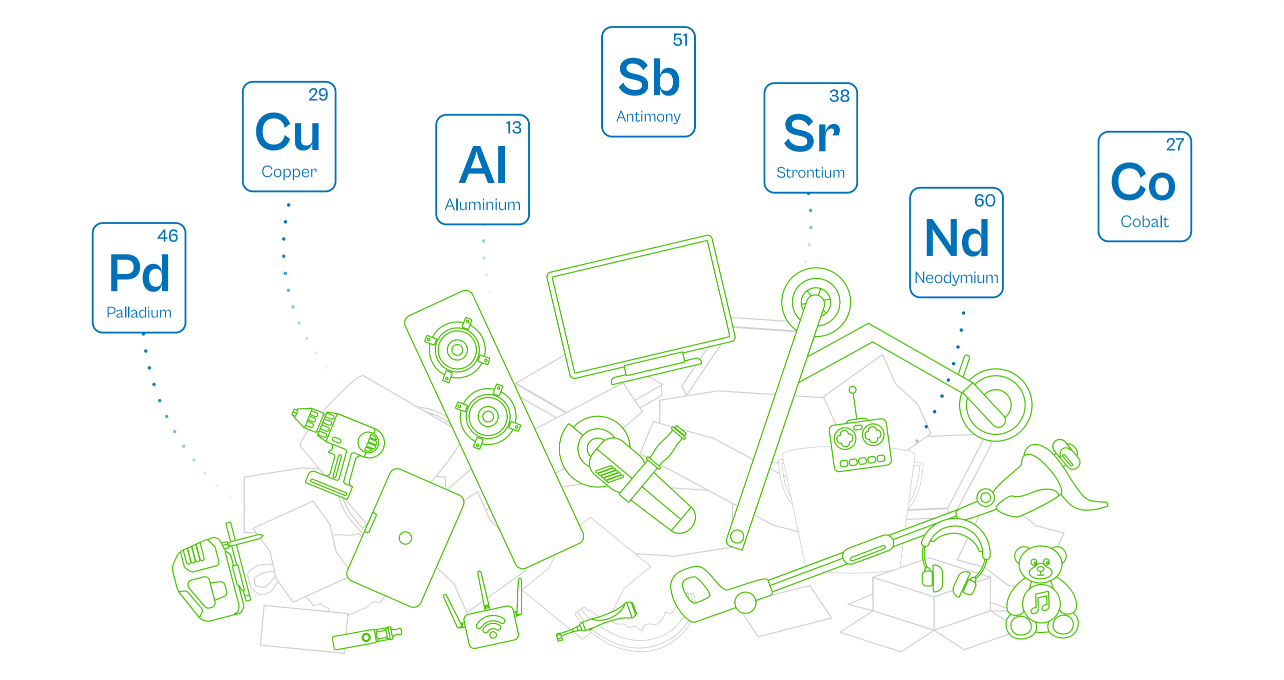
FutuRaM

Future availability
of secondary
raw materials



2050 Critical Raw Materials Outlook for Waste Electrical and Electronic Equipment in European Union plus Iceland, Norway, Switzerland and United Kingdom

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G. Iattoni, S. Bottausci, T. Yamamoto, M. Schubert, V. Forti, K. Kippert, R. Hu, V.S. Rotter, M. Charytanowicz, A. Bizouard, A. Perello-Y-Bestard, A. Perello-Y-Bes R. Kuehr, C.P. Baldé

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Overall coordination and writing of the publication was provided by Giulia Iattoni, Sara Bottausci and Cornelis P. Baldé from UNITAR-SCYCLE Programme, together with input from Magdalena Charytanowicz from WEEE Forum on the usage and contextualization for International E-waste Day. The following persons (their affiliations are included for identification purposes) contributed to the report in varying capacities. Regarding the WEEE composition data: Maximilian Schubert, Giulia Iattoni, and Vanessa Forti from UNITAR-SCYCLE Programme; Katharina Kippert, Rebecca Hu, and Susanne Rotter from TU Berlin; and Alice Bizouard from ecosystem. Regarding the WEEE recovery model: Tales Yamamoto, Sara Bottausci, Giulia Iattoni, and Vanessa Forti, from UNITAR-SCYCLE; and Adrien Perello Y Bestard from Leiden University. The overall WEEE Stock and Flow model and final calculation of all datasets was developed by Tales Yamamoto, Giulia Iattoni and Cornelis P. Baldé from UNITAR-SCYCLE.

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Future Availability of Secondary Raw Materials (FutuRaM) is an EU funded project that is developing EU-Secondary Raw Materials Knowledge Base on the availability and recoverability of secondary raw materials within the European Union, with a special focus on critical raw materials. The project results will enable fact-based decision making for the recovery and use of secondary raw materials within and outside the EU. For more information: Homepage - FutuRaM

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International E-Waste Day is an annual awareness raising campaign coordinated by the WEEE Forum and its members with the goal of promoting the proper disposal of electronic waste. In 2025 the 8th edition of the #ewasteday focuses on Critical Raw Materials and aims to inform consumers about these elements, that are crucial to enable the green and digital transition but for which there is a high supply risk. International E-Waste Day will highlight the fact that such materials could be potentially recovered from e-waste if greater collection occurs.

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Abbreviations

Abbreviation	Description
BAU	Business As Usual
CIR	Circularity
CRM	Critical Raw Material
EEE	Electrical and Electronic Equipment
EU	European Union
EU27	The 27 Member States of the European Union
EU27+4	The EU27 plus Iceland, Norway, Switzerland and the United Kingdow
GDP	Gross Domestic Product
kg	Kilogram
kt	Kiloton (1,000 tons)
LED	Light-Emitting Diode
Mt	Million tons (1,000,000 tons)
OBS	Observed data
POM	Placed On the Market (also: Placing or Put On the Market)
PPP	Purchasing Power Parity
PV	Photovoltaic
REC	Recovery
t	Ton (1,000 kg)
WEEE	Waste Electrical and Electronical Equipment

Glossary

For the purposes of this report, the following terms and definitions apply. They are provided to support consistency and clarity of use within this document. These definitions are not intended to establish normative usage beyond the scope of this report.

Term	Definition	Source
Components or component groups	Uniquely identifiable parts or subunits of products. Components are usually mechanically removable in one piece and are considered indivisible for a particular function or use. A component can consist of other subcomponents e.g. a printed circuit board may contain a capacitor which is also a component. Some products may contain other products as components, for instance, a car has a battery. In the present report, sub-components embedded in other components (e.g. a permanent magnet which is a sub-component in the component hard disk drive) are included in the mass balance of the main component (i.e. hard disk drive in this example) without double counting.	*(Huisman, et al., 2016a)*
Critical raw materials	'Critical raw materials' are defined as a set of non-energy, non-agricultural raw materials that are considered to be critical due to their high economic importance and their exposure to high supply risk, often caused by a high concentration of supply from a few third countries.	*Critical Raw Material Act, list in Annex II (Regulation (EU) 2024/1252, n.d.)*
Materials	Refers to 'engineered materials' that are composed, manufactured and processed to achieve intended properties.	*(Huisman, et al., 2016a)*
Placing on the market	Placing on the market (also commonly referred to as 'placed on the market' or 'put on the market') means the first time a product is sold on the market within the territory of a country on a professional basis.	*(Directive 2012/19/EU)*
Products	Usually refers to anything that is made to be sold including components and materials. Here it only refers to assemblies (e.g. electrical and electronic equipment) that are made from components, which in turn consist of materials.	*PRODUCT | English meaning - Cambridge Dictionary*
Recovery	Any operation, the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. In this report, 'critical raw materials recovery' refers to the separation and refining of critical raw materials from waste, where part is functionally recycled or made available for further processing, while another part is dissipated into residues. The term also includes recovery of critical raw materials as part of material fractions and components classified as secondary raw materials, which are subsequently sent for further recycling, processing, or recovery.	*(Directive 2008/98/EC, n.d.)*
Secondary raw materials	'Secondary raw materials' are raw materials recovered from a secondary source, i.e. waste, instead of being obtained from a primary source, i.e. an ore, and have undergone all necessary treatment steps to substitute primary raw materials.	*(Regulation (EU) 2025/40) and (UNECE, 2022)*
Stocks and flows	'Stocks' refer to accumulated materials that remain within a system over time. 'Flows' refer to the movement of materials into, through, and out of a system over a specific period. For the purpose of this report, stocks and flows are measured annually in terms of mass. Additionally, the geographical boundaries are the national territories of the EU27+4.	*(European Commission, 2001)*
Strategic raw materials	Materials essential for key strategic technologies related to the green and digital transitions that have high projected demand growth and that face significant challenges in scaling up supply.	*Critical Raw Material Act, list in Annex I (Regulation (EU) 2024/1252, n.d.)*
Waste	Any substance or object which the holder discards, intends to discard or is required to discard.	*(Directive 2008/98/EC, n.d.)*
Waste collected	Household and similar waste, selectively collected in homogeneous fractions by public services, non-profit organisations and private enterprises acting in the field of organised waste collection.	*(Regulation (EC) 2150/2002)*
Waste collection	The gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport.	*(Directive 2008/98/EC, n.d.)* *(UNECE, 2022)*
WEEE collected	WEEE collected, also referred to as "WEEE formally collected" or "WEEE compliantly collected" means waste electrical and electronic equipment collected separately from unsorted municipal waste through systems established in accordance with Articles 5 and 6 of Directive 2012/19/EU, for the purpose of proper treatment, recovery, and reporting under Article 7.	*(Directive 2012/19/EU)*
WEEE generated	'WEEE generated' in a Member State means the total weight[1] of WEEE resulting from EEE within the scope of Directive 2012/19/EU that had been placed on the market of that Member State, prior to any activity such as collection, preparation for reuse, treatment, recovery, including recycling, or export.	*(Regulation (EU) 2017/699)*

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[1] Battery weight is excluded following the principles of the Regulation (EU) 2017/699 and of the WEEE Directive 2012/19/EU, according to which the weight of batteries is excluded from the weight of EEE and has to be treated in accordance with the Batteries Regulation (EU) 2023/1542.

Executive Summary

Electrical and electronic equipment (EEE) plays a central role in modern economic and societal activity, with demand in the EU steadily increasing due to technological innovation, digitalisation, and the transition to a low-carbon economy. Many of these products incorporate critical raw materials that are essential to their performance, alongside hazardous substances requiring careful management when reaching the end of life phase. Understanding future projections on EEE and waste electrical and electronic equipment (WEEE) is therefore essential for contributing to resource security, supporting sustainable growth, and mitigating environmental risks.

The European transition to a green and digital economy relies on a secure and stable supply of raw materials, especially those considered critical and are used in technologies such as batteries, electronics, and wind turbines. Alongside newly mined materials, recovered materials, known as secondary raw materials, play a crucial role in reducing dependence on imports and strengthening supply chain resilience. To support this goal, the European Union introduced the Critical Raw Materials Act[2] (Regulation (EU) 2024/1252, n.d.), a key piece of legislation designed to ensure sustainable and reliable access to the materials most crucial to Europe's future and for which supply is unstable.

To support these efforts, the FutuRaM project, funded by the EU's Horizon Europe[3] research programme, developed comprehensive datasets on WEEE[4]. These datasets cover the life cycle of products, from when they are first sold and placed on the market to their disposal and subsequent treatment, as well as the recovery potential of valuable materials. The project analysed trends from 2010 to 2050 across the EU, Iceland, Norway, Switzerland and the United Kingdom (EU27+4), under three future scenarios: business-as-usual, recovery, and circularity. The business-as-usual scenario assumes current trends continue, the recovery scenario focuses on improved collection and recovery systems, while maintaining current levels of consumption and waste generation, and the circularity scenario envisions a shift toward longer-lasting, repairable products and reduced waste generation, supported by enhanced collection and recovery systems. The key figures from these datasets that are relevant to this report are presented below.

WEEE Generated

In 2022, households and businesses across the EU27+4, generated 10.7 Mt of WEEE, an average of 20 kg per person. Embedded within this waste was an estimated amount of 1.0 Mt of 29 distinct critical raw materials, as identified in Annex I of the Critical Raw Material Act. These include copper in cables, aluminium in casings, rare earth elements in magnets and fluorescent powders, and platinum group metals found in circuit boards and displays.

10.7 Mt

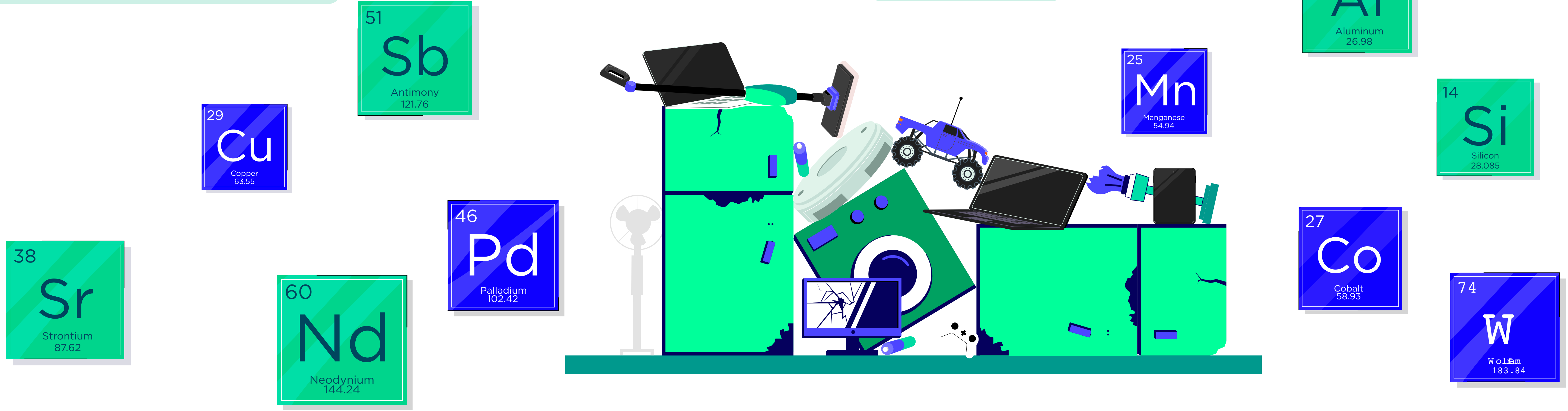
of WEEE generated in 2022 in the European Union, United Kingdom, Iceland, Norway and Switzerland

20 kg

per capita

29

different critical raw materials



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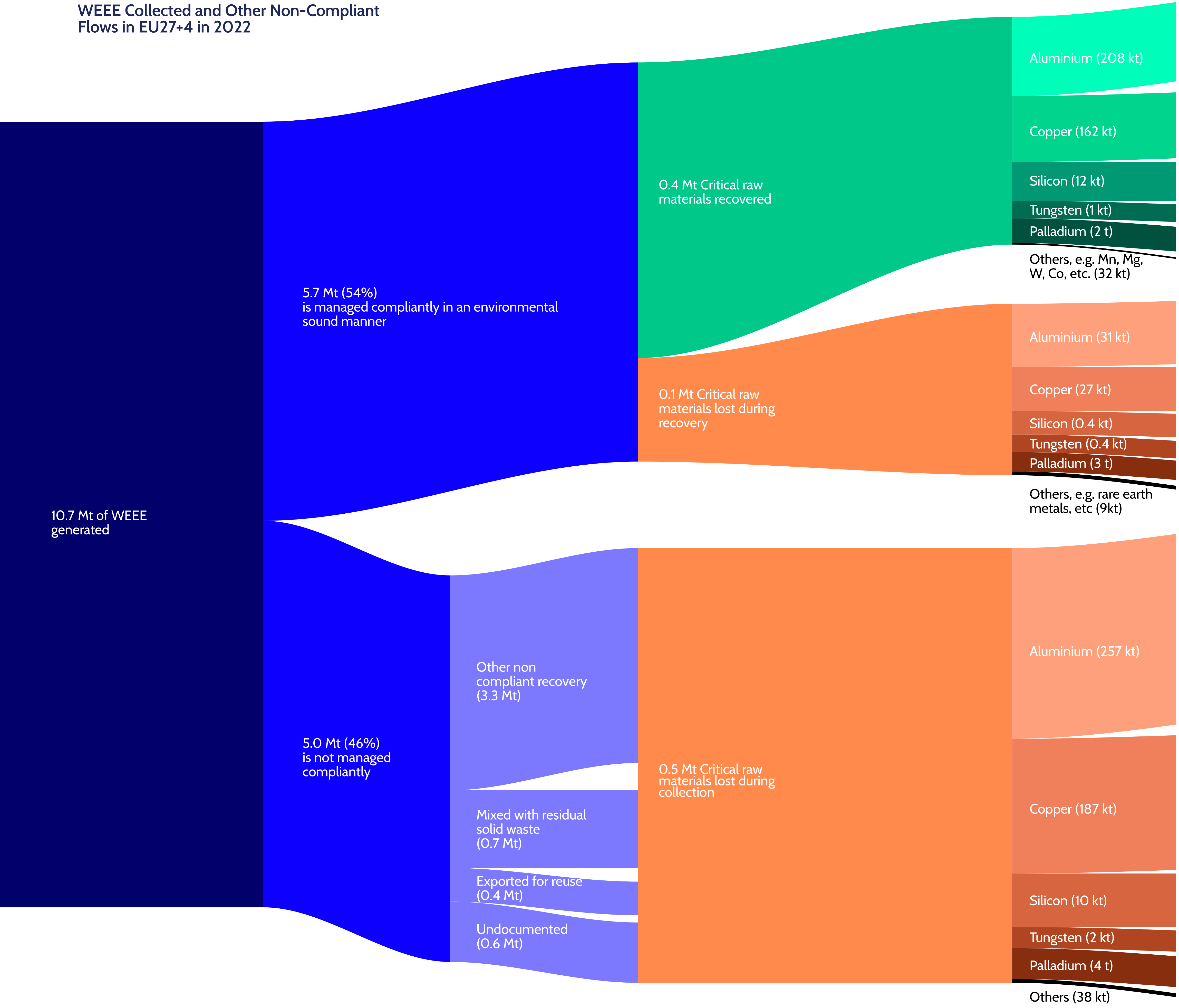
[2] In the present report, we use critical raw materials as a term covering both critical and the strategic raw materials as described in the Critical Raw Material Act, lists in Annex I and II.

[3] Horizon Europe is the EU's key funding program for research and innovation (research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en)

[4] The FutuRaM project covers six waste streams: WEEE, batteries, construction and demolition waste, slags and ashes, end-of-life vehicles and mining waste. This report only focuses on the WEEE data.

WEEE Collected and Other Non-Compliant Flows in EU27+4 in 2022



Of the 10.7 Mt of WEEE generated in 2022, only 5.7 Mt (54%) were collected and appropriately treated in a compliant manner, i.e. in accordance with EU regulations, such as the WEEE Directive. These volumes were collected through retailers, municipal collection points, and commercial collection companies. Following treatment, approximately 0.4 Mt of critical raw materials were successfully recovered[5], including, among others, 162 kilotons (kt) of copper, 208 kt of aluminium, 12 kt of silicon, 1 kt of tungsten, and 2 t of palladium. Precious metals such as gold and silver, along with steel and other ferrous materials, were also recovered. However, despite compliant collection and treatment, 0.1 Mt of critical raw materials were not recovered, mostly rare earth elements e.g., neodymium, dysprosium, yttrium, and europium, which are vital materials found in magnets, fluorescent powders, and electronics.

The remaining 46% of WEEE, about 5.0 Mt, is not compliantly collected or treated, increasing the chance of losing valuable materials and releasing hazardous substances into the environment. The largest quantity, 3.3 Mt, falls under other non compliant recovery, including WEEE mixed with metal and plastic waste, where only some materials, such as iron or steel, may be recovered, often at lower standards. Another 0.7 Mt is discarded with residual solid waste and sent to landfill or incineration. Approximately 0.4 Mt is exported for reuse. The remaining share is undocumented, likely either exported illegally or processed through informal or unregulated channels.

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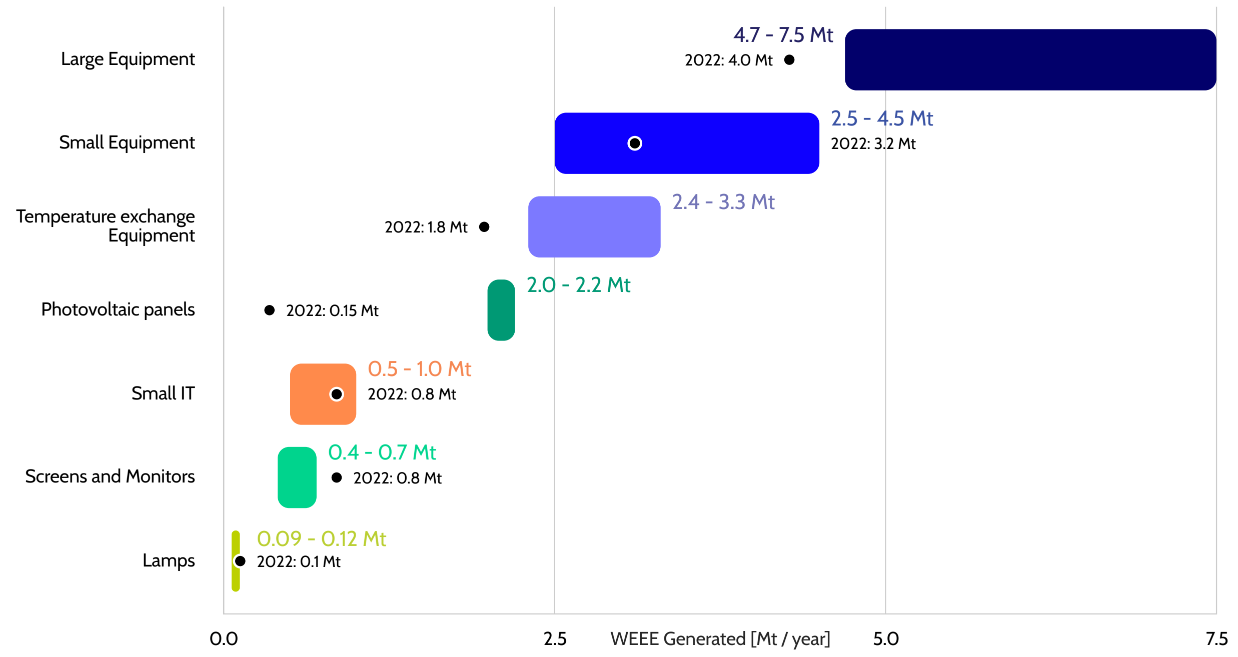
[5] FutuRaM uses the term «theoretically available» instead of «recovery», as the real recovery at the final treatment operator stage has not been researched. For this report, this term has been simplified to "recovery".

Future WEEE Generated in 2050

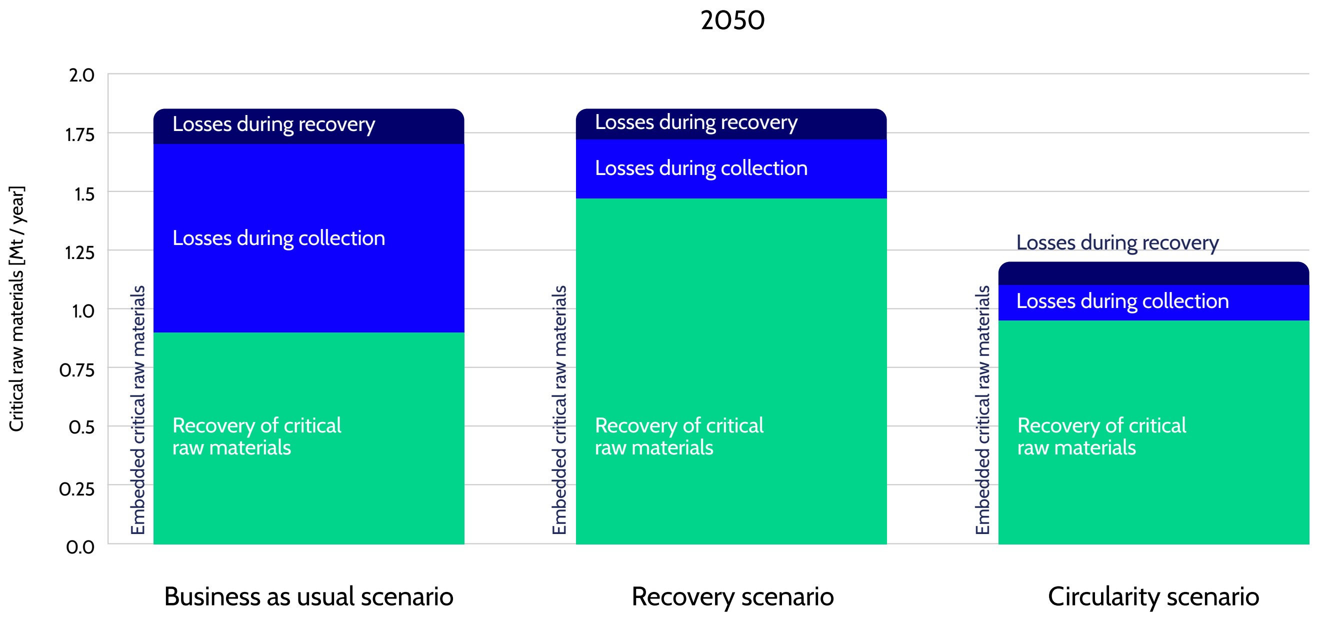
The total amount of WEEE in the EU27+4 is projected to increase from 10.7 Mt in 2022 to between 12.5 and 19 Mt by 2050. These projections are based on the three future scenarios developed in FutuRaM: business-as-usual, recovery, and circularity. In the first two, current consumption patterns persist, leading to growing volumes of WEEE generated. In contrast, the circularity scenario assumes longer product lifespans, greater repair and reuse, and fewer new devices entering the market, leading to significantly lower waste generation. As the future trajectory remains uncertain, projections are presented as a range.

Among all categories as defined in the WEEE Directive, photovoltaic panels are expected to experience the most significant growth, from 0.15 Mt in 2022 to 2.0–2.2 Mt in 2050, reflecting Europe's shift to solar energy. Large equipment, such as washing machines, dishwashers, and servers, remains the biggest contributor, growing from 4 Mt to 4.7–7.5 Mt. Other categories show more modest changes. Temperature exchange equipment, such as fridges and air conditioners, is projected to grow from 1.8 Mt in 2022 to 2.4–3.3 Mt by 2050. Small equipment, including devices like toasters and drills, is projected to range from 3.2 Mt to 2.5–4.5 Mt. Small IT, including mobile phones and accessories, may remain stable or even decrease, ranging from 0.8 Mt in 2022 to 0.5–1.0 Mt. Screens and monitors are expected to decline overall, from 0.8 Mt in 2022 to 0.4–0.7 Mt, while lamps remain largely unchanged, with volumes staying close to 0.1 Mt.



Critical Raw Materials in WEEE in 2050

By 2050, the amount of critical raw materials in WEEE could rise to between 1.2 and 1.9 Mt, with the outcome varying according to waste generation trends in the different future scenarios and assuming the same critical raw materials list as defined in 2023 (Regulation (EU) 2024/1252, n.d.). In 2050, projected recovery ranges from 0.9 to 1.5 Mt depending on how waste management systems progress. The lower end of the range reflects limited improvements in current systems (business-as-usual), while the upper end assumes significant advancements in collection and recovery (recovery scenario). In the circularity scenario, recovery efficiency remains high, but total recovery is lower due to reduced WEEE generation overall. Nonetheless, material losses persist. Depending on the scenario, between 0.2 and 0.8 Mt could be lost during collection, and an additional 0.1 to 0.2 Mt during recovery.



Recovery of Critical Raw Materials from WEEE

Some critical raw materials (e.g. copper, aluminium, and those found in printed circuit boards) are already being recovered from WEEE at scale. For these, increasing the collection rates of WEEE could significantly enhance recovery. However, other materials, such as rare earths in magnets or palladium in printed circuit boards, can only be recovered if the specific components that contain them (e.g. hard drives, cables, compressors, displays, and photovoltaic cells) are properly identified and separated during sorting and dismantling. Improving product design to facilitate dismantling, expanding recovery capacity in Europe, and creating stronger economic incentives are all essential for scaling up the recovery of these materials[6].

How to enhance the recovery of Critical Raw Materials?

Improve collection rates

Improve product design to dismantle

Identify products and components rich in critical raw materials

Improve policy landscape to incentivise economic conditions for recovery of critical raw materials

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[6] The findings presented in the report support the implementation of the Critical Raw Materials Act and waste-related legislation (such as the WEEE Directive). Discussions are ongoing with various EU bodies - such as the Directorate-General for Internal Market, Industry, Entrepreneurship and Small and Medium Enterprises (DG GROW), the Joint Research Centre (JRC), and the Directorate-General for Environment (DG ENV) - to ensure data access and enable evidence-based policymaking at the EU level.

Introduction

Electrical and Electronic Equipment (EEE) refers to all products that rely on electric currents or electromagnetic fields to function, including those powered by batteries. EEE encompasses a wide range of household and professional devices, from large appliances like refrigerators and washing machines to personal electronics such as mobile phones, headphones, and tablets (Baldé et al., 2024). These products vary significantly in material composition, weight, lifespan, and recyclability. Improper disposal can cause environmental harm and pose health risks due to the presence of hazardous substances.

To manage this diversity, in the production of statistics EEE is classified into product-centric categories, known as UNU-KEYs, based on similar function, material content, average weight, and end-of-life characteristics. These UNU-KEYs can be directly linked to the six WEEE categories defined in the WEEE Directive, enabling consistent classification and reporting. The full list of UNU-KEYs and the correspondence with the six WEEE categories is available in 8.1 (adapted and extended from Annex I of Forti et al., 2018).

EEE becomes Waste Electrical and Electronic Equipment (WEEE) once it is discarded by its holder with no intention of reuse. Notably, batteries and other energy storage devices are excluded from EEE definitions in most legislation, as they require distinct end-of-life treatment. EEE components designed solely for use within vehicles or similar apparatus are also excluded, as they do not function as standalone devices.

The WEEE Directive classifies WEEE into six general categories and sets binding targets for their collection, reuse, recycling, and recovery (Directive 2012/19/EU, n.d.):

- Temperature exchange equipment (e.g., refrigerators, air conditioners, heat pumps)
- Screens and monitors (e.g., televisions, monitors, laptops)
- Lamps (e.g., fluorescent and LED lamps)
- Large equipment (with any outer dimension over 50 cm, excluding items in categories 1–3) (e.g. washing machines, clothes dryers, electric stoves, photo copiers, furniture with EEE components)
- Small equipment (under 50 cm, not included in categories 1–3 or 6) (e.g. vacuum cleaners, microwave ovens, toasters, electronic kettles, radios, e-cigarettes, electronic scales)
- Small IT and telecommunication equipment (e.g., mobile phones, game consoles, keyboards, routers, GPS devices)

In addition to these six categories, photovoltaic (PV) panels are included under category 4 – Large equipment, but have specific reporting requirements under the WEEE Directive, reflecting their growing importance and distinct end-of-life management needs.

The Directive mandates the separate collection of WEEE and prohibits its disposal as unsorted municipal waste. A central provision is extended producer responsibility, which requires producers to finance and organize the collection, transport, treatment, and proper disposal of their products at end-of-life. Under the extended producer responsibility system, producers must also meet minimum targets for material recovery and ensure the safe removal of hazardous components. EU Member States are required to report annually on WEEE collection, treatment, and recovery rates to the European Commission, enabling effective policy monitoring and evaluation.

The WEEE Directive is part of a broader EU policy framework focused on resource efficiency, secure supply of critical raw materials, and circular economy. The treatment and recovery of materials from WEEE are essential for addressing resource scarcity, reducing environmental impacts, and advancing the circular economy. Strategies such as urban mining, the adoption of advanced technologies, and the improvement of collection infrastructure are key to achieving both critical raw material recovery goals and broader circular economy objectives. The Critical Raw Materials Act complements the WEEE Directive by setting concrete benchmarks which are directly relevant also to the WEEE sector, as many critical and strategic raw materials, such as rare earth elements, lithium, and cobalt, are embedded in discarded electronic products (Regulation (EU) 2024/1252, n.d.).

WEEE is one of the fastest-growing waste streams globally, driven by rapid technological innovation, increased consumption of electronics, and shorter product life cycles. According to The Global E-waste Monitor 2024, 62 million metric tons of WEEE were generated worldwide in 2022, yet only 22.3% was properly collected and recovered (Baldé et al., 2024).

To assess WEEE generation and the associated end-of-life flows across Europe, this report builds extensively on the FutuRaM project, which provides the data foundation and methodological framework presented. The project developed a comprehensive methodology to estimate quantities of WEEE and the theoretical availability[7] of secondary raw materials, including critical raw materials (details of the project in the box below). The project aims to enhance data availability and provide a robust, forward-looking modelling framework to support policy and industry decision-making.

In terms of composition, WEEE contains a complex mixture of materials and components, including

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[7] In FutuRaM, the term «theoretical availability» refers to the quantity of critical raw materials that could be recovered, as actual recovery at the final treatment operator stage was not assessed. For the purposes of this report, this term has been sometimes simplified to «recovery».

both valuable substances and hazardous elements. On average, typical WEEE is composed of: ferrous metals (e.g., steel), non-ferrous metals (e.g., aluminium, copper), plastics, glass, ceramics, and composites, precious metals (e.g., gold, silver), critical raw materials (e.g., cobalt, rare earth elements like neodymium, dysprosium, europium) and hazardous components (e.g., mercury, lead, brominated flame retardants, capacitors). The material composition varies greatly depending on the product type, its generation year, and miniaturization trends. Understanding composition is essential for designing effective recovery strategies and meeting recovery targets.

A central component of the FutuRaM approach is the application of a stock and flow model, which quantifies the main WEEE statistics indicators from their placement on the market (POM), through their active in-use stock, to their transition into end-of-life flows. By linking product composition data to WEEE flows and recovery pathways, the FutuRaM model supports a mass-balanced understanding of theoretical availability and losses of secondary raw materials over a time horizon extending to 2050. This contributes with valuable insights into how the WEEE stream can be better managed to meet future resource needs, reduce waste, and promote circularity in the EU27+4.

The present report is structured as follows:

- Chapter 2 details the methodology and modelling framework used in the FutuRaM project, which are the basis for the outcomes discussed in the report. This includes the development of UNU-KEY product composition profiles, the stock-and-flow modelling of EEE and WEEE, the construction of WEEE category compositions, and the implementation of a recovery model to estimate the theoretical availability of critical raw materials in WEEE.

- Chapter 3 presents key outcomes of the FutuRaM project with regards to WEEE, including estimates of WEEE generation, WEEE collected in compliance with the WEEE Directive, and complementary flows i.e. through non-compliant routes. These results are provided both at the aggregated EU27+4 level and for individual countries, covering the period from 2010 to 2050 and disaggregated by WEEE category.

- Chapter 4 focuses on critical raw materials, examining their presence within WEEE, estimating their theoretical availability, and providing policy recommendations to enhance their recovery in line with EU strategic objectives.

- Chapter 5 presents three factsheets visualising FutuRaM data on selected critical raw materials. They illustrate material generation, potential losses during collection and recovery, and theoretical availability across three scenarios, as well as the main WEEE categories and components in which these materials occur.

- Chapter 6 concludes the report by summarizing the key findings and outlines how the data and tools developed will support decision-making through the FutuRaM Urban Mine Platform.

Concerning the terminology adopted in the present report, the Critical Raw Materials Act distinguishes between critical raw materials and strategic raw materials. However, it also specifies that all strategic raw materials are a subset of critical raw materials, meaning that the “strategic” designation is an additional classification applied to certain critical raw materials based on their strategic importance. Therefore, in this report, the term “critical raw materials” will be used inclusively to refer to both critical and strategic raw materials. The quantitative analyses presented herein are based on the list of critical raw materials established in the Critical Raw Materials Act of 2023 (Regulation (EU) 2024/1252, n.d.); for the forward-looking assessment to 2050, it is assumed that this list remains unchanged, notwithstanding the fact that it is subject to periodic revision and may evolve over time.

References in this report to a recovered element (e.g., copper) include both the amount of the element recovered in its pure form and the quantity of the same element embedded within a material fraction (e.g., copper-rich fractions) or a component (e.g., printed circuit boards, cables) that is recovered and intended/sent for further processing.

In addition, the term "losses" refer to the waste and material fractions which are not retained within the compliant collection and recovery system, either because they are not retrieved during the collection phase or because they are discarded as residues during dismantling and recovery processes.

It should be noted that the WEEE dataset developed in FutuRaM does not include batteries, even though they are a component of many EEE devices. Batteries were treated and analysed as a separate stream throughout the project and therefore have a dedicated dataset. This choice is in line with the methodology for the calculation of the weight of EEE placed on the market and WEEE generated (Regulation (EU) 2017/699) and of the WEEE Directive 2012/19/EU, according to which the weight of batteries is excluded from the weight of EEE and has to be treated in accordance with the Batteries Regulation (Battery Regulation (EU) 2023/1542, 2023).

About FutuRaM

The Future Availability of Secondary Raw Materials (FutuRaM) project seeks to develop knowledge on the availability and recoverability of secondary raw materials within the European Union (EU), with a special focus on strategic and critical raw materials, to enable fact-based decision making for their exploitation in the EU and third countries. FutuRaM focuses on six waste streams: waste batteries, waste electrical and electronic equipment, end-of-life vehicles, mining waste, slags and ashes, and construction and demolition waste. The FutuRaM project will establish a methodology, reporting structure, and guidance to improve the raw materials knowledge base up to 2050.

In addition, the concept of the United Nations Framework Classification is being developed for use in secondary raw materials projects along with the creation of scenario analyses up to 2050.

The provided datasets will be integrated into the FutuRaM Urban Mine Platform web portal. Its search, filter, visualization, and download functions support the identification of material hotspots - an essential first step in helping the EU and member states develop coherent policies for improved recovery of critical and strategic materials. The proposed methodological framework, extendable to waste from other waste streams, also supports monitoring secondary, strategic, and critical raw materials via official statistics.

FutuRaM is a four-year project funded by the European Union’s Horizon Europe research and innovation programme that started in June 2022. The consortium of the FutuRaM project is composed of 28 partners.

FutuRaM
Future availability
of secondary
raw materials

Methodology

This chapter outlines the key steps of the FutuRaM project to quantify mass-balanced WEEE datasets over the time horizon from 2010 to 2050 (see Figure 1). The methodology expands the scope of conventional waste flow statistics, aligning with the waste statistics framework proposed by (UNECE, 2022) and the principles set out in The E-waste Statistics Guidelines (Forti et al., 2018).

The approach consists of the following main methodological steps, which have been further described in the FutuRaM project (Iattoni et al., 2025 and Yamamoto et al., 2025):

- Product composition
- Stock and flow modelling
- Waste composition
- Recovery modelling
- Future scenarios to 2050

Product composition was assumed to be uniform across the EU27+4. In contrast, the stock and flow model was applied individually to each country in this group to capture national variations in product use and waste generation. The product composition was then used as input for the stock and flow model to derive waste composition over the entire 2010–2050 period. This was based on the lifetime distribution of historically marketed products and their respective material composition.

In the final step, the recovery model was applied using three key inputs: the total mass of WEEE compliantly collected, the corresponding waste composition, and the recovery data referred to in the project as "transfer coefficients." These coefficients allow for the calculation of the fractions retained, recovered, or lost at each treatment stage (see 2.4 for more details). The model simulates WEEE management processes and was applied uniformly across the EU27+4, generating aggregated results for the entire region.

These main methodological building blocks relied on observed data up to 2022, consisting of reported, literature-obtained, and modelled data, followed by projections under three contrasting future scenarios - business-as-usual, recovery, and circularity - extending to 2050 (see 2.5).

This framework enabled the quantification of key novel outputs for the WEEE datasets: namely, the secondary and critical raw materials recovered, and those lost during either the collection or the recovery phases.

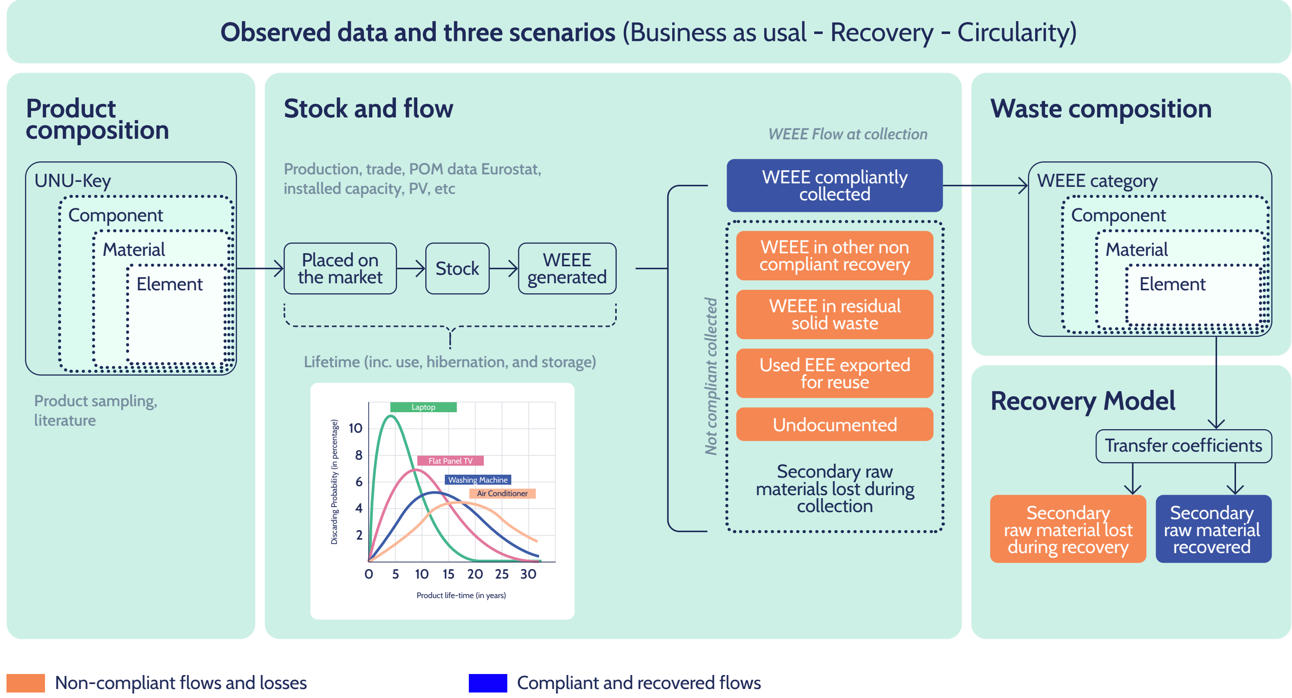

Figure 1 - Main steps of the applied methodology (adapted from the FutuRaM project, see Iattoni et al., 2025 and Yamamoto et al., 2025).

The building blocks of the applied methodology and the overarching future scenarios quantification are briefly explained in the respective sections below.

2.1. Product composition

The product composition was further extended using as a basis the hierarchical approach developed in the ProSUM project (European Commission, 2023). At this stage, the composition per UNU-KEY is calculated hierarchically and split into mutual exclusive layers of components, materials, and elements. Each element is associated with a specific material, which is linked to a component and then to a product (Figure 2).

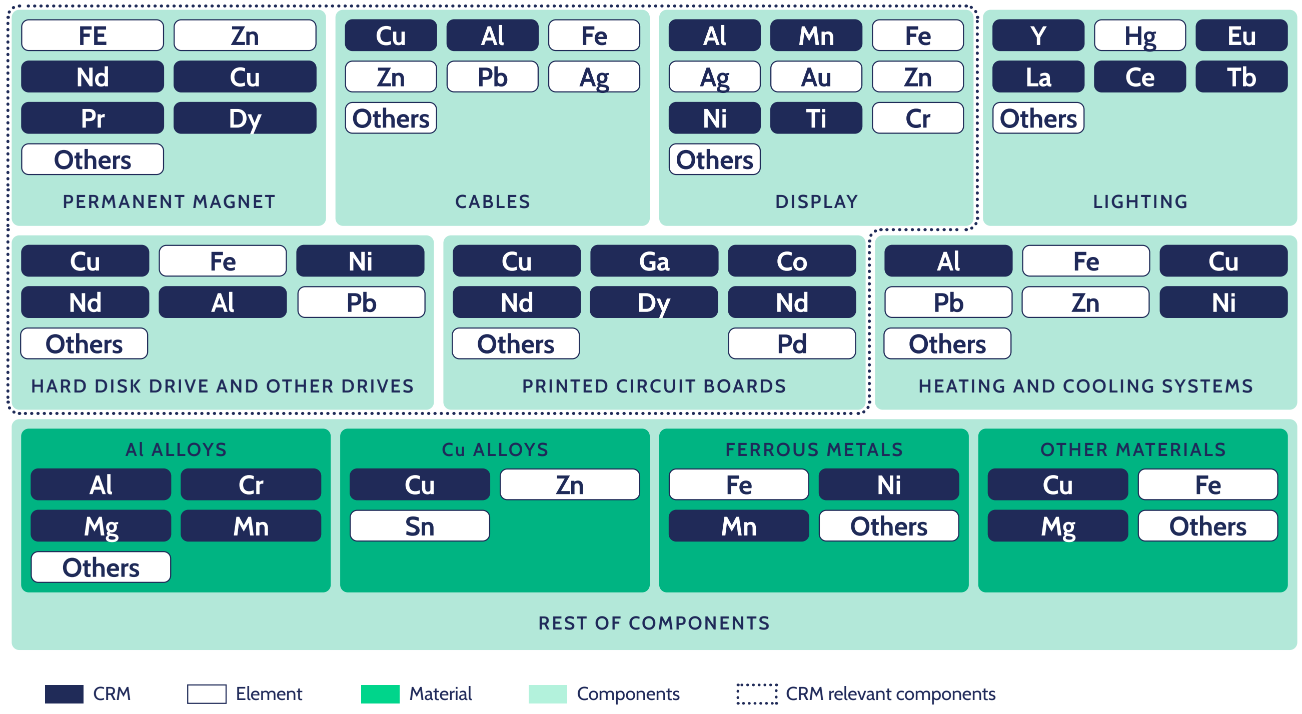

Figure 2 - Non-exhaustive mapping of the FutuRaM nested composition data including components, materials and elements for a specific product - example of laptop (UNU-KEY: 0303, category: Screens and monitors)[8].

The EEE composition dataset developed covers 80 components, including key ones that are rich in critical raw materials, such as printed circuit boards, hard disk drives, permanent magnets, compressors (specifically for temperature exchange equipment), various display types (e.g., cathode ray tube, liquid crystal, plasma - especially for the category 'screens and monitors'), cables, photovoltaic cells, and photovoltaic frames. In the composition dataset, sub-components embedded in other components (e.g. a permanent magnet which is a sub-component in the component hard disk drive) are included in the mass balance of the main component (i.e. hard disk drive in this example) without double counting.

The dataset includes 23 materials, among which the main ones influencing the waste management output fractions are aluminium and aluminium alloys, copper and copper alloys, ferrous metals, non-copper and aluminium alloys, silicon semiconductor, and magnetic materials. Other important fractions include plastics and glass and ceramics.

Additionally, the dataset encompasses a total of 64 elements, including critical raw materials (e.g., Al, Ni, Mn, Eu), critical raw materials that are also strategic raw materials (e.g., Cu, Co, Dy, Nd, Pr, Pd, Si), as shown in 8.4 of this report, precious metals (e.g. Ag and Au), and other elements (e.g. Fe).

Because the variety of products within the WEEE stream is large and complete mapping is data-intensive, with inevitable data gaps even within a single UNU-KEY, a model has been developed that integrates data from waste sampling and literature, while accounting for missing information through gap-filling approaches. Data were collected from a range of sources, including past project outputs (e.g., Huisman et al, 2017 and Løvik et al., 2017), contributions from the FutuRaM project partners (e.g. Ecosystem, 2023 – the French producer responsibility organisation), and literature (e.g. Babbitt et al., 2019; P.E.P. Association, 2023). The raw data were consolidated and harmonised to fill gaps, detect outliers, and ensure consistency with the modelling framework described in this section. The final consolidated dataset was then aggregated by WEEE Directive category and integrated into the stock and flow model (see 2.2).

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[8] The battery component is not shown, as it was excluded from the WEEE dataset and methodology. Additional materials and subcomponents may also be present but are not visualized for simplification. The selection of CRM relevant components has been obtained through the prioritization work, conducted in collaboration with the Joint Research Centre in the context of the revision of Article 26 of the Critical Raw Materials Act (Regulation (EU) 2024/1252), currently unpublished (Lodato et al., 2025).

2.2. Stock and flow modelling

A stock-and-flow model is used to quantify the mass of EEE placed-on-market (POM), in-use stocks, and WEEE generation per UNU-KEY. The amount of EEE placed-on-market is calculated through the apparent consumption methodology (Regulation (EU) 2017/699) using trade and domestic production statistics from Eurostat (Eurostat, 2022a), cross-checked with the data on EEE placed-on-market reported to the WEEE directive at WEEE category level per country, per year (Eurostat, 2025).

A lifetime model (Annex 2, Forti et al., 2018) differentiated per UNU-KEY is then applied to estimate the amount of WEEE generated over time and to consequently derive the EEE in stock. The lifetime profile shows how likely it is that EEE sold in a given year will become waste in the subsequent years. The discard-based lifetime profile for a product can be modelled using several probability functions. The Weibull distribution function is the most suitable to describe discard behaviour for EEE and has been applied in the EU and in scientific literature (Wang, 2014; Zeng et al., 2016). The variation for the lifetime between the countries in the EU has been observed to be small for most products (Magalini et al., 2014) and therefore they have been applied uniformly for all countries in the EU27+4 (Annex 2, Forti et al., 2018).

For WEEE generated, the definition from (Regulation (EU) 2017/699) is applied, which defines it as the total weight of WEEE arising from the amount of EEE within the scope of Directive 2012/19/EU that was placed on the market of a Member State, prior to any activities such as collection, reuse preparation, treatment, recovery (including recycling), or export.

In the methodology applied, the calculations for EEE placed on the market up to WEEE generated are produced per UNU-KEY level. The data is then aggregated into the WEEE categories as defined in the WEEE Directive, with a split for photovoltaic panels, to model the WEEE management at the end-of-life.

In particular, the stock and flow model covers the most commonly occurring WEEE end-of-life pathways, comprising:

- WEEE managed in a compliant manner in accordance with the WEEE Directive and used for reporting to the WEEE Directive (also referred to as "WEEE compliantly collected")
- WEEE not managed compliantly with the WEEE Directive, split into
    - WEEE mixed with residual solid waste
    - WEEE in other non compliant recovery (e.g. mixed with other metal and plastic waste)
    - Used EEE exported for reuse
    - WEEE undocumented

Data on WEEE compliantly collected were derived from Eurostat reporting (Eurostat, 2025) while data on other WEEE flows were obtained from a combination of peer-reviewed publications (e.g., Baldé et al., 2020, Baldé, Iattoni, et al., 2022), past project outcomes (Huisman et al., 2016b, Wolk-Lewanowicz et al., 2016, and Huisman et al., 2017), grey literature from compliance schemes, and input from the FutuRaM consortium partners. In particular, data for WEEE in other non-compliant recovery (mainly treated with metal waste and plastic waste), WEEE mixed with the residual solid waste and used EEE exported for reuse comes from national studies conducted in ten countries (Austria, Belgium, Czech Republic, Denmark, France, Ireland, Netherlands, Norway, Sweden, United Kingdom) and obtained from three compliance schemes (Luxembourg, Romania, Netherlands) for the years 2010-2023, and it is estimated for the other countries based on averages and the mass balance of the WEEE flows. Where necessary, missing data were estimated, and outliers were checked through cross-country comparisons. The amount of WEEE undocumented is determined using a mass balance calculation.

2.3. Waste composition

As a next step, the waste composition is calculated for each WEEE category. This is done through several stages. First, the EEE POM obtained from the stock and flow model is multiplied by the respective product composition for each UNU-KEY, country, and year. The amount of EEE POM with the related product composition was then used as input again for the stock and flow model to derive waste composition over the entire 2010–2050 period. This is obtained through the lifetime distribution of products historically placed on the market and their respective material composition. This approach is necessary considering that the characteristics of EEE composition has changed considerably in the past couple of decades. In the example of mobile phones, earlier models were relatively simple, while modern smartphones incorporate complex components and advanced materials.

As consumers adopt newer models, the in-use stock of mobile phones evolves accordingly, so the WEEE generated each year reflects a mix of past product generations, consequently composition also changes (Iattoni et al., 2025 and Yamamoto et al., 2025). The results are then aggregated by WEEE category, year, and country. As a result, the waste composition at the WEEE category level is uniquely linked to, and mutually exclusive across, each UNU-KEY, product component, material, and element which are part of that category (see example for category screens and monitors in Figure 3 and Figure 4). In these figures, the large number of components, materials, and elements in the composition data results in not all slices being individually labelled. The charts are therefore intended to illustrate the structural complexity of the composition rather than to allow detailed identification of each entry.

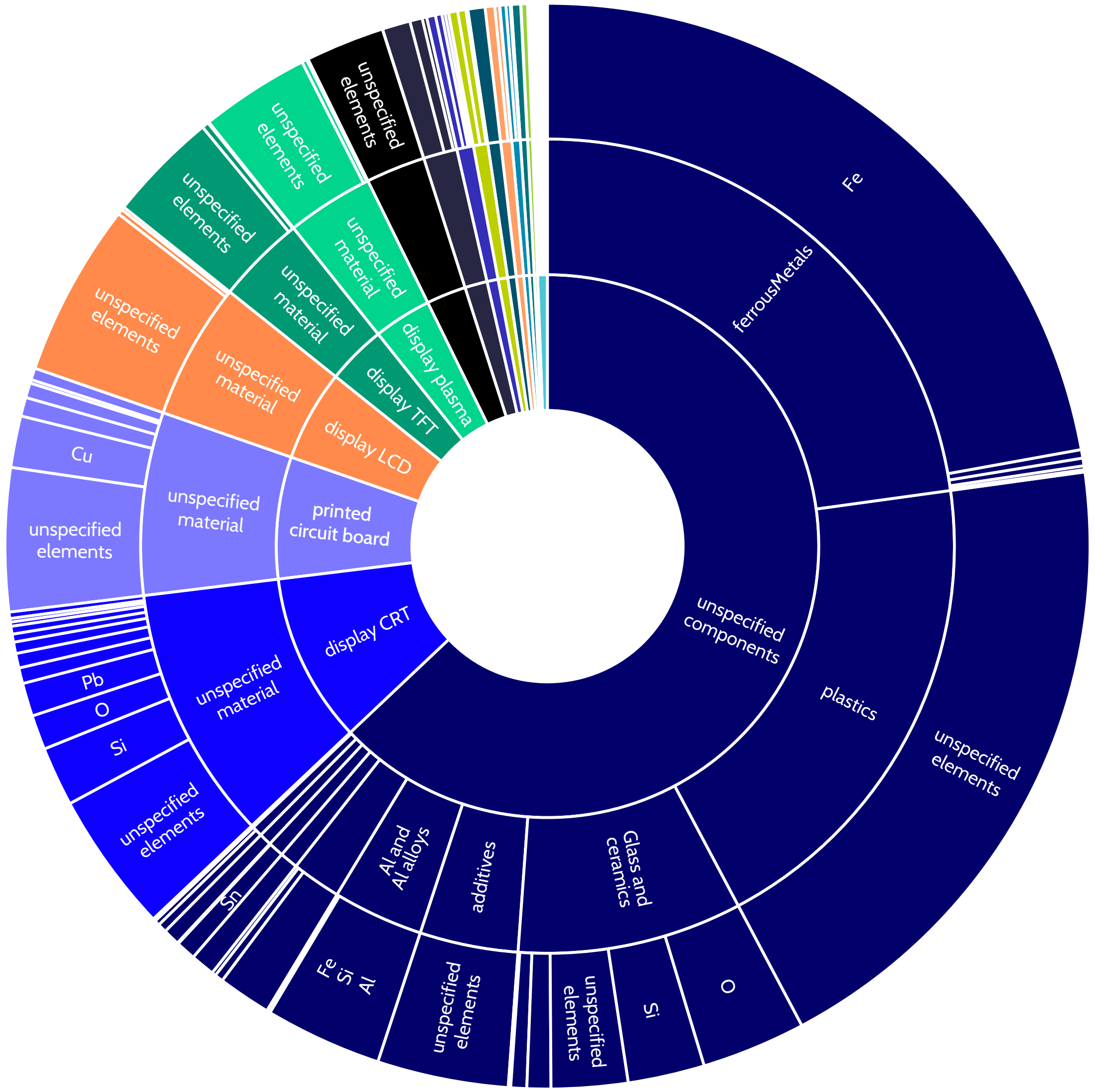

Figure 3 - Hierarchical distribution of composition data (p—c—m—e) aggregated for the WEEE category Screens and monitors[9]. The chart includes all components, materials, and elements, including "unspecified", which refers to unidentified components, materials, and elements introduced as placeholders in the dataset to maintain overall mass balance.

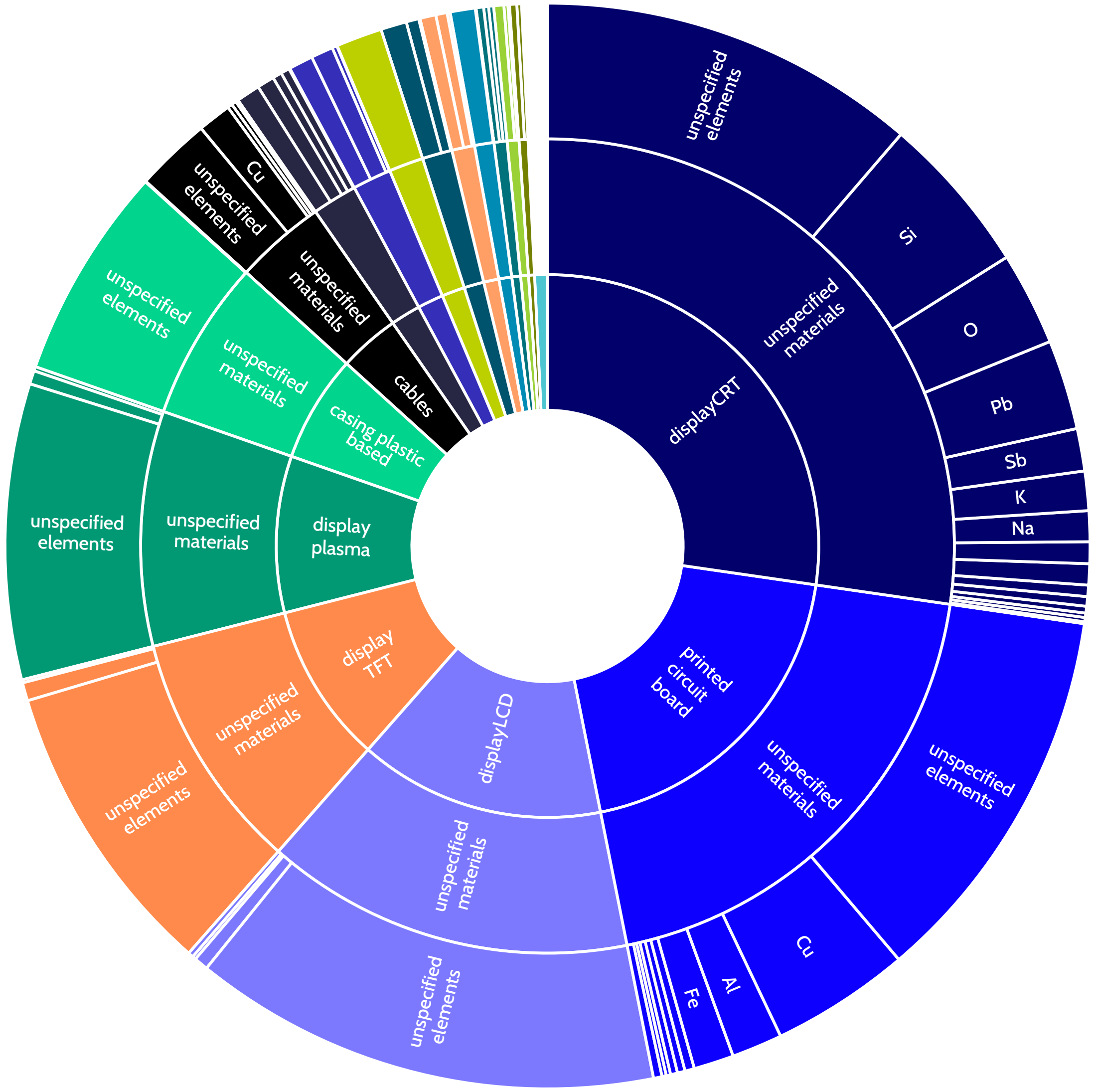

Figure 4 - Hierarchical distribution of composition data (p—c—m—e) aggregated for the WEEE category Screens and monitors. All components, materials, and elements are shown except the item «unspecified components» and the related materials/elements embedded, which was removed to improve visibility. This chart therefore covers approximately 37% of the total composition.[10]

The results of the WEEE composition analysis are subsequently distributed based on the shares of WEEE compliantly collected each year in each country. Flows that are not managed in compliance with the WEEE Directive lead to losses of secondary and critical raw materials at the collection stage, as these materials are not properly gathered and therefore not processed. In contrast, the share of WEEE generated that is compliantly managed under the WEEE Directive, is transferred as input to the recovery model.

This data is essential for understanding the presence and theoretical availability of secondary, strategic, and critical raw materials - including where these materials are located (e.g., in specific components or materials) and which measures could support their recovery (Iattoni et al., 2025 and Yamamoto et al., 2025).

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[9] The inner layer displays the components, the middle layer shows the materials embedded in these components, and the outer layer represents the elements present in those materials (and, consequently, in the components). A distinct colour is assigned to each component, and the same colour is consistently applied to its corresponding materials and elements, enabling visual traceability from component > material > element.

[10] Visualization remark: in Figures 3 and 4, the white space at the top of the graph does not indicate missing data, but rather the very large quantities of some inputs, which visually compress the others.

2.4. Recovery modelling

The theoretical availability of critical raw materials from WEEE was estimated using the recovery model developed in the FutuRaM project (Iattoni et al., 2025 and Yamamoto et al., 2025). In FutuRaM, the term «theoretical availability» refers to the quantity of critical raw materials that could be recovered, as actual recovery at the final treatment operator stage was not assessed. For the purposes of this report this term is sometimes simplified to «recovery».

The recovery model developed in FutuRaM ensures that the hierarchical structure of products-components-material-element defined at the composition level is preserved. It supports the exploration of multiple future scenarios by allowing recovery assumptions (e.g. transfer coefficients, process applications) to be adapted over time. The results indicate how much critical raw material is recovered, lost during collection, or lost in treatment within the EU27+4, and are presented in aggregated form.

Key input data to the recovery model include:

- Total mass of WEEE compliantly collected
- Waste composition of WEEE compliantly collected
- Transfer coefficients

The system boundary of the recovery model begins at WEEE compliantly collected (from the stock and flow model), including its embedded waste composition, and is modelled via the application of transfer coefficients to obtain subsequent treatment flows. These flows, that are part of the formal WEEE treatment system, cover dismantling processes and shredding and separation processes. A schematic representation of the system boundaries, input, and output fractions of the recovery model applied for copper (Cu) in the category screens and monitors is shown in Figure 5.

Transfer coefficients are collected at product (UNU-KEY) level and then aggregated at WEEE category level to reflect the resolution of the input data used in the recovery model. They are applied at each layer of the waste composition (i.e. component, material, element) to calculate the fraction that is retained, recovered, or lost during each step of the treatment process. The model ensures that all flows remain consistent in mass and structure.

FutuRaM recovery model system boundaries

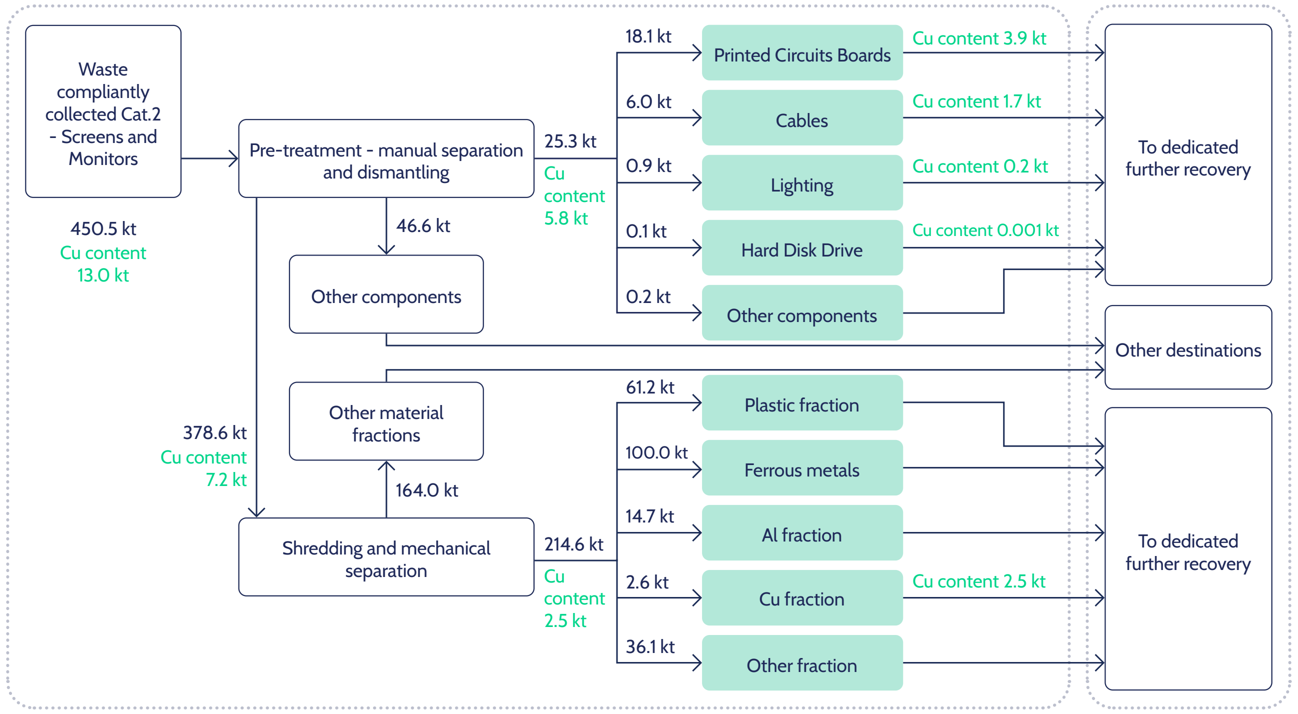


Figure 5 - Flowchart representing the system boundaries, input, and output fractions of the recovery model developed in FutuRaM for copper (Cu) in category Screens and monitors (reference year: 2022). Where Cu content is not explicitly indicated in certain flows, this reflects a lack of available data; Cu may still be present, but likely only in minor quantities.

Transfer coefficient data used in the WEEE recovery model were sourced from both primary contributions and existing literature (e.g. Deubzer et al., 2025 and Hämmer & Wambach, 2024). Primary data were obtained through confidential submissions from industry stakeholders and official reporting mechanisms, including inputs from producer responsibility organisations (e.g., WEEE Forum, 2025) involved in the FutuRaM project. A stakeholder consultation, conducted in collaboration with the WEEE Forum and its members, including industry representatives, research institutions, and producer responsibility organisations, was used to address remaining data gaps and verify the robustness of the collected information.

2.5. Future scenarios to 2050

The future projections to 2050 are based on the correlations between placed on the market data, population, and gross domestic product (GDP) corrected through purchasing power parity (PPP) and are distinguished according to three different scenarios: Business-as-usual (BAU), Recovery (REC), and Circularity (CIR).

In the business-as-usual scenario, consumption of electronics continues increasing at the same rate, which keeps the amount of WEEE generated at high levels. The WEEE management characteristics remain proportionally mostly the same.

In the recovery scenario, EEE consumption and WEEE generation are modelled as in the business-as-usual scenario, while the main change is in the waste management system. The recovery scenario assumes improved recovery, which could result from improved collection, sorting, and recovery. The changes in the waste treatment operations are represented by adjustments to transfer coefficients for recovery processes (see 2.4), which will then change over time or in a specific year when a particular change in the waste treatment processes is assumed to be implemented.

The circularity scenario shows a shift toward circular economy practices. In this scenario, electronic products are increasingly made to last longer, be easier to repair, upgrade, and recycle, following the «Design for Circularity" approach. Instead of owning devices, people may use service-based models (like renting or subscriptions), which help to reduce the quantity of WEEE generated. Longer product lifespans, more repair and reuse, and less frequent buying of new products lead to less EEE placed on the market, WEEE generated, and slower stock growth. Additionally, the same improvements to the WEEE management system (i.e. higher collection and recovery) of the recovery scenario are also reflected in this scenario.

This circularity scenario is based on the report 2050 Electrical and Electronic Waste Outlook in West Asia (UNEP & UNITAR, 2023). It includes several strategies, also referred to as five circular economy pathways, to move away from business-as-usual:

- Obsolescence: some products may disappear by 2050, like DVD players being replaced by smartphones and streaming.
- Saturation of stock per person: for some appliances like refrigerators, there's a natural limit to how many a household needs, even as incomes rise.
- Better durability: products may last longer thanks to better design or being reused more often through second-hand markets.
- Less hoarding: items like laptops or phones are used longer, passed on, or recovered instead of being stored and forgotten.
- More sharing: products are shared more (e.g., shared devices or appliances), which means fewer are needed overall, though this may cause them to wear out faster due to heavier use.

Each scenario shares the same background data on gross domestic product (corrected through purchasing power parity), population, and EU targets. The composition data also remains constant across scenarios. Regarding the stock and flow, the trends observed on POM, lifespan, and WEEE generation are applied equally for the business-as-usual and the recovery scenario, while the circularity scenario applies specific assumptions (e.g. lifespan extension for better durability, less products placed on the market, etc.). The same assumptions of improved compliant collection and less complementary flows are applied to the recovery and circularity scenarios. To model the theoretical availability of secondary raw materials, the same transfer coefficients reflecting better recovery technologies are applied for the recovery and circularity scenarios.

A summary table of the future scenarios for WEEE is shown in Table 1.

Table 1 - Future scenarios narrative and implementation on background data, product composition, stock and flow, and recovery model.

Scenario	Business as usual	Recovery	Circularity
Narrative	Extrapolation of current trends	Improved sorting, collection and recovery	Reduced demand, improved sorting, collection and recovery
Background Data (GDP, PPP, Population, EU targets)	Same accross all	Same accross all	Same accross all
Product composition	Same accross all	Same accross all	Same accross all
Stock and flow (POM, lifespan, WEEE generation)	Business as usual assumptions	Business as usual assumptions	Circularity assumptions
Stock and flow (WEEE formal collection and complementary flows)	Business as usual assumptions	Circularity assumptions	Circularity assumptions
Recovery model (and transfer coefficients)	Business as usual assumptions	Recovery assumptions	Recovery assumptions

More information on how the five circular economy pathways have been parametrized for each UNU-KEY is available in 8.2 and 8.3.

Data until 2022 are referred to as "observed" (OBS) and consists of reported, literature-obtained, and modelled data.

2.6. Further information

Further details on the data sources and methodology are available in the Supplementary information on WEEE to Deliverable 4.1 "Future trends of secondary raw materials and critical raw materials" (Yamamoto et al., 2025).

Key figures on WEEE flows

WEEE Generation is projected to grow at an accelerated rate under both the business-as-usual and the recovery scenario, reaching 19 Mt in 2050. In contrast, the circularity scenario is projected to result in a lower WEEE generation of 12.5 Mt.

Between 2010 and 2022, the volume of WEEE generated in Europe increased from 8.3 Mt (16 kg per capita) to 10.7 Mt (20 kg per capita), with an average annual increase of 0.2 Mt (see Figure 6). Future projections suggest an acceleration in growth to an average of 0.3 Mt per year, leading to 19 Mt (36 kg per capita) by 2050 under the business-as-usual and recovery scenarios. This growth is expected to be driven by the emergence of new waste types, such as photovoltaic panels and open scope equipment, as well as general factors, such as a population growth from 529 million in 2022 to 538 million in 2050 (Eurostat & European Commission, 2023, ONS, 2022, Vanella et al., 2020), and the increase of consumption due to a higher gross domestic product (GDP) (OECD, 2021). In contrast, under a circularity scenario, WEEE generation is projected to peak between 2035 and 2040 at 14.5 Mt (27 kg per capita), before declining to 12.5 Mt (23.5 kg per capita) after 2040. This decline is mainly attributed to lifetime extension through reuse and repair, and reduced hoarding of functioning equipment, which are the main assumptions under the circularity scenario. However, some WEEE categories, such as photovoltaic panels, are still expected to grow even in a circularity scenario.

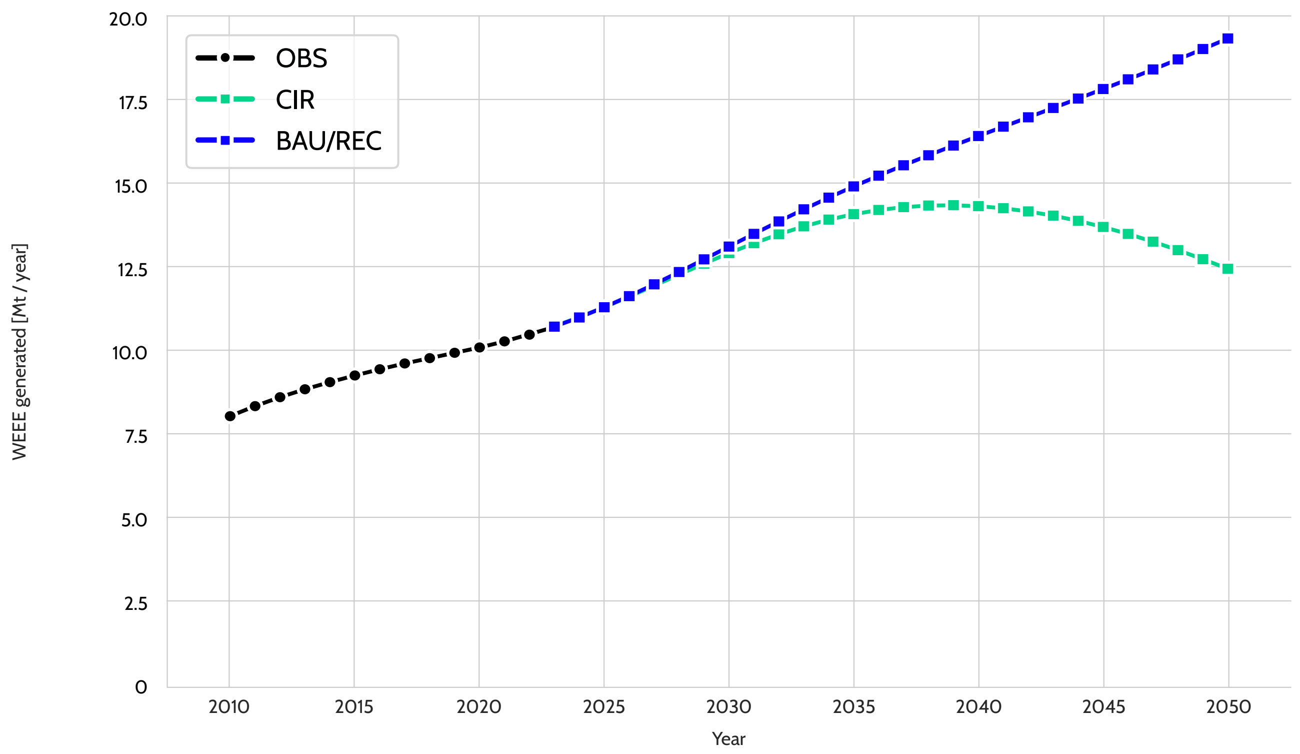


Figure 6 - Total WEEE generated in the EU27+4: observed data (OBS) for 2010–2022 and projections for 2023–2050 under three scenarios - business-as-usual (BAU), recovery (REC), and circularity (CIR).

In 2022, WEEE generation in EU27+4 countries ranged from 11.9 to 27.5 kg per capita, with an average of 20.2 kg, and is projected to rise to an average of 36.2 kg per capita by 2050 under business-as-usual and recovery scenarios, while remaining lower, at an average of 23.5 kg per capita, under a circularity scenario.

In 2022, the total quantity of WEEE generation per country ranged between 11.9 kg/capita in Latvia to 27.5 kg/capita in Norway. The EU27+4 average was 20.2 kg per capita in 2022. When projecting to 2050, the WEEE generation increases to on average 36.2 kg per capita in 2050. The quantities range from below 30 kg/capita in Malta, Romania, Slovakia and Czech Republic to above 40 kg/capita in Finland, Switzerland, United Kingdom, Ireland, Netherlands and Norway. In the circularity scenario, per capita WEEE generation is projected to continue rising in most countries by 2050 compared to 2022, although at a slower pace than the business-as-usual and recovery scenario. Under a circularity scenario, WEEE Generation ranges from under 20 kg per capita in Slovakia and Malta to over 25 kg per capita in Switzerland, Denmark, Estonia, Finland, Great Britain, Lithuania, and the Netherlands, with an EU27+4 average of 23.5 kg per capita (see Figure 7). The spread in the minimum and maximum of WEEE generation between the countries is 8 kg per capita in the circularity scenario. This is less than the spread observed in 2022 of 16 kg per capita, and less than the spread of 17 kg per capita in 2050 in the recovery scenario. Some ostensible distortions in the per capita figures may arise due to changes in the population in 2050. In particular, if the population decreases in a country (i.e. Bulgaria, Finland, Greece, Croatia, Hungary, Italy, Lithuania, Latvia, Poland, Portugal, Romania, Slovakia, and Slovenia) the total tonnage of WEEE generated may not directly decrease and hence may lead to higher kg/capita figures in 2050.

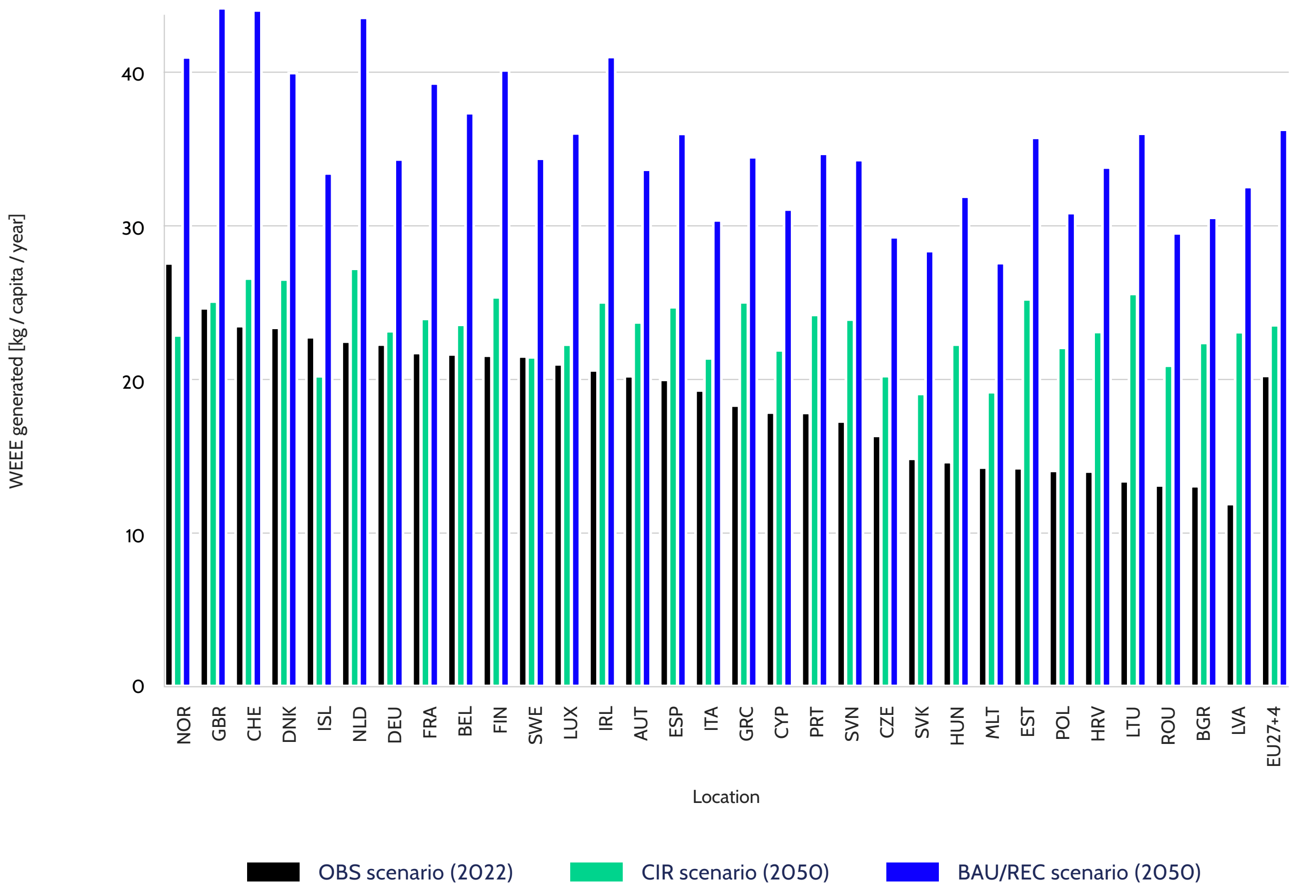
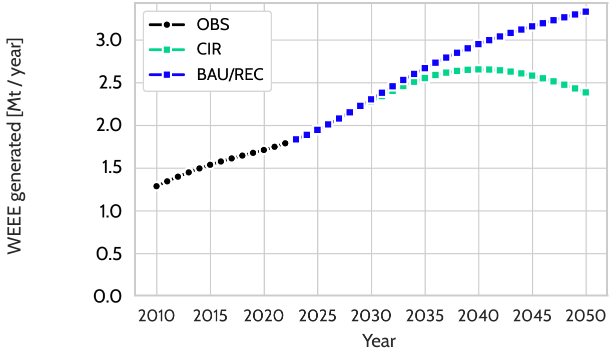


Figure 7 - Total WEEE generated per capita by country in the EU27+4: observed data (OBS) for 2022 and projections for 2050 under three scenarios - business-as-usual (BAU), recovery (REC), and circularity (CIR).

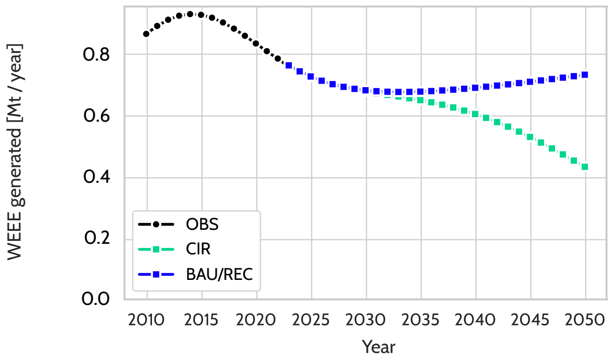
All WEEE categories are projected to increase by 2050, with the exception of screens and monitors, which show a temporary decline around 2035. The most pronounced growth is observed for photovoltaic panels, where volumes are projected to expand by more than an order of magnitude.

All WEEE categories are projected to grow from 2023 to 2050, except for screens and monitors, which are projected to decline between 2025 and 2035 and then increase slightly to 2050. Growth is greater in the recovery and business-as-usual scenarios than in the circularity scenario, where most categories decline after 2040. The categories temperature exchange equipment, screens and monitors, large equipment small equipment and small IT and telecommunication equipment show biggest potential for circularity interventions. In particular, photovoltaic panels are expected to grow substantially from 0.15 Mt in 2023 to 2.2 Mt in 2050. This is further explained per WEEE category below (see Figure 8).

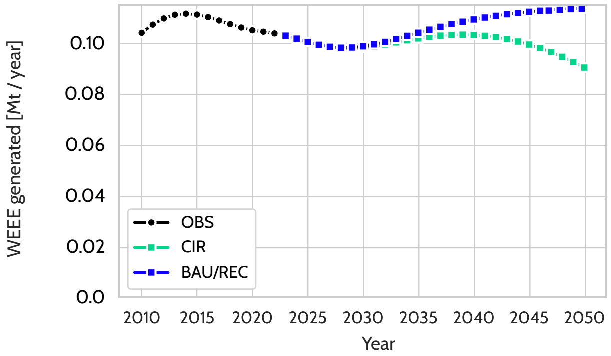
Temperature Exchange Equipment comprises refrigerators, freezers, heat-pumps and air-conditioners. In 2010 this category was at 1.3 Mt, in 2023 it raised to 1.8 Mt, and it is projected to be almost 3.3 Mt by 2050, driven by an increase in heat pumps and air conditioners reaching end-of-life. When lifespans are extended through design improvements and maintenance practices (circularity scenario), waste generation is expected to peak around 2040 at 2.6 Mt and then could decline further to 2.4 Mt in 2050.



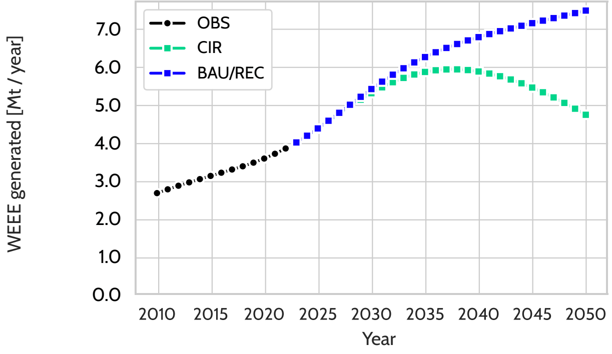
Screens and Monitors comprises laptops, tablets, monitors and televisions. The heavy cathode ray tube screens are expected to completely phase out in the next decade, causing the waste stream to stabilize at around 0.68 Mt between 2030 and 2035. The decline continues in a circularity scenario, in which lifetimes are extended, and less new screens are placed on market. In the business-as-usual and recovery scenario, waste generation is projected to grow to above 0.7 Mt.

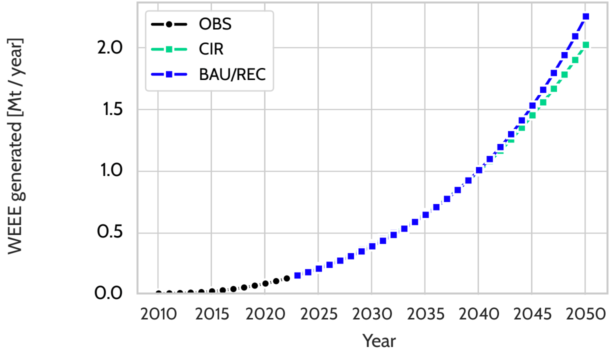


Lamps is the smallest category in terms of mass. It remains at around 0.1 Mt from 2023 to 2035. Within the category, there is a shift from fluorescent lamps to light emitting diodes (LEDs). After 2035, the scenarios are showing contrasting developments. Due to longer lifespans, and slightly lower unit weight of LEDs vs fluorescent lamps the waste generated in the circularity scenario could decrease to 0.09 Mt in 2050. In the business-as-usual and recovery scenarios, waste generation is projected to grow to 0.12 Mt.

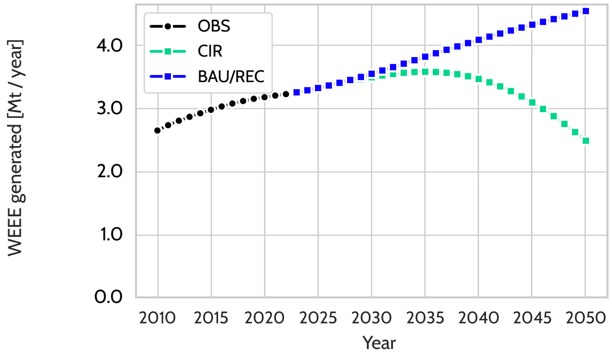


Large Equipment excluding PV comprises heavy units, such as washing machines, dishwashers and ventilators, as well as data servers and large photocopiers. This category was at 2.7 Mt in 2010. The amounts are projected to almost double from 4.0 Mt in 2023 to 7.5 Mt by 2050 in the business-as-usual and recovery scenario. In a circularity scenario, the waste generation is projected to peak at 6.0 Mt and then decline.

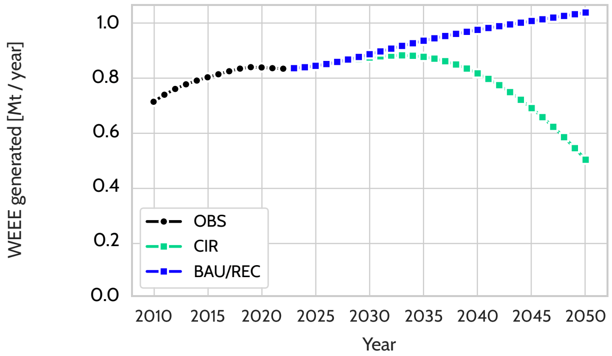




Photovoltaic panels is the waste stream that is projected to grow the most. In 2023, it was 0.15 Mt and is expected to grow to 2.2 Mt by 2050. The same stock projection of photovoltaic panels was used in all three scenarios. Circularity credentials are expected to be minimal for photovoltaic panels since their lifespan is around 25 years, hence the effects of circularity may only show up after 2050.



Small Equipment comprises a broad range of products, from clocks, luminaires, electric toothbrushes and toasters, to vacuum cleaners, ventilation equipment, microwaves, and radio sets. Despite being low in weight per unit, the quantity generated was 2.7 Mt in 2010 and 3.2 Mt in 2023. Due to their size and low unit price they are not often repaired and have shorter lifespans, this fuels greater waste generation, which is projected to reach 4.5 Mt by 2050 under the business-as-usual and recovery scenarios. In the circularity scenario, lifespans are increased due to improved repair, thus waste generation peaks in 2035 at 3.6 Mt before declining to 2.5 Mt.



Small IT and Telecommunication equipment, comprises a broad range of IT products such as mobile phones, IT accessories, desktop PCs and small photocopiers. The waste generated in 2023 was just over 0.8 Mt. Due to limited repair and constant innovations, lifespans are short, and consumption stays high, driving waste generation to over 1.0 Mt by 2050. In a circularity scenario, waste is modelled to peak around 2035 and then rapidly decline.

Figure 8 - Total WEEE generated by WEEE category for the EU27+4: observed data (OBS) for 2010-2022 and projections for 2050 under three scenarios—business-as-usual (BAU), recovery (REC), and circularity (CIR).

The current WEEE collection rate in the EU27+4 is 5.7 Mt, which equates to a 54% collection rate based on WEEE Generated. The quantity of WEEE that is not compliantly managed within the scope of the WEEE Directive is typically found in four non-compliant complementary flows: (1) mixed in residual solid waste, (2) other non-compliant recovery, (3) exported for reuse, and (4) undocumented. WEEE collection is projected to grow to between 11 Mt and 17 Mt by 2050, depending on the scenario considered.

In 2022, an estimated 10.7 Mt of WEEE was generated. Of this total, 5.7 Mt was collected and managed in compliance with the WEEE Directive (see Figure 9). This comprises WEEE being separately collected at retailers, municipal collection points, and commercial collection companies, after which it is sent for dismantling. During dismantling, hazardous and valuable components (i.e. cables, printed circuit boards, etc.), are removed and sent for specific treatment (depollution) and/or material recovery. The remainder is shredded then separated before ferrous, copper and aluminium fractions are recovered with other parts sent for energy recovery.

The remaining 5.0 Mt was not managed through official or compliant channels. These non-compliant flows are estimated to consist of 0.7 Mt of WEEE mixed with residual solid waste which is then landfilled or incinerated. Some European countries may use magnetic separation or recovery of bottom ashes to extract certain metals. Around 3.3 Mt of WEEE is mixed with other waste streams recovered outside of the WEEE Directive (e.g. metal waste, plastic waste, etc.), corresponding to the flow other non-compliant recovery as defined above. In the case of metal waste, WEEE is likely shredded and separated into ferrous, aluminium, and copper fractions. However, other metals and alloys are generally not recovered for similar functional usage when WEEE is treated within the metal scrap stream. There are around 0.4 Mt exported for reuse, some of which is through legal channels but in some cases, this is uncontrolled and undocumented (Baldé et al., 2024). Studies show that undocumented shipments, mostly to low- and middle-income countries, may contain up to 30% to 70% of WEEE which are declared as second-hand and functioning EEE or undeclared. This is illegal according to the Basel Convention (Baldé, D'Angelo et al., 2022). The remaining amount of WEEE generated is unaccounted for and its fate remains undocumented.

Under the business-as-usual scenario, the proportion of compliant to non-compliant WEEE flows is assumed to remain constant. However, due to the increase of WEEE generation, the quantity of WEEE in each flow increases. In the recovery and circularity scenarios, the model assumes that 85% of WEEE generated is compliantly collected. Due to the projected change in total WEEE generation, this results in an estimated 17 Mt collected in the recovery scenario and 11 Mt in the circularity scenario. The remaining non-compliant flows are correspondingly reduced. The key difference between the two scenarios is that overall WEEE generation is lower in the circularity scenario, due to longer product lifespans and reduced consumption.

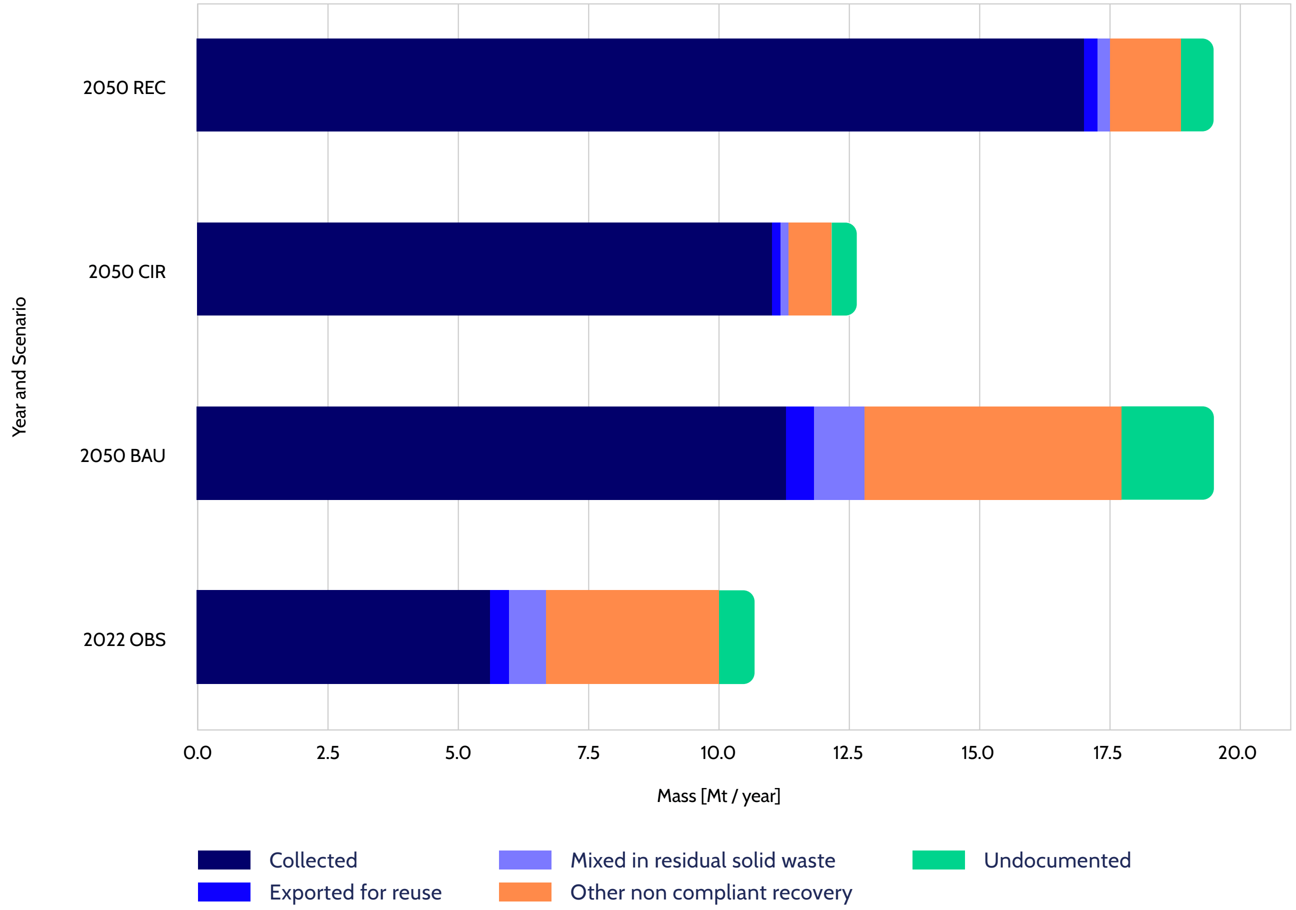


Figure 9 - Breakdown of WEEE generated that is compliantly collected (in dark blue) and complementary flows (exported for reuse in blue, mixed in residual solid waste in violet, other non compliant recovery in orange and undocumented in green) in the EU27+4: observed data (OBS) for 2022 and projections for 2050 under three scenarios - business-as-usual (BAU), recovery (REC), and circularity (CIR).

Key figures on Critical Raw Materials in WEEE

WEEE generated in 2022 contained 29 critical raw materials, each with quantities above 1 t. This equated to 1.0 Mt of critical raw materials in 2022 and is projected to grow to between 1.2 Mt and 1.9 Mt by 2050. The most abundant elements are aluminium, copper, manganese and silicon.

The data presented in this chapter are based on the list of critical raw materials as defined in the Critical Raw Materials Act published in 2023 (Regulation (EU) 2024/1252, n.d.), and for the 2050 outlook it is assumed that this list will remain the same, although the list is subject to regular updates and may change in the future.

In the WEEE generated, 29 critical raw materials can be found, each with quantities above 1 t. As of 2022, the total critical raw materials contained in WEEE Generated (10.7 Mt) was 1.0 Mt. This is expected to increase to around 1.2 Mt under the circularity scenario and to 1.9 Mt under the business-as-usual scenario by 2050 (see Figure 10). A large variety of critical raw materials can be found in the WEEE stream. The most abundant critical raw materials found in WEEE are aluminium (Al), followed by copper (Cu). They are found across all WEEE categories and in 2022 were at approximately 500 kt and 370 kt, respectively. These quantities are projected to increase in the next decades as WEEE generation increases. Other critical raw materials that are abundant in WEEE include manganese (Mn), primarily found in stainless steel, and silicon (Si), found in both stainless steel and photovoltaic panels. Silicon found in glass and ceramic materials is excluded from the calculations because not present in metallic form. Significant decreases are observed for rare earth elements contained in fluorescent powders, due to the decreasing presence of the fluorescent powder components in WEEE. They comprise yttrium (Y), lanthanum (La), terbium (Tb), cerium (Ce) and europium (Eu). The presence of Antimony (Sb) is also decreasing due to the phase-out of cathode ray tubes, although it remains in use in other applications, such as printed circuit boards.

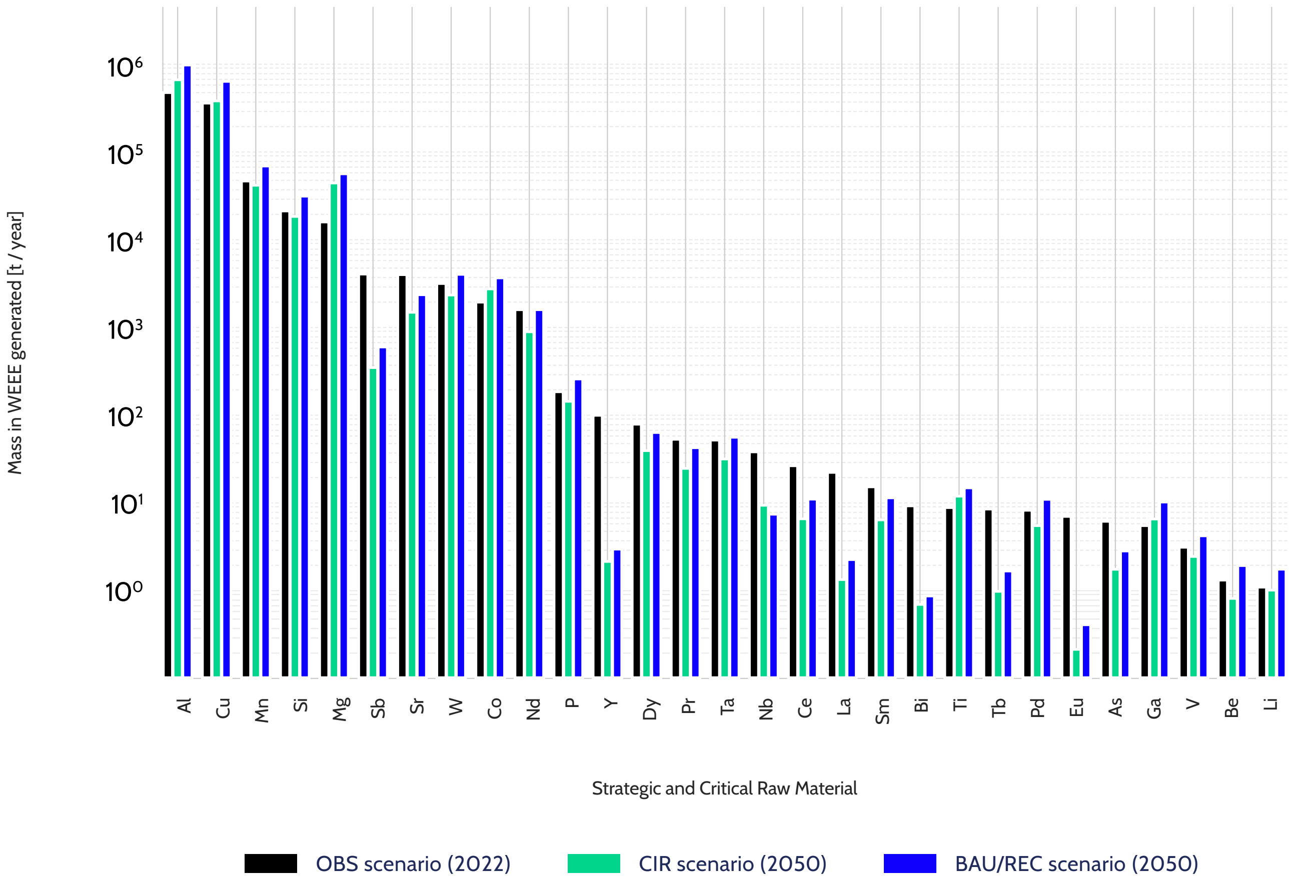


Figure 10 - Mass of selected critical raw materials (present in quantities above 1 t) embedded in WEEE generated in the EU27+4: observed data (OBS) for 2022 and projections for 2050 under three scenarios—business-as-usual (BAU), recovery (REC), and circularity (CIR).

The recovery of critical raw materials from WEEE totalled 0.4 Mt in 2022 and is projected to increase to between 0.9 Mt and 1.5 Mt by 2050. Depending on the future scenarios, currently unrecovered elements, such as neodymium and dysprosium in permanent magnets, or palladium in printed circuit boards could be recovered.

In 2022, 1.0 Mt of critical raw materials was embedded in the WEEE generated, of which, 0.4 Mt were recovered, 0.5 Mt were lost during collection and 0.1 Mt during recovery as shown in Table 2.

Aluminium and copper represented the largest quantities of critical raw materials found in WEEE. Although significant amounts were recovered (370 kt for both), a large share was still lost (500 kt) - especially during the collection phase.

Magnesium and manganese were also present in relatively large amounts in WEEE, but recovery rates remained low.

Several less common critical raw materials, such as antimony, strontium, and yttrium, were almost entirely not recovered during waste management in 2022 as shown in Table 2. These elements are usually present in small amounts and spread across many different types of products, which makes their recovery technically difficult and often not economically viable with current technologies.

The ranges shown in Table 2 for 2050 reflect the projected recovery of critical raw materials under three different future scenarios. The minimum values correspond to the business-as-usual scenario, where current trends in WEEE generation, collection, and treatment persist, and most critical raw materials remain unrecovered due to economic and technical barriers. The maximum values represent the recovery scenario, which assumes major and realistic advancements in collection, dismantling, and recovery systems, resulting in significantly higher recovery rates and less losses. The circularity scenario, while sharing similar improvements in recovery efficiency, assumes reduced overall WEEE generation due to extended product lifetimes, greater reuse and repair, and shifts toward service-based models. Therefore, although recovery efficiency remains high in circularity, the total mass recovered is lower, since less WEEE is generated.

Palladium, widely used in printed circuit boards and other electronic components, also showed low recovery. Only 2 t were recovered out of a total of 9 t in 2022. If recovery technologies improve, it is estimated that up to 9 t could be recovered by 2050.

The group labelled as “Others”, which includes several trace critical raw materials, had a total loss of 46 t in 2022, 28 t during collection and 18 t during recovery. These materials are mostly found in complex components such as printed circuit boards, displays, and hard disk drives.
Rare earth elements such as lanthanum, terbium, and europium also showed very limited recovery in 2022. Without specific recovery technologies or policies targeting these elements, most of them will likely continue to be lost even by 2050.

Gallium, which is used in semiconductors and LED lighting, is expected to be found in greater quantities in WEEE by 2050 (up to 11 t), but only a small portion (2 to 8 t) is likely to be recovered unless sorting and recovery processes are improved.

Phosphorus, used in cables of most WEEE categories, shows relatively high recovery potential. While 36 t were recovered in 2022, projections for 2050 suggest this could increase to as much as 230 t. However, further analysis is needed to determine whether this recovered phosphorus will meet the purity and quality standards required for industrial reuse.

Overall, the data indicates that losses during WEEE compliant collection remain the most significant barrier to increasing the availability of critical raw materials. To enhance their recovery, several actions should be undertaken. First, improving separate collection systems is essential to reduce the volume of critical raw materials lost before they even reach treatment facilities. Second, product design must evolve to support dismantling and easier identification of critical raw materials-rich components, such as permanent magnets in hard drives or palladium in printed circuit boards. For instance, improved design of speakers or cooling fans can facilitate the removal of neodymium-based magnets, which are otherwise hard to isolate. Third, investments in advanced recovery technologies and a stronger policy framework are necessary to create economic incentives for critical raw materials recovery. These include measures such as eco-modulation of fees, mandatory design standards, and targeted support for infrastructure.

Table 2 - Critical raw materials embedded in WEEE generated, recovered and lost either during collection or recovery in 2022 and 2050 (ranges based on the minimum and maximum values across the three future scenarios). Unit of measure expressed in kt and t, depending on the individual mass content.

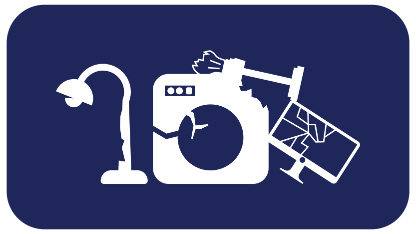
	2022				2050			
	WEEE Generated	Recovered	Loss on collection	Loss on recovery	Mass in WEEE Generated	Recovered	Loss on collection	Loss on recovery
Critical Raw material (unit kt)								
Al	496	208	257	31	694 to 1022	506 to 806	98 to 452	48 to 72
Cu	376	162	187	27	399 to 665	307 to 533	48 to 284	29 to 73
Mn	49	25	23	1	44 to 72	37 to 62	5 to 30	1 to 2
Si	22	12	10	0.4	19 to 33	17 to 28	2 to 13	1 to 1
Mg	17	6	9	2	46 to 59	29 to 45	7 to 23	4 to 7
Sb	4.3	0.1	1.9	2.2	0 to 1	0 to 0	0 to 0	0 to 0
Sr	4.2	0.0	2.0	2.2	2 to 2	0 to 2	0 to 1	0 to 1
W	3.3	1.0	1.9	0.4	2 to 4	1 to 3	0 to 2	0 to 1
Co	2.0	0.6	1.1	0.3	3 to 4	1 to 3	0 to 2	0 to 1
Nd	1.7	0.0	0.8	0.9	1 to 2	0 to 1	0 to 1	0 to 1
Critical Raw material (unit t)								
P	194	36	109	50	151 to 272	116 to 230	22 to 155	1 to 1
Y	105	0	58	47	2 to 3	1 to 2	0 to 1	1 to 1
Dy	83	0	38	45	41 to 67	1 to 53	5 to 29	4 to 37
Pr	56	0	29	26	26 to 45	0 to 35	3 to 23	2 to 22
Ta	55	17	25	12	33 to 59	17 to 49	4 to 29	1 to 13
Nb	40	0	22	17	8 to 10	1 to 1	1 to 3	4 to 8
La	23	0	13	10	1.4 to 2.4	0.6 to 1.7	0.2 to 1.1	0.3 to 0.6
Sm	16	0	9	7	7 to 12	0 to 9	1 to 6	1 to 6
Tb	9	0	5	4	1 to 1.8	0.1 to 1.3	0.1 to 0.9	0.2 to 0.8
Pd	9	2	4	3	6 to 12	2 to 9	1 to 6	0 to 3
Eu	7	0	4	3	0.2 to 0.4	0 to 0.2	0 to 0.2	0.1 to 0.2
Ga	6	1	3	2	7 to 11	2 to 8	1 to 5	1 to 4
V	3	1	2	1	3 to 4	1 to 4	0 to 2	0 to 1
Others	59	13	28	18	26 to 40	14 to 32	3 to 19	2 to 7
Total (Mt)	1.0	0.4	0.5	0.1	1.2 to 1.9	0.9 to 1.5	0.2 to 0.8	0.1 to 0.2

Note: the ranges displayed are outcomes of minimum and maximum values of the three scenarios.

Critical Raw Materials factsheets - three examples

This section presents three factsheets that visualise FutuRaM data for selected critical raw materials. They show their generation, potential losses during collection and recovery, and theoretical availability under three scenarios in the EU27+4, alongside the main WEEE categories and components where these critical raw materials are found. Together, these insights illustrate the role of recovery in achieving the EU's circular economy and critical raw materials strategies. Copper and aluminium demonstrate the benefits of large-scale recovery already in place, while palladium highlights the opportunities available, with growing investment in innovative recovery technologies.

Aluminium



Al in WEEE generated (kt)

2022: 496

2030 (business-as-usual): 608
2030 (recovery): 608
2030 (circularity): 600

2050 (business-as-usual): 1,022
2050 (recovery): 1,022
2050 (circularity): 694

Al losses in collection and recovery (kt)

2022: 288

2030 (business-as-usual): 339
2030 (recovery): 247
2030 (circularity): 244

2050 (business-as-usual): 516
2050 (recovery): 215
2050 (circularity): 146

Al theoretical availability for recovery (kt)

2022: 208

2030 (business-as-usual): 269
2030 (recovery): 361
2030 (circularity): 356

2050 (business-as-usual): 506
2050 (recovery): 806
2050 (circularity): 548

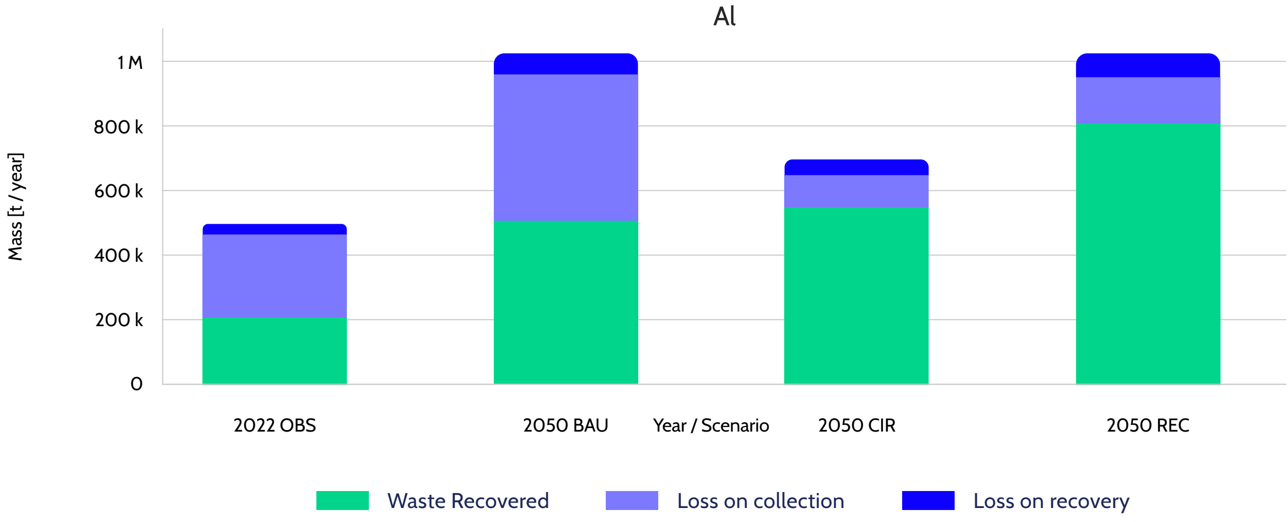


Figure 11 - Recovery and losses of aluminium in WEEE generated: observed data (OBS) for 2022 and projections for 2050 under three scenarios—business-as-usual (BAU), recovery (REC), and circularity (CIR).

Aluminium (Al) is widely present in WEEE, particularly in printed circuit boards, PV frames and cables. It can also be found in other components from all other WEEE categories. Model estimates for 2022 indicate that around 200 kt of aluminium were recovered, with approximately 300 kt lost during collection and recovery. By 2050, assuming higher collection rates, improved dismantling practices, and enhanced recovery processes, annual aluminium recovery is projected between 500 and 800 kt. This range is based on the outcomes of the three scenarios developed in FutuRaM.

Note: Recovered critical raw materials refers to the amount embedded within a component (e.g., printed circuit boards, cables) that is separated from the waste product and is intended to be sent for further processing (e.g. a smelter). In certain cases (e.g. copper or aluminium), it also includes the amount found in metal scraps (copper and aluminium scraps, respectively), as these can be further processed if separated correctly to the right waste fraction.

Main applications

Aluminium can be found in all WEEE categories and especially in Small equipment, Large equipment and Temperature exchange equipment. In particular:

- Printed circuit boards in categories Small Equipment and Small IT and Telecommunication Equipment
- Cables in Small equipment and other categories
- Photovoltaic panel frames in Photovoltaic panels
- Unspecified components (in all categories)

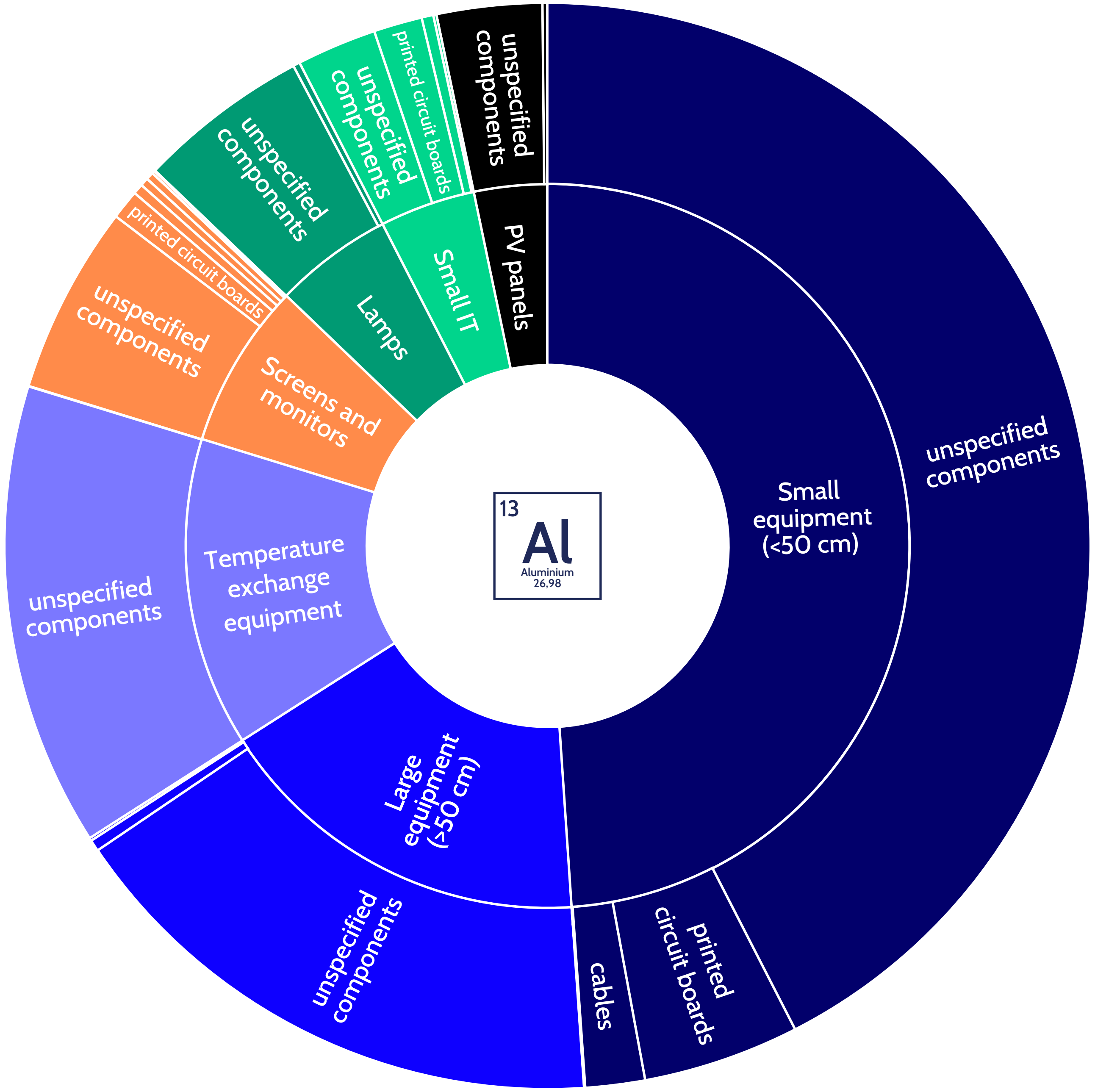
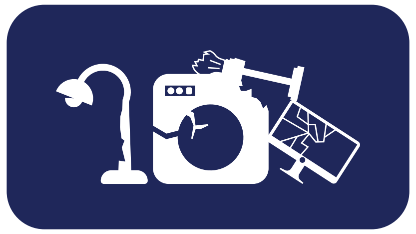


Figure 12 - Main aluminium applications across WEEE categories and components (reference year: 2022).

Copper



Cu in WEEE generated (kt)

2022: 376

2030 (business-as-usual): 460
2030 (recovery): 460
2030 (circularity): 454

2050 (business-as-usual): 665
2050 (recovery): 665
2050 (circularity): 399

Cu losses in collection and recovery (kt)

2022: 214

2030 (business-as-usual): 258
2030 (recovery): 194
2030 (circularity): 194

2050 (business-as-usual): 358
2050 (recovery): 132
2050 (circularity): 77

Cu theoretical availability for recovery (kt)

2022: 162

2030 (business-as-usual): 202
2030 (recovery): 264
2030 (circularity): 260

2050 (business-as-usual): 307
2050 (recovery): 533
2050 (circularity): 322

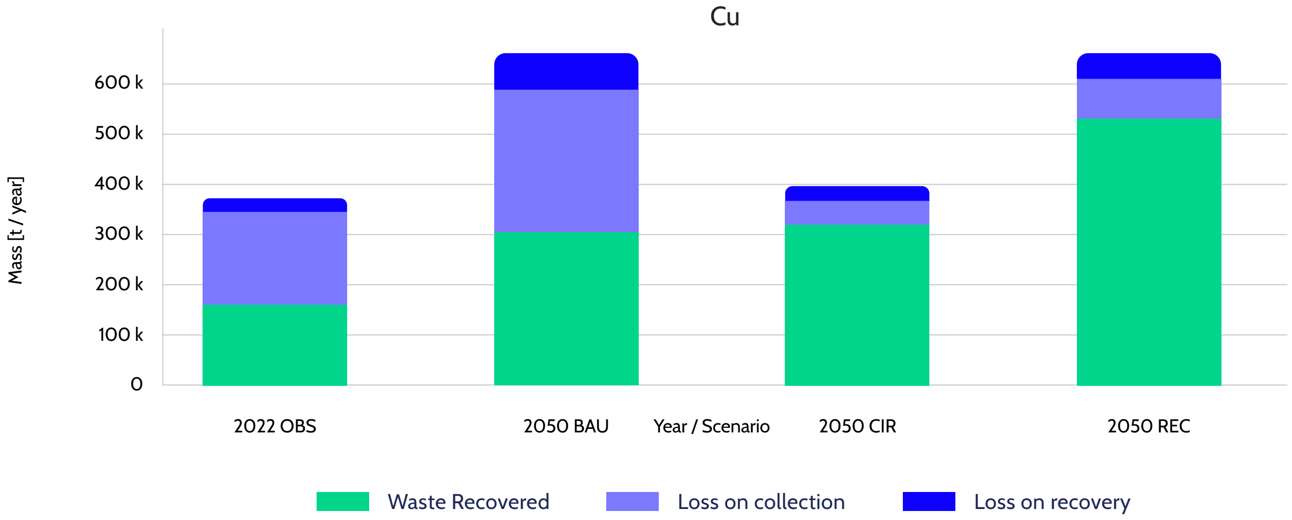


Figure 13 - Recovery and losses of copper in WEEE generated: observed data (OBS) for 2022 and projections for 2050 under three scenarios—business-as-usual (BAU), recovery (REC), and circularity (CIR).

Copper (Cu) is contained in various WEEE components, including printed circuit boards, cables, inductors, screws, compressors, and other unspecified components. Model estimates for 2022 suggest that around 170 kt of copper were recovered, with approximately 190 kt lost during collection and about 20 kt lost during recovery. By 2050, assuming higher collection rates, improved separation of copper-rich fractions, and enhanced recovery processes, annual copper recovery is projected to reach between 320 kt and 530 kt, depending on the scenario.

Note: Recovered critical raw materials refers to the amount embedded within a component (e.g., printed circuit boards, cables) that is separated from the waste product and is intended to be sent for further processing (e.g. a smelter). In certain cases (e.g. copper or aluminium), it also includes the amount found in metal scraps (copper and aluminium scraps, respectively), as these can be further processed if separated correctly to the right waste fraction.

Main applications

Copper can be found in many WEEE categories and especially in Small equipment, Large equipment and Temperature exchange equipment. In particular:

- Printed circuit boards in categories Small equipment, Small IT and Screens and monitors
- Cables in Small equipment, Large equipment, and Small IT
- Inductors in Small equipment and Large equipment
- Compressors in Temperature exchange equipment
- Unspecified components from all WEEE categories

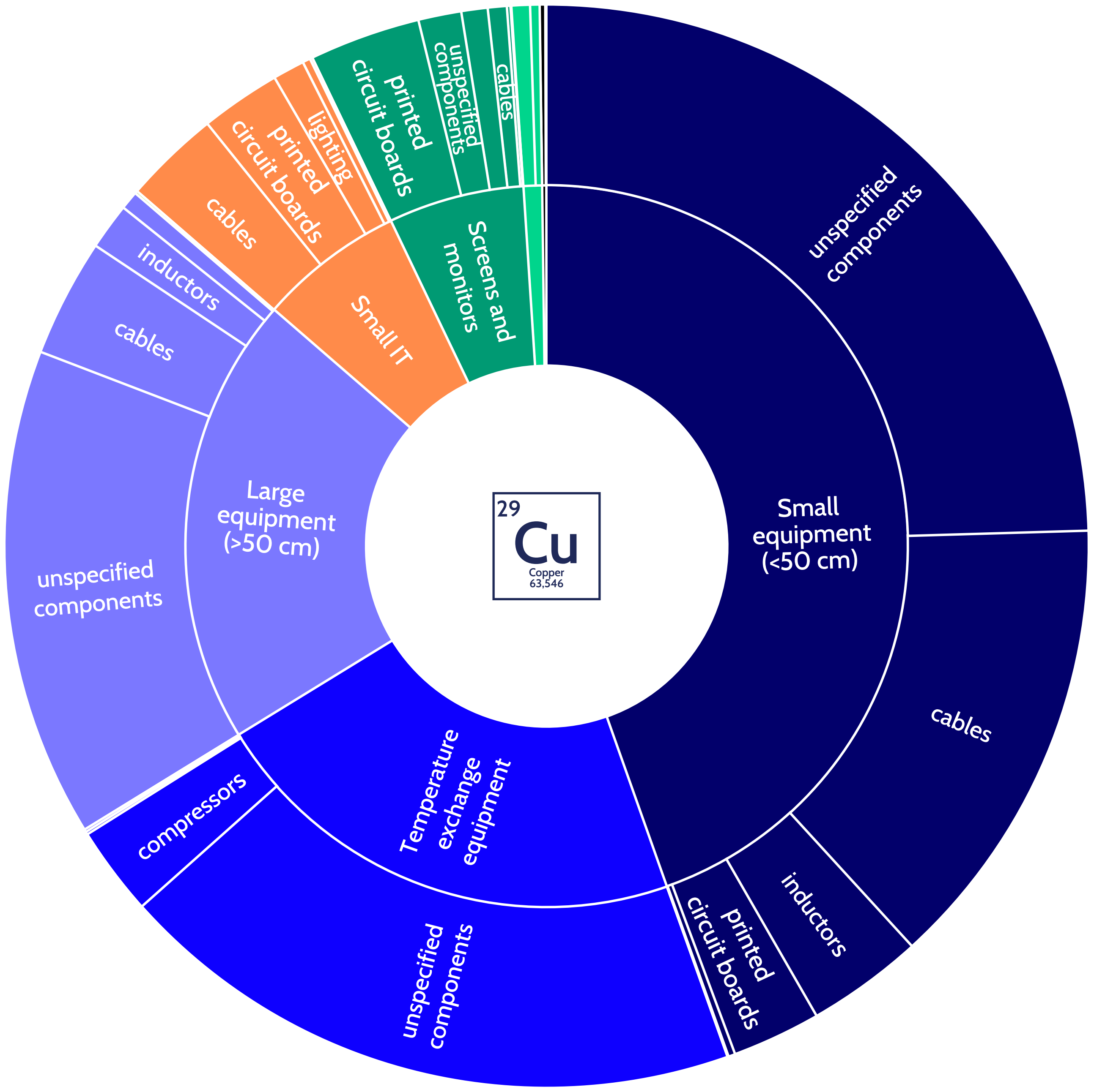
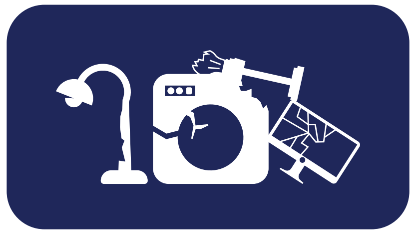


Figure 14 - Main copper applications across WEEE categories and components (reference year: 2022).

Palladium

46
Pd
Palladium
106,42



Pd in WEEE generated (t)

2022: 9

2030 (business-as-usual): 10
2030 (recovery): 10
2030 (circularity): 9

2050 (business-as-usual): 12
2050 (recovery): 12
2050 (circularity): 6

Pd losses in collection and recovery (t)

2022: 7

2030 (business-as-usual): 8
2030 (recovery): 7
2030 (circularity): 6

2050 (business-as-usual): 9
2050 (recovery): 2
2050 (circularity): 1

Pd theoretical availability for recovery (t)

2022: 2

2030 (business-as-usual): 2
2030 (recovery): 3
2030 (circularity): 3

2050 (business-as-usual): 2
2050 (recovery): 9
2050 (circularity): 5

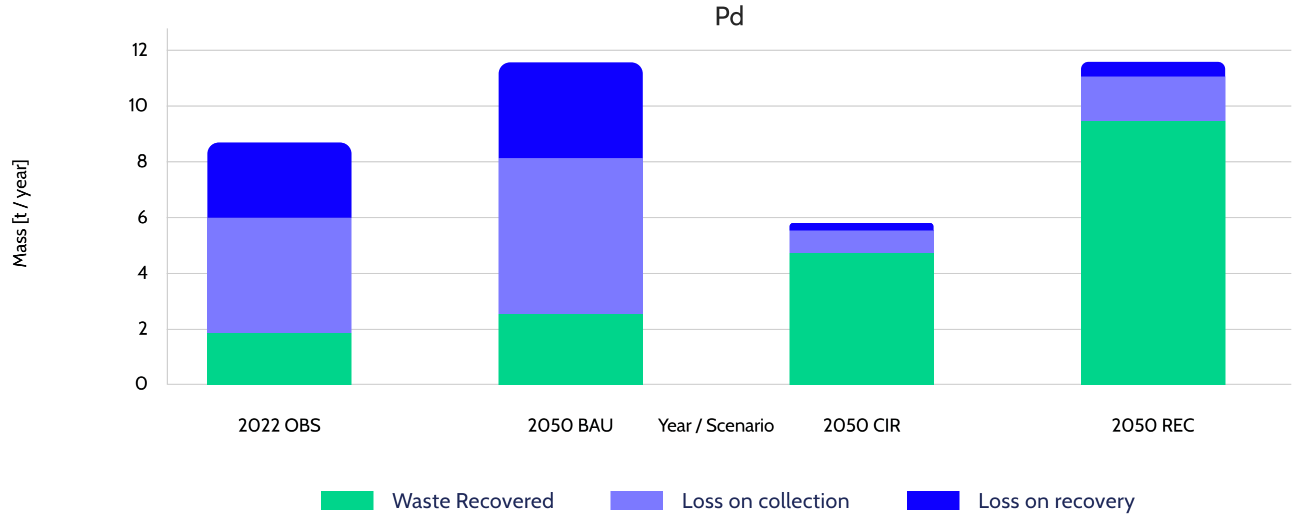


Figure 15 - Recovery and losses of palladium in WEEE generated: observed data (OBS) for 2022 and projections for 2050 under three scenarios—business-as-usual (BAU), recovery (REC), and circularity (CIR).

Palladium (Pd) is present in printed circuit boards, hard disk drives, LCD and plasma displays, and unspecified components from other WEEE categories. Model estimates for 2022 indicate that approximately 2 t of palladium were recovered, with around 4 t lost during collection and 3 t during recovery. By 2050, assuming higher collection rates, improved dismantling of printed circuit boards, and enhanced recovery from LCD and plasma screens, palladium recovery is projected to reach between 5 and 9 t, depending on the scenarios.

Recovered critical raw materials refers to the amount embedded within a component (e.g., printed circuit boards, cables) that is separated from the waste product and is intended to be sent for further processing (e.g. a smelter).

Main applications

Palladium can be found in many WEEE categories and especially in Screens and monitors, Small IT and Telecommunication equipment, and Small equipment. In particular:

- Printed circuit boards (in all categories)
- LCD displays and plasma displays in Small IT and Screens and monitors
- Hard disk drives in Small IT
- Unspecified components (in all categories)

In the chart, Pd appears under the Display LCD component. In reality, Pd is more likely present in subcomponents within the display module, such as printed circuit boards, connectors, wires, or other electronic items. This detail is not visible due to the structure of the dataset and the visualization method, so the chart should be interpreted as an approximation of material distribution rather than a definitive mapping.

Figure 16 - Main palladium applications in terms of WEEE categories and components (reference year: 2022).

Conclusions

This report identifies and quantifies the availability of secondary and critical raw materials in WEEE at product, component, material, and element levels across the EU27+4. The state-of-the-art of FutuRaM datasets and models have been developed by collecting and harmonizing data from official statistics, literature, industry sources, and waste sampling. Where possible, data collection and calculations were checked and cross-referenced across various dimensions of each waste stream: components, materials, elements, countries, and years.

Multiple end-of-life pathways prior to material recovery were developed to evaluate the future theoretical availability of critical raw materials under three scenarios:

- Business-as-usual scenario, reflecting current trends and developments
- Recovery scenario, assuming ambitious technological advancement in recovery that enables higher recirculation of secondary raw materials
- Circularity scenario, prioritizing longer product and material lifespans through reuse, repair, and extended use, together with ambitious technological advancement in recovery.

Among the key findings, the report highlights that WEEE generated in the EU27+4 is expected to increase to 19 Mt by 2050. Per capita WEEE generation could almost double under the business-as-usual and recovery scenarios (36 kg), while remaining lower under the circularity scenario (23.5 kg). Circularity would also help reduce disparities in per capita generation across countries.

Most categories of WEEE are projected to see growth in overall weight, with photovoltaic panels showing the steepest increase. Only screens and monitors are expected to decline slightly, due to the obsolescence of those containing heavier cathode ray tubes; this is projected to occur around 2035. At present, 54% of WEEE is formally collected, while the remainder is often lost through residual waste, other non compliant recovery, exported for reuse (legally or illegally), or channelled through other undocumented routes. Even with improvements, such material losses are likely to remain a challenge.

At the same time, WEEE represents an increasing potential source of critical raw materials. Large amounts of aluminium, copper, manganese, and silicon are already recovered from WEEE, but many valuable elements such as neodymium, dysprosium, palladium, and tungsten are not captured. Unlocking this potential will require better product design, more efficient separation, expanded recovery capacity, and stronger incentives.

Building on these findings, FutuRaM will continue to analyse data to improve the identification of critical raw materials theoretically available in WEEE. The project has designed an information system, the Urban Mine Platform[11] to enable access to the results of the project. Equipped with advanced search, filtering, visualization, and download functionalities, the Urban Mine Platform will, amongst other things, allow users to highlight material hotspots, an essential step for setting recovery targets and shaping coherent policies for the improved recovery of critical raw materials.

By providing harmonized, high-quality data, FutuRaM will directly support the implementation of the 2023 Critical Raw Materials Act, enabling the EU and its Member States to monitor critical raw materials flows, assess supply risks, and design effective interventions. The methodological framework has already been tested for multiple waste streams under the scope of the project, including batteries, construction and demolition waste from buildings and wind turbines, end-of-life vehicles, mining waste, and slag and ashes, and can be further extended to other waste streams, thereby enhancing the capacity to track secondary, strategic, and critical raw materials through official statistics and to support evidence-based policymaking and long-term resource security strategies.

Interested parties can follow the project and its results by registering to FutuRaM's stakeholder network: futuram.eu/get-involved.

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[11] The final datasets will be integrated into the FutuRaM Urban Mine Platform web portal, which is planned for full release at the end of the project in June 2026, with the possibility of an earlier public launch by the end of 2025.

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Annex

8.1. Annex I UNU-KEYs description and link to WEEE Directive category

Table 3 - UNU- KEY product classification and correspondence to WEEE directive classification (6 categories plus PV panels).

UNU-Key	Description	WEEE Category as defined in WEEE Directive 2012/19/EU
0001	Central Heating (household installed)	Large Equipment excl. PV panels
0002	Photovoltaic Panels (incl. inverters)	Photovoltaic panels
0101	Professional Heating & Ventilation (excl. cooling equipment)	Large Equipment excl. PV panels
0102	Dishwashers	Large Equipment excl. PV panels
0103	Kitchen equipment (e.g., large furnaces, ovens, cooking equipment)	Large Equipment excl. PV panels
0104	Washing Machines (incl. combined dryers)	Large Equipment excl. PV panels
0105	Dryers (wash dryers, centrifuges)	Large Equipment excl. PV panels
0106	Household Heating & Ventilation (e.g., hoods, ventilators, space heaters)	Large Equipment excl. PV panels
0108	Fridges (incl. combi-fridges)	Temperature Exchange Equipment
0109	Freezers	Temperature Exchange Equipment
0111	Air Conditioners (household installed and portable)	Temperature Exchange Equipment
0112	Other Cooling equipment (e.g., dehumidifiers, heat pump dryers)	Temperature Exchange Equipment
0113	Professional Cooling equipment (e.g., large air conditioners, cooling displays)	Temperature Exchange Equipment
0114	Microwaves (incl. combined, excl. grills)	Small Equipment
0201	Other small household equipment (e.g., small ventilators, irons, clocks, adapters)	Small Equipment
0202	Equipment for food preparation (e.g. toaster, grills, food processing, frying pans)	Small Equipment
0203	Small household equipment for hot water preparation (e.g., coffee, tea, water cookers)	Small Equipment
0204	Vacuum Cleaners (excl. professional)	Small Equipment
0205	Personal Care equipment (e.g. tooth brushes, hair dryers, razors)	Small Equipment
0301	Small IT equipment (e.g., routers, mice, keyboards, external drives & accessories)	Small IT and Telecommunication Equipment
0302	Desktop PCs (excl. monitors, accessories)	Small IT and Telecommunication Equipment
0303	Laptops (incl. tablets)	Screens and Monitors
0304	Printers (e.g., scanners, multi functionals, faxes)	Small IT and Telecommunication Equipment
0305	Telecommunication equipment (e.g. (cordless) phones, answering machines)	Small IT and Telecommunication Equipment

0306	Mobile Phones (incl. smartphones, pagers)	Small IT and Telecommunication Equipment
0307	Professional IT equipment (e.g., servers, routers, data storage, copiers)	Large Equipment excl. PV panels
0308	Cathode Ray Tube Monitors	Screens and Monitors
0309	Flat Display Panel Monitors (LCD, LED)	Screens and Monitors
0401	Small Consumer Electronics (e.g., headphones, remote controls)	Small Equipment
0402	Portable Audio & Video (e.g., MP3, e-readers, car navigation)	Small Equipment
0403	Music Instruments, Radio, Hi-Fi (incl. audio sets)	Small Equipment
0404	Video (e.g., Video recorders, DVD, Blue Ray, set-top boxes) and projectors	Small Equipment
0405	Speakers	Small Equipment
0406	Cameras (e.g., camcorders, photo & digital still cameras)	Small Equipment
0407	Cathode Ray Tube TVs	Screens and Monitors
0408	Flat Display Panel TVs (LCD, LED, Plasma)	Screens and Monitors
0501	Small lighting equipment (excl. LED & incandescent)	Small Equipment
0502	Compact Fluorescent Lamps (incl. retrofit & non-retrofit)	Lamps
0503	Straight Tube Fluorescent Lamps	Lamps
0504	Special Lamps (e.g., professional mercury, high & low pressure sodium)	Lamps
0505	LED Lamps (incl. retrofit LED lamps)	Lamps
0506	Household Luminaires (incl. household incandescent fittings & household LED luminaires)	Small Equipment
0507	Professional Luminaires (offices, public space, industry)	Small Equipment
0601	Household Tools (e.g., drills, saws, high pressure cleaners, lawn mowers)	Small Equipment
0602	Professional Tools (e.g., for welding, soldering, milling)	Large Equipment excl. PV panels
0701	Toys (e.g., car racing sets, electric trains, music toys, biking computers, drones)	Small Equipment
0702	Game Consoles	Small IT and Telecommunication Equipment
0703	Leisure equipment (e.g., sports equipment, electric bikes, juke boxes)	Large Equipment excl. PV panels
0801	Household Medical equipment (e.g. thermometers, blood pressure meters)	Small Equipment
0802	Professional Medical equipment (e.g., hospital, dentist, diagnostics)	Large Equipment excl. PV panels
0901	Household Monitoring & Control equipment (alarm, heat, smoke, excl. screens)	Small Equipment
0902	Professional Monitoring & Control equipment (e.g., laboratory, control panels)	Large Equipment excl. PV panels
1001	Non- cooled Dispensers (e.g., for vending, hot drinks, tickets, money)	Large Equipment excl. PV panels
1002	Cooled Dispensers (e.g., for vending, cold drinks)	Temperature Exchange Equipment

3001	e-bikes	Large Equipment excl. PV panels
9010	Large temperature exchange equipment in buildings cat 1 open scope	Temperature Exchange Equipment
9019	Cat 1 other open scope	Temperature Exchange Equipment
9041	Cat 4 large central heating in building	Large Equipment excl. PV panels
9049	Cat 4 other open scope	Large Equipment excl. PV panels

8.2. Annex II Parametrization of Circularity scenario

Table 4 - Parametrisation of the five circular economy consumer behaviour and technology pathways for the EEE sector, according to the corresponding changes in product lifetime, POM, and stock per capita.

Circularity Pathway	Lifetime changes	POM changes	Stock per capita changes
Full/Partial obsolescence	no changes	100% (relative to baseline) by 2050 for full obsolescence, and -90% or -75% by 2050 for partial obsolescence	follows POM target
Saturation constraint	no changes	-W% by 2050 tuned to the relevant stock constraint (see 8.3)	actual stock per capita value specified individually for each UNU key to which the constraint is applicable (e.g. 0.5 fridges per person)
Improved durability	+30% by 2050	-W% by 2050 tuned to the relevant stock constraint (see 8.3)	constant stock constraint
Less hoarding	no changes, assuming hoarding is replaced by second-hand use with negligible lifespan changes	-X% by 2050 tuned to constant stock constraint , and given increases in lifespan	-15% by 2050, assuming hoarding is replaced by second-hand use, but with overall stock being reduced
More sharing	reduction in lifespan EQUAL to the prescribed change in stock (-15% by 2050)	-Z% by 2050 tuned to the prescribed change in stock (-15% by 2050)	-15% by 2050, tuned through POM reductions (Z), AND in line with the prescribed lifespan reductions (EQUAL to the stock reductions)

Table 5 - Parametrisations of the five circular economy consumer behaviour and technology pathways for the EEE sector, formulated separately for each UNU-KEY.

UNU-Key	Obsolescence POM target relative	Saturation Stock PPI* target absolute	Improved Durability	Less Hoarding	More Sharing
0001	0	0.1	X	X	
0002			X		
0101		0.015	X		
0102		0.4	X	X	
0103		0.6	X		
0104		0.4	X	X	X
0105		0.15	X	X	X
0106		0.8	X	X	
0108		0.7	X	X	
0109		0.15	X	X	
0111		0.6	X	X	
0112		0.06	X	X	
0113		0.5	X		
0114		0.4	X	X	
0201		4	X	X	
0201		3	X	X	
0203		1.25	X	X	
0204		0.7	X	X	
0205		2	X	X	
0301		2	X	X	
0302	0.1		X	X	
0303		1.5	X	X	X
0304		0.4	X	X	X
0305	0			X	
0306		2	X	X	
0307		0.05	X		
0308	0			X	
0309		0.2	X	X	
0401		4	X	X	
0402	0			X	
0403	0.2		X	X	
0404	0.1		X	X	
0405		1.25	X	X	
0406	0		X	X	
0407	0		X	X	
0408		1	X	X	
0501			X	X	
0502	0			X	
0503	0.5		X	X	
0504		1	X	X	
0505			X	X	
0506		60	X	X	
0507		6	X		
0601		3	X	X	X
0602		0.05	X		X
0701		10	X	X	
0702		0.4	X	X	
0703			X	X	X
0801			X	X	X
0802			X		
0901			X	X	
0902			X		
1001		0.0015	X		
1002		0.05	X		
3001			X	X	X
9010			X		
9019			X		
9041			X		
9049			X		

** Pieces per inhabitant*

8.3. Annex IV List of critical raw materials, precious metals and other elements

Table 6 - List of critical raw materials (and strategic raw materials), precious metals and other elements as defined in the Critical Raw Materials Act Annex I and II and in the Raw Materials Information System from the European Commission. The type "others" refers to other elements not classified as critical or strategic.

Element	Abbreviation	Type
Aluminium / Bauxite	Al	Critical raw material
Antimony	Sb	Critical raw material
Arsenic	As	Critical raw material
Baryte	Ba	Critical raw material
Beryllium	Be	Critical raw material
Bismuth	Bi	Critical raw material (also strategic raw material)
Borates	B	Critical raw material
Boron	B	Critical raw material (also strategic raw material)
Cerium	Ce	Critical raw material (also strategic raw material)
Cobalt	Co	Critical raw material (also strategic raw material)
Coking Coal	Coking Coal	Critical raw material
Copper	Cu	Critical raw material (also strategic raw material)
Dysprosium	Dy	Critical raw material (also strategic raw material)
Erbium	Er	Critical raw material
Europium	Eu	Critical raw material
Feldspar		Critical raw material
Fluorspar	F	Critical raw material
Gadolilium	Gd	Critical raw material
Gallium	Ga	Critical raw material (also strategic raw material)
Germanium	Ge	Critical raw material (also strategic raw material)
Gold	Au	Precious metals
Hafnium	Hf	Critical raw material
Helium	He	Critical raw material
Homium	Ho	Critical raw material
Indium	In	Others
Iridium	Ir	Critical raw material (also strategic raw material)
Lanthanum	La	Critical raw material
Lithium	Li	Critical raw material
Lithium	Li	Critical raw material (also strategic raw material)
Lutetium	Lu	Critical raw material
Magnesium	Mg	Critical raw material (also strategic raw material)
Magnesium	Mg	Others
Manganese	Mn	Critical raw material
Manganese	Mn	Critical raw material (also strategic raw material)
Natural Graphite	Natural Graphite	Critical raw material (also strategic raw material)
Natural Graphite	Natural Graphite	Critical raw material
Natural Rubber	Natural Rubber	Others
Neodymium	Nd	Critical raw material (also strategic raw material)
Nickel	Ni	Critical raw material

Nickel	Ni	Critical raw material (also strategic raw material)
Niobium	Nb	Critical raw material
Osmium	Os	Others
Palladium	Pd	Critical raw material (also strategic raw material)
Phosphate rock		Critical raw material
Phosphorous	P	Critical raw material
Platinum	Pt	Critical raw material (also strategic raw material)
Praseodymium	Pr	Critical raw material (also strategic raw material)
Rhenium	Re	Others
Rhodium	Rh	Critical raw material (also strategic raw material)
Ruthenium	Ru	Critical raw material (also strategic raw material)
Samarium	Sm	Critical raw material (also strategic raw material)
Scandium	Sc	Critical raw material
Silicon metal	Si	Critical raw material (also strategic raw material)
Silica	Si	Others
Silver	Ag	Precious metals
Strontium	Sr	Critical raw material
Tantalum	Ta	Critical raw material
Terbium	Tb	Critical raw material (also strategic raw material)
Thulium	Tm	Critical raw material
Titanium	Ti	Others
Titanium	Ti	Critical raw material (also strategic raw material)
Tungsten	W	Critical raw material (also strategic raw material)
Vanadium	V	Critical raw material
Ytterbium	Yb	Critical raw material
Yttrium	Y	Critical raw material

8.4. Annex V Critical raw materials embedded in WEEE by country for 2022 and 2050

Table 7 - Total amount of critical raw materials embedded in WEEE generated per country in 2022 and in 2050 (unit: kt).

Country	2022	2050
AUT	16	21-30
BEL	23	29-47
BGR	8	13-17
CHE	20	26-45
CYP	2	2-3
CZE	16	20-28
DEU	169	189-276
DNK	12	15-23
ESP	93	124-184
EST	2	3-5
FIN	11	13-22
FRA	130	157-259
GBR	153	174-303
GRC	17	24-33
HRV	5	7-11
HUN	13	19-27
IRL	9	14-24
ISL	1	1-2
ITA	104	115-162
LTU	3	6-8
LUX	1	2-3
LVA	2	3-5
MLT	1	1-2
NLD	36	52-81
NOR	14	13-26
POL	46	71-100
PRT	17	22-32
ROU	21	32-45
SVK	7	8-13
SVN	3	5-7
SWE	20	25-40

Note: the 2050 ranges are derived from the three scenarios evaluated in the FutuRaM project. The lower bound corresponds to the circularity scenario, which assumes reduced consumption and, consequently, lower volumes of WEEE generation. The upper bound reflects both the recovery scenario and the business-as-usual scenario, which were modelled with similar assumptions regarding WEEE generation.