologies, precise material characterisation, and integrated decision-making frameworks will not only reduce



environmental risks but also secure access to critical raw materials and strengthen their position in a resource-constrained economy. For policymakers, the imperative is clear: foster collaboration between industry and research, incentivise innovation, and enforce standards that promote transparency and circularity. For future leaders, the challenge is to think beyond recycling as a technical process and embrace it as part of a broader sustainability strategy – one that balances environmental responsibility with economic competitiveness. E-waste is both a challenge and an opportunity; the question is whether we can turn this paradox into a model for sustainable growth.

### Questions

1. Why is e-waste described as a ‘paradoxical mix of opportunity and risk’?
2. What are the estimated economic losses and potential benefits associated with current and improved e-waste management practices?
3. What role do regulations and producer responsibility play in shaping sustainable e-waste practices?
4. List three structural challenges in the global e-waste ecosystem.
5. What makes managing e-waste particularly complex compared to other types of waste?

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