Ecodesign preparatory study for product specific measures on scarce, environmentally relevant and critical raw materials and on recycled content

Study Report

Phase 2: Preparatory study

Main report

Draft 14 April 2025

Prepared by Viegand Maagøe, Van Holsteijn en Kemna, Fraunhofer ISI and VITO

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Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

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1. Introduction

1.1. This report

This report presents the main results of Phase 2: Preparatory study. It explains the background for the study and the scope and gives an introduction to scarce, environmentally relevant and critical raw materials and to recycled content

The main results will be presented at an open stakeholder consultation meeting after which written comments can be provided by the stakeholders. Based on the stakeholder input and Commission comments, the report will be finalised and published.

1.2. About the study

The purpose of the study is to conduct an Ecodesign preparatory study on potential product-specific requirements on recycled content and on scarce, environmentally relevant and critical raw materials, and to propose possible implementing measures under the Ecodesign and energy labelling regulatory framework.

The study objectives are:

- investigating in more detail the materials and the products that could be subject to these requirements,
- investigating the technical, economic, environmental, market and societal impacts of these potential requirements, and
- providing the elements needed for the identification of policy options in the subsequent impact assessment

If, on the basis of the study findings, the Commission considers it appropriate to develop implementing measures under the Ecodesign and the Ecodesign for Sustainable Products Regulation (ESPR) legal frameworks and/or the Energy Labelling Regulation, the study shall also provide inputs for the draft working documents on these implementing measures.

The study consists of two phases:

- Phase 1: Prioritisation of materials and product groups: This is a scoping phase aiming at assessing and identifying products and materials combinations to be proposed for the detailed studies in Phase 2. The prioritisation was based on assessment of products in scope and data for these products with certain selection criteria related to materials and products. The products selected were computers, imaging equipment, household fridges, household washing machines and electric motors.
- Phase 2: Execution of the preparatory study: The preparatory study contains five mini Ecodesign studies, following Methodology for Ecodesign of Energy-related Products (MEErP) focusing on recycled content and on scarce, environmentally relevant and critical raw materials for the products and materials selected in Phase 1. The studies assessed possibilities and environmental and economic impact on a number of policy options. Based on the outcome of these studies, input to draft working documents for regulations for the specific measures on materials has been prepared.

Stakeholder consultations take place during both phases. The consultations are supported by a study website (www.ecodesignmaterials.eu) with published documents, information on the study and news. Registration for updates and for meetings takes also place via the website.

The study includes at least three stakeholder meetings (one online stakeholder introductory meeting and two hybrid (online and physical presence) meetings) followed by the opportunity of submitting written comments. The online introductory meeting was held on 9 October 2023 and the second meeting was held on 2 July 2024. Presentations and minutes from the meetings can be found at www.ecodesignmaterials.eu/documents.

1.3. Political context

Highlights of the political context for this study include:

- The Circular Economy Action Plans (December 2015 and March 2020) (CEAP)
- The Ecodesign Directive (2009/125/EC) (ED)
- The Energy Labelling Framework Regulation ((EU) 2017/1369)
- The Sustainable Products Initiative (SPI) and the Ecodesign for Sustainable Products Regulation[1] substituting the Ecodesign Directive
- The Ecodesign and Energy Labelling Working Plan 2022-2024 and specifically the horizontal aspect of recycled content and of scarce, environmentally relevant and critical raw materials, including the technical study behind the Working Plan (Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024)[2]
- European Critical Raw Materials Act (CRMA)[3]

The Ecodesign Directive requires product manufacturers to improve the environmental performance of their products by meeting minimum energy efficiency requirements, as well as other environmental requirements such as water consumption, emission levels or minimum durability of certain components. The Energy Labelling Regulation complements Ecodesign by enabling end-users to identify the better-performing products, via the well-known A-G/green-to-red labelling grading.

The Circular Economy Action Plans (CEAP) target how products are designed, promoting circular economy processes and sustainable consumption, and aiming to ensure that waste is prevented, and the resources used are kept in the EU economy for as long as possible. CEAP 2020[4] announces a sustainable product policy legislative initiative to make products fit

[1] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC

[2] https://www.Ecodesignworkingplan20-24.eu/

[3] Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020

[4] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

for a climate neutral, resource efficient and circular economy, reduce waste and ensure that the performance of frontrunners in sustainability progressively becomes the norm.

The aim of the Sustainable Products Initiative (SPI) is to revise the Ecodesign Directive to set out the EU policy framework necessary to achieve the CEAP objectives. The initiative also addresses the presence of harmful chemicals in products such as electronics and ICT equipment. The Ecodesign for Sustainable Products Regulation was published by the Commission on 13 June 2024[1].

The Preparatory study for the Ecodesign and Energy Labelling Working Plan 2022-2024 (carried out by Viegand Maagøe, VHK and Oeko-institut) recommended after detailed analyses of a broad range of product groups and horizontal initiatives among others to include in the Ecodesign and Energy Labelling Working Plan two horizontal initiatives, namely post-consumer recycled content and scarce and critical raw materials. Implementation of measures for recycled content was assessed as having a very high saving potential, estimated at 160 PJ.

In May 2022, the Commission published the Working Plan and in addition to product specific priorities, three horizontal aspects contributing to the circular economy were selected, of which recycled content and scarce, environmentally relevant and critical raw materials were two of these aspects and durability, firmware and software as the third one.

The Working Plan emphasises the following focus points as background for selecting recycled content and scarce, environmentally relevant and critical raw materials as important horizontal aspects:

- They are a continuation of prior circular economy measures in the Ecodesign work for energy-related product, especially the measures adopted in 2019 and they should contribute to the transition to the ESPR (Ecodesign for Sustainable Products Regulation)
- Horizontal standards on material efficiency aspects for energy-related products under Mandate 543 are now in place, which can be the basis for developing product-specific material efficiency standards for energy-related products.
- The Methodology of Ecodesign for Energy-related Products (MEErP) and the corresponding EcoReport Tool (ERT) have been updated introducing a more systematic way of covering circular economy aspects for studies on specific product groups. it is expected to be published soon.

The Working Plan states that the Commission will assess the possibility and appropriateness of establishing product-specific requirements on recycled content and scarce, environmentally relevant and critical raw materials for energy related products, where dedicated preparatory studies will be needed to help identifying the product categories that are most relevant for potential regulatory approaches. The current study has been designed to provide technical assistance to the Commission for establishing these product-specific requirements.

1.4. Scope

1.4.1. Product scope

The product scope for the study is energy related products covered by the Ecodesign Directive 2009/125[5] or the Ecodesign for Sustainable Products Regulation[1] with a focus on products that are already comprised by implementing ecodesign measures[6]. The reason for the latter is that it would need a complete preparatory study if a product was not regulated. Preferable, the products should be under a review, because it would be easier to include requirements stemming from this study.

1.4.2. Material scope

The material scope is materials, which are more commonly present in energy related products and with a focus on scarce, environmentally relevant and critical raw materials. Both plastic and non-plastic (ferrous and non-ferrous metals) materials should be considered.

1.4.3. Typology of requirements

The typology of requirements to be analysed within the mini-preparatory studies include, but are not limited to:

- Information requirements (on material weight, weight range, recycled raw material content)
- Requirements on the ease of dismantling (in order to recover more easily the material and/or the component
- Requirements setting a minimum level of content of recycled raw materials
- Requirements based on the definition of product specific indexes on product recyclability
- Other requirement on recyclability and product reusability

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009L0125-20121204

[6] https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products_en

1.5. Introduction to scarce, environmentally relevant and critical raw materials

1.5.1. Approach for materials

The Preparatory study for the Ecodesign and Energy Labelling Working Plan 2022-2024 recommended including as a priority topic in the Working Plan critical raw materials (CRMs) due to their supply risks and scarcity from an EU perspective, and in a broader sense, other raw materials with high environmental and/or social risks and impacts.

The reasons for looking at raw materials in a broader sense than just CRMs is that the concept of CRM is mainly based on supply risk and thereby economic factors. This means that the CRM concept focuses on the scarcity of the materials rather than on their environmental impact, although some environmental aspects are indirectly addressed in the evaluation of the supply risk.

Furthermore, the fact that many mining and processing practices are associated with substantial environmental impacts (such as ecosystem damage, soil removal, and the use of water, energy, and chemicals) can represent a future supply risk if such external environmental and social costs are increasingly internalised through effective implementation of standards and requirements, which can lead to an increase in raw material prices (ecological raw material availability).

1.5.2. Critical Raw Materials

The most recent list of CRMs[7] contains 34 CRMs. The CRM list consists of raw materials meeting the requirements according to the published EU criticality methodology[8]. The methodology to define the Strategic Raw Materials (SRM) relevant for the green and digital transition as well as defence and aerospace applications is set out in Annex I. The CRM are regarded as such for their importance to key sectors combined with a risk of demand outstripping supply and expected difficulties in increasing supply to compensate for the lack of CRM and SRM. SRM are considered CRM even if they do not simultaneously meet the CRM criteria. This is the case for copper and nickel.

Other non-CRM materials with high environmental impacts are e.g. gold, lead, molybdenum, rhenium, selenium, silver, tellurium and zinc.

All CRMs of the finally agreed list were included in the study.

1.5.3. Potential implementing measures

Potential measures on CRMs and other raw materials related to product design and information and within the typology of requirements previously described (Section 1.4.3) include:

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[7] Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020

[8] https://data.europa.eu/doi/10.2873/769526

- Implementing measures facilitating durability of the products and/or components containing relevant CRMs and other raw materials.
- Implementing measures facilitating the recyclability of those products and/or components containing relevant CRMs and other raw materials, such as
  - requirements on design for disassembly;
  - requirements on information and declaration for facilitating recycling operations based on the guidance of standard EN 45558:2019 with regard to substance, amount and location in components of the energy related products; and
  - requirements on dismantling information for facilitating recycling operations such as the sequence of dismantling steps, tools or technologies needed to access the targeted component.
- Promoting the use of recycled raw materials via
  - design requirements setting a minimum share of recycled raw materials, and
  - labelling requirements on the applied share of recycled raw materials
- Implementing measures for enhancing the recovery rate from the waste flows or streams.
- Increasing the collection or take back rate of appliances and goods that contain CRMs.

As it can be seen, potential measures on CRMs and other raw materials in product design are much linked to measures on recycled content and facilitating recycling, as well as to product durability. These measures could contribute to reduce the pace of further resource extraction, thus reducing the associated environmental impacts, and, insofar as extraction also occurs within the EU, facilitate a reduction in the import dependence of EU industry on non-EU sources.

The main focus of this study is recycled content and recyclability because of a high potential and because these types of measures have not yet been implemented in ecodesign regulations. Introductions to the measures are provided in the following sections.

Further information on recycled content policies, test standards, market figures, usages, technologies, availability and quality of the material, market surveillance, impact on energy, emissions and costs and saving potential as of 2021 can be accessed in Preparatory study for the Ecodesign and Energy Labelling Working Plan 2022-2024, Task 3 preliminary analysis of product groups and horizontal initiatives.[9]

1.6. Introduction to recycled content

Recycled material for manufacturing of new products is a very effective measure for material efficiency and with a very high estimated potential (160 PJ in primary energy savings).[10] It is an important element of the circular economy, where recycled materials play a significant role in reducing the environmental footprint of manufacturing processes by conserving raw materials including critical raw materials, reducing energy consumption, and minimising waste. It is also important for reducing the dependence of the EU industry on extra-EU

[9] https://www.ecodesignworkingplan20-24.eu/documents

[10] Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024. Task 3 Preliminary Analysis of Product Groups and Horizontal Initiatives

imports. A standard providing a methodology on assessing the proportion of recycled material content in energy-related products has been developed and is publicly available.[11]

Therefore, it is strategically important to assess fundamentally new directions for the circular economy and potential Ecodesign regulatory measures.

Recycled content can be broadly categorised into two main types: post-consumer recycled content and pre-consumer (or post-industrial) recycled content. Each type has its unique sources and applications in the production of new goods. The term "consumer" should be understood broadly i.e. not restricted to household consumers.

Post-consumer recycled content refers to materials that have been used and disposed of by consumers, then collected, processed, and repurposed into new products. This type of recycled content is pivotal in closing the loop of product lifecycles, encouraging circular economy principles. The process of recycling post-consumer materials often involves collection, sorting, cleaning, and processing to make them suitable for use in manufacturing new products.

Pre-consumer (or post-industrial) recycled content comes from materials that were discarded during the manufacturing process before reaching the consumer. This category includes scraps, trimmings, and other by-products that are recovered and reused in new or similar products, thus preventing waste and reducing the demand for virgin materials. The utilisation of pre-consumer recycled content can also take place by industrial symbiosis, where waste from one process becomes the raw material for another. In some cases, it is needed to process the pre-consumer materials before they can be used in parallel with virgin materials.

In the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2022-2024, the assessments were based on post-consumer recycled content, which also will be the main focus for the current study, but without discarding assessing opportunities for pre-consumer recycled content. Use of pre-consumer recycled content can especially be relevant if the material is not recycled in the same production process from where it has been recovered, but e.g. at a third party recycler, possibly mixed with post-consumer materials.

Waste can be used directly as a raw material in the production of products that have recycled content. Or the waste can be transformed into recycled-based feedstock. In all cases, means of verification should be considered.

Recycled content is the amount of recycled material that goes into the manufacturing of a new product, expressed either as a fraction of the total material input (in %) or in absolute numbers (kg per unit, million tonnes Mt in aggregates). The scope is to increase the amount recycled content a part of a holistic and balanced material efficiency policy, also within Ecodesign.

Generally, there are two typical basic recycling loops:

- Recycled content from recycling of the same product type or even of the manufacturer's own products via take-back schemes
- Recycled content from generic sources via recycled materials suppliers, both as mechanically and chemically recycled materials

When considering requirements on recycled content, they should be agnostic to recycling technology, source of material etc.

[11] EN 45557:2020: General method for assessing the proportion of recycled material content in energy-related products

Considerations on use of recycled content include:

- Sufficient supplies of recycled materials of sufficient quality and competitive price
- Technology readiness of recycled materials and content in final product
- Reliable determination and verification of amount of recycled content of a product without excessive administrative burden and laboratory costs
- Needs for additional test standards
- Impact on costs and the economy
- Impact on the environment

An area of increased focus in recent years is recycling of plastics. A Circular Plastics Alliance has been established with currently over 330 signatories from European plastics value chains. The signatories commit to take action to boost the EU market for recycled plastics up to 10 million tonnes by 2025.[12,13] By reaching this goal, the EU will attain an almost 20 % success rate of recycled plastics uptake into new products for all applications.[14]

Further information on recycled content policies, test standards, market figures, usages, technologies, availability and quality of the material, market surveillance, impact on energy, emissions and costs and saving potential as of 2021 can be found in the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2022-2024.[15]

1.7. Introduction to recyclability

Recyclability refers to the ability of a product or material to be collected, dismantled, processed, and manufactured wholly or partly into a new product after its initial use. It plays a critical role in advancing circular economy principles by reducing use of virgin materials and thereby conserving natural resources, and minimizing environmental impact.

Designing for recyclability involves evaluating the full lifecycle of a product to ensure that products can be dismantled and materials can be efficiently separated and recovered and reintegrated into manufacturing streams with minimal loss of quality or value. Higher recyclability of products will increase the amounts of higher quality recycled materials.

A policy option for design for recyclability includes a recyclability index, which is a quantifiable metric that assesses how easily a product can be recycled within existing waste management systems. It provides a standardized way to evaluate and compare products based on their end-of-life recovery potential, offering a practical tool for manufacturers, policymakers, and consumers to make informed decisions that support a circular economy.

The index can also be included in a regulation as a minimum performance index requiring a minimum level of recyclability. Developing a recyclability index involves defining clear and

[12] https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/circular-plastics-alliance_en

[13] https://circular-plastics-alliance.com/en/

[14] Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024. Task 3 Preliminary Analysis of Product Groups and Horizontal Initiatives

[15] https://www.ecodesignworkingplan20-24.eu/documents

measurable criteria that reflect both the technical recyclability of materials and the real-world effectiveness of recycling processes. Key components may include:

- Material composition: The presence of recyclable vs. non-recyclable materials, including contamination or composite structures.
- Ease of dismantlability: The extent to which components can be separated without specialized tools or processes and reducing the number of steps to dismantle components and/or recover materials.
- Availability of recycling infrastructure: Compatibility with existing collection, sorting, and recycling technologies.
- Environmental impact: The emissions, energy use etc. associated with the recycling process and the avoided extraction and processing virgin materials.
- Market viability: The demand for the specific recycled output and its capacity to retain value depending on price, quality, availability etc.

The index can be scored on a scale, with higher scores representing greater recyclability. Weighting can be applied to prioritize factors depending on product type or sector-specific goals. A harmonized recyclability index could serve for information purposes and for minimum ecodesign requirements.

Currently, a study is ongoing study for the development of recyclability indexes for photovoltaic products (PV modules and inverters).[16] Outcome of this study can be a useful source of information.

1.8. Stakeholder consultation

Stakeholder consultations are essential for ensuring that decisions are informed; based on data, information and practices from the market players; inclusive; and aligned with the interests of those who are directly or indirectly affected. They involve engaging with a broad range of actors –including industry representatives, Member States bodies, non-governmental organizations (NGOs), consumers, academia etc.

Public consultations carried out during the study until the date of publishing this report are:

- 19 October 2023: Online information stakeholder meeting introducing the background and objectives of the study; the methodology; the work plan and expected timeline and answering questions from the participants
- 2 July 2024: Hybrid (physical and online presence) stakeholder meeting presenting and discussing the Phase 1 report including the recommendations on the product groups for the following mini-preparatory studies.
- 25 April 2025 (to be held): Hybrid (physical and online presence) stakeholder meeting presenting and discussing the draft results of the analysis carried out in the phase 2 of the study for two case studies, i.e. domestic computers and imaging equipment, and the cross-cutting assessments of topics relevant for all five case studies.

[16] https://www.pv-recyclability-index.eu/

Additionally, the study team held individual meetings with selected stakeholders for information and data collection.

2. Horizontal assessments

In this section we provide the relevant parts of assessments that are crosscutting allfive product groups.

2.1. Standards

Standards and standardisation activities related to recycled content, recyclability and material efficiency include the following:

- EN 4555x series developed by CEN-CENELEC Joint Technical Committee 10 on Energy-related products - Material Efficiency Aspects for Ecodesign (CEN-CLC/JTC 10):
  - CLC/TR 45550:2020 Definitions related to material efficiency
  - EN 45552:2020 ‘General method for the assessment of the durability of energy-related products’;
  - EN 45553:2020 ‘General method for the assessment of the ability to remanufacture energy-related products’;
  - EN 45554:2020 ‘General methods for the assessment of the ability to repair, reuse and upgrade energy-related products’;
  - EN 45555:2019 ‘General methods for assessing the recyclability and recoverability of energy-related products’;
  - EN 45556:2019 ‘General method for assessing the proportion of reused components in energy-related products’;
  - EN 45557:2020 ‘General method for assessing the proportion of recycled material content in energy-related products’;
  - EN 45558:2019 ‘General method to declare the use of critical raw materials in energy-related products’;
  - EN 45559:2019 ‘Methods for providing information relating to material efficiency aspects of energy-related products’.
  - EN 45560:2024 ‘Method to achieve circular designs of products’
- EN 15343:2007 Plastics - Recycled Plastics - Plastics recycling traceability and assessment of conformity and recycled content
- CLC/TR 50727:2022 Material efficiency - Household and similar electrical appliances - Assessment of applicability of EN 4555X
- WG 12 "Design for plastics recycling" TS 50752, foreseen publication in 2026
- prTS 50752:20YY Design for recycling guidelines for styrenics and polyolefins products and parts in electrical and electronic equipment, with focus on ABS, PP and PS. This draft technical specification describes the best practices and technical solutions that manufacturers of electrical and electronic equipment (EEE) can adopt during the design phase, to enable consistent and effective recycling of styrenics and polyolefins plastics composing the equipment, during the Waste of Electrical and Electronic Equipment (WEEE) management.

- EN 303 808 V1.1.1:2023 Environmental Engineering (EE); Applicability of EN 45552 to EN 45559 methods for assessment of material efficiency aspects of ICT network infrastructure goods in the context of circular economy
- EN 303 800-3 V1.1.1:2025 Environmental Engineering (EE); Assessment of material efficiency of ICT network infrastructure goods (circular economy); Part 3: Server and data storage product availability of firmware and of security updates to firmware
- EN 303 800-5 V1.1.1:2024 Environmental Engineering (EE); Assessment of material efficiency of ICT network infrastructure goods (circular economy); Part 5: Server and data storage product disassembly and disassembly instruction
- prEN 18065 – Plastics – Recycled Plastics – Classification of recycled plastics based on Data Quality Levels and provides guidelines for the labelling of the recyclate type and recycled content in compounds (based in DIN SPEC 91446)
- Draft act on rules for the application of Directive (EU) 2019/904 of the European Parliament and of the Council as regards the calculation verification and reporting of data on recycled plastic content in single-use plastic beverage bottles[17]

2.2. Recyclability and use of recycled content

2.2.1. Plastic

2.2.1.1. Material types

Plastics are critical materials in product design, offering properties such as impact resistance, thermal stability, chemical resistance, and moldability that make them suitable for a range of applications. Specific polymers are chosen based on the demands of the application, considering their mechanical, thermal, and chemical properties. As illustrated in the graph below (Plastics Europe, 2022), the selection of polymer types aligns closely with their use cases across industries such as packaging, automotive, and electronics.

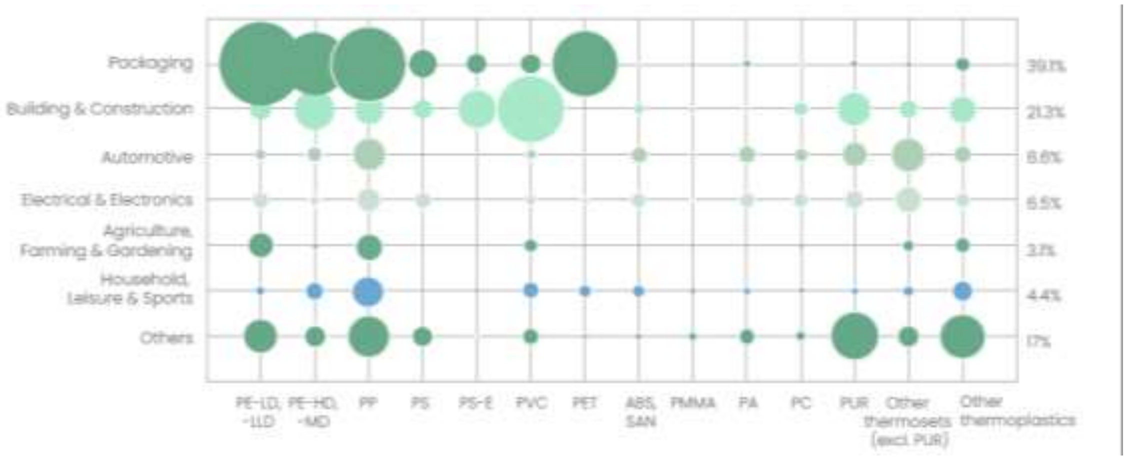

Figure 1: European plastics converters' demand by application and type[18]

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=pi_com:Ares(2023)3075282

The matrix above highlights the dominant role of polymers such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) in applications like packaging. However, it does not provide detailed insights into the specific polymers used for components in computers, imaging equipment, household fridges, washing machines, and electric motors.

APPLiA's Statistical Reports[19] provide detailed insights into the material composition of large home appliances, such as washing machines and refrigerators. These reports highlight the predominant use of metals, particularly iron and steel, in large appliances, while plastics also contribute significantly to their construction. In washing machines, the most commonly used polymers are polypropylene (PP), which accounts for 13.2% of the material composition on average, and acrylonitrile butadiene styrene (ABS), which constitutes 3.1%. For refrigerators, the main plastics include polyurethane (PUR) for insulation (10.6%), polystyrene (PS) and high-impact polystyrene (HIPS) for internal linings and structural components (9.5% and 8.4%, respectively), and PP (5.8%).

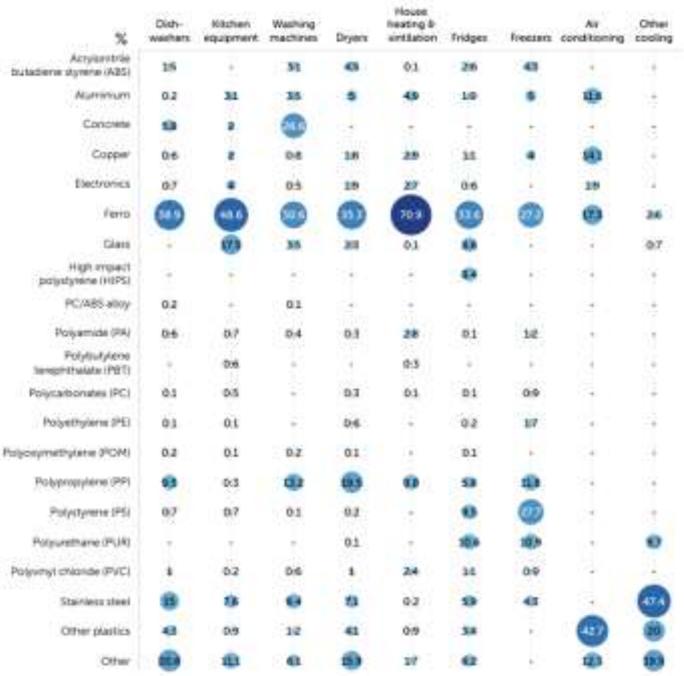

Figure 2: The average material composition of large home appliances. Source APPLiA

Building on these data, the following sections will present examples of typical polymers and their roles in key components within the selected product groups of this study, providing a detailed understanding of material selection and its connection to product functionality and performance.

In household fridges, interior parts like wall panels and door linings are typically made from polystyrene (PS) high-impact polystyrene (HIPS), or polypropylene (PP) because they are durable, easy to clean, and hold up well in cold temperatures. Insulation is usually made with polyurethane (PUR), which helps improve energy efficiency by reducing heat transfer.

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[18] Plastics Europe 2022 – "Plastics – the facts 2022" [Plastics - the Facts 2022 • Plastics Europe]

[19] [Home | APPLiA statistical report 2022-2023]

In computers, imaging equipment, and similar electronic devices, plastics are used for both structural and functional purposes. ABS is commonly used for outer casings because it provides durability, impact resistance, and a smooth finish for both appearance and function. High-impact polystyrene (HIPS) is another popular choice for lightweight structural parts due to its strength and rigidity. Printed circuit boards (PCBs) are typically made from epoxy resin reinforced with fiberglass (FR-4), which ensures stability and resistance to heat for electronic components. Connectors, sockets, and mechanical parts often use polycarbonate or nylon (polyamide, PA) for their strength and resistance to heat deformation.

In washing machines, polypropylene (PP) is widely used for internal components such as detergent trays, pump housings, and tubs due to its resistance to chemicals and moisture. Acrylonitrile butadiene styrene (ABS) is often used for external casings and detergent trays, offering impact resistance, rigidity, and a smooth finish. Polyvinyl chloride (PVC) is commonly utilized for piping purposes. Components that handle greater mechanical stress, such as drum supports, are often made from glass-filled nylon (PA), which provides excellent tensile strength and durability.

Choosing plastics for these applications depends on meeting performance requirements while balancing those choices with cost, weight, and ease of manufacturing. When recycled plastics are used in technical applications, they must meet the same high standards for strength, heat resistance, chemical stability, and manufacturability. However, recycled materials can be more challenging to work with because their quality and properties may vary. Issues like contamination, weakened polymer chains from previous use, and mixed additives or polymers can impact their performance.

2.2.1.2. Biobased plastics

Biobased plastics are derived partially or entirely from biological resources, such as plants, as opposed to fossil-fuel based feedstocks. It is important to distinguish between biobased and biodegradable plastics, as the terms are often confused. Biobased refers to the origin of the material, indicating that it comes from renewable sources like corn, sugarcane, or starch, but it does not necessarily mean the plastic is biodegradable. Biodegradable refers to the ability of a material to break down under specific environmental conditions, regardless of whether it is derived from biological or fossil sources.

Types of Biobased Plastics

Biobased plastics fall into several categories, depending on their feedstock and applications:

- Ethanol-Based Plastics: Ethanol, derived from sugarcane or corn, is converted into ethylene, which can then be polymerized into biobased polyethylene (PE) or polyethylene terephthalate (PET). These materials are chemically identical to their fossil-based counterparts, such as low-density polyethylene (LDPE), and can seamlessly integrate into existing recycling streams.
- Starch-Based Plastics: Derived from crops like potatoes or maize, these materials can be used to produce thermoplastic starch, often blended with other polymers for enhanced properties.
- Polylactic Acid (PLA): Made from fermented plant sugars, PLA is widely used in packaging and is biodegradable under industrial composting conditions.

Some biobased plastics, such as bio-PET or bio-PE, are identical in structure to fossil-based plastics and provide the same mechanical and thermal performance, making them suitable for technical applications like those in refrigerators, washing machines, and imaging equipment.

Climate and Environmental Considerations

Biobased plastics are often promoted for their potential to reduce greenhouse gas emissions compared to fossil-based plastics. For example across seven case studies, biobased plastics show 14% lower climate change impacts compared to fossil-based plastics when the current EU End-of-Life (EoL) mix is considered[20]. Biobased plastics are derived from biomass that absorbs CO2 during its growth. This biogenic carbon is considered neutral when accounted for in lifecycle assessments (LCAs), offering potential GHG savings. Furthermore, producing biobased plastics often requires less energy than producing conventional plastics, particularly when the feedstock is grown in efficient agricultural systems.

Despite their potential benefits, biobased plastics come with several challenges and trade-offs:

- Feedstock Source: The environmental performance of biobased plastics depends heavily on whether the feedstock is derived from waste products or virgin crops. Using agricultural waste (e.g., corn stover or sugarcane bagasse) minimizes competition with food production and avoids land use change. Conversely, relying on primary crops can lead to significant environmental issues.
- Direct and Indirect Land Use Change (LUC): Cultivating crops specifically for plastic production can result in direct land use change, such as deforestation, and indirect land use change, where agricultural land shifts from food production to bioplastic feedstocks. Both contribute to GHG emissions and biodiversity loss. Direct and indirect land use changes are shown to contribute 14% of total greenhouse gas emissions in a cradle-to-grave LCA of seven different plastic products.
- End-of-Life: Biodegradability is often seen as an advantage of some biobased plastics, but it presents challenges in the context of circularity. Many biodegradable plastics require specific industrial composting facilities to break down effectively, which are not universally available. Without proper disposal infrastructure, these materials can persist in the environment, contributing to pollution similarly to conventional plastics. Additionally, biodegradable plastics degrade into non-reusable components, meaning they do not contribute to the production of new materials, thus failing to support closed-loop systems.

Although biobased plastics can reduce climate change impacts under specific conditions, the associated challenges, especially those related to land use changes, production inefficiencies, and recycling limitations, make their net benefits uncertain. Because of this, setting up requirements on biobased plastics as a universal solution is premature. However, components in biobased materials could be exempt from e.g. recycled content requirements.

2.2.1.3. Recycling technologies

In 2023, Europe used 54 million tonnes (Mt) of plastics, but only 13.4% came from post-consumer recycled sources. This shows how much the EU's plastic system still relies on

[20] Environmental impact assessments of innovative bio-based product. Task 1 of "Study on Support to R&I Policy in the Area of Bio-based Products and Services " - Publications Office of the EU

virgin raw materials. Out of the 32.3 Mt of post-consumer plastic waste collected in 2022, only 26.9% (8.7 Mt) was actually recycled. Furthermore, only about half of the installed capacity for plastics recycling is currently utilised. This underuse is largely due to a combination of factors, including low market demand for recycled plastics, the availability of cheaper virgin materials, and insufficient economic incentives to encourage manufacturers to design products that incorporate recycled content. Without stronger policies or market drivers, much of the existing recycling infrastructure remains idle, limiting the potential to increase recycling rates and reduce the reliance on virgin plastics.[21]

Recycling plastics relies on two overarching technologies: mechanical recycling and chemical recycling. These methods form the foundation of efforts to repurpose plastic waste into reusable materials, each with distinct advantages and challenges depending on the type and quality of plastic being processed. The suitability of recycled materials for high-performance applications depends heavily on how well these technologies can meet specific mechanical, thermal, and chemical requirements.

Mechanical Recycling

Mechanical recycling is the most widely used and mature plastic recycling technology. It involves collecting, sorting, washing, shredding, and remelting plastic waste to create granules or flakes for reuse. This method works well for thermoplastics such as polypropylene (PP), polyethylene (PE), and polystyrene (PS), which can be repeatedly melted and reshaped[22].

While mechanically recycled plastics are widely used in non-technical applications, their quality is often lower than virgin materials due to polymer degradation during processing and contamination from mixed materials or additives. For example, impurities such as labels, pigments, or incompatible polymers can reduce the recycled material's strength, durability, and thermal stability.

Industrial scrap, also known as pre-consumer waste, poses fewer challenges when used in manufacturing since it is clean, sorted, and consistent. However, using this material is better described as optimised resource use rather than true recycling, as it involves reintroducing unused material back into production processes. Additionally, the market for pre-consumer recycled materials is already well-saturated, meaning further legislation promoting it is unlikely to result in significant societal or market changes or improvements.

Chemical Recycling

Chemical recycling offers a more advanced approach by breaking plastics down into their chemical building blocks, enabling the production of materials with properties comparable to virgin plastics. This category encompasses technologies such as pyrolysis, depolymerisation, and solvent-based recycling[23], each suited to specific types of plastic waste:

- Pyrolysis: Heats plastic waste in the absence of oxygen to break it down into smaller hydrocarbons, which can be used to produce new plastics or fuels. A significant issue with pyrolysis is that the market often favours the conversion of plastics into fuels, which are more economically viable due to higher demand and pricing. This practice risks diverting materials away from circular recycling systems.

[21] EURiC - EU Plastics Recyclers' Roadmap: For a competitive & innovative industry

[22] Less than one-fifth of EU plastic was recycled in 2019, but 2025 targets can be still reached - European Commission

[23] Plastic recycling technologies – Group for Sustainability and Technology | ETH Zurich

- Depolymerisation: Breaks down polymers into monomers using heat, pressure, or chemical agents, enabling re-polymerisation into new plastics. This process is particularly useful for some engineering plastics, such as nylon.
- Solvent-Based Recycling: Dissolves polymers into solvents to remove impurities, allowing the recovery and reuse of purified polymers. This method is valuable for handling highly contaminated waste but is still in the early stages of development.

While chemical recycling has the potential to process mixed or contaminated waste streams that are unsuitable for mechanical recycling, the technologies remain in early stages of commercialisation. Challenges such as high energy demand, scalability, and competition with fuel production raise concerns about its economic and environmental feasibility.

Avoid Adding Substances that Increase Difficulty of Recycling

A range of different chemicals are often added to plastic, such as stabilisers (addressing light, heat or other factors), antioxidants, colour agents, flame retardants, plasticizers, anti-static agents, and so-on. Of these, globally, the largest group of plastic additives are plasticisers, followed by flame retardants, and then anti-oxidants and photostabilisers (Hahladakis et al., 2018). Recent research across the global plastics industry indicates that there are over 10,000 substances used across more than 25 different applications (Weisinger et al., 2021). Unfortunately, adding substances to plastics will make it more difficult to recycle, and thus they should only be used when absolutely necessary.

2.2.1.4. Market aspects

According to the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024[24] the EU's demand for plastics (51 Mt) far exceeds the registered plastic waste (29 Mt), with a gap of 22 Mt. For long-lifespan products such as household fridges, washing machines, imaging equipment, and computers, this gap is largely due to the time delay between production and disposal. Some of these products often remain in use for over a decade. During this time, market growth and increasing product sizes, such as larger refrigerators, mean that the material used in production years ago was significantly less than what is required for today’s demand. Even with perfect recycling systems, this time gap limits the potential for fully closed-loop recycling. At best, products like these can achieve a maximum recycled content of approximately 60% under optimal conditions, highlighting the challenges of meeting high recycled content targets in technical applications.

2.2.2. Critical Raw Materials

2.2.2.1. Recyclability and current recycling practice of Critical and Strategic Raw Materials

Recycling of critical and strategic raw materials differs strongly among raw materials and products due to a variety of factors such as the amount of a given raw material in a product, the accessibility of these products at the end of their service lifetimes, the existence of appropriate infrastructures for collection, and the accessibility of the raw materials in the products themselves

[24] Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024, TASK 3 PRELIMINARY ANALYSIS OF PRODUCT GROUPS AND HORIZONTAL INITIATIVES, April 2021

once collected for recycling[25,26]. Table 1 presents a summary of the recycling rates used in the latest EU criticality study for all critical and strategic raw materials[27]. Notice that, because of data gaps and differences in the underlying studies, not all recycling rates are calculated using the same definition or geographical scope[28]. Nevertheless, the values shown in Table 1 provide a good indication of current recycling practice both in the EU and globally regarding critical raw materials.

[25] Tercero Espinoza, Luis A. (2012). The contribution of recycling to the supply of metals and minerals. POLINARES working paper n. 20. In: POLINARES (Ed.). Identification of potential sources of competition, tension and conflict and potential technological solutions. Deliverable D02.1 of POLINARES (EU Policy on Natural Resources-Competition and collaboration access to oil, gas and minerals). Project co-funded by European Commission 7th RTD Programme.

[26] Tercero Espinoza, Luis A./Rostek, Leon/Loibl, Antonia/Stijepic, Denis (2020). The promise and limits of Urban Mining. Fraunhofer ISI. Karlsruhe. Available online at https://publica.fraunhofer.de/bitstreams/31ba6c53-5eb1-4b96-b7d8-247e67a923b9/download (accessed 6/21/2023).

[27] European Commission (2023). Study on the Critical Raw Materials for the EU 2023. Final Report. Available online at https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en.

[28] Luis A. Tercero Espinoza (2021), Critical appraisal of recycling indicators used in European criticality exercises and circularity monitoring, Resources Policy, https://doi.org/10.1016/j.resourpol.2021.102208.

Table 1: Summary of recycling rates used in the latest criticality exercise[29] and in the EcoReport tool. The numbers should reflect the end-of-life recycling input rate. In practice, they are a mix of scopes and definitions due to data limitations (cf. Tercero Espinoza 2021[30] and references in European Commission 2023[31] and for the EcoReport tool).

			End-of-life Recycling Input Rate in %	
Raw material	Critical	Strategic	Latest criticality exercise	EcoReport tool
Aluminium/bauxite	■		32	32
Antimony	■		28	28
Arsenic	■		0	0
Baryte	■		0	0
Beryllium	■		0	0
Bismuth	■	■	0	0
Boron	■	■	1	1
Cobalt	■	■	22	22
Coking coal	■		0	0
Copper		■	55	17
Feldspar	■		1	1
Fluorspar	■		1	1
Gallium	■	■	0	0
Germanium	■	■	2	2
Hafnium	■		0	0
Helium	■		2	2
HREE	■	■	1	4
Lithium	■	■	0	0
LREE	■	■	1	3
Magnesium	■	■	13	13
Manganese	■	■	9	9
Natural graphite	■	■	3	3
Nickel		■	16	16
Niobium	■		0	0
PGM	■	■	12	10
Phosphate rock	■		0	17
Phosphorus	■		0	0
Scandium	■		0	0
Silicon metal	■	■	0	0
Strontium	■		0	0
Tantalum	■		1	0
Titanium metal	■	■	1	19
Tungsten	■	■	42	42
Vanadium	■		6	1

To a first approximation, the price of the raw material and the size of the overall market can signal the need for an economic viability of recycling. However, given the wide variety of raw materials classified as critical or strategic, and the plethora of end-uses for these raw materials (which to a

[29] European Commission (2023). Study on the Critical Raw Materials for the EU 2023. Final Report. Available online at https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en.

[30] Luis A. Tercero Espinoza (2021), Critical appraisal of recycling indicators used in European criticality exercises and circularity monitoring, Resources Policy, https://doi.org/10.1016/j.resourpol.2021.102208.

[31] European Commission (2023). Study on the Critical Raw Materials for the EU 2023. Final Report. Available online at https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en.

large extent determines end-of-life collection and processing), these two factors are ultimately not sufficient to predict the degree of recycling of a raw material. Figure 3 shows this using indicative prices and global market tonnages, both as reported in the Factsheets accompanying the List of Critical Raw Materials maintained by the SCRREEN Consortium[32] and supplemented by price data by DERA (2024), where necessary. We would like to point out four features of Figure 3:

1. Use and price of raw materials: taking production figures as a direct proxy for use, it is (intuitively) clear that cheaper raw materials are generally used more than expensive raw materials.
2. Influence of price on recycling: Also fitting intuition, some materials appear to be so cheap that it is not viable to recycle them economically. The threshold appears to lie around one thousand US dollars per ton. Materials with prices below this threshold show little or no recycling while many raw materials above this threshold show extensive recycling. However, in many cases recycling is simply impractical (e.g., boron and feldspars used in glass) and many other factors influence the recycling rate beyond the price of the raw material (s. examples below).
3. Influence of market size (tonnage) on recycling: One of the key issues for EoL recycling is securing enough scrap feed to achieve a proper scale at each recycling facility. It appears logical that raw materials that are used in lower quantities tend to be recycled less as it is more difficult to secure scrap supply. However, this logic is heavily influenced by technological and organizational aspects (s. below).
4. There are many exceptions and pitfalls in the trends sketched above – so many, that the trends can only be used as a rough first indication. These exceptions are due to the properties of the raw materials themselves, and the way they are used, collected and processed. We illustrate this with some examples below:
    a. The use of raw materials in alloys tends to hinder their functional recycling. A good example of this is niobium (Nb), which by price and tonnage "should" show a higher recycling (input) rate. However, Nb is used in high-strength low-alloy (HSLA) steel and remains in the steel insofar as this steel is recycled[33]; Nb is not recovered in its pure form[34]. Whether the Nb content in the recycled steel is used or just tolerated depends on scrap sorting and the specific products/clients of the recycling plants. The same applies to other steel and aluminum alloying elements[35].
    b. Some raw materials are not recoverable with standard recycling techniques despite their high value. The reasons for this differ strongly with circumstances, but include low concentrations in complex products (e.g., 0.4 mg of In in a smartphone[36], sorting into disadvantageous streams (e.g., platinum group metals (PGM) in electronic waste is not recycled when shredding sends the PGM to the plastics fraction[37]) and the design and economics of the recycling plant itself.
    c. Raw materials that are used in easily identifiable and separable components tend to exhibit higher recycling rates. Examples include tungsten (W) used in hard

[32] SCRREEN consortium (2023). SCRREEN factsheets on CRM 2023. Available online at https://scrreen.eu/crms-2023/.

[33] UNEP (2013). Metal recycling. Opportunities, limits, infrastructure. UNEP. Nairobi. International resource panel.

[34] SCRREEN consortium (2023). SCRREEN factsheets on CRM 2023. Available online at https://scrreen.eu/crms-2023/.

[35] UNEP (2013). Metal recycling. Opportunities, limits, infrastructure. UNEP. Nairobi. International resource panel.

[36] Bookhagen, B./Bastian, D./Buchholz, P./Faulstich, M./Opper, C./Irrgeher, J./Prohaska, T./Koeberl, C. (2020). Metallic resources in smartphones. Resources Policy 68, 101750. https://doi.org/10.1016/j.resourpol.2020.101750.

[37] Chancerel, Perrine/Meskers, Christina E.M/Hagelüken, Christian/Rotter, Vera Susanne (2009). Assessment of Precious Metal Flows During Preprocessing of Waste Electrical and Electronic Equipment. Journal of Industrial Ecology 13 (5), 791–810. https://doi.org/10.1111/j.1530-9290.2009.00171.x

metal tools and PGMs used in catalytic converters for vehicles with internal combustion engines[38]. The recycling of PGM is also favored by their electrochemical properties[39]. Ease of separation simplifies the subsequent recycling processes by removing excessive complexity.

d. Dedicated product-centric solutions (a combination of organization and technology) may also show large effects on recycling. Examples include the recycling of PGMs in chemical catalysts and rare earth magnet recycling from computer hard disk drives[40], both leading to higher EoL recycling rates within the respective focal systems compared to the overall recycling of the same raw materials.

[38] Cimprich, Alexander/Young, Steven B./Schrijvers, Dieuwertje/Ku, Anthony Y./Hagelüken, Christian/Christmann, Patrice/Eggert, Roderick/Habib, Komal/Hirohata, Atsufumi/Hurd, Alan J./Lee, Min-Ha/Peck, David/Petavratzi, Evi/Tercero Espinoza, Luis A./Wäger, Patrick/Hool, Alessandra (2023). The role of industrial actors in the circular economy for critical raw materials: a framework with case studies across a range of industries. Mineral Economics 36 (2), 301–319. https://doi.org/10.1007/s13563-022-00304-8.

[39] UNEP (2013). Metal recycling. Opportunities, limits, infrastructure. UNEP. Nairobi. International resource panel.

[40] Cimprich, Alexander/Young, Steven B./Schrijvers, Dieuwertje/Ku, Anthony Y./Hagelüken, Christian/Christmann, Patrice/Eggert, Roderick/Habib, Komal/Hirohata, Atsufumi/Hurd, Alan J./Lee, Min-Ha/Peck, David/Petavratzi, Evi/Tercero Espinoza, Luis A./Wäger, Patrick/Hool, Alessandra (2023). The role of industrial actors in the circular economy for critical raw materials: a framework with case studies across a range of industries. Mineral Economics 36 (2), 301–319. https://doi.org/10.1007/s13563-022-00304-8.

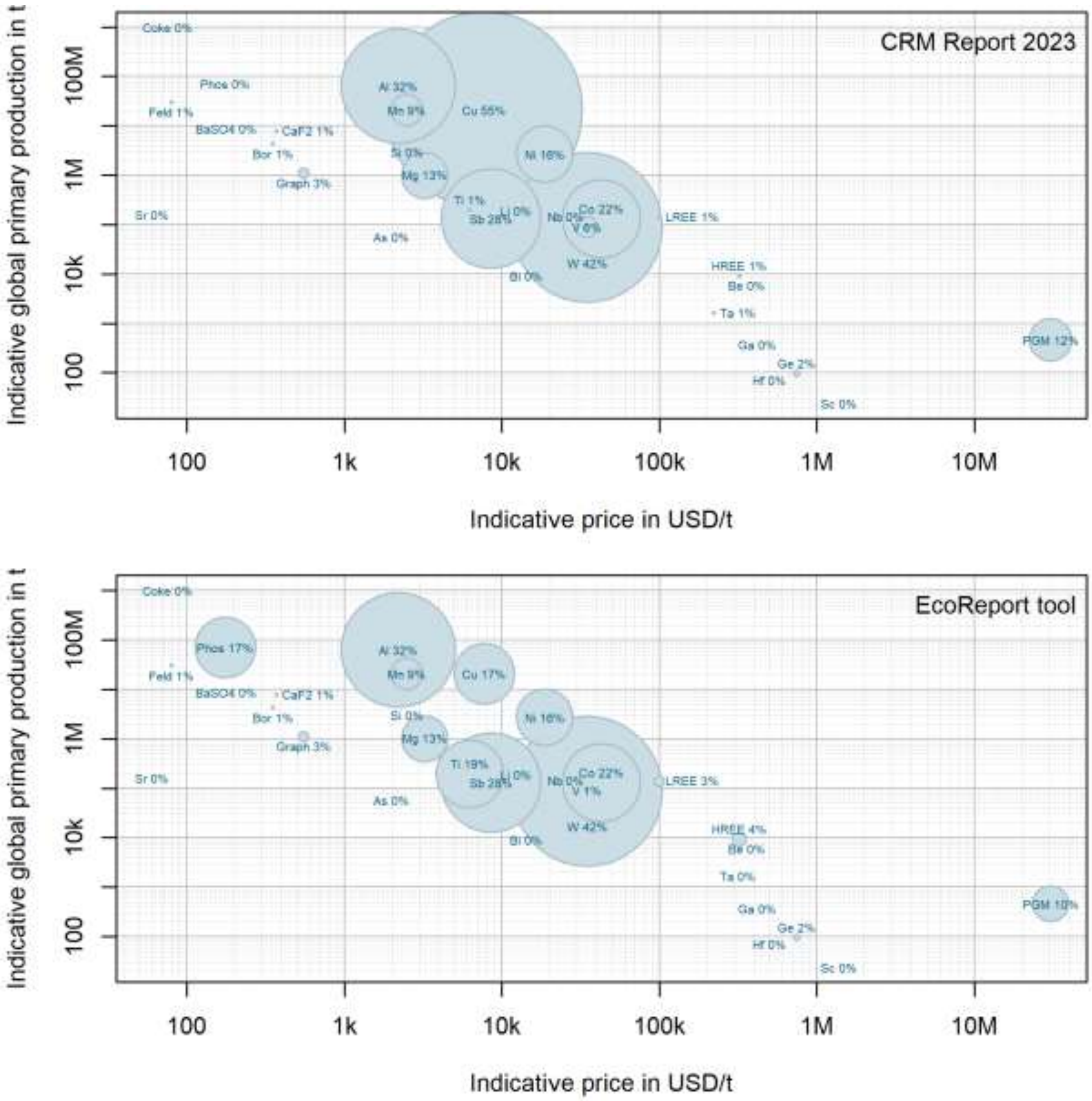

Figure 3: (Top) Recycling rates of critical and strategic raw materials as used in the latest EU criticality exercise[41]. Indicative prices retrieved from the SCRREEN (2023) and DERA (2024). (Coke = coking coal; Phos = phosphate rock; Feld = feldspar; Bor = Boron/borate; Graph = natural graphite, LREE/HREE = light/heavy rare earth elements; PGM = platinum group metals; all other identifiers are standard chemical nomenclature/symbols)

The depicted recycling rate is labeled as the end-of-life recycling input rate (EoL-RIR) by the European Commission (2023)[42], ideally following the definitions set out by Talens Peiró et al. (2018-10)[43]. However, given data limitations, this is not possible for all raw materials shown, see

[41] European Commission (2023). Study on the Critical Raw Materials for the EU 2023. Final Report. Available online at https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en.

[42] European Commission (2023). Study on the Critical Raw Materials for the EU 2023. Final Report. Available online at https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en.

[43] Talens Peiró, Laura/Nuss, Philip/Mathieux, Fabrice/Blengini, Gian Andrea (2018). Towards recycling indicators based on EU flows and Raw Materials System Analsis data. Supporting the EU-28 Raw Materials and Circular Economy policies through RMIS. Joint Research Centre. Luxembourg. JRC Technical Reports EUR 29435 EN. https://doi.org/10.2760/092885.

Tercero Espinoza (2021)[44] for a discussion and overview of this issue[45]. (See bottom Figure:) Recycling rates of critical and strategic raw materials as used in the EcoReport tool. Notice that both scales are logarithmic. The size of the circles scales linearly with the given recycling rate insofar as the recycling rate is non-zero; raw materials with no recycling are positioned but have no point/circle.

2.2.3. Relevant CRM Materials

Electric motors

High-efficient electrical motors are generally made with NdFeB permanent magnets, which represent between 2% and 4% of the total mass of the motor. NdFeB alloy is typically composed of 30% of neodymium (Nb), 1% of boron (B) 1% of dysprosium (Dy) and 1% of niobium (Nb), less than 1% of aluminium (Al) and the rest is iron (66%)[46]. Around 77 kt of primary rare earth elements (REE) for magnets (Ce, Dy, Gd, Nd, Pr, Sm and Tb) are produced worldwide per year, the market almost doubled between 2017 and 2021, with China accounting for 60% of the primary production. Two thirds of the refined REE production for magnets is based on primary materials and one third on secondary materials. The end-of-life recycling input rate – reflecting the total material into the production that comes from recycling of post-consumer scrap - is only 1%[47] .

Imaging equipment

The most important CRMs for imaging equipment are palladium, bismuth, bauxite and atimony. For palladium, Russia and South Africa are current primary producers, while Finland is the top producer within the EU[48]. China is the main global producer and EU supplier for bismuth. Bismuth is difficult to recycle because it is mainly used in many dissipative applications[49]. Bauxite is the primary raw material used to produce aluminium metal. Australia, China and Guinea are among the most relevant global producers, with the latter being the most important EU supplier. Around 400.000 megatonnes of bauxite are produced annually. While bauxite can't be recycled, as little as 5% of the energy originally used for its primary production is necessary for recycling, if it is produced into aluminum metal[50]. Antimony is used in batteries and as flame retardant. China is a main producer and Turkey the most relevant EU supplier. 83.000 kilotonnes of primary antimony are produced annually worldwide[51].

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[44] Luis A. Tercero Espinoza (2021), Critical appraisal of recycling indicators used in European criticality exercises and circularity monitoring, Resources Policy, https://doi.org/10.1016/j.resourpol.2021.102208.

[45] Tercero Espinoza, Luis A. (2021). Critical appraisal of recycling indicators used in European criticality exercises and circularity monitoring. Resources Policy 73, 102208. https://doi.org/10.1016/j.resourpol.2021.102208.

[46] https://eu-more.eu/

[47] https://rmis.jrc.ec.europa.eu/rmp/Rare%20Earth%20Elements%20for%20magnets

[48] https://rmis.jrc.ec.europa.eu/rmp/Palladium

[49] https://scrreen.eu/wp-content/uploads/2023/12/SCRREEN2_factsheets_BISMUTH_V1.pdf

[50] https://scrreen.eu/wp-content/uploads/2024/01/SCRREEN2_factsheets_ALUMINIUM-update2.pdf

[51] https://scrreen.eu/wp-content/uploads/2023/12/SCRREEN2_factsheets_ANTIMONY-update.pdf

Computers

For computers, the most important CRMs are tantalum, cobalt, and copper. Tantalum is used in capacitors for motherboards and other electronic components. The Democratic Republic of Congo, Rwanda, and Brazil are main source countries for the EU. In 2022, up to 1.440 kilotonnes of primary tantalum were produced worldwide. Spain is among the top producers of tantalum in the EU, but the EU holds a share of 1.1% worldwide. The EoL recycling rate of tantalum is at 13%[52].

Cobalt is used in lithium-ion batteries and some electronic components. Finland is among the top producers in the EU. In 2022, more than 161,000 kilotonnes of refined Cobalt were produced worldwide. The EoL recycling rate for cobalt is at 22%[53].

Copper is essential for electrical wiring and connections in computer hardware. Poland and Germany are among the top producers in the EU. In 2022, more than 22,200 kilotonnes of refined Copper were produced worldwide. The EoL recycling rate for copper is at 22%[54].

Besides valuable metals such as gold and silver, printed circuit boards (PCBs) in PCs can generally contain various CRMs such as platinum, palladium, antimony, beryllium and tantalum[55, 56]. Beyond the presence of valuable materials, PCBs are notable due to the presence of hazardous materials and their complex composition. Several pyrometallurgical, hydrometallurgical, bio-hydrometallurgical, physical–mechanical processes have already been proposed on an experimental level for overcoming the challenges of recycling PCBs[57]. On an applied level however, only Palladium is commonly recovered from PCBs, alongside the copper recovery process.

2.2.4. Cost of Recycling for CRM Materials

Recycling critical raw materials involves significant costs and challenges, often due to their low concentrations in waste streams and the complexity of recovery processes. While some materials show high economic viability, others face substantial hurdles that need innovative solutions to become economically feasible. Factors influencing these costs include the complexity of the devices, the efficiency of the recycling technology used, and the logistics involved in collecting and processing the electronic waste.

In many cases, the cost of recycling can be offset by the value of other recovered materials. PCs and more specifically their printed circuit boards (PCBs) are one such example. Palladium, which commonly appears in PCBs, can cost-effectively be recovered in most modern copper smelting processes followed by metal-specific refining. In contrary to the recovery of other CRMs in PCBs, the recovery of pallardium does usually not require complex additional processes, as it can be recovered alongside the copper recovery process.

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52 RMIS - Raw materials' profiles

53 RMIS - Raw materials' profiles

54 RMIS - Raw materials' profiles

55 Martinez-Ballesteros, G., Valenzuela-García, J. L., Gómez-Alvarez, A., Encinas-Romero, M. A., Mejía-Zamudio, F. A., Rosas-Durazo, A. D. J., & Valenzuela-Frisby, R. (2021). Recovery of Ag, Au, and Pt from printed circuit boards by pressure leaching. *Recycling*, *6*(4), 67.

56 Tsydenova, O. (2022). *Environmental and human health risks: associated with the end-of-life treatment of electrical and electronic equipment*. Institute for Global Environmental Strategies.

57 Birloaga, I., De Michelis, I., Ferella, F., Buzatu, M., & Vegliò, F. (2013). Study on the influence of various factors in the hydrometallurgical processing of waste printed circuit boards for copper and gold recovery. *Waste management*, *33*(4), 935-941.

Tantalum on the other hand, which also appears in PCs, is often lost in the slags of copper smelting due to its ignoble character, making economic recovery often unfeasible. Generally, the low or unknown tantalum content in many waste streams and the small total mass of tantalum make its recovery economically challenging. There is often a conflict between recovering precious metals and tantalum, complicating the recycling process. Hydrometallurgical recovery could overcome this conflict, allowing the recovery of precious metals from the tantalum concentrate. However, the process adds to the overall costs. Several studies that assessed tantalum recovery confirmed its possibility but also its lack of financial viability based on the current output products' market value of tantalum and quantity produced[58,59]. Efficient recycling of neodymium is also still challenging and costly due to the scattered distribution of neodymium in various products[60][61]

Recycling copper and cobalt from electronic waste (e-waste) can be economically viable. For cobalt, the total costs of recycling process were estimated at $23.20 when considering 1 kg of Co recycled in hydrometallurgical treatment[62]. For copper, A small-scale facility processing 10,000 tonnes/year of waste printed circuit boards (PCBs) in Australia has an estimated cost € 3.20/kg of waste PCB, with potential revenues ranging from € 4.38/kg to € 5.58/kg. Recycled copper has a value of 7,07€/kg[63].

2.2.5. Ferrous and non-ferrous materials

2.2.5.1. Material types

Relevant material types for the five product cases are steel, aluminium and copper, which are detailed in the following.

2.2.5.2. Market for recycled metals

Steel

European steel scrap recycling collects and re-processes more than the demand for steel scrap in the EU. In 2018, the domestic supply of the EU-28 exceeded 112 million tonnes. Steel scrap use (consumption) for steelmaking in EU was 94 million tonnes same year. The

[58] Römer, Felix; Elwert, Tobias (2017): Recycling of tantalum from waste electrical and electronic equipment through mechanical processing and hydrometallurgical separation of precious metals. In: *Proceedings - European Metallurgical Conference, EMC 2017* 1. Online: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85081299275&partnerID=40&md5=94686be088cc21e15962784e217db45b.

[59] Römer, F., Elwert, T., & Goldmann, D. (2016, September). Challenges and a possible solution for the recycling of tantalum from waste electrical and electronic equipment. In *Proceedings of the XXVIII International Mineral Processing Congress (IMPC 2016). Québec City, Canada* (pp. 11-15).

60 Patil, A. B., Thalmann, N., Torrent, L., Tarik, M., Struis, R. P., & Ludwig, C. (2023). Surfactant-based enrichment of rare earth elements from NdFeB magnet e-waste: Optimisation of cloud formation and rare earths extraction. *Journal of Molecular Liquids*, *382*, 121905.

[62] Cao, Y., Li, L., Zhang, Y., Liu, Z., Wang, L., Wu, F., & You, J. (2023). Co-products recovery does not necessarily mitigate environmental and economic tradeoffs in lithium-ion battery recycling. *Resources, Conservation and Recycling*, *188*, 106689.

[63] Ravilla, A., Gullickson, E., Tomes, A., & Celik, I. (2024). Economic and environmental sustainability of copper indium gallium selenide (CIGS) solar panels recycling. *Science of The Total Environment*, *951*, 175670.

surplus was exported. The proportion of steel scrap used in relation to crude steel production in the EU is 56%[64]. 16% of steel in the EU is used for domestic appliances.

The proportion of steel scrap used in relation to crude steel production in the EU is 56%. Steel scrap use (consumption) for steelmaking was 93.8 million tonnes in the EU in 2018.

Over 90% of EoL stainless steel is currently collected and recycled into new products.

Aluminium

Of the total amount of aluminium scrap generated in the EU at EoL (i.e., 4,338 thousand tonnes of aluminium), about 2,986 thousand tonnes of aluminium were collected and recycled, resulting in an EoL recycling rate of 69%.[65]

Secondary aluminium production represents globally twice the production of primary aluminium. As a result, aluminium scrap from recycling is a valued commodity, traded worldwide, and the major source of total aluminium production.

In the coming decades, demand for aluminium is expected to increase by a further 50% by 2050, reaching over 9 million tonnes of scrap demand in the EU.

Copper

The modest natural deposits of copper within the EU (48 million tonnes) drive a strong reliance on recycling, otherwise imports of primary and secondary forms to meet the domestic demand would increase.

Of the total amount of copper scrap generated at EoL (i.e., 2.6 million tonnes of copper), about 1.6 million tonnes of copper (61%) were collected and recycled within the EU. 44% of EU copper demand comes from recycled sources and 70% of copper in EoL products is recycled.

The modest natural deposits of copper within the EU (48,000 thousand tonnes) drive a strong reliance on recycling, otherwise imports of primary and secondary forms to meet the domestic demand would increase.

The EU-28 is a net-exporter of secondary copper, totally the EU exported 986,000 tonnes of copper scrap in 2016.

Copper is a scarcity market, where demand is higher than supply. Therefore, measures for increasing end-of-life collection and recycling rates could be relevant for increasing the supply of recycled material.

No focus on recycled metal content

Based on the information presented above and information provided by the stakeholders, it seems that the recycling chain for metals is well established. Due to the fixed availability of waste metal supply (as it depends on the volume of old cars and appliances, etc., that are scrapped), introducing minimum ecodesign requirements for recycled metals for the five product cases might lead to a shift of supply of metals with recycled content between sectors

[64] https://circulareconomy.europa.eu/platform/sites/default/files/euric_metal_recycling_factsheet.pdf. The publication is from 2020, but reported data are older.

that use steel, such as e.g. the construction industry. Hence, such requirements do not assist the recycling industry, resolve waste stream problems, or reduce environmental impacts.

Consequently, setting minimum recycled content requirements on metals used in fridges has not been a study focus. For further information see also the general, horizontal part of the study report on recycled content and CRMs.

2.3. Verification

Verification of ecodesign requirements on recycled content and recyclability is naturally very important – as it is for other types of ecodesign requirements. Verification supports the among others the following goals:

- Environmental benefits realized in practice
- Level playing field for the manufactures and suppliers
- Customer trust
- Realisation of the policy goals
- Avoidance of greenwashing
- Legal and trade compliance

The EU Member States are responsible for the market surveillance of the ecodesign and energy labelling requirements. The market surveillance often takes place in a combination of check of the technical documentation and laboratory test. The same kind of market surveillance can be used for recycled content and for recyclability.

For testing amounts of recycled content of a specific material in the final product, there may not be test methods available, at least for some materials and/or some recycling processes such as chemical processing and melting processes for e.g. metals. Other market surveillance practices may be used, such as document checks at the production sites, use of notified body checks etc.

This is a topic still to be assessed.

3. SUMMARY OF PRODUCT CASES

[Summaries of the product cases for imaging equipment, computers, household fridges, household washing machines and electric moters will be provided in the final draft version of this report.]

4. CONCLUSION AND RECOMMENDATIONS

[Conclusion and recommendations will be provided in the final draft version of this report.]

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