



# Unlocking the supply of e-waste for materials recovery: Regulatory complexity in transboundary movement

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## Table of Contents

1	Transboundary movement of e-waste
1	Advanced disassembly of e-waste for efficient material recovery
2	Barriers posed by diverse regulations on e-waste movement
3	Mixed waste streams and challenges to recycling
4	The need to standardize the logistics of e-waste movement
6	References

## Transboundary movement of e-waste

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Globally only about 17% of e-waste generated was collected and recycled in 2019, with the remaining landfilled, reused or recycled informally, largely in developing regions [1]. While global e-waste generation has grown by an astounding 9.2 Mt between 2014 and 2019, e-waste recycling grew only by 1.8 Mt [1].

A key challenge to unlocking the supply of e-waste for materials recovery is the regulatory complexity associated with transboundary movement of e-waste.

International waste management policies such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989) and The Organization for Economic Co-operation and Development (OECD) Council Decision (2001-107/FINAL) aim to protect human health and the environment from the adverse impacts of hazardous waste management by controlling its transboundary movement. Both the Basel Convention and the OECD Council Decision have been successful in setting global norms for environmentally sound e-waste management and developing multi-stakeholder partnerships to innovate sustainable approaches to emerging waste challenges. Examples include: the Basel Convention's Partnership for Action on Computing Equipment (PACE) to develop tools and facilitate training on environmentally-friendly refurbishment and recycling of e-waste particularly in developing countries; and 'pre-consented recovery facilities' designated by the OECD Council Decision to promote recovery of recyclable materials from waste in OECD member countries. However, international and national waste management policies often create unintended barriers to export and import of end-of-life recyclable products and components, with a general trend towards keeping resources within domestic boundaries [2]. Issues such as discrepancies in definitions and classification of equipment, non-standardized protocols, administrative challenges with tracking waste and non-uniform enforcement of regulations, often lead to unanticipated delays and cost increases in e-waste movement [3], thus posing barriers to developing a reliable supply of secondary materials from e-waste.

## Advanced disassembly of e-waste for efficient material recovery

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Advanced technical capabilities that use robotics and automation to disassemble end-of-life electronic products into components can enable efficient material recovery. For example, Apple's Daisy robot is capable of disassembling 23 models of iPhone, including all models between iPhone 5 to iPhone 12. One metric ton of iPhone main logic boards, flexes, and camera modules recovered by Daisy is equivalent to more than 2000 metric tons of mined rock in terms of gold and copper recoverable [4]. Sourcing post-consumer recycled materials from a brand's own end-of-life products is a critical pathway to recover custom alloys (e.g. 100% recycled aluminum in Apple products) as well as materials traditionally not recycled (e.g. rare earth elements, tungsten, and tantalum). Apple reports that the Daisy robot allows targeted disassembly of iPhones and enables recovery of materials that would otherwise be lost in markets and systems optimized to recover primarily high value materials such as precious metals, copper and steel. But for the first few years of operation, the Daisy robot only processed

iPhones collected domestically in the Netherlands due to restrictions within the EU on cross-boundary movement of post-consumer end-of-life electronics.

Moving feedstock (i.e. end-of-life phones to disassembly facilities and disassembled components to recyclers) throughout the globe is heavily burdened by permits and regulations blocking critical circularity pathways.

## Barriers posed by diverse regulations on e-waste movement

The Basel Convention, the OECD Council Decision, and the EU Waste Shipment Regulation are key legislations governing the transboundary movement of e-waste in Europe. The European Union Waste Shipment Regulation (EU WSR) makes the OECD Council Decision and the Basel Convention legally binding for EU Member States.

The diversity of regional legislation governing e-waste movement across Europe has led to varying definitions and classification of e-waste.

The EU WSR classifies e-waste by component (e.g. printed circuit boards) and not by material like the OECD Council Decision and Basel Convention (e.g. mercury), which results in irregularities in data collection and reporting [5]. The OECD Council Decision is considering classifying electronic waste suitable for material recovery in the ‘amber’ or sufficiently high risk category [6]. Thus e-waste may be subject to strict control through official notifications and licensing requirements, with an added caveat that special requirements for different member countries may also need to be met [7].

Contractual requirements and transactional details needed for transport (e.g. terms of shipment, liability of waste, etc.) vary depending on national legislation, and thus logistical success in transboundary shipment of e-waste varies by country.

Shipment from certain countries (e.g. Denmark and more recently Germany) to the Netherlands, where the Daisy robot is located, has been enabled by targeting specific authorities and developing key administrative contacts. However, many countries promote their domestic e-waste material recovery industry (e.g. Czech Republic and its Secondary Raw Materials Policy [8]) and discourage export of e-waste. Differences in documentation for e-waste transport required by different legislations often lead to delays in interpretation of policies and licensing, which in turn increases costs of transboundary transport. For example, the EU WSR [9] establishes an EU-wide procedure of written notification that includes requirements for a financial guarantee that covers waste shipment, storage, and processing costs; after the withdrawal of the UK from the EU in 2020, exports from the UK are subject to the Basel Convention that defers to national legislation for financial guarantees for transboundary transport. This shift in contractual requirements and the resulting differences in the issuance of financial guarantees and notifications of consent between the UK and the Netherlands led to an impasse in e-waste movement between the UK and disassembly facilities in the Netherlands.

Similar challenges exist across the globe. In the US, regulations vary by State and so do rules of classification of e-waste [10]. For example, the State of California considers electronic waste ‘universal waste’, a category of hazardous waste, and has strict regulations around who can transport and receive such waste, being the first State in the US with severe restrictions on overseas export of e-waste to developing countries [11], while others such as Texas (where end-of-life iPhones are robotically disassembled in the US) defer to federal regulations which are not comprehensive or explicit in coverage of e-waste. There is no federal law on recycling e-waste and the Resource Conservation and Recovery Act (1976) only regulates certain e-waste classified as ‘hazardous’ based on the toxicity of material components, such as cathode ray tubes [10]. All the way across the world, China as a signatory to the Basel Convention banned the import of e-waste in 2000, but exercises import controls only on mainland China. Under China’s ‘One Country, Two Systems’ policy, Hong Kong, which is responsible for implementing its own controls on transboundary movement and allows licensed import of e-waste, initially (in the 2000s) created a channel for e-waste imports into China through Hong Kong. However, stringent controls on transboundary transport to mainland China over the last decade has resulted in dumping of e-waste in Hong Kong [12], [13]. In Hong Kong, e-waste is known to be processed in unsafe working conditions [14], and thus differences in legislation have created a loophole in the accountability mechanism the Basel Convention is intended to provide.

Outbound movement of disassembled components to recyclers located in other countries is still largely blocked by regulation. In 2019, less than 10% of total global e-waste generated (53.6 Mt) crossed country borders, and of this only a third was shipped in a controlled manner (~3% of total e-waste generated) while the remaining moved illegally [1]. The Basel Convention classifies e-waste containing certain materials (e.g. mercury) as hazardous and institutes restrictions and prior consent procedures on transboundary waste movement. The Philippines is a signatory to the Basel Convention and restricts the import of e-waste, considered hazardous by the Department of Environment and Natural Resources in the Philippines [15] and a fast growing problem in the country, to a few categories such as scrap metals. Additionally, the Basel Convention does not allow trade between member and non-member parties such as the US; similar restrictions are in place within the framework of OECD, where the US is a member but not the Philippines. Both Basel Convention and OECD Council Decision restrict transboundary movement of waste to member parties, with EU law banning export of hazardous waste to non-OECD countries [9]. Thus, disassembled e-waste components such as iPhone audio and haptics modules that can be processed by specialty recyclers in the Philippines to recover rare earth elements currently cannot be legally exported from disassembly locations in the Netherlands and the US.

While existing legislations serve to prevent the harmful effect of processing hazardous waste, particularly exported from developed to developing countries, they also act as barriers to transboundary movement when materials can be recovered in an environmentally sound manner.

## Mixed waste streams and challenges to recycling

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E-waste recycling facilities that extract materials from components are hindered by the mixed nature of waste streams which include a wide and unspecified range of product composition and contaminants, and are often economically unviable due to low profit margins and high labor

costs [16], [17]. This results in low investment in new sorting and separation technologies and in turn leads to a limited range of materials recovered at these facilities, with loss of materials such as rare earth elements, tungsten and tantalum during the recovery of precious metals, copper, aluminum and steel. Recyclers also have to deal with evolving product composition and complexity in materials and assembly across brands. In a traditional electronic waste recycling process a product's battery is manually removed, and then the rest of the device is shredded in an attempt to liberate the materials. Modern electronics are often highly integrated, and shredding does not adequately break apart the individual target materials in a way that makes them separable afterwards. The result is that output fractions from shredding and sorting processes have high contamination rates of non-target materials. For example, a magnetic separator may remove a piece of aluminum which still had a single steel screw in it, resulting in the loss of that aluminum to the steel recycling process. New and widely adoptable approaches are needed to first disassemble the devices into more discrete pieces, followed by advanced sorting systems which more accurately sort these pieces into output fractions that maximize the overall recovery of target materials. However, this in turn needs cross-industry efforts on transparency of product compositions to develop economies of scale and higher volumes of secondary material supply.

One way of sharing information across supply chains is by digitizing processes and making product composition data electronically accessible to enable recovery of key materials and improve traceability through the supply chain. Easily accessible data on cross-industry product composition would allow e-waste recyclers to optimize end-of-life recovery processes and maximize material recovery and safe handling; moreover, data on volume of devices by brand would highlight opportunities for recovery. But traceability mechanisms such as digitized processes need to be feasible to implement and not inhibit material recovery through unintended administrative barriers.

## The need to standardize the logistics of e-waste movement

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Even when specialty recyclers have the necessary technology to recover specific or a wide range of materials, acquiring permits and certification is an additional cost and regulatory barrier to e-waste recycling across the globe. For example, national legislations require tracking physical documentation for transboundary movement of e-waste from China to Japan [18], [19], which has led to delays in processing permits from Japan's Ministry of Environment and China's Ministry of Ecology and Environment. Standardized processes along with digital tracking would enhance the efficiency of the process.

Policy frameworks governing transboundary movement of e-waste could play a significant role in expanding the material recovery economy by implementing standardized definitions and protocols and electronic permit approval systems, digitization of transport logistics, improving availability of global data on recyclers and recovery rates for different materials, and enabling the targeting of recyclers for recovery of specific materials.

Instituting global 'resource recovery lanes' (such as those recommended by the OECD Council Decision for waste movement between member countries) that allow auto-processing of permits for pre-consented materials and best-in-class recyclers would help optimize the handling of specific materials for efficient, environmentally sound resource recovery. Developing traceable systems for transboundary movement can increase the supply of e-waste for responsible material recovery without blocking the movement of e-waste. Such systems can help track national regulatory changes and testing requirements by including definitions and classifications of waste, and recycling standards and capabilities across countries, and ensure material recovery occurs in an environmentally and socially sustainable manner.

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