International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Address: IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria
Email: permissions@iiasa.ac.at

Young Scientists Summer Program

From Waste to Resource? Obstacles and Leverage Points for a more Sustainable and Circular E-waste Management in the EU

Nora Krenmayr
nora.krenmayr@boku.ac.at

Approved by:

Mentors: Adriana Gomez Sanabria and Pallav Purohit
Program: PM-ECE
Date: 30/09/2022

This report represents the work completed by the author during the IIASA Young Scientists Summer Program (YSSP) with approval from the YSSP mentor.

It was finished by October 6th 2022 and has not been altered or revised since.

Mentor signature:

Table of contents

ZVR 524808900

Abstract

Waste from electrical and electronic equipment (WEEE or e-waste) is one of the fastest-growing waste streams and contains both toxic chemicals as well as precious metals (gold, silver, iron, aluminum, and copper) and plastics. Therefore, e-waste management and recycling pose a unique conundrum of economic incentives and environmental and health hazards. Europe has a high per capita production of e-waste but also shows the highest formal collection and recycling rate globally with 42.5%. This can be attributed to EU policies, pursuing a collection rate of 65 % and setting targets for reuse and recycling for different categories of WEEE, as part of efforts towards building a circular economy through higher resource efficiency. The exploratory study aims to identify obstacles and leverage points for the implementation of these targets and follows a qualitative research design, including a literature review, document analysis, and fourteen semi-structured expert interviews.

About the author

Nora Krenmayr holds a BA in International Development from the University of Vienna and obtained her MSc in Social and Human Ecology from Alpen-Adria University in 2020. Currently, she is a first-year Ph.D. student in the Doctoral School of Social Ecology at the University of Natural Resources and Life Sciences, Vienna (BOKU). She carries out Ph.D. research under the supervision of Prof. Christoph Görg in the project "Challenges for Social-Ecological Transformations – Addressing institutional dimensions of long-term and global resource use" funded by the Austrian Science Funds (FWF). (Contact: nora.krenmayr@boku.ac.at)

Acknowledgments

I thank my mentors Andriana and Pallav for their valuable feedback during the summer and the members of the ECE group, who took the time to come to the YSSP rehearsal presentations and social events. I enjoyed the talks and interactions very much. My fellow YSSPers I am immensely grateful for making everyday life in the office so joyful during the summer.

Introduction

Digitalization is a dominant driver of transformation changing global production networks while impacting national and international socioeconomic power structures. Digitalization and the service is or are often regarded not only as important potential contributors to resource efficiency and relative decoupling of gross domestic product (GDP) and resource use but also as harbingers of absolute decoupling, allowing for continued GDP growth while resource use declines. However, so far digitalization has led to increased energy consumption and the prospect of absolute decoupling seems unlikely under current conditions (Lange, Pohl, and Santarius 2020). Moreover, the amount of resources and energy necessary for the production of information communications technology (ICT) 'hardware' and its usage is often underestimated.

Waste from electrical and electronic equipment (WEEE or e-waste) is a major environmental polluter, that has been widely overlooked in debates about sustainability and digitalization but recently gained attention as part of the circular strategy. E-waste includes discarded computers, monitors, motherboards, mobile phones and chargers, headphones, television sets as well as air conditioners and refrigerators. These appliances contain both toxic chemicals and hazardous pollutants as well as precious metals (gold, silver, iron, aluminum, and copper) and plastics (Ilankoon et al. 2018). Therefore E-waste recycling poses a unique conundrum of economic incentives and environmental and health hazards (Theis 2021). According to the Global E-Waste Monitor 53.6 Mt of e-waste is produced annually (Forti et al. 2020). This is projected to grow to 74.7 Mt by 2030, making it one of the fastest-growing waste streams both globally and in Europe (ibid.).

This exploratory study identifies obstacles to the adoption of circular and sustainable E-waste Management in the EU and provides leverage points for policymakers and stakeholders. The study follows a qualitative research design, including a literature review, document analysis, and fourteen semi-structured expert interviews. The guiding research questions are:

1. Who are important stakeholders?
2. How are collection and recycling structures, recycling work, and e-waste flows changing because of new regulations and recycling techniques?
3. What are the technical and regulatory constraints of better e-waste management?
4. What policies need to be implemented?

Global Movement and Recycling of E-Waste

Currently, over 80 percent of e-waste flows (44.3 megatons) are not accounted for in the global accounts. The volume of (illegal) transboundary movements of e-waste is estimated to be 7-20 percent (Forti et al. 2020). Since 1989, the objective of **the Basel Convention** has been to control transboundary movements of hazardous wastes and their disposal (UNEP 2010). Yet it is unclear whether the convention accurately addresses the bulk of flows amidst changing trade patterns (Lepawsky 2018). The problem is often framed in terms of the dumping of e-waste by the Global North in countries of the Global South (Petridis, Petridis, and Stiakakis 2020). Such trade does occur but a more nuanced interpretation of the international trade in e-waste is needed as patterns of trade have evolved markedly over the last decades (Lepawsky 2014).

The data on exported e-waste is limited as they only show estimated flows based on global trade data (Eurostat, COMTRADE) - taking information about the production or sales of new products and making assumptions for device lifetime and prevailing export practices per country. These assumptions rely on a qualitative investigation of the geographic routes and exchanges. Yet for illicit trade, shipping containers may bounce from port to port without any control, making it impossible to track and monitor the movement of illegal waste (Lee et al. 2018). Further, the existing trade data contains no specific commodity codes related to reuse, repair, refurbishment, or, recovery (Lepawsky 2014). However, repairing and refurbishing ICT for resale is common practice in the Global South and prolongs the value of the product and materials (Corwin 2018). Along with disassembly for material recovery, this work provides jobs and income along with cheap access to technology on the second-hand market (Lee et al. 2018).

Globally practices in recycling e-waste vary greatly. Manhart (2011: 18-20) distinguishes three types of recovery approaches that are present in different world regions and notes that the boundaries between the recycling systems are blurred.

Type 1: Low-tech, low yields, severe pollution - Africa

Here the focus is on refurbishing spare parts with limited technological know-how. Typically, only easily accessible metal fractions are recovered manually in labor-intensive and informal backyard industries. For example, the burning of cables to recover copper. Other fractions are disposed of or burned which is associated with severe pollution, and health impacts on workers and communities.

Type 2: Mid-tech, medium yields, extreme pollution - China, India

The process is mostly focused on gold and no other precious materials are recovered by manual dismantling followed by wet chemical leaching to recover gold from Printed Circuit Boards. However, the yields of gold are low (36-60%) and therefore economically unprofitable. For the informal sector, however, this activity can generate some profit due to lower labor costs but at the expense of negative health and environmental impacts.

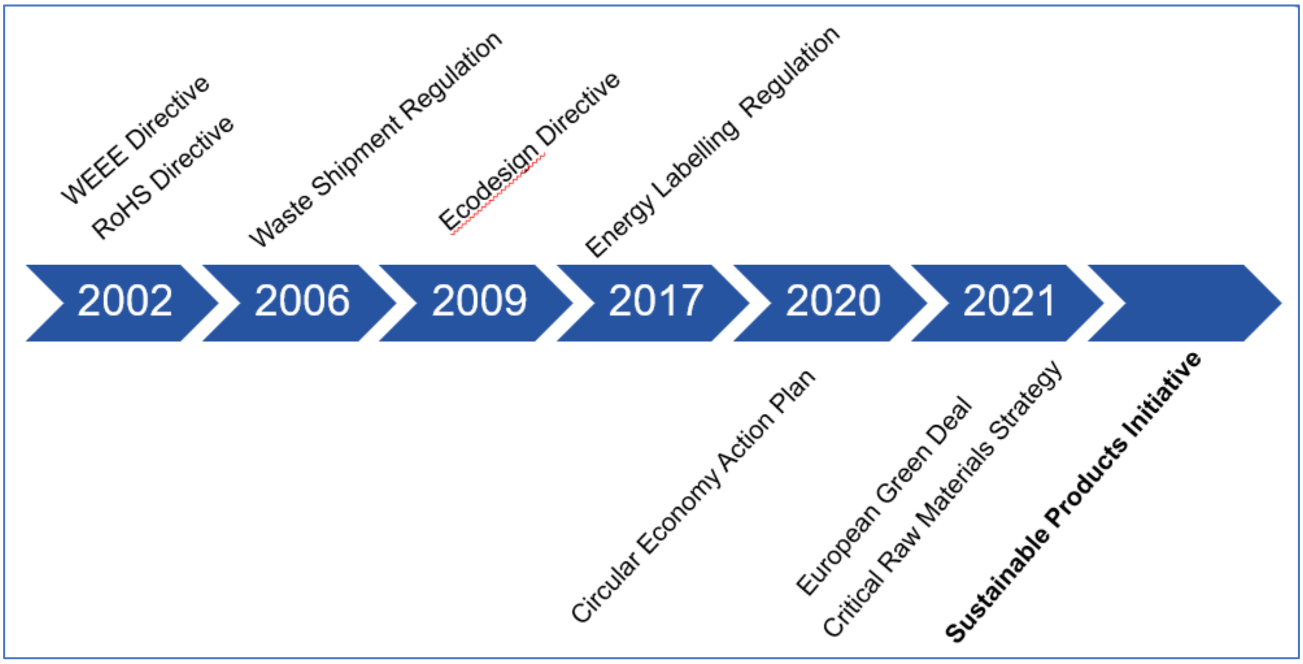
Type 3: High-tech, high yield, low pollution - Global North

Manual disassembly and sorting are kept to a minimum due to high labor costs. After the mechanical pre-treatment, the separate treatment of different fractions takes place in specialized facilities. In metallurgic refining processes, the recovery rates for copper and precious metals are above 95%. However, there are still technical limits that lead to the loss of metals into other fractions, which are estimated to be 20% of the input material. The output fractions are not perfectly pure due to mechanical shredding and sorting. The smelters require high investments, therefore, economies of scale are important, and currently, only 5-10 plants exist at a global level.

E-waste in Europe

In the literature, Europe is named the leading collector of E-waste (Shahabuddin et al. 2022) and the categorization of the WEEE has been a role model for E-waste related legislation globally (Borthakur 2020; 2022; Murthy and Ramakrishna 2022). Though Europe has the highest per capita production of e-waste (16.2 kg/inch), it also shows the highest formal collection and recycling rate with 42.5% (Forti et al. 2020). This can be attributed to EU policies as part of efforts toward building a circular economy through higher resource efficiency, constituting a clear shift in the European discourse from merely treating e-waste as 'waste' to e-waste as a potential 'resource' (Theis 2021). However as only 42% of E-waste in the EU is documented to be recycled in environmentally sound facilities, the fate of 58% of E-Waste is unknown (Baldé et al. 2022). The Countering WEEE Illegal Trade Project found that the E-waste that is not accounted for is either recycled under non-compliant conditions in Europe, scavenged for valuable parts, simply thrown in waste bins, or exported – which is estimated to be 1.3 Mt (CWIT 2015). The high cost of treatment and proper disposal of refuse from recycling and unprocessed material results in high quantities of E-waste being exported (Salhofer et al. 2016; Ilankoon et al. 2018). In 2019 only 2-17 kt was estimated to be seized as illegal e-waste, which is probably only a small amount of the uncontrolled shipments from the EU. Inspection capacities are limited and do not keep up with the overall movement (Baldé et al. 2022). Uncontrolled exports of used EEE or e-waste from Europe happen intercontinental (e.g. to Africa), but also exist as an intraregional movement from Europe toward Eastern Europe, which is emerging as an import hotspot (Baldé et al. 2022).

Important EU legislation and strategic documents



Graph 1. EU legislation and strategic documents, own illustration.

The **Restriction of Hazardous Substances Directive** (RoHS 2002a) regulates the use of hazardous substances in products and the **Waste Electronic and Electrical Equipment Directive** (WEEE 2002b) sets recycling targets and makes producers and distributors responsible for collection and recycling. The **Waste Shipment Regulation** (European Commission 2006b) is the European implementation of the Basel Convention.

The **Ecodesign Directive** (2009) and the **Energy Labeling Regulation** (2017) addressing energy-related products have achieved substantial energy savings in the past but focused mainly on the use phase of products (Schlegel, McAlister, and Spiliotopoulos 2019). The **Sustainable Products Initiative** (SPI) with its product category on electronics & ICT equipment builds on Ecodesign Directive and Energy Labeling Regulation and can be seen in the context of the **Circular Economy Action Plan** (European Commission 2020) and **European Green Deal** (European Commission 2021b)**.** The proposal for SPI by the Commission was published in March 2022 and until June 2022 there was a public consultation process. The proposed regulation aims to further promote the durability, repairability, and recyclability of products, enhance resource efficiency in addition to energy efficiency and boost circular business models (European Commission 2022b).

An important and highly discussed part of the Sustainable Product Initiative is the **Digital Product Passport**, a mandatory tool that will require end products to disclose information on components and recyclability potential and enable tracking of substances along the supply chain (European Commission 2022a). Further, the **Right to Repair** which already exists for washing machines, dishwashers, refrigerators, televisions, and lighting for up to ten years, shall be extended to smartphones, laptops other small electrical devices; including a right to update obsolete software. The current discussion revolves around the concrete form of repair, whether it shall be possible to be undertaken by non-professionals, and whether spare parts and manuals are made available directly to the consumers as advocated by consumer organizations. Business organizations hold against that, with the argument that intellectual property shall not be compromised and are in favor of professional repairs (European Parliament 2022a).

A recent success was the agreement on new rules for a **common charger** in June 2022 by European Parliament and Council. From autumn 2024 onwards there shall be only one single charger for small and medium-sized portable electronics (USB Type-C) and buyers are going to be able to choose if they purchase a new device with or without a charging device. The rule will apply to mobile phones, tablets, e-readers, earbuds, digital cameras, headphones and headsets, handheld videogame consoles and portable speakers and laptops will have to be adapted to the requirements 40 months after the entry into force (European Parliament 2022b). In the last decade, the number of mobile phone chargers was already limited from 30 to 3 by a voluntary approach working together with the industry, but a complete solution could not be reached due to disagreement by some companies arguing that innovation could be hampered. Therefore, the Commission finally proposed legislation for one common standard for chargers, stating that "if a new standard emerges that is better than USB-C, we can adapt the rules." (European Parliament 2021)

Categorization of E-Waste

Since the reference year, 2019 WEEE is classified within 6 product categories (**Eurostat** 2022)

1. Temperature exchange equipment
2. Screens, monitors, and equipment containing screens having a surface greater than 100 cm2
3. Lamps
4. Large equipment (any external dimension more than 50 cm) including, but not limited to: Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure, and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3.
5. Small equipment (no external dimension more than 50 cm) including, but not limited to: Household appliances; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure, and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6.
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)

Until the year 2018 WEEE was divided into 10 product categories:

1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment and photovoltaic panels
5. Lighting equipment
6. Electrical and electronic tools (except large-scale stationary industrial tools)
7. Toys, leisure, and sports equipment
8. Medical devices (except all implanted and infected products)
9. Monitoring and control instruments
10. Automatic dispensers

Please note that there are separate directives in place for *batteries and accumulators* (European Commission 2006a) and *End-of-Life Vehicles* (European Commission 2000), which are currently both undergoing revision processes. In a recent position paper, *the European Electronics Recyclers Association* (EERA) calls for an integration of the End-of-Life Vehicles directive the and WEEE directive due to the increase of electrical parts in vehicles. Further, the paper states that a better categorization of WEEE is needed to ensure proper recycling concerning the quality of recovery of critical raw materials. Currently, there exists divergence between different countries and some member states use a combination of the previous and recent WEEE categories. EERA criticizes the current classification according to size (small and large equipment) as it leads to a mix of products with components and materials that are not comparable. The recovery of critical raw materials would be easier within product groups with similar content that requires the same processing methods (EERA 2022).

Collection and Recycling of E-Waste in the EU

The WEEE Directive sets an overall collection target and individual targets for the reuse, recovery, and recycling of the six different categories of E-Waste.

The **reuse and recycling rate** is calculated by dividing the weight of WEEE that enters the recycling/preparing for re-use facility by the weight of all separately collected WEEE (both in mass unit) considering that the total amount of collected WEEE is sent to treatment/recycling facilities (Eurostat 2020).
The **collection rate** equals the volumes collected of WEEE in the reference year divided by the average quantity of electrical and electronic equipment (EEE) put on the market in the previous three years (both expressed in mass units). The minimum rates for the collection of WEEE increased in 2019 from 45% to 65% "of EEE put on the market, calculated based on the total weight of WEEE collected and the average weight of EEE put on the market in the three preceding years - OR 85% of WEEE generated on the territory of that Member State" (Eurostat 2018).

In Europe, WEEE collection is mainly based on existing **municipal collection schemes**. Additionally, retail or other take-back channels are in place. The **Extended Producer Responsibility** (EPR) schemes play an important role in the management of WEEE. Companies selling EEE must organize collection and treatment, which has led to a large number of Producer Responsibility Organizations (PRO). These systems are financed by producers and importers and seek to fulfill the legal requirements at optimized costs (Salhofer et al 2016). However, the national implementation of the WEEE Directive is not uniform across member states and the roles of local authorities, producers d retailers are designed in different ways. There are both monopolistic and competitive compliance schemes in place, which have specific advantages and disadvantages (Salhofer et al. 2016). The main challenge for reaching a higher reuse and recycling rate is to intensify collection through better information for citizens and improved collection services. Additional municipal collection options are to p curbside collection, and container collection at retail outlets (Salhofer et al. 2016; Interreg Europe 2022). According to Eurostat data from 2019 24 out of 27 member states did not reach the EU collection target, because they failed to collect sufficient WEEE separately (European Environmental Bureau 2022). It has to be highlighted that the quantities of WEEE generated vary considerably between wealthy and less affluent EU countries. Sweden, Austria, Belgium, France, and Germany show the highest quantities with more than 20 kg/cap/yr, while for example Bulgaria only generates 10 kg/cap/yr (Balde 2015). Furthe,r the recycling rates vary greatly among countries, see Table 1.

Table 1. Recycling Rate of E-waste in EU member states (Eurostat 2020)

Member state	Recycling Rate
Croatia	81.3
Estonia	69.8
Bulgaria	68.8
Hungary	51.1
Austria	50.1
Finland	48.2
Ireland	47.7
Sweden	47.0
Czechia	46.5
Slovakia	46.5
Luxembourg	45.5
Portugal	43.5
Netherlands	42.1
Spain	41.0
Latvia	40.6
Germany	38.7
Belgium	38.6
Denmark	38.5
France	36.6
Poland	36.1
Lithuania	35.1
Slovenia	33.4
Greece	32.9
Italy	32.1
Cyprus	27.0
Romania	25.0
Malta	20.8

Following is the **Recycling treatment sequence** of the collected WEEE in the EU:

1. **Sorting**
2. **Dismantling:** Due to the high cost of manual labor in Europe manual dismantling has been widely replaced by the mechanical dismantling of appliances ("smasher" and "cross-flow shredder"). In the next step hazardous and valuable components are sorted.
3. **Processing:** Crushing and separation with technologies such as hammer mills, magnetic separation, sieves, and eddy current separators, which are applied thoroughly produce high-quality secondary products (metal concentrates).
4. **End-Processing:** Batteries are sent to specialized recycling facilities. Printed Circuit Boards (PCB) go to specialized metallurgic treatment facilities (only 3 in Europe: Aurubis, Boliden, Umicore). Plastics are sorted sensor-based or with heavy media separators and partly recycled but also incinerated or disposed of in landfills. Hazardous components and non-recyclable materials are disposed of by incineration, landfill, and waste treatment (Salhofer et al. 2016).

The typical **composition of materials** in E-Waste is Metals (60.19%), Metal-plastic mixture (4.97%), Screens (cathode-ray tube and liquid crystal display) (11.87%), Plastics (15.21%), Cables (1.97%), Printed circuit boards (1.71%), Pollutants (2.7%), others (1.38%) (Ilankoon et al. 2018).

There exist European Standards for the Treatment of WEEE such as **CENELEC Standards** which foster harmonization of WEEE treatment in the member states, including collection, logistics, recycling, recovery, and preparation for reuse (CENELEC 2017). They contain general requirements and technical specifications and are in relation to the requirements of the WEEE Directive (European Commission 2021c). However, they remain voluntary, and therefore the European Electronics Recyclers Association calls for a WEEE *Regulation* instead of a *Directive* to harmonize obligations and conditions for recyclers in EU member states. They state that mandatory treatment standards are necessary to have a level playing field, which would also require harmonized training for inspectors and auditors between the Member States as well as the harmonization of waste codes (EERA 2022).

Stakeholders in EU E-waste Management

Table 2. Overview of the Stakeholders in EU E-waste Management with the groups highlighted I conducted interviews with, adapted from Sinha et al. (2010).

Stakeholders	Representatives	Role	Interest	Degree of influence
Government: Environment sector Policymakers National governments Enforcement agencies	European Commission National authorities Inspectorates	Creating a directive Creating legislation and Enforcing Enforcement	To create effectively coherent guidelines that will fit its purpose To maintain effectively enforcement with available resources	High, by creating an effective, enforceable directive High, by consistently monitoring and penalizing offenders
Producers: Information Technology Household appliances Office appliances	Trade and Industry Associations Large producers Producer Responsibility Organisations (PROs)	Responsibility towards and financing of collecting and recycling discarded appliances Eco designing	To comply with the regulations at the lowest possible cost and strains To have a good image as a brand	High, can design appliances environmentally sound Can set ambitious goals for collection and recycling

Collective compliance systems	System managers have created a joint platform: WEEE Forum	Collecting and recycling discarded appliances Funding operations	To meet the needs and interests of producers regarding their responsibilities. To comply with WEEE Directive and RoHS To keep costs low	High, by setting effective collection and setting high recycling standards
Consumers: Households Corporate Public	Consumer associations	Discarding appliances	To discard appliances with least effort	Limited, although associations are able to influence public opinion
Recyclers: informal sector	Transporters of illegal shipments Recyclers	Recycling discarded appliances	To make a profit on valuable materials	Negative influence on (registered) results in case e-waste is not recycled in a prescribed way
Recyclers: formal sector	Recyclers Recyclers associations	Recycling discarded appliances	To make a profit on responsible recycling	High, by achieving high recycling standards and innovating recycling techniques
Collectors (Municipalities)	Associations of waste management and environmental services	Collecting and/or accepting discarded appliances	To meet municipal duties Keep costs at an affordable level	High, by encouraging the public to separate e-waste
Collectors (retailers)	Retail associations Big retailers	Accepting discarded appliances	To sell appliances To minimize effort of handling discarded appliances	High, by encouraging consumers to return discarded appliances to their shop
Waste handling companies: Collectors, sorting companies, recyclers	Transporters Sorters	Handling discarded appliances	To make a profit from waste handling	Low

Methods

In addition to the literature review and document analysis, I conducted fourteen semi-structured **expert interviews**. According to Meuser and Nagel, experts are perceived as functionaries who act within a specific organizational or institutional context. Expert interviews, therefore, refer to the responsibilities and activities associated with the function. In this sense, experts are persons who do not view a situation from the outside, but who are themselves part of the field of action that is relevant to the research question (Meuser and Nagel 1991). Bogner et al. (2014) distinguish between *technical knowledge, process knowledg*e, and *interpretive knowledge* of experts. For this study, all three knowledge types are relevant. For exploring the circularity potential of e-waste, **interpretive knowledge** plays an important role, which includes subjective perspectives, interpretations, and explanatory patterns of the experts. Interpretive knowledge is not purely 'factual' knowledge, but the subjective perspective of the interviewees, which also includes objectives and evaluations. However, the fact that the perspective is subjective does not necessarily mean that it is individual, because perspectives are often shared within circles of experts and organizations. Bogner et al. (2014) refer to this as *collectively shared interpretive perspectives*, and these are of research interest. However, interpretive knowledge must be dealt with methodically as a perspective that cannot be separated from the subjects.

The experts were selected through conference attendance, desk research, and snowball sampling, where interview partners recommended the names of further potential interviewees. I aimed at a higher number of interview partners and tried to cover different areas of expertise, but the response rate to my email requests was only around 40 percent. At this point, I have interviews with representatives from academia (3), public administration and government (3), hardware producers (3), recycling companies (3), a repair enterprise (1), and a manager of a producer responsibility organization (1) (see table 3).

Table 3. Overview of the interview partners.

Respondent	Title	Institution Type	Location
E1	Advisor	Local Government	Germany
E2	Researcher	Academia	Netherlands
E3	Researcher	Academia	Austria
E4	Planer	Hardware Producer	Germany
E5	Planer	Government	Germany
E6	Researcher	Academia	Austria
E7	Manager	Private Sector, Social Enterprise	Austria
E8	Advisor	Government	Germany
E9	Manager	Recycler (Plastics)	Austria with branches in Hungary, Czech Republic, Romania
E10	Project Manager	Recycler (CRM)	Belgium with global branches
E11	Project Manager	Hardware Producer	Germany with global branches
E12	Project Manager	Hardware Producer	Germany with global branches
E13	Manager	Producer Responsibility Organization	Austria
E14	Manager	Recycler	Austria

In the interviews, I asked these representatives about the general context of e-waste management in the EU and the respective policies and strategies as well as conflicts. In semi-structured interviews, a guideline helps to mediate between structure and openness in the interview. It contains some central topics and questions that are relevant to the research question and is used in an adapted form in all interviews. However, the guideline should encourage the interviewees to present their perspectives and ideas in detail and to link different topics with each other. This can be achieved by not prescribing a fixed formulation of questions, by asking supplementary and in-depth questions as needed, and by not being rigidly fixed on the order and sequence of all questions (Strübing 2013).

The following standard questions were asked: Why do you think the management of e-waste is important from your perspective? What are the most important regulations of the last years/decades and why? What strategies would be most effective to manage e-waste? What are the main barriers? Who are the main stakeholders? How do you envision e-waste management in the future? What policies are needed for that at what levels?

The interviews were conducted in the spring and summer of 2022 and lasted between 30 and 60 minutes. The respondents were guaranteed anonymity, therefore throughout the report they are quoted as E1 to E14. During the first three more informal scoping interviews I only took notes, but the rest of the interviews were recorded and transcribed with F4. I coded them with Atlas.ti with 'Obstacles' and 'Leverage Points' as overarching categories, which were aligned to the stakeholder groups: consumers, hardware producers, recyclers, and policy and standardization.

Obstacles and Leverage Points

The following section follows a data-driven structure and elaborates on a selection of the obstacles and leverage points, presenting direct quotes from the interviews (italicized) and occasionally drawing on additional sources to enrich the qualitative data (Sovacool 2019).

Table 4. summarizes the main points of discussion from the interviews categorized into obstacles and leverage points and aligned to the stakeholder groups consumers, hardware producers, recyclers, and policy and standardization.

	Obstacles	**Leverage points**
Consumers	Purchase of newest devices Lack of repair culture Stock-piling at home Improper disposal of residual waste	Longer Use of devices Incentives for repair Leasing and sharing options Increase collection

Hardware producers	Lack of product-specific information for repair, reuse, and recycling Lack of Software updates Lack of spare parts for repair Planned obsolescence e.g., embedded batteries Use of a wide variety of plastics limits recovery Pressure to keep prices low and make a profit Different perceptions of what a sustainable product is	Products as a service Change product design
Recyclers	Lack of economic incentive and sorting technology to recycle all materials High labor costs drive mechanical dismantling instead of manual dismantling, which produces purer material fractions High upfront investment and ramp-up periods for recycling facilities Complicated notification systems for shipment Lack of cooperation between hardware producers and recyclers Time lag between production, market placement, and recycling of product	Rising raw material prices drive recycling Better segregation of material New recycling methods/technologies Mandatory treating requirements Cooperation with producers
Policy and Standardization	Clear alignment between different legislation is missing (products, waste, chemicals) Inadequate quotas for collection, reuse, and recycling Discussions around the standardization of indicators, measurement methodologies, and labeling Slow legislative process Lack of market surveillance Unreported Collection, Uncontrolled Exports, Informal Recycling	Geopolitical strategy - reducing import dependence on materials New Regulations will change business models Testing methods against planned obsolescence Mandatory standards for the collection, reuse, and recycling Improve enforcement of legislation

Consumers

Consumers were named as important stakeholders by several interview partners (E4, E6, E7, E10, E14). As major obstacles to more circularity of electrical devices on their side were identified the **purchase of newest devices** going hand in hand with a **lack of repair culture**. As an interviewee explained: *If a mixer stops working after two years, we have learned to live with it and buy a new one, because to have it repaired would be economically unreasonable anyway* (E7). Further, interestingly many devices are **stockpiled at home** after the use phase, keeping them from being reused or recycled.

A severe issue is the **improper disposal of e-waste in residual waste,** which was underlined especially by recycling companies and technical scientists (E4, E6, E14). According to recent estimates 0.6 Mt of E-waste ends up in waste bins in European countries (Baldé et al. 2022) and "there is a low chance of separation and e-waste is likely to be burnt in incineration or dumped with other waste" (Shahabuddin et al. 2022).
A danger in this regard is lithium-based batteries, as they are flammable and when a device goes through a shredder in a sorting plant there is a risk of fire (E6, E10). The manager of a recycling facility put it in drastic terms: *A big issue for us in the whole plant technology is the issue of lithium batteries. Because we get a lot of the old electrical equipment still including the battery pack. And that poses a huge fire risk for us in the plants. Unfortunately, we have fire incidents in our plants at regular intervals, because devices still contain batteries, which then short-circuit and develop an ignition effect. And this is an issue that cuts across many waste streams because unfortunately, we find batteries not only in old electrical appliances but also in residual waste* (E14).
Particularly problematic are electrified products with hidden batteries for which an illustrative example was given with 'illuminated shoes for children that have a battery embedded into the bottom of the sole, that is not accessible and the end customer can hardly be expected to dispose of them separately (E14). Interviewees underlined that it would be very important to improve collection and separation for example through a take-back system for batteries with a compulsory deposit for the end customer (E10, E14). An important role in this has the **retail sector**, which faces the logistical challenges of such take-back systems and needs suitable incentives to implement them (E13).

When looking at consumption there should be made a distinction between private consumers, the business sector, and public procurement and the respective needs and barriers. This distinction is beyond the scope of this study, but a few notes can be made:
1) With refurbished ICT, the private and public sectors face the problem that they need large numbers of the same product models at once. This is so far a challenge to offer for most refurbishment companies (E3).
2) Data Security is an important issue for companies, the public sector, and especially the military when handing over devices for reuse and recycling and there are concerns with using refurbished ICT. It is also relevant for private consumers (photos, chats) and is named a major reason for the stock-piling of e-waste in homes (E3).
3) Leasing options are more common from Business-to-Business. Business to private consumers currently takes place on a low scale and remains mostly on a pilot level (E10, E12).

Hardware producers

Major obstacles regarding hardware producers are the **lack of product-specific information for repair, reuse, and recycling** as well as the **lack of spare parts** provided (E3, E5, E6, E7, E10, E14). A manager of a recycling company said: *What we see in recycling, and what has been an observable trend in recent years, is simply to generate increasing sales figures, the repair-friendliness of the devices has greatly decreased* (E14). Another Interview partner from a repair company illustrates this: *Try to find out whether the tub of a particular washing machine is made of plastic or stainless steel. You won't succeed, not even the technical data sheets will tell you* (E7).

Often named is the **planned obsolescence** that minimizes the lifetime of products for example due to embedded batteries that are not removable. Producers argue that it enhances the durability of the products and reduces the risk of consumers wrongly replacing batteries (E4, E10). An issue regarding obsolescence is also the **lack of software updates** which hinders the longer use of devices even though the hardware still functions. A reason named for the resistance of the hardware industry to provide updates was that it is cost-intensive for longer periods (E4).
A manager from a hardware company, however, said that there is a lot of progress in repair in recent years, which is also due to websites and web shops, where producers can offer spare parts and information, as an example he gave ifixit.com. However, he also mentioned that it is a challenge to make sure that private consumers repair products purposefully and safely. They as a company face risks if consumers get injured, therefore they prefer to collaborate with repair companies over self-repair by consumers (E12).

Concerning the **Digital Product Passport** by the European Commission interview partners highlighted several discussion points. It is currently discussed if the product passport shall be static or dynamic. A dynamic passport would mean that repairs and new parts are accounted for. Further, there is the question of how far back in the supply chain information has to be provided in the passport (E4). Two researchers said that the hardware industry blocks in some aspects because it would be an enormous effort for them to trace the content of their devices along the value chain (E3, E6). A hardware producer confirms that: *Everyone doesn't have the motivation for it, because it's an extra effort, makes everything much more complex, and of course, there is confidential information that you might not want to share* (E12). However, he states that the passport makes sense conceptually and sees potential for innovations and start-ups that can offer a solution for implementation to producers (E12). An interview partner from standardization noted that he can understand the resistance by companies because: *If I write something on it, I am also liable for it. And it still needs to be clarified who is responsible for the information. [However] that it will come is clear, the question is only when and how and this is being worked on now* (E5).

A manager from a hardware company was very open about the **pressure to keep prices low and make a profit,** which hinders the production of more sustainable products: *From a company's perspective one of the biggest challenges we have is that we need to be able to sell our products. Because as long as we don't sell products, we don't make a turnover, and if you don't make a turnover, you cannot make a profit and if you don't make a profit you cannot invest. That is pretty simple, that is the economy, so we need to find the right balance between regulatory requirements, improvements for a more sustainable product, production costs, and market price. […] We know solutions where we can make our products much more sustainable, but we are not sure that we are going to be able to sell them for the price that we need to get from those products to make a living. And that is the biggest challenge I think that we have. When there are legal requirements, then of course the competition has the same requirements and we all have the same problem. Products will get more expensive, and then it will possibly be easier to pass the price on to the retail and the end consumer* (E11).

Recyclers

Interviewees from different areas pointed to the **lack of economic incentives and sorting technology to recycle all materials** as hindering more circularity (E4, E5, E6, E13). A technical scientist stated that recycling technologies and processes would be available but *the crucial question is more on the regulatory level or the economic level - are there business models for this? If money can be made with it, it will be done in the end* (E6). And an interview partner from standardization said: *In my experience, the big bottleneck is the recyclers, they don't move a bit as long as they can't make a profit. That's okay in a way, it's a profit-maximizing industry, but they don't think very far ahead, they block a lot* (E5). This situation is further aggravated by the decrease in the value of materials in e-waste due to less use of metals and the use of cheaper materials, which compromises the economic viability of recycling even more and presents a risk for recyclers (EERA 2022). A manager from a recycling company reported that they are currently facing many uncertainties and financial risks due to changing volumes of e-waste and volatile market prices for recycled materials (E14).

A further obstacle faced by recyclers is the **high upfront investment and ramp-up periods for recycling facilities** (E3, E8, E9, E10). Therefore there is a **trend toward large-scale plants***, as the more concentrated the quantities are, the deeper the processing can go, because the plant technology required for processing old electrical equipment is quite considerable and certain economies of scale are needed to make the whole thing worthwhile* (E14). This applies particularly for metallurgy processing because *if you want to recover precious metals […] efficiently, meaning a high yield [..] then you need large-scale processes that blend e-waste with other materials so that you chemically, metallurgically can take out those metals properly. Scale, know-how, and the right material you need to have, and that right material is besides e-waste, more than five, ten times other materials like residue from other industries* (E10).
Currently, there are only three large smelters in the EU, which achieve a material recovery of 95% compared to 50-70% with cheaper methods (E3, E8, E10; see also Manhart 2011). This does not necessarily have to be

an obstacle, but it means that material flows have to be international with *processors in different countries who specialize in very specific niches and are then able to produce something really valuable from very specific waste streams* (E14). As an interview partner from a globally operating smelter pointed out: *The unfortunate thing is, many companies and authorities don't like it. They don't want to be dependent [and there] is a tendency that you see, it has to do with resource scarcity and protectionism. Authorities say what those big smelters can do, we can also do and we can do it with another technology, that is much smaller, much simpler, and where we put in e-waste only e-waste and what comes out is the gold and the silver and the copper and the palladium* (E10). This **technological optimism** *hovers over the entire waste management industry […but] the technology is simply not yet mature enough to allow you to throw in mixed waste electrical equipment at the front and get highly pure fractions at the end of the day* (E14).

With the available recycling infrastructure, it is possible to efficiently recover metals such as copper, gold, steel, and aluminum but for example, **critical raw materials** (CRM) do not show high recycling rates due to their low concentration in e-waste and complex product design, making it economically not feasible to recover them (Parajuly et al. 2019). In the case of some specific CRMs recycling and recovery technology are still absent (EERA 2022: 16). And as an interview put it: *the question is whether it pays off at all if you want to go into these raw materials that are only present in traces in electrical devices* (E13).

A particular role plays **sorting** for the recovery of materials and a lack thereof leads to limited recycling rates and downcycling of material (E4, E5). An interviewee described the current situation at recyclers: *a large sea container arrives and is dumped onto the conveyor belt. And the conveyor belt runs through, then four or five employees stand there with a hammer and look to see what could be a device with a battery. And they take the battery out. The rest goes through the shredder and then you have a lot of confetti in the end. […] A lot is being done to drive the technology forward, especially to improve sorting, the automatic sorting at the recyclers. But that's just where things are still stuck, there's still a bit of technological maturity missing* (E4).

In Europe, **high labor costs drive mechanical dismantling instead of manual dismantling.** According to some experts, manual dismantling produces purer material fractions (E4, E9). Opinions diverge however and one interviewee explained: *We have done both. What you gain in processing depth [with manual dismantling], you lose in productivity in throughput. There are so many factors* (E13). A manager from a recycling facility stated that a **combination** of the two methods is the most promising way as *there are things that can be separated very well mechanically. I'm thinking of magnetic separation, where the magnet is of course much more efficient than manual sorting. Certain impurities cannot be avoided in both manual and mechanical sorting, because if I have a component of an old electrical appliance that is made of iron but also has a plastic coating attached to it, even an employee in manual sorting has not had the time to start tugging at the part and trying to get it apart somehow manually* [..] *With certain fractions, however, it is very much the case that manual sorting allows the material to be handled much more gently. I am thinking of a printed circuit board, where every further mechanical step if the attached valuable fractions were to be scraped off, even more, would cause* *even more damage to the printed circuit board itself. We rely more on the manual sorting out of such sensitive fractions. That's why I see it today in such a way, one needs both. On the one hand, mechanization and technologization have their justification and advantages, and on the other hand, it is the skill of the plant operator to find an optimal combination. Because, of course, the personnel costs for such manual sorting are considerable given the wage costs in Central Europe. And waste management has to deal with the question of how we can replace this manual step in the best possible way because we are experiencing a shortage of personnel at the moment* (E14).

What has been proposed by some stakeholders in this regard is the 'Best of- of-two-worlds approach', meaning the improvement of the interface between pretreatment through manual processing in Global South with smelting in Global North to minimize metal loss. However, this approach is very dependent on raw material prices and would only be economical for devices with a high concentration of precious metals (Manhart 2011).

What has been mentioned many times in the interviews is the **time lag between production, market placement, and recycling of products** (E1, E3, E5, E10). The time until products arrive at the recycler can be 5 to 25 years (E9, E11) and therefore it *is the difficult task of a recycler to deal with what is coming back now and to develop for what will come back in the future* (E11). Electronic appliances undergo rapid technology innovations and new product groups emerge constantly. The trend toward miniaturization and new functions of devices poses a challenge for recyclers as they have to adapt their technologies and operations according to the new developments. Further, material compositions and concentrations of valuable material change constantly due to technological progress and high resource prices. It is very hard to predict future material compositions and therefore also revenues from recycling, which makes recycling a very dynamic and unstable business (Manhart 2011). Therefore information channels among producers, recyclers, and scientists would be required and EERA calls on "producers [to] work more in-hand with recyclers to develop options to ensure that issues are approached in advance rather than when the end-of-life is reached" (EERA 2022). As an example, for future challenges for recyclers, the report names new hybrid products with mixed EEE (smart home appliances). It further reads that it would be essential to link the product design to recyclability, including:

-removability of batteries, circuit boards, and hazardous parts

-clear labeling/marking of substances, materials, and components

-mandatory percentages of recycled content for new products to boost the market for recycled materials

-modularity of components and parts

-standardization of materials to decrease variety (in particular of plastics)

-restriction of gum and glue that hinder dismantling (EERA 2022).

Many interviewees agree that there is currently a **lack of cooperation between hardware producers and recyclers** (E4, E9, E10, E12, E13, E14).

An illustrative example is the **use of a wide variety of** plastics in ICT products, which is limiting recycling and leads to downcycling (E9, E11, E12). One recycler gave the following account: *It is very difficult to process them and produce a concentrate that can be reused as a material. This is due to the different variety, and the* *colorful bouquet of different plastics that are used […] We have already tried to say design for recycling means please don't use 17 different plastics for one product, maybe 5 are enough* (E9). A manager from a hardware producer agreed with this by saying: S*ometimes it is completely over the top, we are using too many different plastics. You know that in an average dishwasher there are forty different plastics, forty. That is completely ridiculous. So also, from our side, we need to rethink and reduce the number of different plastics* (E11). Both recyclers and hardware producers underlined the necessity to find solutions together and the importance of standardized specifications for recycled plastics on the CENELEC level as well as the development of new plastic recycling technology (E9, E11, E12).

The essential point for new plastic recycling methods is their profitability because if the process and hence the recyclate are too expensive producers will prefer the cheaper virgin material (E9, E12, E13). One interviewee, therefore, opted for the mandatory use of recycled plastics in new products: *If a producer only wants to avoid problems and knows that he has better quality than if he uses recycled material, then he will logically only use virgin material. But if I force him by saying you need at least 30% recycled material in your product, then suddenly a new market emerges. Then he has to buy 30% recycled material at whatever price. It simply has to be there, even if this recycled material is more expensive than virgin material* (E13).

Currently, the available quantities of recycled plastics are not enough to cover the demand of large hardware producers due to a lack of input material and long ramp-up periods. Further plastic recyclers struggle to provide the quality of recyclates that is needed for the use in new products (E9, E11, E12). As a recycler put it, the test cycles are *very lengthy, and those responsible for the product at the OEMs, who then sign their name and vouch for the quality will not do anything and say we are now switching from standard plastic to recycled material because we have uncertainties: Is the quantity available? Is the quality always the same? Is it good enough for my requirements? Why should I do that now? So that's where the regulatory pressure has to come. But at the same time, we can never meet the quantities. That's why we need more recyclers who get into material recycling and keep more plastics in circulation* (E9). However, due to the uncertain legal framework that will become even stricter in the future, he thinks it is unlikely that companies will take the financial risk (E9).

Connected to plastics recycling is the issue of **brominated flame-retardants**, additives that were used in plastics to make devices (i.e., television, microwave) fireproof for decades (E4, E9, E11, E14). Studies showed that these substances are toxic and they were therefore included in the chemical legislation and their use prohibited. This is a challenge for safe recycling and limits the quantity that can be recovered because, *in the classic mechanical recycling processes, you can't get these flame retardants out* (E4). A recycler described the challenge as follows: *Then we are told that brominated flame retardants must be separated and thermally destroyed. And the producers are quick to adapt and say okay, I may no longer use these brominated types, then there are perhaps others that are still permitted or we use another technology. And for them, the issue is then relatively quickly over. But for us, it takes another 5 to 25 years and we still have to deal with these issues. […] Material recycling is going to be more difficult for us and it's going to be difficult commercially* (E9).

Policy and Standardization

An interview partner involved in standardization elaborates that in regard to brominated flame-retardants **legislation is not coherently aligned**: *More and more substances are being put on the REACH list or are banned altogether by RoHS. Now products are coming back from 15 years ago when we didn't have this legislation yet, where the material is supposed to be recycled, but there are substances in it that you are no longer allowed to put into circulation. That is a problem that has not yet been solved politically* (E4).

Several interviewees stated that EU quotas for **collection and recycling targets are inadequate** as they are weight-based (E4, E6, E9, E10, E11, E13).

An interviewee elaborated on the **collection target**: *A general collection target of 65%, which means 65% of what you have collected in 2022 for example, what you have collected referred to the average of what you have placed on the market over the last 3 years […] it is a ridiculous indicator because it does not take into account market realities and it does not take into account the evolution of products* (E11). For the evolution of products, he gave two examples. First television sets, used to be built with cathode ray tubes, which are very heavy, while new generations of televisions have flat panels and are much lighter, which leads to a collection rate of more than 100%. Second tumble dryers, where the newer generation is more material intense due to the use of heat pumps, which leads to a lower collection rate as *you compare something heavy today to something light yesterday* (E11). Further rising production and sales figures are not taken into account adequately by the target (E4, E11, E13).

Regarding current **recycling and recovery targets** that use weight-based metrics, it is critiqued that they should focus on the quality and value of the recovered material, not the quantity (E6, E10). A researcher explained that with mass quotas *no consideration is given to whether these are valuable metals or non-valuable metals*. *In other words, they can or will try to recover not the rare and critical metals, but primarily those that make up a large proportion of the mass. And that ends up being iron, copper, and aluminum* (E6). The manager of a smelter agrees: *The yields of precious metals, […] or critical metals that you find in electronics are not incentivized at all by the WEEE directive. So that is a missed link, there should be an improvement* (E10).

Further, interviewees noted that **quotas are not comparable across member states** (E6, E9, E13). As the manager of a recycling company put it: *Unfortunately, the WEEE Directive is not a regulation. Each country is allowed to do it themselves and therefore there are simply differences in the collection because the collection groups are different, and the collection systems have different logic* (E9). The manager of a Producer Responsibility Organization gave batteries as an example for different collection groups: *None of these can be compared. I looked in connection with this quota discussion, at return rates for batteries in Switzerland and return rates for electrical appliances in Norway, where they have extremely high return rates. Only, in reality, all these figures are not comparable. The Swiss have a proportion of lead batteries in their batteries, which we do not have. They are heavy and then make the same amount of return. The Norwegians, for example, do not* *differentiate between electrical appliances from industry or households. Those are counted separately here. We don't know the figures for the industry very well, because they don't run through the systems. And the Bulgarians always meet the quotas anyway. Excel is patient. Honestly, it's sad. It's really sad for the people who have to make a policy because the basic data they have is not reliable.* (E13) A researcher argued in a similar vein that member countries can easily use statistical tricks: *If you have quotas, it always depends on what is in the numerator and what is in the denominator. In the numerator is what they collect and in the denominator is what was put into circulation. So, what is the base quantity? And if, for example, they use statistical tricks to reduce the base quantity, because they don't include everything, then they can increase their quotas purely on paper. That certainly happens in one country or another* (E6).

Several interviewees called for improved and mandatory **standardized indicators, measurement methodologies, and product labeling** (E4, E5, E10, E11). *- There is a huge task for the European standardization organization - CEN, CENELEC, ETSI - to develop measurement methodologies for every requirement that the commission is going to come up with* (E11).
As an interviewee from standardization put it: *Politics is needed and politics must ensure that appropriate labeling can take place* (E5). He named the **slow legislative process** at the European level as a major obstacle and described the complex processes in Brussels that lead to back-lock effects over years. This becomes apparent in the new "Ecodesign and Energy Labelling Working Plan 2022-2024" that has adopted large parts of the earlier working plan because the objectives have not been implemented (E5). The Working Plan highlights the need for product tests to be accurate and reproducible and reads "given the diversity of technologies and user behavior, the timely development of harmonized standards with methods representing a good compromise between criteria is an inherent and often difficult, resource-intensive challenge" (European Commission 2022c). For example, in the original Ecodesign Directive material efficiency is already mentioned but it was not addressed for years, only energy efficiency as it is the 'lower hanging fruit' (E5).

An interesting point made by an interview partner was that there are very **different perceptions of what a sustainable product is**, which has consequences for life cycle accounting and product labeling (E4). He gives the example of products that are trimmed towards durability while leaving out recyclability: *What [criteria] is to be weighted more heavily that is a question that is discussed differently by the producers, among others, but also studies come to different results. (..) and that's a bit of a problem. Every [producer] does what he is convinced is the best way, but there is no black and white. There are probably many paths that lead somewhere* (E4).
In this regard, an interview partner highlights that it is essential to have indicators for *each stage of the circle* and that is not useful to push one indicator only to realize five years later that it was at the expense of other indicators *- So you always have to look at the overall aspect, and that's where standardization is necessary. Without standardization, I can't understand it, and the political will is already there. The holistic view is expressed everywhere, whether, in the Green Deal, or Circular Economy Action Plan, it is written everywhere,*

but I can't do it if not everyone does it in the same way, otherwise I always talk past each other. There needs to be a basic assessment methodology and how I then assess that is politics (E5).

A manager from a hardware producer underlines that regulation has to take into account that indicators (recycled content, recyclability, durability, and repairability) are interdependent and can negatively affect each other. He further elaborates that the circularity and environmental impact of products is not necessarily positively correlated, which can lead to conflicts of interest between stakeholders. As an example, he gives the Right to Repair Initiative *that focuses only on repairability and on the fact that appliances should be repairable - of course, this can have a positive impact on durability but it might have not a positive impact on other elements, like recycled content or reliability* (E11). He sees an important step in the initiative 'Substantiating Green Claims' by the European Commission, which envisages that claims on the sustainability of products made by producers and retailers have to be substantiated by only one method (E11). The Commission proposes environmental footprint methods, which were developed by the joint research center of the European Commission (European Commission 2021a)

An interview partner is involved in developing a test method against planned obsolescence, which he called *the next thumbscrew for producers* (E7). The method is being developed at the moment and shall be referenced in the Ecodesign Directive and made available to producers, consumer associations, and market surveillance authorities (E7).

Connected to more standardization and legislation is the need for more **market surveillance,** as otherwise there is a risk of fraud and freeriding (E10, E11, E13). A hardware producer noted that this is especially a problem with producers from outside of Europe who risk paying a fine instead of adhering to the rules if the chances of getting caught are low. Therefore, he elaborated: *We are always pleading as industry sector for more market surveillance, but it does not come. It is not happening, and the reason why is very simple: it costs money* (E11). Another interview partner from a producer responsibility organization argued in a similar direction regarding the implementation of fees that manufacturers and distributors have to pay into collection and recycling systems. He said that it is complicated to ensure that everything is reported correctly and compliant with the law, in particular with online retailers that deliver products directly to end consumers (E13).

Unreported Collection, Uncontrolled Exports, and Informal Recycling are issues that were taken up by several interview partners (E3, E7, E8, E9, E10, E11, E13, E14).

An important note from an interview partner is that though exports from (Central) Europe partly happen due to high treatment costs of e-waste, the main driver is informal second-hand trade with the aim of reuse (E8). Problematic in this regard is the **false labeling of broken appliances as a reuse** (E9, E10, E13, E14). As one interviewee elaborates: *It is logical, the illegal flows are mixed with reuse devices, for which there is a large market in Africa. […] If the container is filled with a hundred working TVs, you can be sure that 30 broken ones will also be added and will end up at the dump somewhere in Africa. That is the problem. And you can't monitor that. We looked at that in the port of Hamburg - forget it* (E13). Another interviewee stated that *the line is thin between reuse and 'I may well intentionally take something abroad for reuse, but find no buyer there and it then ends up in informal disposal'* (E14).

A common portrayal of e-waste exports by media, NGOs, and researchers are that of the Global North dumping e-waste on vulnerable communities in the Global South e.g. Africa, which is framed as an **environmental justice** issue (Akese and Little 2018). As one interview partner for example portrays it: *On the one hand, we have the situation that raw materials are exploited in the countries of the South. And then products are made from these raw materials, usually in emerging countries, with the exploitation of workers. The absurd part of the story is that countries that supply raw materials, such as Ghana, are then also flooded with electronic waste. I don't know, you might know this Agbogbloshie landfill, where the people who work there live to be 35 years old on average because they are exposed to all these poisons, which they produce themselves during recycling* (E7). However, these scrapyards provide a source of livelihood for vulnerable and unskilled workers and present a complex governance challenge (Sovacool 2019), because as Davis et al. (2019: 43) write: "While removing e-waste imports from these hubs might reduce pollution going forward, less often considered are the unintended negative consequences to e-waste-dependent economies: a return to high unemployment, squandered sunk costs in equipment, and underutilized expert knowledge – all while leaving e-waste hubs with an enduring toxic legacy."

A manager from a recycling company in Austria also mentioned the **robbery of recyclable materials***: at various points in the process, all the cables are cut away, printed circuit boards are removed, and then all we get is a worthless plastic housing with several problematic materials, and this makes it very difficult for us to operate a processing plant economically* (E14). As a manager from a Producer Responsibility Organization explains this robbery starts *with the worker at the recycling center, who moves all the cables to one side or cuts the cables from the electrical appliances and sells them on his own to the nearest scrap dealer [..] if the worker doesn't do it, then the municipality gets a good idea, I have such a valuable material and I have a scrap dealer in town, he should get it right away and pay us a lot of money for it. (E13).* Scrap dealers often do not report through collection systems because they have no obligation to and the price of raw materials already covers the costs (E13).

An interview partner, therefore, demands: *that everybody who touches WEEE will have to report what they have collected, how much they have collected, what they have done with it, and if they have treated it according to European standards. Because there are European treatment standards for WEEE. So that should happen, everybody should be obliged to report whenever they touch WEEE and everybody should have to treat the WEEE that they have collected according to European standards. That should be legally enshrined, which is not the case for the time being (E11).*

Two interviewees reported that there are criminal organizations that collect e-waste and move it to Eastern Europe, where for example copper cables *are burned at night, then you don't see the smoke and so the insulation material is gone and you only have the pure copper and that is then sold* (E9). These streams are hard to quantify (E13).

Further to note is that Europe also imports e-waste, mostly printed circuit boards for treatment by specialized smelters for which the driving factor is commercial as printed circuit boards have high concentrations of metals (E3, E8) (see also Baldé et al. 2022).

Interview partners from recycling companies stated that their business is hindered by **lengthy and complicated notification systems for the shipment of e-waste** (E9, E10, E14). As an Austrian plastic recycler describes: *Cross-border transport has become very difficult. You need notifications for all fractions. Even our subsidiary in Budapest needs a notification if it wants to deliver material to us in Austria, although we are certified according to CENELEG and can handle e-waste properly* (E9). A manager from a globally operating company explains that a further challenge is that not only the authorities and companies of destination need to approve the shipment but all the transit countries on the transport route as well. Therefore, companies have to apply for notifications with a specified route but due to a lack of vessel availability, routes can change on short notice, *paralyzing the business* (E10).

Two of the interviewees hold the opinion that the notification system does not prevent illegal movement but only hampers the business of compliant companies (E9, E14). As one elaborates: *[Authorities] make the notification process even more accurate and more detailed, in the belief that this will prevent illegal waste exports. Our opinion is that those who want to export waste illegally will not register a notification anyway. This means that all this additional bureaucracy by the authorities makes it difficult for us to target innovative international solutions, and we certainly need more pragmatic approaches, simpler approaches, in the future* (E14). Similar statements are to be found in the EERA Report, which describes technical requirements, lengthy waiting periods, bureaucratic notifications, and high administrative costs as hampering the necessary movement of e-waste flows. Therefore the association demands that shipment between compliant recyclers should be facilitated by a register for companies and fast-track notifications systems (EERA 2022).

Policy Recommendations drawn from interviews

1) **Clearer alignment between EU and national legislation on products, waste, and chemicals**

2) **Increased collection and revision of weight-based collection targets**

3) **Revision of mass-based recycling quotas putting a focus on the recovery of precious and critical raw materials and quality of the recycled material**

4) **Standardization of indicators, measurement methodologies, and labeling**

5) **Mandatory standards for companies involved in the collection, reuse, and recycling**

6) **Increased market surveillance**

7) **Incentives for circular business models**

Conclusion

A major obstacle to a more circular E-waste management is the lack of collection due to stockpiling at home by consumers, improper disposal of municipal waste, unreported collection, and informal recycling.
Further obstacles on the part of the producers are 1) lack of product-specific information for repair, reuse, and recycling, 2) limited software updates and provision of spare parts, 3) planned obsolescence of products (e.g., embedded batteries), 4) use of a wide variety of plastics in products that limit recovery, 5) pressure to keep prices low and make profits, 6) contesting perceptions of what a sustainable product is.
On the part of the recyclers the following obstacles were identified 1) lack of economic incentives and sorting technology to recycle all materials, 2) high labor costs that drive mechanical dismantling instead of manual dismantling, which produces purer material fractions, 3) high upfront investment and ramp-up periods for recycling facilities, 4) complicated notification systems for shipment.
Generally, there is insufficient cooperation between producers and recyclers and a constant time gap between the production and recycling of products leading to recycling technologies lagging behind and contradictions regarding recycling targets and the changing regulation on hazardous substances. Therefore, interviewees pointed to the importance of 1) a clear alignment between EU and national legislation on products, waste, and chemicals. Further leverage points in policy are 2) a revision of the mass-based quotas for collection, reuse, and recycling putting a focus on the recovery of precious and critical raw materials and quality of the recycled material, 4) standardization of indicators, measurement methodologies and labeling 5) mandatory standards for companies involved in the collection, reuse, and recycling, 6) increased market surveillance and 7) incentives for circular business models.

Closing material loops and ensuring high standards of recycling requires changes in production and consumption patterns, stricter regulation and harmonization among EU member states as well as cooperation between all stakeholders along the value chain. The EU is taking important steps in this direction with the proposal of the Sustainable Product Initiative, which promotes durability, repairability, and recyclability of products and seeks to enhance resource efficiency in addition to energy efficiency and boost circular business models.

References

Akese, Grace A., and Peter C. Little. 2018. "Electronic Waste and the Environmental Justice Challenge in Agbogbloshie." *Environmental Justice* 11 (2): 77–83. https://doi.org/10.1089/env.2017.0039.

Baldé, C.P., E. D'Angelo, V. Luda, O. Deubzer, and R. Kuehr. 2022. "Global Transboundary E-Waste Flows Monitor - 2022." Bonn, Germany: United Nations Institute for Training and Research (UNITAR).

Bogner, Alexander, Beate Littig, and Wolfgang Menz. 2014. *Interviews Mit Experten*. Wiesbaden: Springer Fachmedien.

Borthakur, Anwesha. 2020. "Policy Approaches on E-Waste in the Emerging Economies: A Review of the Existing Governance with Special Reference to India and South Africa." *Journal of Cleaner Production* 252 (April): 119885. https://doi.org/10.1016/j.jclepro.2019.119885.

———. 2022. "Design, Adoption and Implementation of Electronic Waste Policies in India." *Environmental Science and Pollution Research*, February. https://doi.org/10.1007/s11356-022-18836-5.

CENELEC. 2017. "European Standards for Waste Electrical and Electronic Equipment (WEEE)." https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Environment%20and%20Sustainability/Quicklinks%20General/Documentation%20and%20Materials/weee-brochure.pdf.

Corwin, Julia Eleanor. 2018. "'Nothing Is Useless in Nature': Delhi's Repair Economies and Value-Creation in an Electronics 'Waste' Sector." *Environment and Planning A: Economy and Space* 50 (1): 14–30. https://doi.org/10.1177/0308518X17739006.

CWIT. 2015. "Countering WEEE Illegal Trade Summary Report, Market Assessment, Legal Analysis, Crime Analysis and Recommendations Roadmap." Lyon.

Davis, John-Michael, Grace Akese, and Yaakov Garb. 2019. "Beyond the Pollution Haven Hypothesis: Where and Why Do e-Waste Hubs Emerge and What Does This Mean for Policies and Interventions?" *Geoforum* 98 (January): 36–45. https://doi.org/10.1016/j.geoforum.2018.09.020.

EERA. 2022. "Towards an EU WEEE Regulation: The Position of the European Electronics Recyclers Association." European Electronics Recyclers Association. https://www.eera-recyclers.com/files/final-eera-report-13-1-22-2.pdf.

European Commission. 2000. "End-of-Life Vehicles." https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en.

———. 2002a. "Restriction of Hazardous Substances in Electrical and Electronic Equipment." https://ec.europa.eu/environment/topics/waste-and-recycling/rohs-directive_en.

———. 2002b. "Waste from Electrical and Electronic Equipment." https://ec.europa.eu/environment/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en.

———. 2006a. "Batteries Directive." https://environment.ec.europa.eu/topics/waste-and-recycling/batteries-and-accumulators_en.

———. 2006b. "Waste Shipment Regulation." https://environment.ec.europa.eu/topics/waste-and-recycling/waste-shipments_en.

———. 2009. "Ecodesign and Energy Labelling." https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/ecodesign_en.

———. 2020. "Circular Economy Action Plan." https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en.

———. 2021a. "Commission Recommendation on the Use of the Environmental Footprint Methods to Measure and Communicate the Life Cycle Environmental Performance of Products and Organisations." https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm.

———. 2021b. "European Green Deal." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

———. 2021c. *Study on Quality Standards for the Treatment of Waste Electrical and Electronic Equipment (WEEE): Final Report.* LU: Publications Office. https://data.europa.eu/doi/10.2779/69374.

———. 2022a. "Green Deal: New Proposals to Make Sustainable Products the Norm and Boost Europe's Resource Independence." Brussels. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013.

———. 2022b. "Sustainable Products Initiative." https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en.

———. 2022c. "Ecodesign and Energy Labelling Working Plan 2022-2024 (2022/C 182/01)." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022XC0504%2801%29&qid=1651649049970.
European Environmental Bureau. 2022. "Most EU Member States Miss Collection Target for Electronic Waste, NGOs Demand Quick Action from European Commission." March 2022. https://eeb.org/eu-miss-collection-target-for-electronic-waste/.
European Parliament. 2021. "A Common Charger: Better for Consumers and the Environment." *Presse Release* (blog). October 2021. https://www.europarl.europa.eu/news/en/headlines/priorities/circular-economy/20211008STO14517/a-common-charger-better-for-consumers-and-the-environment.
———. 2022a. "Right to Repair." Brussels. https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698869/EPRS_BRI(2022)698869_EN.pdf.
———. 2022b. "Deal on Common Charger: Reducing Hassle for Consumers and Curbing e-Waste." Brussels. https://www.europarl.europa.eu/news/de/press-room/20220603IPR32196/deal-on-common-charger-reducing-hassle-for-consumers-and-curbing-e-waste.
Eurostat. 2018. "Summary Document of the Waste Electrical and Electronic Equipment Rates and Targets." https://ec.europa.eu/eurostat/documents/342366/351758/Target-Rates-WEEE.
———. 2020. "Recycling Rate of E-Waste." https://ec.europa.eu/eurostat/databrowser/view/T2020_RT130/bookmark/table?lang=en&bookmarkId=a69be825-957e-473c-a81f-f02866dc9141.
———. 2022. "Waste Statistics - Electrical and Electronic Equipment." https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment#Electronic_equipment_.28EEE.29_put_on_the_market_and_WEEE_processed_in_the_EU.
Forti, Vanessa, Cornelis Peter Baldé, Ruediger Kuehr, and Garam Bel. 2020. "The Global E-Waste Monitor 2020. Quantities, Flows, and the Circular Economy Potential." United Nations University.
Ilankoon, I.M.S.K., Yousef Ghorbani, Meng Nan Chong, Gamini Herath, Thandazile Moyo, and Jochen Petersen. 2018. "E-Waste in the International Context – A Review of Trade Flows, Regulations, Hazards, Waste Management Strategies and Technologies for Value Recovery." *Waste Management* 82 (December): 258–75. https://doi.org/10.1016/j.wasman.2018.10.018.
Interreg Europe. 2022. "Collection and Recycling of WEEE: Key Learnings."
Lange, Steffen, Johanna Pohl, and Tilman Santarius. 2020. "Digitalization and Energy Consumption. Does ICT Reduce Energy Demand?" *Ecological Economics* 176 (October): 106760. https://doi.org/10.1016/j.ecolecon.2020.106760.
Lee, David, Dietmar Offenhuber, Fábio Duarte, Assaf Biderman, and Carlo Ratti. 2018. "Monitour: Tracking Global Routes of Electronic Waste." *Waste Management* 72 (February): 362–70. https://doi.org/10.1016/j.wasman.2017.11.014.
Lepawsky, Josh. 2014. "The Changing Geography of Global Trade in Electronic Discards: Time to Rethink the E-waste Problem." *The Geographical Journal* 181 (2): 147–59. https://doi.org/10.1111/geoj.12077.
———. 2018. *Reassembling Rubbish: Worlding Electronic Waste*. Cambridge, Massachusetts: The MIT Press. https://scalar.usc.edu/works/worlding-electronic-waste/table-of-contents?path=index.
Manhart, Andreas. 2011. "International Cooperation for Metal Recycling From Waste Electrical and Electronic Equipment: An Assessment of the 'Best-of-Two-Worlds' Approach." *Journal of Industrial Ecology* 15 (1): 13–30. https://doi.org/10.1111/j.1530-9290.2010.00307.x.
Meuser, Michael, and Ulrike Nagel. 1991. "ExpertInneninterviews - Vielfach Erprobt, Wenig Bedacht: Ein Beitrag Zur Qualitativen Methodendiskussion." In *Qualitativ-Empirische Sozialforschung. Konzepte, Methoden, Analysen*, edited by Detlef Garz and Klaus Kraimer, 441–71. Wiesbaden: VS Verlag für Sozialwissenschaften.
Murthy, Venkatesha, and Seeram Ramakrishna. 2022. "A Review on Global E-Waste Management: Urban Mining towards a Sustainable Future and Circular Economy." *Sustainability* 14 (2): 647. https://doi.org/10.3390/su14020647.
Parajuly, Keshav, Ruediger Kuehr, Abhishek Kumar Awasthi, Colin Fitzpatrick, Josh Lepawsky, Elisabeth Smith, R. Widmer, and X. Zeng. 2019. "Future E-Waste Scenarios." Edited by StEP (Bonn), UNU ViE-SCYCLE (Bonn), and UNEP IETC (Osaka). https://ewastemonitor.info/wp-content/uploads/2020/11/FUTURE-E-WASTE-SCENARIOS_UNU_2019.pdf.
Petridis, Nikolaos E., Konstantinos Petridis, and Emmanouil Stiakakis. 2020. "Global E-Waste Trade Network Analysis." *Resources, Conservation and Recycling* 158 (July): 104742. https://doi.org/10.1016/j.resconrec.2020.104742.

Salhofer, S., B. Steuer, R. Ramusch, and P. Beigl. 2016. "WEEE Management in Europe and China – A Comparison." *Waste Management* 57 (November): 27–35. https://doi.org/10.1016/j.wasman.2015.11.014.
Schlegel, M.-C., C. McAlister, and C. Spiliotopoulos. 2019. "Ecodesign Spinning towards the Circular Economy - the Contribution of New Standards on Resource Efficiency." In *Product Lifetimes and the Environment*. Berlin.
Shahabuddin, M., M. Nur Uddin, J. I. Chowdhury, S. F. Ahmed, M. N. Uddin, M. Mofijur, and M. A. Uddin. 2022. "A Review of the Recent Development, Challenges, and Opportunities of Electronic Waste (e-Waste)." *International Journal of Environmental Science and Technology*, May. https://doi.org/10.1007/s13762-022-04274-w.
Sinha, Satish, Priti Mahesh, Erik Donders, and Wim Van Breusegem. 2010. "Waste Electrical and Electronic Equipment. The EU and India: Sharing Best Practices." India: Toxic Links. https://eeas.europa.eu/archives/delegations/india/documents/eu_india/final_e_waste_book_en.pdf.
Sovacool, Benjamin K. 2019. "Toxic Transitions in the Lifecycle Externalities of a Digital Society: The Complex Afterlives of Electronic Waste in Ghana." *Resources Policy* 64 (December): 101459. https://doi.org/10.1016/j.resourpol.2019.101459.
Strübing, Jörg. 2013. *Qualitative Sozialforschung: Eine Einführung*. Berlin/Boston: De Gruyter Oldenbourg.
Theis, Nicholas. 2021. "The Global Trade in E-Waste: A Network Approach." *Environmental Sociology* 7 (1): 76–89. https://doi.org/10.1080/23251042.2020.1824308.
UNEP. 2010. "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal." https://legal.un.org/avl/pdf/ha/bcctmhwd/bcctmhwd_e.pdf.